Aquaculture: Down on the Salmon Farm

High School Lesson Plan

Topic Science and technology

Grade Levels 9-12

Overview

This QUEST episode, *Aquaculture: Down on the Salmon Farm*, provides an overview of the growth and development of the aquaculture industry in New England. Beginning in the 1980's on the Downeast coast of Maine, fish farming started as a small, family-owned business. Today, salmon farming is one of the fastest-growing food sources, with huge fish pens in many countries. This exponential growth has caused some problems, which, in turn, have been solved through new technologies. The QUEST video explores these challenges and discusses some new, competing strategies that are currently being studied to enhance the industry and reduce some negative effects that it can have on the environment and the community.

Introduction

In this teaching unit, students will explore the problems, technological solutions, subsequent challenges, and proposed strategies for continued development of the finfish aquaculture industry. To begin, students will be presented with the following scenario: A foundation that supports research in aquaculture technology has received proposals involving three new techniques for farming finfish. The foundation would like the students to review these ideas and render an opinion on which would be the best one to support.

Next, students will view the QUEST *Aquaculture: Down on the Salmon Farm* video. As they watch, they will record the key issues that have arisen in finfish aquaculture in New England, the causes of the problems, and the solutions. They will then discuss ways in which science and technology have been utilized to address these issues. Students will categorize the problems and solutions described in the video according to how they impact the ecosystem, recognizing that some solutions have actually caused further problems.

Finally, students will do an analysis of the three proposals for future aquaculture techniques as presented in the video (land-based, open ocean, and ocean drifting). For each strategy, they will determine which current problem the technique is designed to address, what potential new problems might arise from it, and what further scientific research and/or technological development may be needed. They will compile their analysis into a presentation or report for the foundation board.

Time Allotment Five 45-minute class periods.

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Accessing Prior Knowledge

Students should have a basic understanding of how social-technological developments can impact the environment. In particular, some background knowledge of eutrophication of water bodies and the resulting degradation of the ecosystem would be helpful. In addition, some familiarity with genetics and bioengineering would also be beneficial.

Concepts to Clarify

Many students, even high school students, feel that scientists and engineers are the "experts," and that they therefore are the best qualified to make decisions about issues that might affect the public. Students may feel that these professionals know all the facts and are not influenced by personal motivation or special interests.

CONNECTIONS TO THE STANDARDS

National Science Education Standards	Benchmarks for Science Literacy	Maine Learning Results	New Hampshire Curriculum Framework	Vermont Learning Standards
Science and Technology E2: Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human	Issues in Technology In deciding on proposals to introduce new technologies or to curtail existing ones, some key questions arise concerning alternatives, risks, costs and benefits. What alternative ways are there to achieve the same ends, and how do the alternatives compare with the plans being put forward? Who benefits and who suffers? What are the financial and social costs, do they change over time, and who bears	Science and Technology 4: Analyze the impacts of various scientific and technological developments.	Science, Technology and Society 2f: Describe immediate and long-term consequences of various alternative solutions for science and/or technology-related issues, e.g., natural catastrophes, interactions of populations, resources and environment, health, and disease.	Technological Systems 7.17: Students apply knowledge and understanding of technological systems to respond to a variety of issues. This is evident when students: (7.17.ddd) Evaluate complex technological outputs based on the original design specifications, and create modifications to improve that system.

CONNECTIONS TO THE STANDARDS cont.

aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.	them? What are the risks associated with using (or not using) the new technology, how serious are they, and who is in jeopardy? What human, material, and energy resources will be needed to build, install, operate, maintain, and replace the new technology, and where will they come from? How will the new technology and its waste products be disposed of, and at what costs?			

MATERIALS NEEDED

- TV with VCR
- QUEST *Aquaculture: Down on the Salmon Farm* video
- Colored pencils or markers
- Plain white paper
- Chart paper or board with markers
- Copies of each of the following reproducible handouts:
  - Student Handout 1: The Bluewater Revolution
  - Student Handout 2: What Is the Difference Between Science and Technology?
  - Student Handout 3: New England Fish Farm Foundation Letter
  - Student Handout 4: QUEST *Aquaculture: Down on the Salmon Farm* Video Viewing Guide
  - Student Handout 5: Analyzing the Problems in Farming Fish
  - Student Handout 6: *QUEST* at Home – Farmed Fish at the Supermarket?

1. Introducing the Concepts

Activity 1

In this activity, students read a news article on aquaculture. They will analyze the scientific and technological background needed for a career in finfish aquaculture. Students will then be asked by a fictitious foundation to research three new technologies being developed for aquaculture. Finally, they will determine which of the three technologies the foundation should support.

Step 1

Distribute copies of Student Handout 1 (The Bluewater Revolution). This handout contains an article from Wired magazine on new trends in aquaculture. You may choose to assign this rather long article as in-class reading, or you may prefer to have students read it as homework.

Step 2

Arrange students in teams of 2-3. Distribute copies of Student Handout 2 (What Is the Difference Between Science and Technology?). Direct each team to review the directions on the handout. Based on the article they read, ask students to brainstorm a list of the background that someone with a career in finfish aquaculture would need to be successful.

Step 3

Next, distribute a sheet of plain white paper to each student. Have students work individually to make a concept map of the list they have just brainstormed using the white paper. Instruct them to link related ideas with arrows to show their connections; also have them add words along the arrows to describe the pertinent relationships.

Step 4

Ask students to rejoin their teams. Working together, each team should identify which of the ideas on the brainstormed list are science skills, which of the ideas on the list focus on developing new technologies, and which ideas might be a bit of both. Have students color-code their individual concept maps accordingly. Then direct them to fill out the T-chart on their copies of Student Handout 2.

Step 5

As a whole class, discuss students' ideas. On chart paper or the board, create a master T-chart that categorizes each concept as either representing scientific knowledge or technological understanding. Then direct students to complete the T-charts on their copies of Student Handout 2. Finally, have a wrap-up discussion to ensure that students can determine the relationship between science and technology. Ask students to explain this in their own words on item 5 of Student Handout 2.

Step 6

Distribute copies of Student Handout 3 (New England Fish Farm Foundation Letter). The letter on the handout asks students' advice on three proposals for new technologies that are being presented to support finfish aquaculture. Explain that during this teaching unit, the class will be researching the background of finfish aquaculture and the problems it has caused. Also tell students that they will ultimately be asked to respond formally to the New England Fish Farm Foundation.

2. Exploring the Concepts

Activity 2

In the activity that follows, students will view the QUEST episode *Aquaculture: Down on the Salmon Farm.* They will take notes to document the changing technologies of aquaculture and some proposed new strategies to deal with the negative ramifications.

Step 1

Distribute Student Handout 4 (QUEST *Aquaculture: Down on the Salmon Farm* Video Viewing Guide). Review the handout with students, and direct them to complete it while watching the video.

Step 2

Show the video to the class. It may be necessary to stop periodically so that students can complete each item on the handout thoroughly.

Step 3

When the class has finished viewing the video and completing Student Handout 4, have them share their ideas with their teams.

3. Developing the Concepts

Activity 3

In the next activity, students will work first individually, then in teams, to analyze the information they gathered during the QUEST video. They will categorize the problems and issues into certain key areas based on their impact on aquaculture. Examples of such categories include water quality, interbreeding, and disease.

Step 1

Distribute copies of Student Handout 5 (Analyzing the Problems in Farming Fish). Ask students to use their notes from Student Handout 4 and information they gathered from the article on Student Handout 1 to group the problems facing aquaculture into certain basic categories. These categories should represent the type of environmental impact each problem causes, such as water quality, fish stocks or fish breeding, disease, and so on.

Have students first work individually, using Student Handout 4, to categorize the problems cited in the video. They should also identify the solutions currently being proposed, identify any problems the new solutions may pose, and describe any further research they think might be beneficial in resolving the issue.

Step 2

When students have completed their individual charts, have them rejoin their teams. Give teams time to discuss how they completed their handouts and resolve any discrepancies they encounter.

Finally, as a whole class, discuss students' findings. Create a master table for the class on chart paper or the board.

Step 3

Hold a class discussion during which you ask students to identify times in the QUEST video when new technological solutions have been needed and times when new scientific research has been needed. Note that scientific research tends to provide us with information about how the natural world reacts to various impacts, while technological solutions introduce mechanics to solve the problems caused by these impacts. In their charts on Student Handout 5, have students note which of the possible solutions listed are technological in nature and which represent scientific research.

4. Synthesizing and Applying the Concepts

In the culminating activity that follows, teams will develop their presentations for the New England Fish Farm Foundation. They will do further research, if needed, to analyze the alternative approaches to aquaculture. They will create a poster, a presentation, a brochure, or a report for the foundation. Teams will then share their research, analysis, and decisions with their classmates.

Step 1

Have students rejoin their teams. Direct each team to use their notes and handouts, particularly the article on Student Handout 1, as they prepare their presentations. Also encourage them to do further research (as needed) on the three alternative strategies for future finfish aquaculture that are being proposed: open-ocean pens, land-based ponds, and ocean drifter pens.

Explain that as part of their presentations to the New England Fish Farm Foundation, teams will need to identify how each solution will address the current negative environmental impact of fish farming. They will also need to recognize possible additional problems presented by each alternative. Teams should summarize how each strategy benefits or harms each of the key issue areas. In addition, they should consider what further scientific research and/or technological developments they think might be needed. As a bonus, teams can suggest any additional strategies that might improve the proposed solutions, or they may create one or more new possible solutions.

Step 2

Once they have collected all of the information they need, each team will decide which new strategy they think is the best for the foundation to fund. Teams can choose the form in which they prefer to present their recommendations – a poster, report, letter, brochure, or PowerPoint presentation. Remind them to summarize their findings and justify their position. Assign a due date for the completed projects.

Step 3

On the appointed day, students should share their presentations with the class.

5. Extending the Concepts

As a possible take-home activity to do with their families, students can conduct a supermarket survey of the fish available in their local area. They should determine whether each type of fish is farm-raised or wild, and in which country the fish was caught.

QUEST at Home: Supermarket Survey

Step 1

Distribute copies of Student Handout 6 (*QUEST* at Home – Farmed Fish at the Supermarket?). Review the handout with the class and clarify as needed. Assign a due date for the activity to be completed.

Step 2

On the due date, have students bring their completed surveys in to school and share their findings with the class.

Community Connections

– A regional fishing wharf or market can be very interesting to explore. If possible, arrange a field trip to a commercial fishing area to see how the fish are unloaded, boxed, and sold. Discuss with the owner how far away the fish is shipped and how it is sent.

– Go fishing! Encourage students to learn from family members, friends, or local store owners where good fishing sites are. Have students plot these sites on a map. They can also learn about where fish can be found in the region by researching fish habitats at the local library. You could also have a representative of a local sporting club talk to the class about fishing in the area.

– Many people are fascinated by fish and keep aquariums. Some of these are saltwater aquariums, in which people raise species normally found in coastal waters around the world. Encourage students to visit or call a pet store and ask who might be willing to speak to the class about raising fish in an aquarium.

Career Opportunities

Research technicians help design and run equipment used by researchers. They are involved in taking various measurements with highly technical instruments. They maintain the equipment, and often assist in making adaptations to the equipment to improve performance.

Fisheries biologists can conduct research on fish stocks in the wild, raise fish in a hatchery, study fish behavior and reproduction in a laboratory, or work in an aquarium.

Marine biologists study marine ecosystems such as open ocean, marsh, coral reefs, and so on. They examine the health of specific environments and the species that live in them. In addition, they research ocean currents and waves as well as changes in the ocean, such as El Nino.

Marine educators can teach classes at an aquarium, research facility, or in a school setting – from K-12 to adult.

Resources

Fact Sheet: Marine Aquaculture
http://www.seachangecenter.org/learnmore/aquaculture.cfm

Marine Aquaculture in the United States
http://www.pewoceans.org/oceanfacts/2002/01/11/fact_22988.asp

Northeast Regional Aquaculture Center
http://www.old.umassd.edu/specialprograms/nrac/

Salmon Aquaculture Review – Chapter 11: Alternative Salmon Farming Technology
http://www.intrafish.com/laws-and-regulations/report_bc/v1chp11.htm

MIT Robofeeder
http://web.mit.edu/seagrant/aqua/cfer/robofeeder.html

MIT The Ocean Drifter – Fish Farming on a Global Scale *http://web.mit.edu/seagrant/aqua/cfer/#oceandrift*
(based on SeaStation: *http://www.oceanspar.com/seastation.htm*)

The Bluewater Revolution

The oceans of the world are being overfished. The solution: roaming robots that bring fish farming to the open seas.

(by Charles C. Mann, Wired, Issue 12.05, May 2004
http://www.wired.com/wired/archive/12.05/fish.html?pg=1&topic=fish&topic_set=)

About 9 miles southeast of New Hampshire, near the Isles of Shoals, what seems to be an ordinary yellow navigation buoy sways in the Atlantic chop. Like a regular buoy, it's a metal cylinder that extends 10 feet above the surface and blinks its lights to warn away passing ships. Unlike a regular buoy, though, it has an access hatch that leads to an inner chamber crammed with enough electronics to merit its own IT staff. Indeed, this may be the first buoy in history that had its launch delayed by a software glitch.

The buoy is the antenna, eyes, and brain of a sprawling apparatus suspended beneath the surface like a huge aquatic insect, its legs of thick steel chain tethered to the ocean floor. The creature's body is a group of three cages, each resembling a gigantic toy top. Inside the cages are swirling, stupid mobs of fish.

The apparatus, an experiment operated by the University of New Hampshire, makes up the first fish farm ever on the open ocean. But this undertaking is more than the latest step in humankind's long effort to tame the seas. The university's Open Ocean Aquaculture Project may represent the best hope for saving those seas – or at least much of the life within them.

Inside the cages swim halibut, haddock, and cod, species fished in the Northeast for centuries. Of the three, the most important has always been cod, once so abundant that early European visitors reported catching them simply by lowering baskets into the water. "In relation to our present modes of fishing," the eminent biologist T. H. Huxley said in 1883, "a number of the most important sea fisheries, such as the cod fishery are inexhaustible."

Today the abundance Huxley extolled is on the verge of disappearing. Unless something changes soon, biologist Daniel Pauly recently warned in *The New York Times*, there will be nothing left for the next generation but "plankton stew."

Twenty-eight percent of fish stocks worldwide are either overfished or nearing extinction, according to the United Nations Food and Agricultural Organization; another 47 percent are near the limits of sustainability. In waters off the U.S., roughly a third of stocks are in jeopardy, the U.S. National Oceanic and Atmospheric Administration reports. The waters off New England and Newfoundland are by some measures the worst in the world; a University of British Columbia team led by Pauly predicted last year that many large species "will be all but gone from the North Atlantic region within a few decades." Humanity is setting off the aquatic equivalent of a neutron bomb, leaving the marine environment intact but killing off all its inhabitants.

Meanwhile, the demand for fish continues to rise. Driven by a growing human population as well as rising standards of living that lead more people to seek meat in their diets, fish consumption doubled between

1973 and 1997, according to a joint study by two leading think tanks, the International Food Policy Research Institute and the WorldFish Center. By 2020, the catch will have to increase again by nearly half just to keep up with demand. Fishing restrictions won't solve the problem: The seas are too big to police. Moreover, the greatest demand comes from developing nations in Asia, whose citizens can hardly be told to eat less protein than their counterparts in the West.

The answer lies in aquaculture: increasing the supply of fish by farming them as though they were livestock. "Without aquaculture, you'd be talking about a tripling or quadrupling of fish prices by 2020 or 2030, which would have very negative impacts on nutrition in developing countries," says IFPRI's Mark Rosegrant, one of the study's authors. Already, a third of the annual global fish harvest comes from farms, both on land and in shallow water just offshore. But today's methods won't be able to produce the volume of fish needed for tomorrow – they're too dirty, costly, and politically unpopular. Preventing catastrophic overfishing will require aquaculture on an unprecedented scale, and that means forging out into the open ocean. It will demand a shift as dramatic as that of the agricultural Green Revolution in the 1960s and 1970s – a Blue Revolution that is already underway.

The University of New Hampshire experiment, along with similar installations in countries from Portugal to China, is just the beginning. In the future, ocean ranches will be everywhere, except they'll be vastly bigger and fully automated – and mobile. Launched with lab-bred baby fish, these enormous motorized pens will hitch months-long rides on ocean currents and arrive at their destinations filled with mature animals, fattened and ready for market.

"It took thousands of years to make the Neolithic transformation from hunting and gathering to modern agriculture," notes Cliff Goudey, director of MIT's Center for Fisheries Engineering Research. The transition to open-ocean aquaculture, though, will have to take place within a few decades. "If it doesn't happen," he says, "I'm afraid we'll destroy the seas."

For thousands of years, Chinese farmers have raised carp in artificial pools shared by ducks and pigs. George Nardi was aware of that history, but it didn't prepare him for the scope of aquaculture in China today. As chief technical officer for GreatBay Aquaculture, a commercial seafood farm in Portsmouth, New Hampshire, Nardi had been asked to produce 200,000 baby flounder – enough for more than a thousand tons of meat when full-grown – for farms in the seaside city of Qingdao. In October, after he sent off the 1 1/2-inch fingerlings via airfreight, he set out to meet them at their destination.

On his drive from Beijing to Qingdao, Nardi passed scores of land-based fish farms, each housing a dozen concrete tanks 20 feet per side and swarming with turbot or shrimp. When he arrived in Qingdao, his hosts showed him still more, tank after tank filled with salt water from wells deep enough to catch seepage from the sea.

Between 1980 and 1997, the Chinese Bureau of Fisheries reports, aquaculture harvests grew at an annual rate of 16.7 percent, jumping from 1.9 million to nearly 23 million tons – two-thirds of the world's total production, according to the United Nations. By 2020, bureau deputy director-general Wang Yianliang has predicted, fish will be the staple protein of the planet's most populous nation.

Pauly, the University of British Columbia biologist, argues that China's statistics are exaggerated. But no one disputes that China and other Asian countries have made extraordinary strides in aquaculture. According to UN statistics, the six nations that produce the most farmed fish are in Asia. Most intend to increase their annual harvests. And all expect to do it the traditional way, using pools, rivers, and rice paddies.

Just one problem, says IFPRI research director Rosegrant: Even that huge effort won't satisfy the region's appetite. Asia won't be able to meet the growing demand using traditional techniques, and neither will the rest of the world. The usual approaches – the land-based method practiced in China and near-shore farming employed elsewhere – are simply too limited.

The main problem with raising fish on land is that it doesn't – so to speak – scale well. Crowding animals into confined spaces increases the potential for devastating epidemics. At the same time, it creates demands for electricity and water that Asian infrastructures can't fulfill – a serious problem, given that an aeration or filter failure can kill an entire harvest in minutes. "Ultimately," Rosegrant says, "there's only so many fish you can grow on land."

Near-shore operations don't require electricity or well water, but they face a different set of problems. In British Columbia, Newfoundland, and Norway, salmon farmers set baglike nylon pens in bays and inlets, where they're protected from extreme weather. The very calmness of the water, however, means that currents don't disperse the inevitable plume of waste. A farm of 200,000 salmon flushes nitrogen and phosphorus into the water at levels equivalent to the sewage from 20,000 people. Near-shore salmon farms "are a recipe for ecological disaster," says Don Staniford, managing director of the Salmon Farm Protest Group in Scotland.

But the impact of environmentalist complaints pales next to that of the most powerful force pushing aquaculture into deeper water: the limited supply of waterfront real estate. "People in summer homes don't want a bunch of fish cages cluttering up their million-dollar views," says Richard Langan, director of the University of New Hampshire experiment. With zoning in riverways and along shorelines tightening in every part of the world, "there's no room left for farming. The industry is being pushed into the sea."

A peek inside Chris Duffy's office serves to illustrate this point. Duffy is operations manager of GreatBay Aquaculture, and his walls are covered with maps showing every fish farm in northern New England and eastern Canada. "Up here the water is too cold for salmon," he says, pointing to the north. "South of this line" – his finger moves to the tip of Maine – "the state says no aquaculture, because developers don't like it. That leaves only this zone in the middle. There's practically nowhere else to go. That's why everyone is looking in places like" – the finger moves east, into the Atlantic, and taps the map at a location many miles offshore – "like *this*."

The sea is a "high-energy environment," says David Fredriksson, an engineer working on the University of New Hampshire project. High-energy environment is an engineer's way of saying prone to sudden hurricanes, monster waves, and abrupt currents that wreak havoc on human-made objects. The budget of *Waterworld*, Kevin Costner's notorious 1995 bomb, ballooned by millions of dollars after an unseasonable storm tore apart its elaborate floating set, constructed in a supposedly calm patch of the Pacific. *Waterworld* is why people don't set up farms in the middle of the ocean.

Only one year after the release of *Waterworld*, Net Systems, a trawling gear outfit in Bainbridge Island, Washington, became one of the first enterprises to sell equipment for open-ocean aquaculture. "We were way ahead, which was our big mistake," says senior engineer Langley Gace. "When we came out with our first product, nobody knew what it was."

Rather than a floppy nylon pen, Net Systems uses a rigid cage that resembles two huge cones glued end to end, joined by a steel ring around the middle. Fifty feet high and 80 feet at its widest point, the company's largest cage has an inner volume of more than 100,000 cubic feet, enough for tens of thousands of fish. The whole structure is covered tightly with netting and tethered to the buoy that contains the equipment room and feeding mechanism. A steel cylinder 3 feet in diameter runs from the bottom of the cage to the top in a fashion reminiscent of a child's gyroscope. The cylinder is capped by a pump that forces air into and out of its body. Depending on the mix of air and water, the cage floats on the surface or sinks to a desired depth.

The ability to float beneath the waves is the key to solving the *Waterworld* problem. However rough the surface, the sea 60 feet below is "a quiet, almost a gentle environment," says Jim McVey, aquaculture research coordinator for NOAA. "The fish like it. The equipment likes it. Heck, I like it."

In addition to the University of New Hampshire project, aquaculture firms are using Net Systems cages in waters near the Bahamas, China, the Philippines, Portugal, Puerto Rico, and Spain. And Net Systems, with help from the university, is already working on the next stage: a 20-ton buoy that will automatically feed and monitor fish for weeks at a time. "Ultimately, you should be able to run the farm from a desk onshore," says Michael Chambers, project manager of the UNH experiment.

Goudey, the MIT fisheries engineer, views these efforts as small prototypes. Backed by federal funds, he has begun work on an immense next-generation design, 174 feet tall and 270 feet in diameter, called the Ocean Drifter. Unlike its predecessors, which are fixed to the seafloor, this enormous cage will roam the seas, propelled by three electric thruster motors attached to the rig's steel equator. Powered by a diesel generator mounted atop the central spar and steered by software, it will venture hundreds of miles from shore. When the fish are big enough to sell, a specially designed ship will embrace the cage and hoist it aboard.

"The ocean is full of predictable currents, or gyres," Goudey says. "If you could get the cage into one of these gyres, it would essentially stay in the same place, or at least have a predictable trajectory. Even if you had just a slight ability to adjust its movement, you'd be able to control its path pretty exactly." In his view, "you could build a fleet of these things in the Straits of Florida, fill them with fingerlings of, say, cobia, and let them follow the Gulf Stream for nine months until they reached their intended market in Europe with a harvestable crop. Then you'd load them up again and send them back along the southern route with another crop."

Ping-ponging slowly between continents, these enormous, largely automated underwater ranches would drift into big-city harbors – fresh fish by the ton, delivered daily. No more giant factory ships with illegal 20-mile-long drift nets! No more airfreighting frozen slabs of tuna from the Atlantic for auction in Tokyo! Instead, hatcheries in Mexico would send baby tuna to Japan in million-cubic-foot cages. By the time the floating farms reached Tokyo, the fish, cosseted in their cages like Kobe cattle in their stalls, would be ready for sashimi.

Many obstacles stand in the way of this vision, among them a paltry federal ocean-aquaculture research budget ($780,000 this year) and no clear method for obtaining the necessary permits (NOAA recently persuaded Congress to introduce legislation to streamline licensing of commercial aquaculture operations).

"The legal regime is a major issue," MIT's Goudey says. "Is this kind of thing a vessel? If not, what is it? How can you establish title to this kind of object in the open ocean?"

He sighs. "And then, of course, you're going to have to deal with Greenpeace."

Deep-sea farms will spew as much waste into the water as the near-shore facilities opposed by environmentalists, but they'll be operating in the open ocean – an area so devoid of life that it's routinely called a wasteland. In this vast, lightly inhabited ecosystem, sea-ranching advocates say, the stream of waste will serve as a nutrient base for plant and animal life. Much as docks and pilings become centers of aquatic communities, the giant cages will become ecosystems in themselves, with as many fish outside the cages as in them.

"They could – and some of the preliminary research suggests this – enrich the environment, rather than impoverish it," NOAA's McVey says.

Nonetheless, environmentalists still decry the aquaculture revolution. Their fears center less on ordinary waste than on a more insidious kind of pollution: genetic.

When fish farmers select breeding stock, they look for specially fast-growing, meaty creatures. Over generations, the difference between the choices made by humans and those made by nature lead the fish to evolve, in the same way human choices created European cattle breeds from ancestral populations in Asia and Africa. And just as today's huge, gentle milk producers are strikingly unlike their fierce, shaggy ancestors, farmed fish will become ever more distinct from those in the wild. Meanwhile, varieties specially adapted to open-ocean farming are bound to be created through genetic engineering.

Preventing the farmed and the wild from interbreeding is surprisingly difficult. Fish leap from pools and tanks into nearby streams and wriggle through holes in near-shore pens gnawed by seals and sea lions.

To critics like Staniford, such escapes are potential genetic catastrophes. Farmed animals are selected to grow quickly but not to breed successfully – that's done in a lab. Wild fish breed exuberantly but have evolved to grow more slowly so they can ride out drops in the food supply. Laboratory studies suggest that ravenous farmed salmon could monopolize the food supply, then fail to spawn. "They displace the natural population and then neither survive," Staniford says.

Outside the lab, though, that displacement doesn't always occur. Since 1990, more than a million farmed salmon have jumped the fence in Puget Sound and its tributaries, according to NOAA's Northwest Fisheries Science Center. Almost none were seen again, apparently because their docility made them easy prey. Judging by autopsies of escapees, the pen-grown fish also had trouble finding food – they were too dumb to survive.

Moreover, Net Systems' seafaring cages are much harder to escape than traditional tanks and pens. Indeed, Gace knows of no instance in which it has happened. The outer netting is made of Spectra, a superstrong polyethylene fiber used by NASA to tether spacewalking astronauts to the mothership. Wrapped tautly around the frame, it leaves no slack for predators to grip, but the material is built to withstand the most ferocious attacks.

Nothing will ever reduce the chance of genetic pollution to zero – as they say in *Jurassic Park*, life finds a way. To some activists, this is sufficient reason to ban aquaculture altogether. To NOAA's McVey, though, the whole issue is overblown. Humans, inveterate tinkerers, have genetically altered every species grown on farm, garden, and lawn, and these varieties all hybridize with their wild relatives. On roadsides in southern Mexico, for example, crosses between corn and its nearest wild relative, teosinte, are common.

Most of the time, these hybrids are benign; often they can't reproduce. Sometimes, to be sure, they can cause problems. Sugar beet mixes with sea beet, a wild relative, to produce a weed that plagues European agriculture – the hybrid's buried, bulbous roots are woody and hard enough to make fields unplowable.

Farmers have had to be on the lookout for such hybrids for thousands of years. The Blue Revolution is simply moving this process into the sea. It's a momentous change, but one that humankind has seen before.

To aquaculture enthusiasts, the advent of open-ocean farming – giant, autonomous farms ferrying genetically altered fish across the ocean – is both fascinatingly novel and mundanely obvious. On one hand, it's unlike anything that has been attempted before. On the other, it's merely a long-delayed extension of the Green Revolution into the 70 percent of the planet that's covered by water. Like the Green Revolution, it will probably have some negative environmental effects. But it will also feed countless millions – and possibly stop humankind from plundering the seas bare.

"There are risks, absolutely there are," says McVey. "But we have the chance to set in motion a second agricultural revolution in our lifetimes. Plus, as a bonus, we can help save the oceans. I honestly can't think of anything more exciting than that."

What Is the Difference Between Science and Technology?

1. Working with your team, briefly review the article on Student Handout 1. Then, using a separate sheet of paper, brainstorm with your team a list of the kind of background that someone would need for a career in finfish aquaculture.

2. Working individually, create a concept map containing the information from the list you have just brainstormed. Draw arrows between ideas that connect, and label them to explain the connections.

3. Again as a team, discuss the items on your concept maps that you think represent scientific knowledge, which items represent an understanding of technology, and which might represent both. Then color-code your concept maps accordingly.

4. After discussion with your class, complete the chart below to categorize the concepts you listed earlier as either scientific knowledge or technological understanding. If there are any concepts that seem to be both, list them in both columns.

Science	Technology

5. Summarize the relationship between science and technology:

New England Fish Farm Foundation Letter

Coastaltown, New England

Dear Students,

It has come to our attention that your class is studying finfish aquaculture. Our foundation supports research and development of new ideas in this area. Each year we give grants to a small number of businesses and organizations to help them create new tools and techniques for this industry.

This year, we have received a number of very good proposals. Yet, we are unsettled about the merits of each one. We would like to hear the opinions of others familiar with this business.

Here are the three ideas presented in the proposals for funding. We would like you to learn more about these concepts in your class studies, and then, as teams, present your ideas to us on which proposal should be funded. We would like you to examine how well each idea addresses current issues the industry is facing, as well as whether any of the ideas might pose new problems.

> **Proposal #1:** These individuals think that the best future for finfish aquaculture would be to move the pens offshore, anchor them to the bottom, and allow the stronger current to disperse any excess waste.
>
> **Proposal #2:** This team feels that aquaculture should be done in land-based systems that circulate seawater through a controlled system.
>
> **Proposal #3:** This group wants to create floating finfish tanks that would drift with the ocean currents.

We appreciate your class's willingness to help us examine these ideas and resolve an appropriate decision on funding.

Thank you in advance for your time and effort.

Sal Monfish
President
New England Fish Farm Foundation

QUEST: Finfish Aquaculture
Video Viewing Guide

Directions: Respond to the questions below while watching the QUEST video.

1. What is one of the primary types of fish farmed today?

2. Why has aquaculture become so important?

3. How do farm-raised salmon threaten wild salmon?

4. How do farm-raised salmon escape their nets?

5. How is fish food that is given to farmed salmon a threat?

6. What are some of the problems caused by fish farming?

7. What solutions have fish farmers found to prevent these problems?

8. In a table similar to the one below, list some alternative strategies being proposed for new ways to farm fish. Identify what problems they solve as well as what problems they might actually cause.

Strategy	Solution	Possible Problem

Analyzing the Problems in Farming Fish

Directions: Using the notes from the video and the article you read, categorize the problems facing aquaculture (for example, water quality, disease, etc.). Place each specific category in the first column. Identify all of the proposed solutions for each category, using a separate row for each solution. Identify any problems the new solutions may pose, and describe any further research you think might help in deciding how to solve the problem. Continue on another sheet of paper if needed.

Key Issues Facing Aquaculture	Possible Solutions	Possible Problems from New Solution	Further Research

Farmed Fish at the Supermarket?

You're on a Quest!

Many species of fish that are currently available at local supermarkets are farm-raised. Supermarkets will often note this in their display cases, or the individuasl selling the fish will know the source of the fish.

Directions: Take a field trip to your local supermarket. While you are there, complete the table below to record which fish available to you are farm-raised. You will also see how farm-raised and wild fish compare in price.

When you return home, look at a map of the world and locate where each fish species you saw at the market was caught. Estimate how many miles the fish had to be transported. Which traveled the farthest? Which traveled the shortest distance?

Species of Fish	Wild Fish?	Farm-Raised?	Source Country of Fish

Mark any species on the list that could be caught locally. Which species can be caught within New England? Ask your parents how this compares with the fish available when they grew up. Discuss what kinds of technology are now available that can allow fish to be caught and processed so far away and still be fresh when people buy them in the store.

QUEST: Investigating Our World is a regional public television series seen on Maine Public Broadcasting Network, Vermont Public Television, and New Hampshire Public Television

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