

# **Timed Travel:**

## ***Measuring the Relationship Between Stream Temperature and the Development of Salmon***





## Meet the Scientists



◀ **Dr. E. Ashley Steel**, Statistician and Quantitative Ecologist: I have so many favorite science experiences! One cool science experience was when I was standing right in the middle of the Snoqualmie (snō kwōl mē) River. I was thinking about how my 35 water temperature loggers were recording data all across the Snoqualmie River watershed at that very second!

▶ **Ms. Abby Tillotson**, Fisheries Biologist: My favorite science experience so far has been participating in salmon surveys on the Yakima (yak ə ma) River near Cle Elum, Washington. We spent a few days floating the river on rafts, counting redds (salmon egg nests), and pulling over to the bank to count and measure salmon that died after spawning (laying eggs). This photo is of me holding a brown trout on the Sprague River in southeast Oregon.



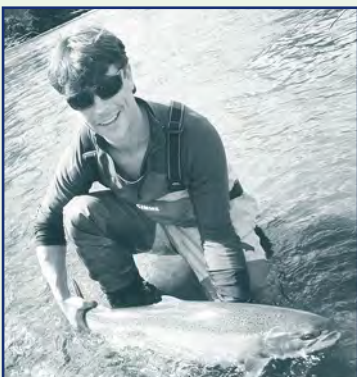
◀ **Dr. Donald Larsen**, Fisheries Biologist: My favorite science experience was rowing a raft down the Yakima River in Washington State. I was collecting data on spring Chinook salmon on a beautiful fall day and thinking...I can't believe I get paid to do this.

▶ **Ms. Aimee Fullerton**, Fisheries Biologist: It is tough to choose my favorite science experience. I'd have to say that it was watching nonnative fish use different habitats in the dark in a lab experiment. We marked fish with fluorescent paint and used a black light so the fish couldn't see us observing them. This process was the subject of my Master of Science research in the late 1990s. You can earn a Master of Science degree after earning your Bachelor's degree in college.

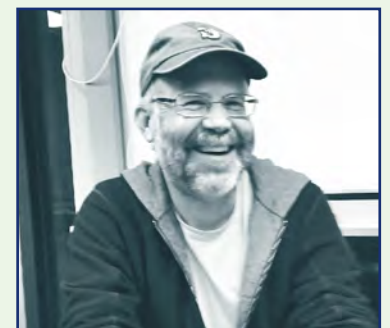


▼ **Mr. Keith Denton**, Fisheries Biologist: My favorite science experience was capturing 40-pound Chinook salmon in the newly

restored Elwha River. The Elwha River is in Olympic National Park in Washington State. I was measuring the impact of large-scale dam removal on salmon recovery.



▶ **Dr. Brian Beckman**, Fisheries Biologist: I enjoy mentoring young scientists, helping them to develop useful and interesting questions and to form thorough and accurate answers. The curiosity and enthusiasm of these bright young people are amazing and I'm fortunate to be able to work with them.



## What Kinds of Scientists Did This Research?

**fisheries biologist:** This scientist studies fish and how the environment and other outside forces affect fish throughout their life cycle.

**statistician:** This scientist uses statistical methods to collect and analyze data and help solve real-world problems in business, engineering, the sciences, or other fields. Statistical methods include the collection, analysis, interpretation, presentation, and organization of data.

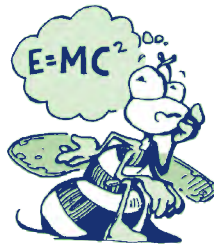
**quantitative ecologist:** This scientist applies statistical methods and mathematics to problems in ecology. Ecology is the study of the interactions of living things with each other and with the nonliving environment.

## Thinking About Science

Part of a scientist's job is to develop, establish, or improve methods of collecting, analyzing, organizing, or presenting data.

Some scientists are particularly interested in helping to improve scientific methods. In this research, the scientists thought that a different method of collecting data might improve scientists' understanding of fish development.

Have you ever thought of a better way to do something? Before you knew for sure that it was better, you would have to try your new way and compare it with an existing way. That is exactly what the scientists did in this research.



## Thinking About the Environment

Over many years, decades, and thousands of years, organisms adapt to different factors in their physical environment. Temperature is one of the environmental factors to which organisms adapt. Many organisms live part, or all, of their lives in water. Water temperature, therefore, is a **variable** that affects the life cycle of many of Earth's organisms.

In this research, the scientists studied the relationship of water temperature to the time it took Chinook salmon eggs to hatch and develop as young fish. The scientists also studied how water temperature affected the rate at which the fish developed. Water temperature can change over time as a result of global climate change, dams, irrigation, and changing **land use**. The scientists in this study, therefore, wanted to understand how **variation** in water temperature can affect the development of young Chinook salmon (**figure 1**).



**Figure 1.** An adult Chinook salmon leaps out of the water. Photo courtesy of <http://iStockphoto.com>.

Glossary words are **bold** and are defined on page 101.



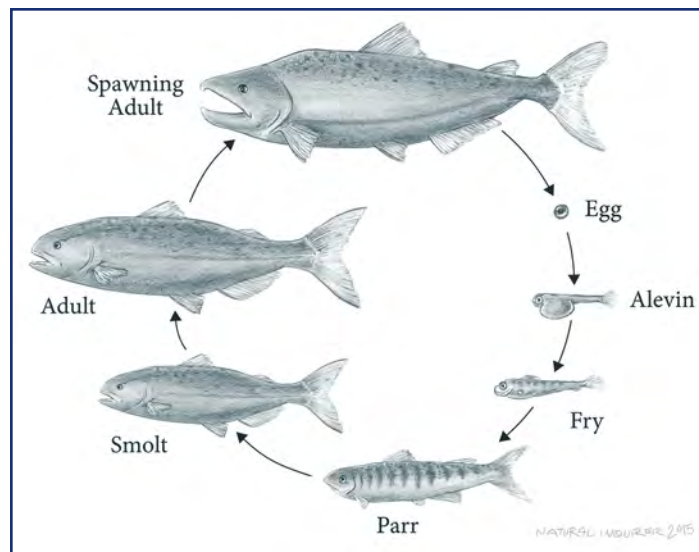
## How Are Salmon Important to the Ecosystem?

Salmon play an important role in their ecosystem. You probably know that salmon provide food for bears. Did you also know that salmon provide food for the soil? Salmon die after they lay their eggs, or spawn. During high water flows, the dead salmon are washed onto riverbanks. As the dead salmon decay, they provide important nutrients to the riverbank soils. To learn more about how salmon help riverbank soils in Alaska, read the *Natural Inquirer* monograph, "Food for the Soil," <http://www.naturalinquirer.org/Food-for-the-Soil-i-37.html>.

## Introduction

Water temperature helps **regulate aquatic** ecosystems. Aquatic scientists, therefore, often measure water temperature. Scientists usually record daily water temperature by calculating the **mean** or average temperature over a 24-hour period. Scientists also calculate degree days. Degree days describe the total temperature units (TU) delivered. One degree day Celsius is equal to a temperature of 1 °Celsius (C) for 1 day. Temperature units describe the amount of energy or heat available to the fish. You will learn about temperature units and degree days in this article.

Aquatic organisms spend their lives in, on, or near water. For many aquatic organisms, life-cycle phases are tied to water temperature. Salmon eggs, for example, generally hatch when a certain number of degree days, or temperature units, have been **accumulated**. Scientists have figured out how many temperature units are required for Chinook salmon eggs to hatch and for young salmon to grow and **emerge** as young fish (**figure 2**). Scientists have focused their

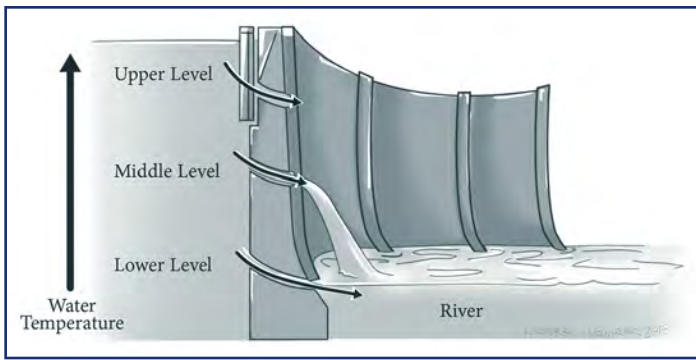


**Figure 2.** The Chinook salmon life cycle. Illustration by Stephanie Pfeiffer.

attention on total temperature units. Until now, they have not given a lot of attention to how those temperature units are delivered. Does it make a difference, for example, if the temperature is 3 °C one day and then 7 °C the next, or if it is just a stable 5 °C every day? Over a month, the same number of temperature units would be delivered but they would be delivered in different ways.

The scientists in this study knew that stream and river water temperature varies in at least two ways. First, the temperature varies across each 24-hour period. Second, water temperature varies within and across seasons. The scientists knew that recent human actions were altering the patterns of water temperature where Chinook salmon laid their eggs. Dams, land-use changes, irrigation, and climate change can cause altered water temperatures (**figures 3, 4, 5, and 6**).

The scientists suspected that fish might respond to more than just total temperature units. They thought that it might matter whether the water temperature was stable or variable. Just knowing the number of total temperature units delivered does not enable scientists to understand how temperature variations affect the life cycle of Chinook salmon. The scientists asked this question: Do daily and



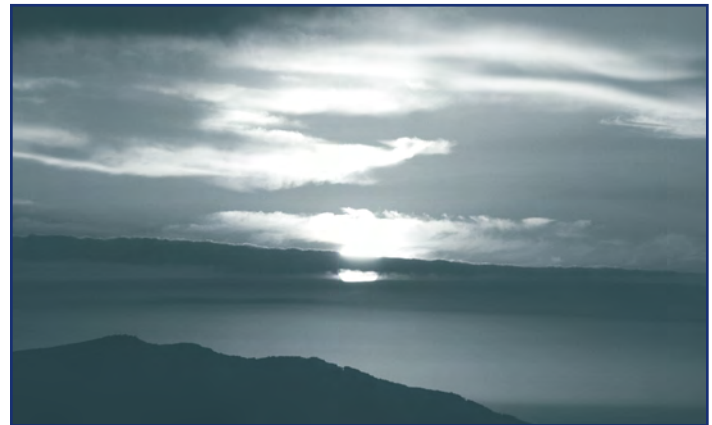
**Figure 3.** Dams can affect the water temperature, depending on the depth at which water is released downstream. Typically, surface water is warm and deep water is cold. When unnaturally warm or cold water is released, the change in water temperature can disrupt fish **habitat**. Illustration by Stephanie Pfeiffer.



**Figure 4.** When vegetation near waterways is disturbed, less plant cover can open waterways to more sunlight and result in higher water temperatures. Photo courtesy of Babs McDonald.



**Figure 5.** Irrigation withdraws water from waterways. This disturbance can cause water temperature changes. Irrigation usually causes the water temperature to rise. Photo courtesy of Babs McDonald.



**Figure 6.** Climate change can cause water temperature to change over time. The same factors that cause air temperature to rise can cause water temperature to rise as well. Photo courtesy of Babs McDonald.

seasonal water-temperature variations affect the development of salmon eggs and alevins (**a lə vənz**), or young salmon, before they become free-swimming **fry**?

To answer their question, the scientists did something new. The scientists observed Chinook salmon development in fish that were exposed to different water-temperature patterns. The scientists altered water temperature experimentally to explore how water temperature variability affects Chinook salmon development.

## Reflection Section



- ❦ Why does stream or river water temperature vary across a 24-hour period?
- ❦ Imagine that you are going camping over the weekend. You will be sleeping in a tent. The average daily air temperature across 24 hours will be 45 °F (7.2 °C). Do you think it would be more helpful for you to know how the air temperature will vary across the 24-hour period? Why or why not?

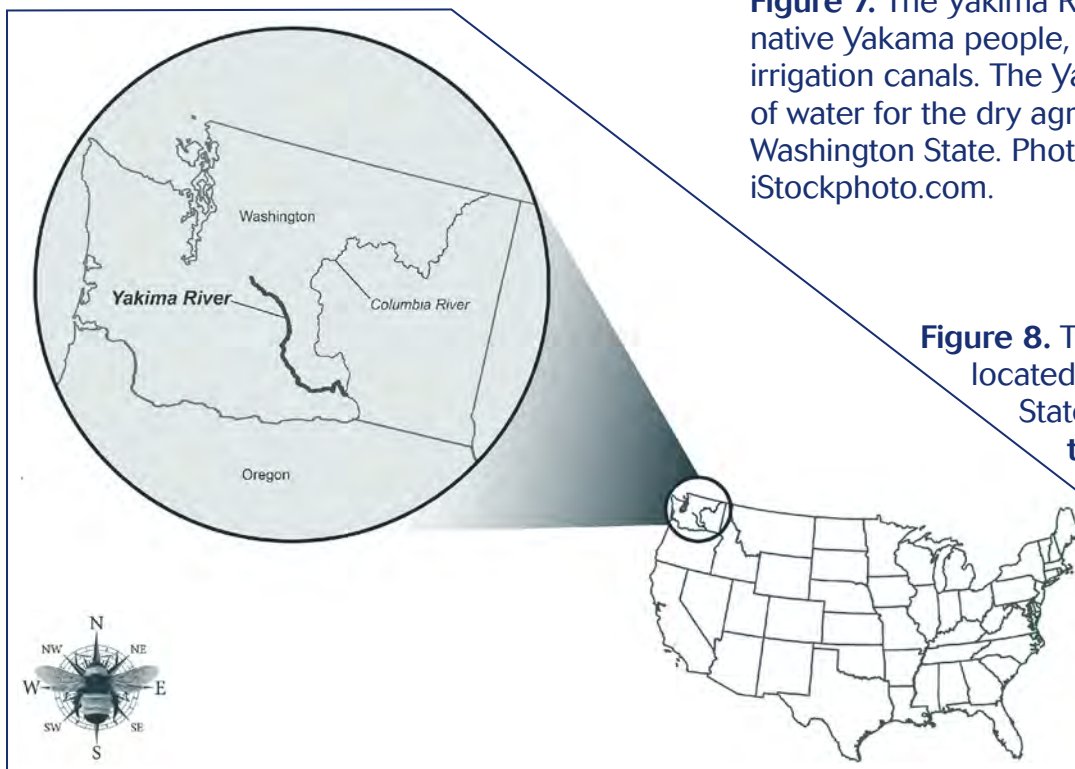


## Methods

The scientists collected adult Chinook salmon near the Roza Dam on the Yakima River in June and July 2009 and took them to a hatchery (**figures 7 and 8**). The salmon spawned (laid eggs) while in the hatchery, and the scientists collected the fertilized eggs (**figure 9**). The scientists put 150 eggs into each of 64 chambers (**figure 10**). These chambers were set up so that the eggs would hatch and the alevins could develop into fry (**figures 11 and 12**).



**Figure 7.** The Yakima River, named for the native Yakama people, has numerous dams and irrigation canals. The Yakima River is a source of water for the dry agricultural region of central Washington State. Photo courtesy of <http://www.iStockphoto.com>.



**Figure 8.** The Yakima River is located in central Washington State. The Yakima River is a **tributary** of the Columbia River and is 214 miles (344 kilometers) long. Map by Carey Burda.



**Figure 9.** Fish hatcheries are large indoor or outdoor facilities where fish eggs are hatched and young fish are allowed to develop. Photo courtesy of Babs McDonald.

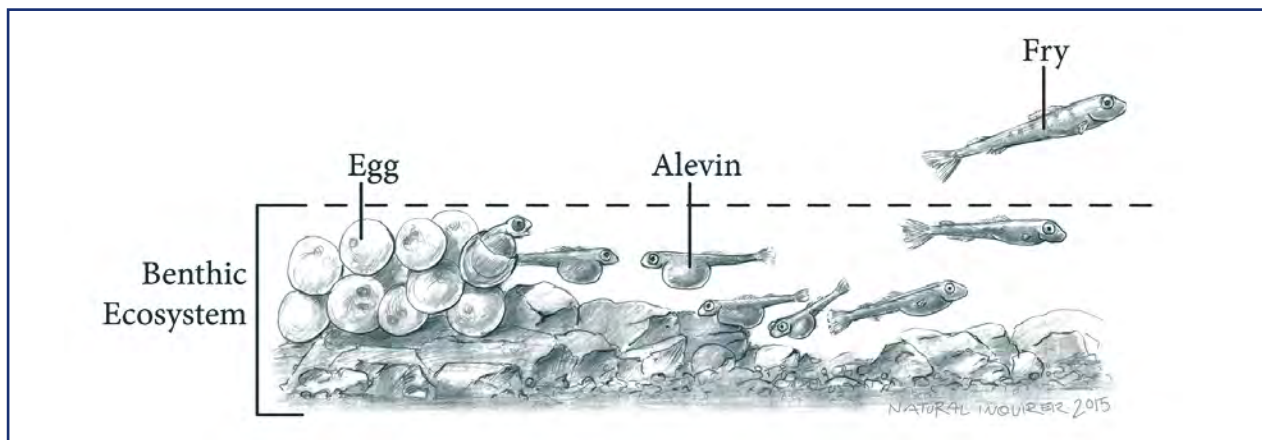
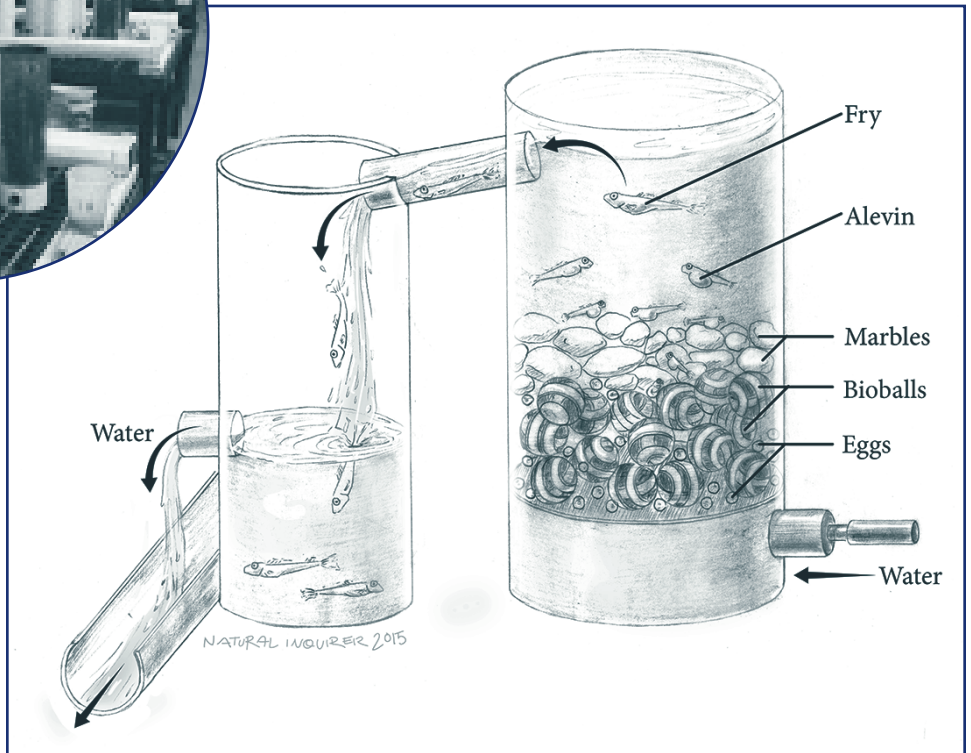
### Number Crunch



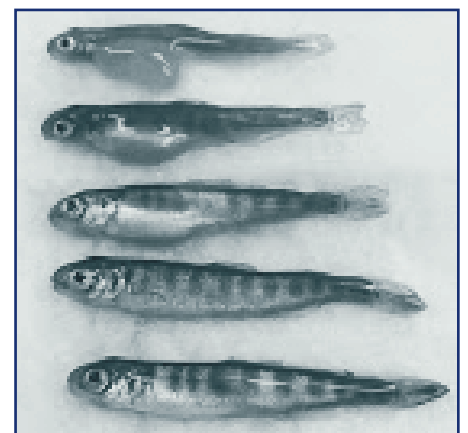
How many alevins were observed overall?



**Figure 10.** The chambers were made with plastic pipe. Each chamber enabled the eggs to hatch and the alevins to develop into fry. The scientists were able to catch, measure, and count the young fry as they emerged from the chamber. Photo courtesy of Dr. E. Ashley Steel and illustration by Stephanie Pfeiffer.



**Figure 11.** Chinook salmon lay eggs in the gravel beds of a river. After hatching, the alevins, or young salmon, live among the gravel on the river's bottom. While alevins are developing, they exist on a yolk sac. As they develop, they slowly absorb the yolk sac. When the yolk sac is gone, the alevins become free-swimming fry and they leave the graveled river bottom. Illustration by Stephanie Pfeiffer.



**Figure 12.** When an alevin's yolk sac has been absorbed, it becomes a free-swimming fry. Photo courtesy of Abby Tillotson.

The scientists controlled the water temperature in the chambers using very large aquarium heaters. They created eight different patterns of water temperature (**figure 13**). The different water-temperature patterns were meant to **simulate** stable temperatures, daily

variation in water temperature, seasonal variation in water temperature, and daily plus seasonal variation in temperature. In two cases, the scientists also simulated completely unnatural patterns just to see if the fish would respond.

<b>A:</b> Water temperature stable at 5 °C	<b>B:</b> Water temperature varied daily from 5 to 10 °C	<b>C:</b> Water temperature varied seasonally by reducing 1 °C per week, then warmed 1 °C per week	<b>D:</b> Daily variation plus seasonal variation (combination of B and C)
<b>E:</b> Extreme seasonal variation by flip flopping 5 °C one week, then 10 °C the next week	<b>F:</b> Extreme daily variation by changing the temperature from 5 to 10 °C twice daily	<b>G:</b> Water temperature stable at 10 °C	<b>H:</b> 10 °C with daily variation as high as 13 °C

**Figure 13.** The eight different water-temperature patterns.

## Number Crunch

- ✿ The scientists divided the temperature treatments equally across all 64 chambers. How many chambers received each of the eight treatments?

The scientists recorded the water temperature every hour. The temperature patterns were designed so that the chambers with variable temperatures delivered about the same total temperature units every day as those with stable temperatures.

## Number Crunches

- ✿ Temperature units (TUs) are usually thought of as degree days, the total amount of temperature delivered in one day. To design the temperature patterns, the scientists calculated TU every hour and then added the 24 hourly measurements together to determine the total temperature units delivered in 1 day.
- ✿ Calculate the TUs delivered in 1 day for a stable pattern of 10 °C:  $(10/24 + 10/24 + 10/24 + 10/24...)$  (Include all 24 hours TUs of  $10/24$ ). What are the total TUs for the day? Note that for a stable water temperature, the TUs for 1 day is equal to the water temperature.
- ✿ Try calculating TUs for a temperature pattern that goes up and down every hour:
  - If the water temperature fluctuated between 9 °C for 1 hour and 11 °C for the next hour, and this pattern repeated across 24 hours:  $(9/24 + 11/24...)$  (include all 24 of TUs in your calculations), what would be the total TUs for the day?
- ✿ Now calculate the TUs for this temperature pattern:
  - If the water temperature was 5 °C for 6 hours, 10 °C for 10 hours, and 7 °C for 8 hours, what would be the total TUs for the day?



At 11:00 a.m. every day, the total temperature units (TUs) for the past 24 hours were recorded for each chamber and the scientists checked to see if any fish had emerged. The scientists noted the day when most of the fish, 125 of the 150 alevins, emerged as fry. At that point, the scientists calculated the total TUs that had accumulated in each chamber over all the days that the alevins had been developing in that chamber.

The scientists designed temperature patterns that delivered about the same daily total TUs but had different kinds of **variability**. By using these patterns, the scientists measured the impact of variation in water temperature on the development of Chinook salmon. Note that everything else was held constant in the experiment. Any differences between the TUs that had been delivered when most of the fry

emerged, therefore, were likely related to the variability in the water-temperature patterns.

The scientists collected a **sample** of fry as they emerged from each chamber. The scientists weighed, measured, and determined the fry's overall condition.

Now, answer the Reflection Section questions on this page.

## Findings

The water-temperature patterns influenced when fry emerged. Eggs and alevins exposed to the most stable water temperature (5 °C and 10 °C) had accumulated a mean of 1,160 (5 °C) and 1,153 (10 °C) TUs by the time most of the fry had emerged. Recall that the scientists used eight chambers for each of the eight temperature patterns. Therefore, the scientists calculated mean accumulated TUs for each of the eight patterns. The scientists expected these numbers to be similar. They expected this similarity because they knew that Chinook salmon eggs require a certain number of TUs to be ready to emerge.

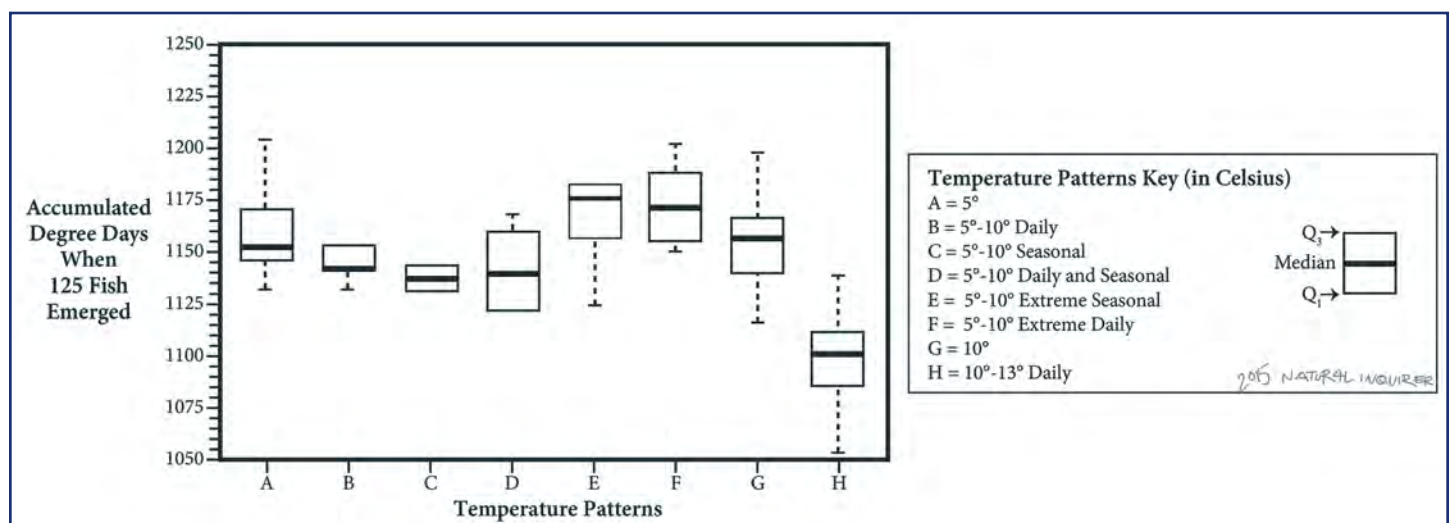
The fry living in the chambers in which the water temperature varied by 5 to 10 °C once per day emerged after accumulating fewer TUs than when the water temperature was held stable (**figure 14**). The scientists

### Reflection Section



Explain in your own words how the experiment was controlled so that any observed differences in fry emergence and condition would most likely be related to water-temperature patterns.

What were the scientists trying to discover in this experiment?



**Figure 14.** The emergence of Chinook salmon fry based on accumulated temperature units for eight water-temperature patterns. Illustration by Stephanie Pfeiffer.

discovered something different for the alevins exposed to water-temperature patterns with extreme daily or extreme seasonal variations. These alevins needed to accumulate more TUs than when the water-temperature was held stable for most of the fish to emerge as fry.

The scientists also discovered that fish exposed to the warmer patterns of water temperature emerged less fully developed than other fish. These fish were four times more likely to still have a visible yolk sac upon emergence.

## Reflection Section



- Based on the scientists' results, what would you conclude about the relationship between water-temperature variability and Chinook salmon development?
- Look at figure 14. What do you notice about fry emergence from this figure?

## How Does a Box Plot Show Interquartile Range?

Figure 14 is a box plot. Box plots are one way to display interquartile range. Calculating an interquartile range helps scientists to understand the variation in their data. To find an interquartile range, the data must be listed in rank order, from the lowest value to the highest value. The middle value (the median) is identified. Then, the middle value of the bottom half and the middle value of the top half is identified. After this step is

complete, the data have been divided into four parts or quartiles, called Q1, Q2, Q3, and Q4. Q2 is the median. The interquartile range is the value of Q3-Q1.

In figure 14, the middle bar in each box is the median. The bottom of the box is Q1 and the top of the box is Q3. The entire box for each temperature pattern represents the interquartile range.

## Discussion

When scientists consider fish development based only on accumulated temperature units, they may be missing an important influence on fish development. This research shows that the timing of Chinook salmon development is dependent upon more than total accumulated temperature units. It matters how those total temperature units are delivered. Daily and seasonal water-temperature variability have an impact on how many temperature units are required for most of the fish to emerge.

The scientists estimate that variability in water temperature may affect fry emergence by as much as 1 week. Fish, like most wildlife

species, have adapted to the availability of food sources in time. Emerging a few days early or late may cause fry to miss important food resources. If human changes to water-temperature patterns affect when fish emerge, fish might emerge at a time with fewer food resources. The possible lack of food resources could affect Chinook salmon survival.

Understanding the relationship between fry emergence and water variability is important now because humans are changing water-temperature patterns. Building dams, changing land cover, irrigating, and changing the global climate may have important impacts on the life cycle of Chinook salmon.



## Reflection Section



🍁 If you were teaching young scientists how to study fish emergence, what would you teach about considering water-temperature variability?

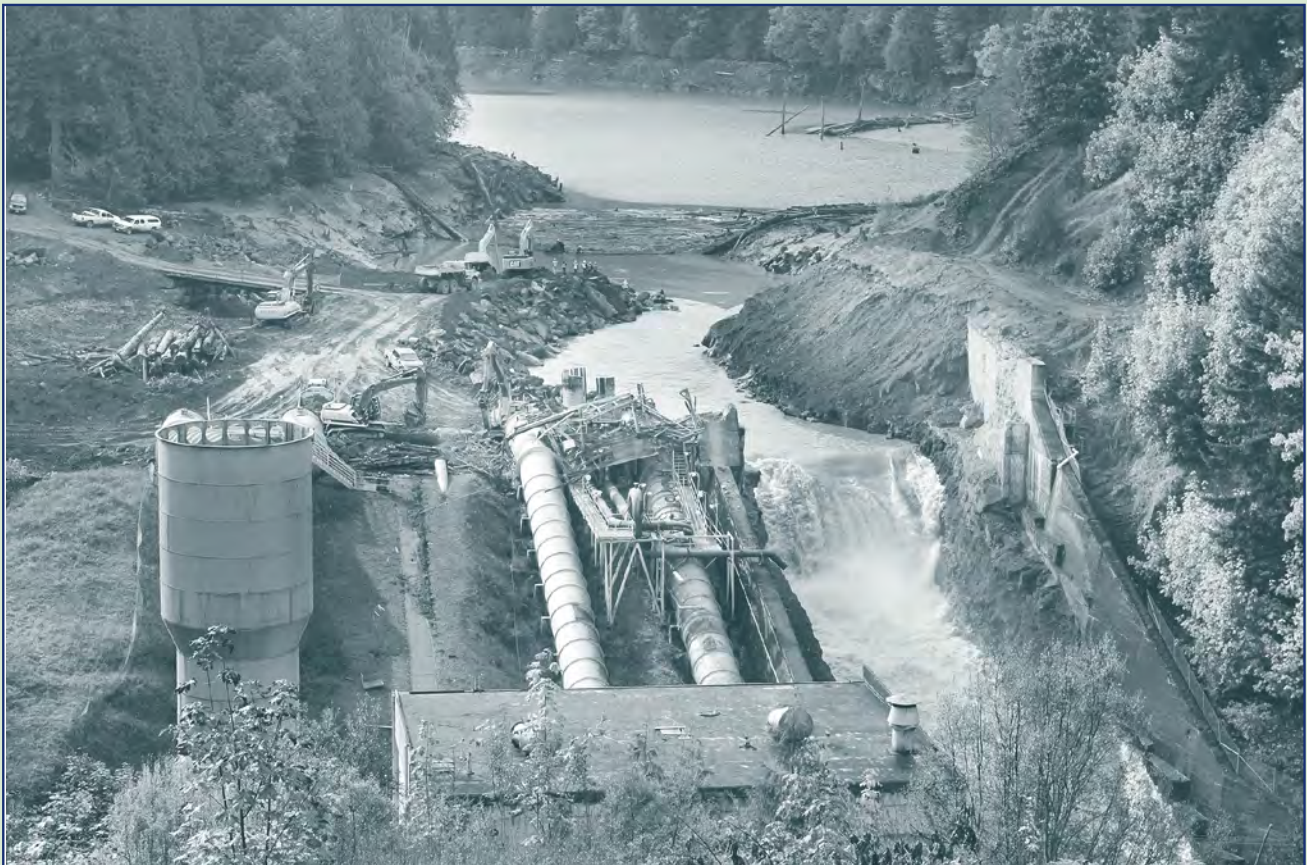
🍁 Do you think the results of this research are convincing? Why or why not?

Adapted from Steel, E.A.; Tillotson, A.; Larsen, D.A.; Fullerton, A.H.; Denton, K.P.; Beckman, B.R. 2012. Beyond the mean: The role of variability in predicting ecological effects of stream temperature on salmon. *Ecosphere*. 3(11): 104. <http://dx.doi.org/10.1890/ES12-00255.1>. [http://www.fs.fed.us/pnw/pubs/journals/pnw\\_2014\\_steel001.pdf](http://www.fs.fed.us/pnw/pubs/journals/pnw_2014_steel001.pdf).

## Why Was the Elwha Dam Removed?

In 2014, the National Park Service completed the removal of two large dams on the Elwha River in Olympic National Park, Washington State (**figure 15**). For 100 years, the dams blocked all but the last 5 miles of the river. This blockage created reservoirs (large lakes) where a river once was, and

stopped natural sediment flow and salmon migration. The dams had dramatically changed the Elwha River ecosystem. Removal of the dams has reopened more than 70 miles of important salmon spawning habitat, restored natural sediment flow, and begun the restoration of the Elwha River ecosystem.



**Figure 15.** The Elwha Dam in the midst of its removal. Photo courtesy of the National Park Service.

## Glossary

**accumulate** (ə kyü m(y)e lāt): To increase gradually in amount as time passes.

**aquatic** (ə kwä tik): (1) Living or found in, on, or near water; (2) of or relating to the animals or plants that live in, on, or near water.

**emerge** (i mərj): To become known or visible.

**fry** (fri): Recently hatched or juvenile fishes.

**habitat** (hə bə tat): The place or environment where a plant or animal naturally or normally lives and grows.

**land use** (land yūs): How people are using the land.

**mean** (mēn): The average of a set of values.

**migratory** (mī grə tōr ē): Having a characteristic of moving from one place to another on a periodic basis.

**regulate** (re gyə lāt): To set or adjust the amount, degree, or rate of something.

**sample** (sam pəl): A small subset group, representative of the entire group.

**sediment** (se də mən): Soil particles carried along in streams and rivers, some of which may settle to the bottom.

**simulate** (sim yə lāt): To create the appearance or effect of something for purposes of evaluation.

**tributary** (tri byə ter ē): A stream that flows into a larger stream or river or into a lake.

**variable** (ver ē ə bəl): Subject to changes.

**variability** (ver ē ə bi-lə tē): The degree to which something is variable.

**variation** (ver ē ā shən): A change in the form, position, condition, or amount of something.

**watershed** (wä tər shed): The area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean.

Accented syllables are in **bold**. Marks and definitions are from <http://www.merriam-webster.com>. Definitions are limited to the word's meaning in the article.

The definition of watershed is taken directly from the U.S. Environmental Protection Agency (<http://www.epa.gov>).

## FACTivity



### Time Needed

- One class period for graphing data or 3 to 4 weeks for downloading and graphing data
- 3 to 4 weeks for observation involving 5 to 10 minutes per day
- One class period for analysis, reporting, and discussion

### Materials (for each small group)

- Observational tools appropriate for the event, such as binoculars or butterfly nets
- Graph paper and pencil
- Copy of the log sheet on page 103

- Daily access to a computer with Internet access (optional) or your teacher will provide daily data (from a Web site)

The question you will answer in this FACTivity is: How do air temperature patterns relate to a yearly natural event?

Your teacher will divide your class into groups. Your group will select an event to study. Identify a natural event that is at least partly dependent upon the air temperature for its occurrence. Your group may select an event from the following list, or identify a yearly natural event of your own:



1. The emergence of a particular species of leaves.
2. The emergence of a particular species of flowers.
3. The first sighting of butterflies.
4. The first sighting of a particular **migratory** bird species.
5. The first occurrence of the developmental stage of an amphibian species.
6. The first leaf color change in the fall.
7. The first frost.
8. The first snowfall.

Identify a yearly natural event that you expect to occur in your area within the next 3 to 4 weeks.

As a group, write down exactly what you will be looking for in the event. For example, you might write: "We are looking for the first sign of autumn color change in the maple tree in the front school yard, beside the front stairs. Color change means any change on any part of a leaf on that tree, from green to red, yellow, orange, or brown."

After you have identified and described your event, look at the science log sheet on page 103. Your group will need three to four copies of the log sheet.

You will either access <http://www.weather.noaa.gov> every day to record hourly temperatures, or your teacher will provide this information to you.

As an alternative, you may record your own hourly temperatures using an outdoor thermometer. If you choose this method, you may have to fill in nighttime temperatures and weekend temperatures from <http://www.weather.noaa.gov>.

Observe daily, watching for your event to happen. When your event happens, record the date. At this point, you may stop recording the hourly temperature.

Using your completed log sheet, calculate the average daytime temperature and average nighttime temperature for each week. For this FACTivity, daytime temperatures

## Project BudBurst™

Timing is everything!

Plants are all around us. Changes in emergence of plants each year can tell scientists about changes in climate. Contribute your observations of plants at home, at school, or at local parks with Project BudBurst (<http://www.budburst.org>), a citizen science project that allows you to become the scientist. Use the QR (Quick Response) code to start collecting data for science.



include those from 9:00 a.m. until 8:00 p.m. Nighttime temperatures include those from 9:00 p.m. until 8:00 a.m.

Make a graph of the two daily temperature averages across the weeks leading up to your event. (See **figure 16** for an example.) You may need to make three or four graphs, one for each week. Blank graph paper is located on page 123.

Your group will analyze your graphs as you think about your event. What patterns do you see in the air temperature in the weeks and days leading up to your event? How could these patterns affect the timing of your event? Write your observations and analysis, using complete sentences. Report your results to the class. Your teacher will hold a class discussion about the patterns you noticed in your data. Compare and contrast between different events.

To find hourly temperatures, visit <http://www.weather.noaa.gov>. Select your State and then select your location. Select the location that is nearest to you.

This Web site displays hourly weather data for the past 3 days. Record the hourly temperatures using the log sheet. On Monday, record air temperature from over the weekend.

Group Members: \_\_\_\_\_

Event: \_\_\_\_\_

Log of Hourly Temperatures by Week

Week of \_\_\_\_\_

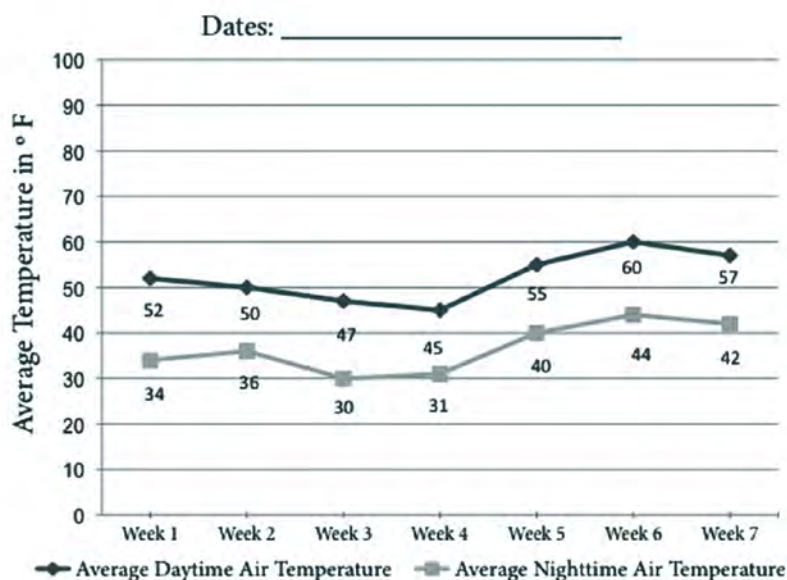
	Sun	Mon	Tue	Wed	Thurs	Fri	Sat
	Degrees Fahrenheit						
12 am							
1 am							
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## FACTivity Extension

As a class, compare and contrast this FACTivity with the salmon research in the article.



**Figure 16.** An example of a graph showing air temperatures over time. Illustration by Stephanie Pfeiffer.

## What's in a Name?

**T**ime travel is the concept of moving either forward or backward in time. In this article, the emergence of young fish from an earlier developmental stage was timed, in a way, by using a value called temperature units.

## Web Resources

National Oceanic and Atmospheric Administration, Chinook Salmon

<http://www.nmfs.noaa.gov/pr/species/fish/chinooksalmon.htm>

National Park Service, Elwha River Restoration

<http://www.nps.gov/olym/naturescience/elwha-ecosystem-restoration.htm>

National Oceanic and Atmospheric Administration, Fisheries: Elwha Restoration

<https://www.youtube.com/watch?v=TP9z5S5oivo>

Project Budburst/National Geographic Growing Degree Days Tool

[http://budburst.org/documents/871408/1044448/FS\\_Unit\\_3.pdf/5b4c635f-2d09-4055-a881-35a174d0085d](http://budburst.org/documents/871408/1044448/FS_Unit_3.pdf/5b4c635f-2d09-4055-a881-35a174d0085d)

Project Budburst

<http://www.budburst.org>

USA National Phenology Network

<https://www.usanpn.org/>

## Natural Inquirer Connections

**y**ou may want to reference these *Natural Inquirer* articles for additional information and FACTivities:

- For more on the impact of dams, read “Mussel Mania” on page 74 of this edition of *Natural Inquirer*.
- For more information on salmon and their ecosystems, read “Food for the Soil” in the *Natural Inquirer* monograph.

These articles, along with others, can be found at: <http://www.naturalinquirer.org/all-issues.html>.