NATURE LAB Educator Resources

ECOSYSTEM INTERDEPENDENCE:
MANAGING SALMON TO SUPPORT HEALTHY FORESTS

Subject Area: Science - Nutrient Cycling, Ecosystems

Grades: Session 1 - 6th-8th grade
Session 2 - 6th-12th grade

Time: Session 1 set-up can be completed in one 45 minute period; additional time will be needed at regular intervals to measure plant growth. An additional 45 minute period will be needed to discuss results and conclude the experiment.

Session 2 will require at least one 45-minute period with computers. Additional time may be required for the extend options.

Essential Question:

- How can managing salmon support healthy forests?

Purpose and Overview:

In this lesson plan, students address the impact of unsustainable fishing practices, as applied to the case of salmon fisheries in the Pacific Northwest. In session 1, they simulate variation in nutrient input by comparing growth of plants with different concentrations of fish-based fertilizer control. In session 2, students test a simple, computer-based interactive population model to estimate sustainable salmon harvest. Extra sessions will be needed to conduct some of the extend options.

Themes:

Forests provide many benefits, including net production of oxygen.

Salmon is a popular and healthy food source.

Healthy forests filter water.

Wood and paper come from forests.

Introduction:

Salmon runs are an important factor in cycling several nutrients, notably phosphorus and nitrogen. As fish return to rivers during their annual spawning run, they are consumed by predators or die at the end of the spawning run. Their carcasses contribute nutrients that are a significant input for forest plants. Overfishing salmon reduces the forest's capacity for growth and regeneration.

Salmon is a healthy, nutritious food, and salmon fisheries employ numerous people. The forests fertilized by salmon provide products such as lumber, jobs, and ecosystem services such as protecting watersheds by filtering water. Therefore, strong salmon runs benefit people directly and indirectly. For this reason, fisheries managers, conservationists and policy makers want to work together to prevent overfishing.

To emphasize the benefits of a sustainable salmon fishery, students explore the connection between the size of salmon runs and forest health. Students address the question: how can managing salmon support healthy forests? To answer the question, students participate in two activities. First, they work with the teacher to test a simple population model (using NetLogo, software free for educators). The model includes parameters that can be varied independently. The students use the model to estimate a sustainable salmon harvest. The second activity is to simulate variation in nutrient input by comparing growth of plants given inputs of different concentrations of fish-based fertilizer with a control.

Objectives:

The student will…

Knowledge

- Describe that salmon runs contribute to the health of forests and thereby affect people.
- Describe that salmon is a popular and healthy food source that benefits people.
- Describe that healthy forests filter water and protect watersheds, and provide numerous other benefits to people.

Comprehension

- Explain how salmon runs contribute to the health of forests by contributing nutrient inputs via consumption of salmon by other animals.

Application

- Demonstrate how the size of salmon runs impact nutrient inputs.

Analysis

- Interpret the consequences of changing salmon runs on nutrient inputs and forest health, and hence how changes in salmon runs impact benefits to people.

Synthesis

- Predict how change in salmon runs affect nutrient inputs and forest health, and thereby impacts benefits to people.

Evaluation

- Assess the value of salmon in terms of their impact on nutrients and forest health, and the benefits salmon and forests provide to people.

Standards:

Next Generation Science Standards

Disciplinary Core Ideas

- LS2.A Interdependent Relationships in Ecosystems
- LS2.B Cycle of Matter and Energy Transfer in Ecosystems
- LS2.C Ecosystem Dynamics, Functioning, and Resilience

Crosscutting Concepts

- Cause and Effect
- Energy and Matter
- Stability and Change

Science and Engineering Practices

- Developing and Using Models
- Analyzing and Interpreting Data
- Constructing Explanations and Designing Solutions
- Engaging in an Argument from Evidence

Performance Expectations Middle School (Sessions 1 and 2)

- MS-LS2-1: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-ES3-4: Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Performance Expectations High School (Session 2)

- HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
- HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

Common Core English and Language Arts Standards for Science and Technical Subjects and Writing Grades 6-8

- CCSS.ELA-LITERACY.RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
- CCSS.ELA-LITERACY.WHST.6-8.1.B Support claim(s) with logical reasoning and relevant, accurate data and evidence that demonstrate an understanding of the topic or text, using credible sources.
- CCSS.ELA-LITERACY.WHST.6-8.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- CCSS.ELA-LITERACY.WHST.6-8.2.D Use precise language and domain-specific vocabulary to inform about or explain the topic.

Vocabulary:

Biomass: The total amount of matter from organisms in a given area. The mass (or weight) of all biological organisms including plants, animals and microbes makes up the total weight in a particular area.

Ecosystem: Groups of organisms that interact in a shared habitat. All the plants and animals are interconnected by ecological relationships such as predation and competition.

Deficiency: Lack of one or more nutrients essential for growth. When a plant is deficient in a nutrient, it grows more slowly or shows signs such as yellowing leaves.

Fisheries: An industry based on fish for food and other products. Fisheries usually focus on a target fish such as salmon.

Nutrient Recycling: Nutrients nourish plants and animals. Organisms combine nutrients using energy into complex molecules that sustain biological processes. Many nutrients are recycled for re-use in a system. Nature recycles many different kinds of materials so that a limited quantity of nutrients can be re-used over and over in different ways.

Materials:

Videos supporting this lesson plan:

- *Salmon – Healthy Dinner, Healthy Forests* introductory video http://vimeo.com/77811134
- Scientist interview question videos:
    1. *Salmon #1: Forest Health* - "How is it possible that the health of the forest depends on salmon?" http://vimeo.com/79497437
    2. *Salmon #2: Fishing* - "What levels of fishing cause the salmon fishery to collapse?" http://vimeo.com/79497432
    3. *Salmon #3: Overfishing* -"Will preventing overfishing help maintain healthy forests?" http://vimeo.com/79497431
    4. *Salmon #4: Science* -"How can science help us maintain sustainable fisheries?" http://vimeo.com/79497438
    5. *Salmon #5: Population Depletion* - "What happens if salmon populations decline to where they contribute no nutrients to the forest?" http://vimeo.com/79497434
- Meet the Scientist video: Jonathan Hoekstra http://vimeo.com/77229004

Session 1 Materials:

Materials for each group of students:

- 5 4" plastic flower pots with drainage holes
- 5 pot saucers to hold the flower pots
- tray to hold pots
- liter measuring cylinder
- milliliter bulb pipette
- pouring jug (to hold 1 or 2 cups of liquid)
- plant seeds (any kind of bean seeds will do, e.g., kidney, lima, etc.)
- ruler
- fish liquid emulsion fertilizer (available from gardening stores)*
- sphagnum peat moss
- perlite
- vermiculite
- plastic wrap
- 4 5 gallon buckets
- digital camera (optional)
- student created data sheet

*Note that fish emulsion fertilizer is not derived from salmon. It is being used here to simulate nutrient inputs provided by salmon to natural forests.

Session 2 Materials:

Teacher prep before lesson:

- Download NetLogo 3.1.5 and Fishery simulation (see instructions in lesson plan)

Materials for each group of students:

- Computer with Internet connection, NetLogo and Fishery simulation already installed
- Printout of student data sheet for each student (at the end of this lesson plan)

Classroom Activities:

Session 1: Simulate variation in nutrient input by comparing growth of plants.

Part 1: Engage

1. Show the *Salmon – Healthy Dinner, Healthy Forests* introductory video. Emphasize that in this activity students will model the "poop loop." Remind students that plants need nutrients to grow. The three key nutrients are nitrogen (N), phosphorus (P) and potassium (K). Commercially available fertilizers are labeled with the proportions of each of these nutrients. Lack of one or more nutrients is evident in plant growth as a nutrient *deficiency*.

2. Students will grow plants from seed in a soilless mix, which does not provide nutrients. Nutrients will be provided solely from the fish fertilizer.

3. Check the label of the fish emulsion for the NPK ratio. It is typically 5-2-2 or 5-1-1. Students will dilute the emulsion and measure plant growth with successively greater dilutions (lower concentrations of nutrients). This experiment simulates the dwindling inputs of nutrients from successively smaller salmon runs.

4. Show the scientist video *Salmon #5: Population Depletion* that answers, "What happens if salmon populations decline to where they contribute no nutrients to the forest?"

Part 2: Explore

1. Students will grow plants fertilized with different concentrations of fish emulsion solution and track their growth.

2. Pre-soak the bean seeds overnight to ensure rapid germination. Discard any seeds that are damaged or discolored.

3. Have students prepare enough soilless mix to fill the plastic pots. They should mix the ingredients as 5 parts of peat moss to 1 part of perlite and 1 part of vermiculite.
4. Plant five seeds at a uniform depth of an inch or so in each of the five pots, making 25 seeds in all. (Students can mark a pencil with the depth and make a hole for each of the seeds.)

5. Cover the seeds with the soilless mix. Place the pots in their individual saucers, and place these in the plant tray.

6. Water gently, being sure not to disturb the soil. Drain any excess water from the tray.

7. Cover the tray with plastic wrap. (The plastic wrap prevents drying out while the seeds germinate.) Place the tray in a brightly lit location at room temperature.

8. After a few days, the seeds will germinate. When the first leaves show, prepare the fish emulsion dilutions in each of the four buckets A through D. as follows. Use distilled water if available:
    A. 30 milliliters of emulsion in 15 liters of water (1:500 dilution)
    B. 3 milliliters of emulsion in 15 liters of water (1:5000)
    C. 1.5 milliliter of emulsion in 15 liters of water (1:10000)
    D. 0.75 milliliter of emulsion in 15 liters of water (1:20000)
    E. Control

    NOTE: A five gallon bucket will hold about 19 liters. A 1:500 dilution of fish emulsion is a typical quantity used for fertilizing plants.

9. Label each of the pots A through D. Label the fifth pot E as a control.

10. Remove the plastic wrap and water each pot, using the liter measuring cylinder to measure an amount of corresponding solution. Use enough water to dampen the soil, about 250 ml. Water the control pot with plain water (no fertilizer). The exact amount is not important so long as each pot receives the same quantity of liquid. Be sure to drain off excess solution. Do not let water from one pot get into the tray of another pot!

11. Ensure the area where the plants are growing is well ventilated since fish emulsion can have an unpleasant odor. (More expensive brands have a deodorizing agent added.) This usually dissipates after a couple of hours.

12. Check the plants regularly and re-water with the corresponding solutions. (The time between watering will vary depending on conditions, but be sure to water each pot at the same time, to drain off excess liquid and to ensure that the water from one saucer does not get into another.)

13. As the plants grow, use the ruler to measure their growth at regular intervals. Have students create a data sheet and record their measurements.

14. Have students note any differences in plant growth. For example, plants with a nitrogen deficiency will exhibit yellowing of leaves. Students can use a digital camera (if available) to record plant growth.

Part 3: Explain

1. Have each group create a concept map or table showing how the experiment is a model of the natural system. Using their concept map, students should compare each feature of the experiment with that of the natural system. For example, salmon provide nutrient inputs, while in the experiment, the fish emulsion substitutes for the nutrient inputs.

2. Have students explain how their model demonstrates that the nutrient inputs fertilize plants and enhance the health of the forest. Students should be able to describe how plants depend on a variety of nutrients and that dead salmon contribute mainly nitrogen, phosphorus and calcium.

3. Have students use their concept map to show how the experiment models the dilution of nutrients in the natural system. In this case, the dilution models the size of the salmon run.

4. Have students illustrate differences between their model and the natural system. For example, in natural systems most of the nutrients are not returned directly to water such as streams and rivers running through forests.

5. Much of the nutrient recycling comes about through direct consumption of dead salmon by bears, birds and other mammals. The so-called "poop loop" results in the excretion of nutrients (primarily nitrogen and phosphorus) up to several hundred meters from riversides where the salmon are consumed.

6. The decomposition of salmon and feeding on the carcass and dead bones by small mammals and invertebrates further contribute to nutrient inputs.

Part 4: Extend

1. Students may need an extra class session to complete the Extend section.

2. Have students brainstorm various ways in which nutrients from salmon contribute to the ecosystem. For example, recycling (the poop loop) increases N and P concentrations in soil. (If students are on a chemistry track, remind them that concentrations are depicted with square brackets, such as [N], [P] and [Ca].) This increases algal biomass and growth of riparian vegetation.

3. Direct consumption benefits the animals that eat salmon. Additional fat deposits increase over-winter survival, fecundity and population density of mammals and birds. Small mammals and invertebrates may also benefit. Due to the positive effect of salmon as a food source, these fish influence the populations of species that feed on them.
4. Additional effects may result. For example, bears eat fruits and berries and are therefore important seed dispersers, contributing to the abundance and variety of forest plants.

Without salmon, the smaller number of bears would result in changes to the forest vegetation.

5. Project Learning Tree provides a case study of a teacher who obtained funding that enabled more than 200 students to participate in a five full-day watershed investigations and to implement a stream restoration project. http://www2.plt.org/cms/pages/36 124 209.html

Part 5: Evaluate
Have students self-evaluate their experiments. How well did they follow instructions and document their observations? Did students understand how the experiment modeled the effect of different sized salmon runs?

Specific questions:
1. Why did the experiment require successive dilutions?
2. Why did the experiment not use undiluted fish fertilizer?
3. How many milliliters of emulsion would be needed in 20 liters of water to achieve a 1:2500 dilution?
4. List impacts of reduced salmon runs on plants & animals in the forest ecosystem.

Scoring Key for Evaluation
1. Successive dilutions model the increasingly fewer nutrients contributed by smaller and smaller salmon runs.
2. Undiluted fish fertilizer would not have represented a realistic comparison with nutrient inputs contributed by salmon. Undiluted fish fertilizer is too strong for plants.
3. Since 1 liter = 2500 ml, 20 liters of water = 20,000 milliliters. Therefore a 1:2500 dilution = 20000/2500 = **8 milliliters**
4. Any three of the following:
    a. Reduced growth and survival of animals such as birds and bears
    b. Smaller populations of birds and bears, and other animals
    c. Reduced growth of riverside vegetation
    d. Altered composition of forest vegetation

Session 2: Use a computer model to estimate a sustainable salmon harvest.

Part 1: Engage

1. Show the *Salmon – Healthy Dinner, Healthy Forests* introductory video.

2. Ask students: Have you eaten salmon?

    a. Describe how salmon is delicious and healthy. Explain that people rely on salmon *fisheries* for jobs.
    b. Tell students that salmon runs were a feature of pioneer life, and before that a tradition of Native Americans.
    c. Much of our salmon comes from fish farms, but a lot of it is still wild-harvested.
    d. Many animals such as bears rely on the annual salmon migration. That is why the forest depends on salmon too.
    e. Remind students of the "poop loop." The poop loop enables *nutrient recycling* via salmon into the forest into plants, enhancing growth of trees and shrubs, upon which many other animals depend. For example, a run of 20 million salmon provides a nutrient input equivalent to the amount of fertilizer needed for 140,000 acres of intensive corn production.
    f. The nutrients provided by salmon to the forest represent a key function in the forest-river-salmon *ecosystem*.

3. Show the *Meet the Scientist: Jonathan Hoekstra* video followed by the scientist video *Salmon #1: Forest Health* that answers the question, "How is it possible that the health of the forest depends on salmon?"

Part 2: Explore

1. Introduce students to the idea that we can model salmon populations with a fisheries model.

2. Have students work in pairs or small groups.

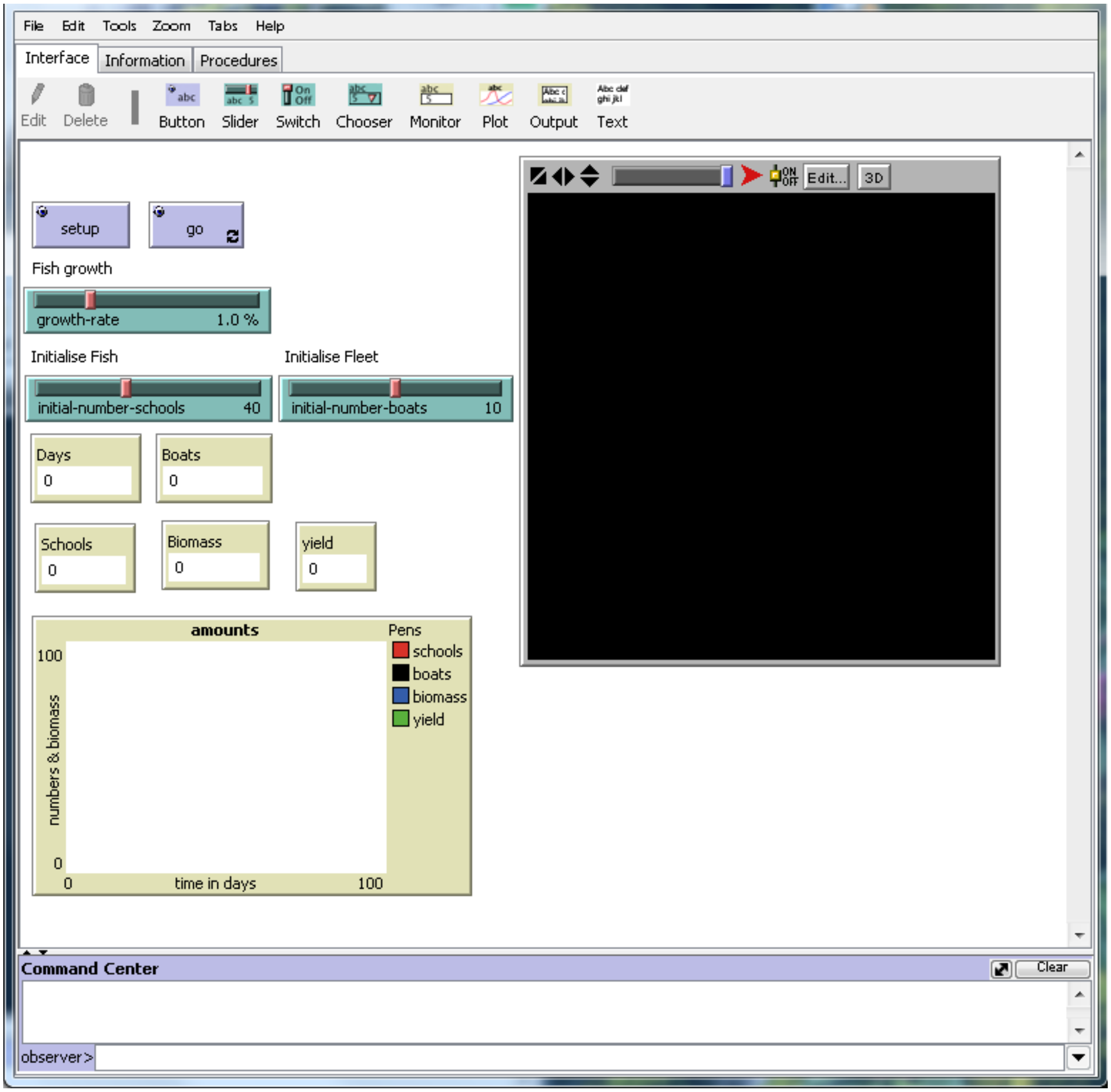
3. They will use an interactive online application to explore how changing the variables in a fishery impacts fish stocks.

4. Go to the NetLogo site and download NetLogo Version 3.1.5 (http://ccl.northwestern.edu/netlogo/3.1.5/). There are newer versions of NetLogo, but it will not run the "Fishery" model.

5. Download the "Fishery" model from the link below and save to your desktop http://ccl.northwestern.edu/netlogo/models/community/Fishery
Then open the NetLogo 3.1.5 program and go to "file" then choose "open" and find the "Fishery" model you saved to your desktop.

6. Review the information on the page (http://ccl.northwestern.edu/netlogo/models/community/Fishery) that describes the model and how it works.

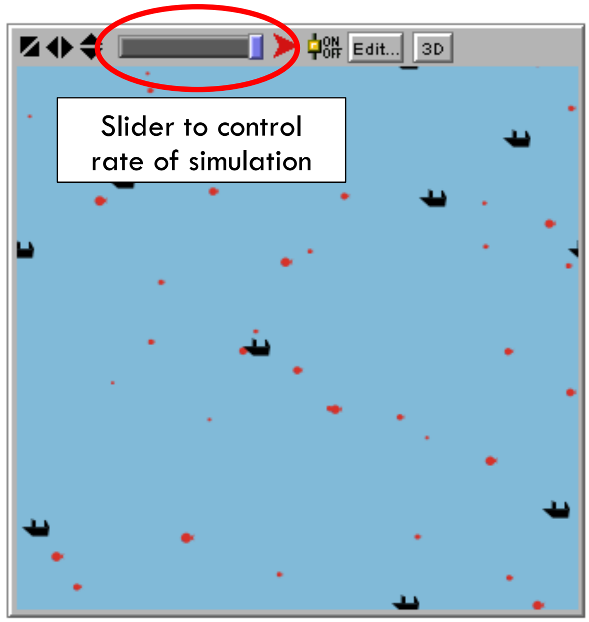
Figure 1. Screen shot of "Fishery" upon opening.



7. There are four variables, which are indicated graphically:
    a. number of boats
    b. number of schools of fish
    c. *biomass* (total weight) of fish
    d. daily yield to the fishery

8. Students set three initial conditions (by using the sliders in the green boxes) that determine how these variables change over time.
    a. Growth rate (how quickly the population grows)
    b. Initial number of schools (the starting population of fish)
    c. Initial number of boats (size of the fishing fleet)

9. Set this goal for students: **find the combination of initial conditions results in the maximum daily yield.**

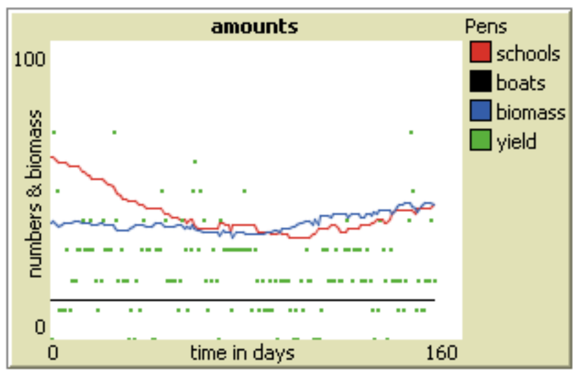


10. Have the students change the variables by using the sliders in the green boxes. It's not important which values they use, but encourage them to be systematic. When the variables are set, click "**setup**" to initiate the model. You will see the fish and boat icons load into the large window. As shown to the right.

11. To change the rate at which the model runs, move the slider at the top of the large window to the left.

12. Click "**go**" to run or stop the simulation.

13. When students change the variables by using the green sliders, they must click setup each time to reinitialize the model and start at Day 0.



14. When the simulation is running, a graph will be generated for that model. As shown to the right.

15. Have the students run 5 simulations, each for 10 days. Students will record the results of each simulation in a table. A student record sheet for the simulation is provided at the end of this lesson plan.

Example Table (five days only)

	VARIABLES			RESULTS						
				Yield					Biomass	
Simulation	Growth Rate (%)	Initial Number of Schools	Initial Number of Boats	1	2	3	4	5	Start	End
1										
2										
3										
4										
5										

For example, hold the growth rate and initial number of schools constant while varying the initial number of boats. An example result is shown for five simulations, each of five days:

Example Results (five days only)

	VARIABLES			RESULTS						
				Yield					Biomass	
Simulation	Growth Rate (%)	Initial Number of Schools	Initial Number of Boats	1	2	3	4	5	Start	End
1	1	50	4	1	0	1	1	0	149	155
2	1	50	8	3	0	1	1	0	150	153
3	1	50	12	2	2	2	2	1	144	140
4	1	50	16	3	3	3	4	4	150	143
5	1	50	20	4	4	4	4	1	158	146

16. Encourage students to explore the model. It will help them understand the system if they run the model faster, for longer. Have students look at the graphical data as well as the numbers. Depending on the inputs, they may see cyclical behavior, a collapse, or peak populations of fish. Have students answer the following questions by exploring the model:
    a. What combination of variables caused the fishery to collapse?
    b. What combination of variables resulted in maximizing salmon populations?
    c. What combination of variables resulted in maximum yields?

17. Show the scientist video *Salmon #2: Fishing* that answers the question, "What levels of fishing cause the salmon fishery to collapse?"

Part 3: Explain

1. Have students show how different inputs affect various elements of the system, and explain that using models helps scientists predict how the system will respond as system variables are changed. Students should explain that salmon populations decline due to overfishing, so the populations become unsustainable.

2. Have students explain that in the example data, 5 days of each simulation scenario, a pattern emerges. Students can discuss the pattern to see that although yields are higher with more initial boats, biomass decreases. When the initial number of boats is fewer, biomass increases.

3. Students should be able to explain that the maximum yields depend on the right combination of initial conditions. For example, if the growth rate is too low, the fish cannot replace their population, and the fishery will decline. Likewise, if the initial number of boats is too high, they will quickly remove all the fish.

4. Have students explain the broader picture in context. They can explain that ecosystems are complex and their parts are interdependent. Humans rely on natural systems for "ecosystem services." We do not exist apart from nature but as part of it. Humans must learn to manage their needs with the needs of natural systems to maintain a balance.

5. Have students explain the role of models, so that students can articulate that models help us predict where the balance is. Students can show that models help resource managers meet the needs of human society and natural systems such as salmon populations and forests.

6. Ensure that students can describe that via the "poop loop," lower salmon biomass results in less nutrient input into the forest during salmon runs. For this reason, fisheries managers must aim for a yield that does not result in a decline in biomass. (Fisheries managers call this concept "Maximum Sustainable Yield.") Show the scientist video *Salmon #3: Overfishing* that answers, "Will preventing overfishing help maintain healthy forests?"

7. Have students explain that salmon hatcheries are one way that resource managers can boost salmon populations.

8. Students should be able to show that much of the salmon that ends up in stores is not wild caught but is farmed. This source of salmon reduces pressure on wild stocks.

Part 4: Extend

1. Students will likely need an extra class session to complete the Extend section.

2. Option 1: Students can vary elements of the model to create more realistic scenarios.

    a. Advanced students can download the NetLogo software to create their own models. (http://ccl.northwestern.edu/netlogo/download.shtml)

    b. Students can add variables to show that if salmon runs decline, nutrient inputs to the forest decrease, and the decline affects plant growth and populations of other animals. Students should work on the premise that every kilogram (kg) of fish body tissue contributes 4.4 grams of phosphorus, 333 grams of nitrogen, and 50 grams of calcium.

    c. Have students address the question, "What happens if salmon populations decline to the point where they contribute nothing to nutrient inputs of the forest?" Students should work on the premise that the annual uptake of nutrients by coniferous trees is 5 kg/ha for phosphorus, 39 kg/ha for nitrogen and 35 kg/ha for calcium.

    d. Have students calculate how many fish are needed per hectare to meet these nutrient needs. Assume the average weight of a mature salmon is 5 kg.

3. Option 2: Another perspective is the role of Native Americans in the salmon fisheries. Tribal cultures have long relied on salmon as part of their sustenance and culture. Have students explore the history of Native American use of salmon fisheries. Have students address the question of how Native American use of salmon differs from commercial fisheries. (See: http://content.lib.washington.edu/salmonweb/index.html)

    a. Have students catalog different kinds of salmon products and make a list.
    b. Have students find a salmon recipe that they might enjoy eating.

   c. Have students review the history of salmon runs. Address questions such as why salmon runs have declined, and what measures have been taken to improve salmon runs.

4. Show the scientist video [Salmon #4: Science]() that answers, "How can science help us maintain sustainable fisheries?"

Part 5: Evaluate
Have students self-evaluate their models for realism and accuracy. Do students take a systematic approach to changing the necessary variables? Specific questions:

1. What happens to biomass when the initial number of fishing boats is set at the maximum with a medium growth rate (2.0%)?
2. What happens to biomass when the initial number of fishing boats is set at the maximum with a low fish growth rate (<1.0%)?
3. Predict what will happen to the forest in these situations.
4. Given the assumptions stated in the lesson, how many fish are needed to adequately fertilize a 50 hectare patch of forest with phosphorus?
5. A healthy salmon run may include 20 million fish.
   a. What is the biomass of this salmon run?
   b. How many hectares would be adequately fertilized for a year with nitrogen given a salmon run this size?
6. In what ways could a salmon hatchery or salmon farm influence the variables in the model?
7. List several different products that come from salmon.

Scoring key for evaluation

1. Biomass rises and falls in an irregular cycle.
2. Biomass quickly drops to zero.
3. If the biomass drops to zero, the salmon runs will decline and no nutrients will be recycled into the forest. Therefore forest growth will diminish.
4. Number of fish to fertilize 50 hectares (124 acres) of forest with phosphorus:
   1) Annual uptake of phosphorus is 5 kg/ha = 50 x 5 = 250 kg needed for 50 hectares.
   2) If one salmon weighs 5 kg, that yields 4.4 x 5 g = 22 grams of phosphorus per fish.
   3) 250 kg = 250,000 grams, therefore the number of fish = 250,000/22 = **11,364 fish**.
5. Biomass of a run with 20 million fish:
   a. 20 million fish = **100 million kg** of fish body tissue
   b. Number of hectares fertilized with 20 million fish:
   1) 100 million kg of body tissue = 0.333 x 100 million kilograms of nitrogen = 33 million kg
   2) Number of hectares fertilized for a year = 33 million/39 = **846,000 hectares** (~ more than twice the area of Rhode Island)
6. A salmon hatchery or salmon farm could increase the effective growth rate of the salmon population or increase the initial number of schools.

7. Salmon products include food for direct consumption and byproducts used in various applications:
   - Fresh or frozen whole salmon or fillets
   - Lox
   - Canned salmon
   - Salmon roe
   - Salmon oil
   - Fish meal
   - Pet food

Additional Online Resources

- How to Keep Salmon in the Trees
  http://blog.nature.org/conservancy/2010/10/22/how-to-keep-salmon-in-the-trees-2/

- NOAA Fisheries Website
  http://www.nmfs.noaa.gov

- The Great Salmon Run: Competition Between Wild and Farmed Salmon
  http://www.iser.uaa.alaska.edu/people/knapp/personal/pubs/TRAFFIC/The_Great_Salmon_Run.pdf

- NetLogo Programming Guide – for students who want to extend the simulation
  http://ccl.northwestern.edu/netlogo/2.0/docs/programming.html

- Southeast Alaska Fish Species
  http://www.fs.usda.gov/detail/tongass/recreation/?cid=stelprdb5413534

Further Reading

- Cole, D. W. & Gessel, S. P. (1992) Fundamentals of tree nutrition. Institute of Forest Resources Contribution No. 73. Seattle, WA: University of Washington; 7-16
  Online - http://www.cfr.washington.edu/research.smc/rfnrp/2FFC_Chap2.pdf

- Gende, S.M. et al. (2002) Pacific Salmon in aquatic and terrestrial ecosystems. BioScience 52: 917-928
  Online - http://www.fs.fed.us/pnw/pubs/journals/pnw_2002_gende001.pdf

Student Record Sheet for NetLogo Fisheries Simulation

Instructions:

1. Enter the initial values for growth rate, number of schools, and number of boats.
2. Run the simulation as directed by your teacher.
3. Enter the initial value for the biomass in the Start column on the far right.
4. After each day has passed enter the yield in columns 1 through 10 for ten days of data. (If you are running the model at fast speed you may need to pause the simulation to get the correcting reading for the yield.)
5. Enter the final value for the biomass in the End column on the far right.
6. Five simulations are enough to reveal patterns related to the variables, but you should run as many rounds of simulations as possible to get the best results.

Key:

# = Simulation number
G = Growth Rate (%)
S = Initial Number of Schools
B = Initial Number of Boats

	VARIABLES			RESULTS											
				Yield										Biomass	
#	**G**	**S**	**B**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Start**	**End**
1															
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