



Harmful Algal Bloom Hunter's Handbook

The Science Behind the Story

"Science at Sea: The Hunt for Killer Algae"

- Classroom Activities and Experiments
- Phytoplankton Identification Chart
 - Glossary of Terms
 - Cruise Journal





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Algae Hunters: Video Exercise



Estimated Time: 45 minutes
Grade Levels: 8-11

Materials

- DVD Player
- Copy of film *Science at Sea: The Hunt for Killer Algae*
- 4-5 Reference copies of Cruise Journal and Glossary

Scientists are constantly observing the world around them, and in this exercise your scientific world will be this video - so pay close attention. As you watch the video about oceanographers searching for toxic algae, rate your powers of observation by how many questions you can answer. Some are challenging! Refer to the Cruise Journal and Glossary at the end if you haven't found all of the answers.

What is the name of the **neurotoxin** produced by the microscopic algae *Pseudo-nitzschia*?

Where is the Juan de Fuca Eddy?

What are the four basic disciplines of oceanography?

Are there volunteers on the research cruise?

How many scientists are on the cruise?

What direction do the winds primarily blow in this area in the summer?

What equipment is used to catch **phytoplankton**?

List three environmental variables that are measured by a **CTD**.

What does a flow injection autoanalyzer measure?

What is a **treatment** and how is it used in an experiment?

Is the use of "Killer Algae" in the title accurate? Why or why not?



Building a Plankton Net



Estimated Time: 50 minutes

Grade Levels: 5-8

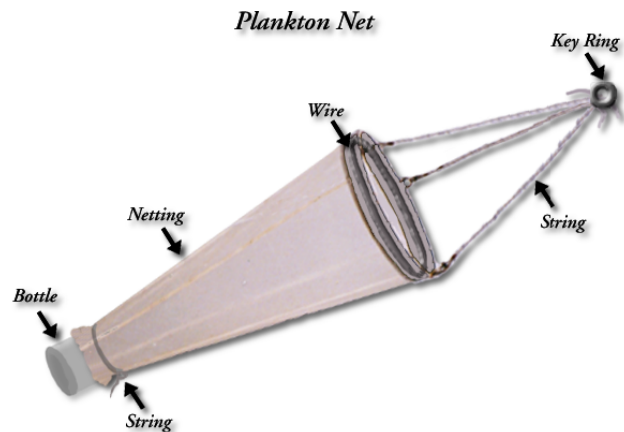
Materials

For each net:

- Thin wire, 50 cm (20 in) in length
- Duct tape
- Electrical tape (optional)
- Nylon stocking or a leg cut from panty hose
- Heavy thread and needle
- Half of a plastic water bottle w/cap
- String
- Scissors
- Key ring (optional)

Plankton are the microbes, plants and animals that drift on the ocean's currents and in lakes and rivers. They are abundant in the surface waters where sunlight and **nutrients** are readily available.

Phytoplankton are the microscopic plant-like organisms that convert sunlight and nutrients to high-energy carbohydrates and other organic matter. In this activity, you will make a simple plankton net from wire and a nylon stocking. The net is a funnel-shaped, fine-mesh net that is towed through the water, to trap the plankton in its path.



Activity

1. Bend the wire into a circle and use the electrical tape or duct tape to fasten the loose ends together.
2. Roll the mouth of the stocking several times around the wire ring. Sew the stocking to the wire using the heavy thread and needle. Alternatively, use duct tape to secure the stocking all the way around the wire.
3. Cut off the foot of the stocking, and then place the end of the stocking around the outside of the water bottle. Use a piece of heavy string to tie the stocking securely to the top of the bottle. Use duct tape to reinforce the connection between the bottle, string, and stocking.
4. Cut three pieces of string, each about 50 cm long, to make the bridle to tow your net. Tie them at equal intervals around your ring. Tie the three loose ends of string to a key ring, or together if not using a key ring. This is the bridle. Your plankton net is complete.
5. To tow for plankton, tie a length of string to your bridle and pull your net through the water. The plankton will collect in the bottle. Remove your sample by unscrewing the cap and drain into a container. View your plankton through a microscope.
6. Why did we use nylon stockings as part of the net? What would happen if you made a plankton net out of burlap? Why is it important to use a fine mesh when constructing a plankton net?



Plankton Identification Bingo



Estimated Time: 50 minutes
Grade Levels: 7-9

Materials

- Plankton samples
- Compound microscopes
- Glass slides and coverslips
- Phytoplankton Identification Chart
- Reference copies of the Glossary and Day 5 of Cruise Journal

Activity

1. Use an eye dropper to collect a few drops of the plankton sample, place on a slide and then cover it with a cover slip. Since the plankton can move up and down in the drop, you may need to refocus your microscope to see plankton at different levels.

3. To distinguish different plankton types, you may wish to discuss how to differentiate oceanic plants from animals. Will they have different colors, sizes, or structures?

3. Work in teams of two. Use the Phytoplankton Identification Chart, Glossary, and Day 5 of the Cruise Journal to identify the following plankton under the microscope, the first team to find five across should call BINGO! Be careful—one *plankter* may count toward multiple boxes! Write the name of the plankter or draw a picture in the boxes as you find them.

Colonial diatom	Zooplankton	FREE SQUARE!	Centric diatom	Contains chloroplasts
Brown or Red in color	FREE SQUARE!	Photosynthetic	Individual diatom	Vertical migrator
Square diatom	Dinoflagellate	Planktonic	Autotroph	FREE SQUARE!
FREE SQUARE!	Chain of 10 or more cells	Cell walls composed of theca	Grazer	Has spines
Reproduces by dividing	Cell walls contain silica	Pennate diatom	FREE SQUARE!	Has flagella



Density and Stratification



Estimated Time: 1 hour
Grade Levels: 7-10

Materials

- Glass or plastic wave tank(s)
- Empty 2-liter pop bottle with small hole cut in bottom (cover with duct tape)
- Cold, saturated salt water
- Very warm, fresh water
- Food coloring
- Duct tape
- Ruler (optional)
- Colored pencils

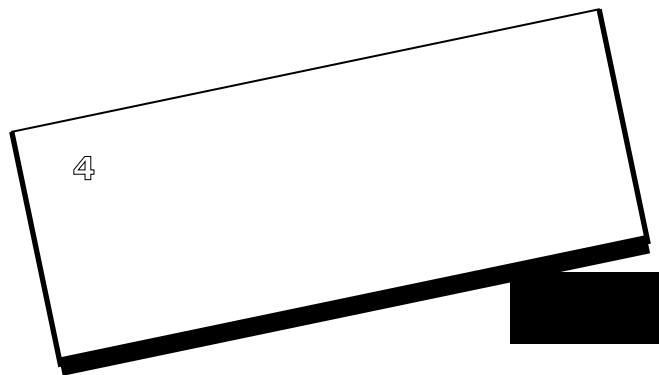
Activity

1. Add warm fresh water to the tank to form a layer 8-10 cm (3-4 in) thick. Add some red food coloring to the water and mix thoroughly.
2. Add some food coloring (blue preferred) to the cold salt water. Fill the pop bottle with this water, and set into the tank. Remove the duct tape from the hole at the bottom, allowing the salty to water to slowly enter the bottom of the tank until a second layer 3-4 inches thick appears. Draw a picture of the tank as the salt water is being added.
3. When you have added the salt water remove the pop bottle very slowly to minimize mixing. Let the tank stabilize for two minutes. Avoid knocking the table to prevent mixing the layers.
4. Slowly lift one end of the tank until the water level almost reaches the top of the tank. Support the end of the tank with books. Draw a picture of the layers in the tank.
5. Slowly and carefully set down the tank. Look closely at the waves between the fresh and salty water. Record your observations.
6. Let the tank settle until the water has formed layers again. With your hand, brush the surface water in one direction (away from the edge of the tank) continuously for about 1 minute and skim from the surface using a container. Draw a picture of what happens to the blue (salty) water.

Draw your observations of steps 2, 4, and 6 here:

2

6

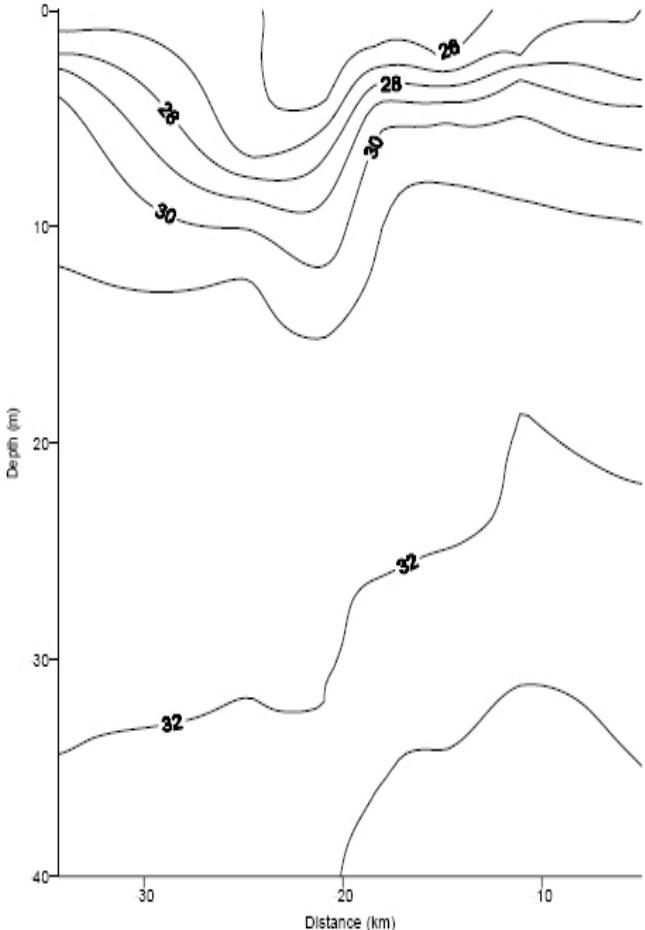


Density and Stratification

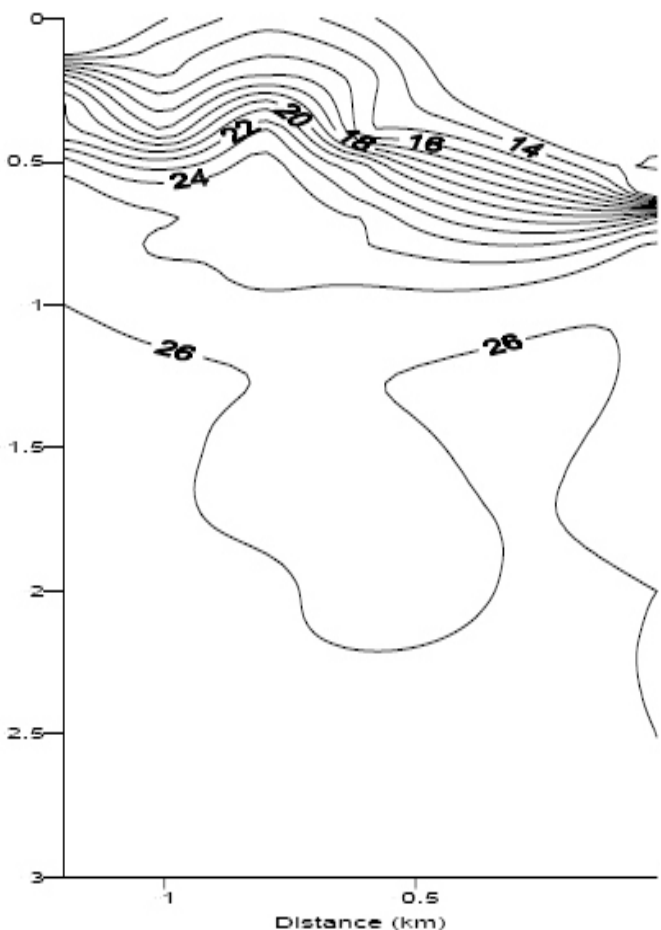


Group Questions and Discussion:

1. Why did the water form layers? Why does the cold, salty water stay on the bottom?
2. What is *density*? What is *salinity*?
3. What do you predict would happen to surface water if it became saltier through high evaporation or creation of ice? Think of two places in the world where this might occur.
4. Examine the two salinity cross section maps below. One is a contour (lines of constant value) map of salinity of the water column off the Washington Coast and the other is contour map of a bay in Puget Sound into which a river flows. Using colored pencils, create a legend and color in layers of different salinity. Read the graphs to fill in the information below each, and determine whether the graph represents Puget Sound or the Coastal water.



Range of salinity values:
 Max depth:
 Max distance from shore:
 Location:



Range of salinity values:
 Max depth:
 Max distance from shore:
 Location:

5. What clues tell you which water is in Puget Sound and which is the Coast?
6. What do you think would happen to the bottom layers if the surface water were pushed offshore by wind?



Coastal Upwelling



Estimated Time: 1 hour
Grade Levels: 8-11

Materials

- Colored pencils
- Reference copies of Day 4 of Cruise Journal

INTRODUCTION

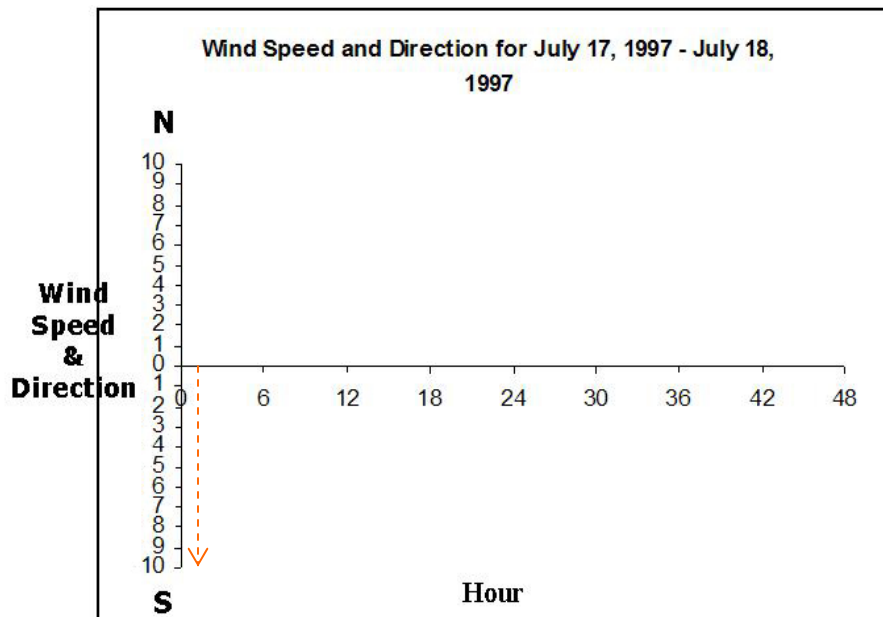
Coastal *upwelling* is the upward movement of water on a coast caused by wind-driven currents. This rising water is usually cooler and more nutrient-rich than the surface water it replaces, and can have an enormous impact on the biological productivity of coastal regions.

Northwest winds: The strongest upwelling occurs when the Washington Coast is experiencing winds from the north blowing parallel to the coast. When these winds are weak or the winds are from the south, the upwelling tends to stop, and waters move from offshore toward the coast.

PART I. GRAPHING

The values in the table are wind speeds and directions for a 48-hour period in July 1997 from the Cape Elizabeth buoy. Starting with hour 0, draw a line on the graph showing the direction and speed of the wind at that time. Hour "2" is plotted for you as a dotted red line. (Note that winds are plotted as the compass direction toward which the wind is blowing.)

Hour	Direction	Speed
17-Jul-97		
0	N	4
2	N	10
4	N	6
6	N	6
8	N	3
10	N	2
12	N	1
14	S	1
16	S	1
18	N	1
20	N	3
22	N	4
18-Jul-97		
24	N	5
26	N	6
28	N	5
30	N	3
32	N	3
34	N	2
36	N	3
38	N	2
40	N	3
42	N	3
44	N	6
46	N	8



1. Given the speed and direction of the winds for this period, can you predict when coastal upwelling is occurring?
2. If upwelling is occurring, will the water along the shore be warmer or cooler than the water offshore? What about when there is no upwelling?
3. What do you predict about productivity along the coast during this time period?



Coastal Upwelling



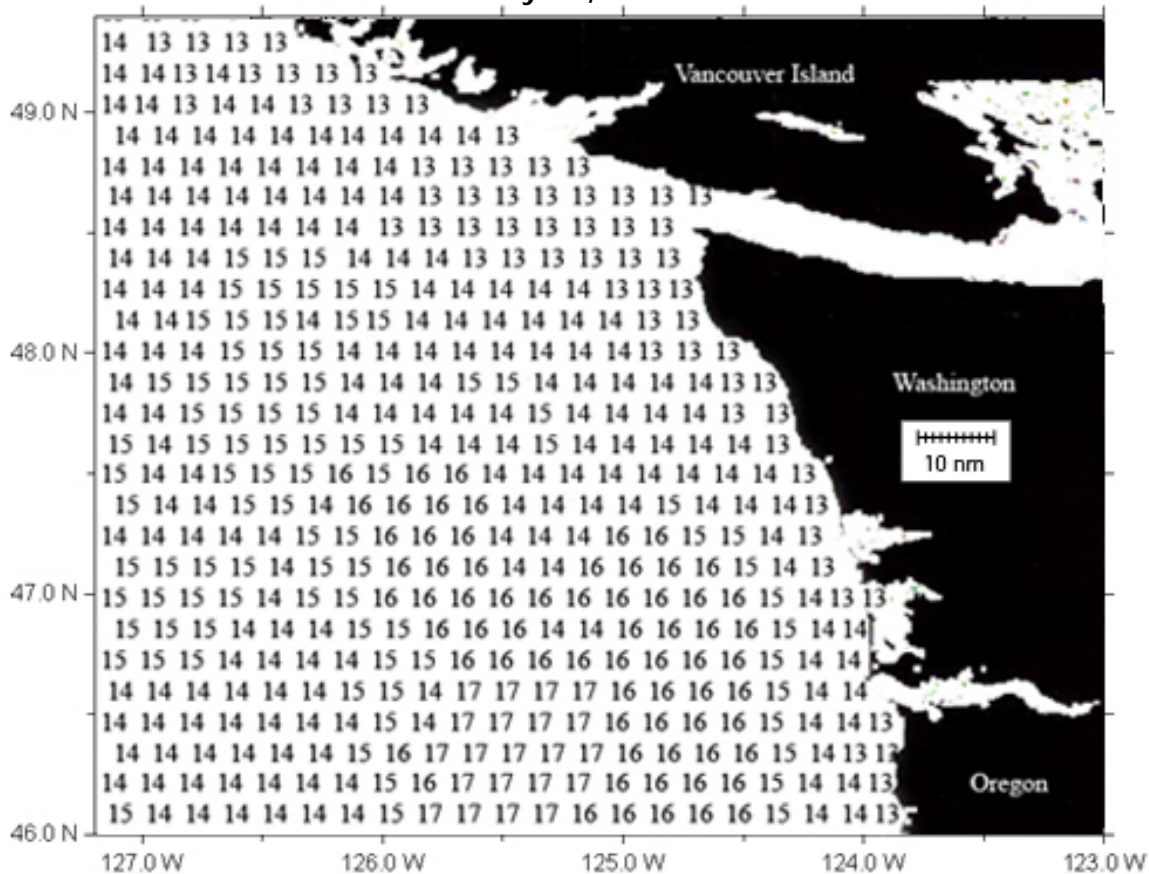
Coriolis Effect: The rotation of Earth causes surface water to move to the right of the wind direction in the northern hemisphere. This movement is known as the Coriolis effect. In Washington State outer coastal areas, winds blowing from the north cause water to flow to the southwest, away from the coast. The water flowing offshore is replaced by the cool, nutrient-rich water which rises up into the coastal area from below, a result of the upwelling phenomena. The upwelled water can be tracked by measuring its cooler temperature, high nutrient content, high **salinity** and high **density**. The nutrients brought to the surface encourage high plankton productivity (fast growth).

Activity

PART II. MAPPING

Use colored pencils to create a map of sea surface temperatures off the Washington Coast. Color the areas using a different color for each temperature. Use the "ROY G. BIV" (Red, Orange, Yellow, Green, Blue, Indigo, Violet) color sequence, with red being the warmest water and violet the coldest. Place a key to the colors you have chosen and their matching temperatures in the margin. It may be easier to first outline an area with a specific temperature and then fill it in with color. Use Day 4 in the Cruise Journal and your completed map to answer the questions at the bottom of the page.

Sea Surface Temperatures for the Washington Coast
July 18, 1997



1. Does this map show evidence of coastal upwelling? Why or why not?
2. Where would you predict the highest (amount per unit volume of water) **nutrients** to be? The highest numbers of phytoplankton?
3. Circle the Juan de Fuca Eddy and estimate the width in nautical miles (nm).
4. How would a map of sea surface temperatures for December be different than in July? (Hint: winds in the winter are generally from the south and air temperatures lower)



Types of Harmful Algal Blooms



Estimated Time: 50 minutes
Grade Levels: 8-10

Materials

- Newspaper articles about harmful algal blooms
- Piece of butcher paper about 8 feet long (or chalkboard)
- Large markers

Algal Blooms vs. Harmful Algal Blooms

Blooms of algae occur when conditions such as light, temperature, salinity, nutrient availability, and low grazing are favorable for growth. Most algal blooms are beneficial because algae are the primary food source that supports marine life. However, some types of algae have characteristics that can make them harmful to other organisms (for example, by producing toxins or poisons) – these are the species that make up the group we call Harmful Algal Bloom (HAB) species. Some HAB species don't produce toxins but result in *anoxic* conditions or cause physical harm.

HABs are a natural occurrence, but their frequency and geographic distribution seem to have increased over the last several decades. The environmental conditions that select for blooms of HAB species are complex and not completely understood. Human activities that may have contributed to the increase in occurrence and distribution of some HAB species include: 1) increases in nutrients to marine systems from sewage and fertilizer runoff, 2) overfishing which can decrease the grazing pressure on HAB species, and 3) ballast water discharge which can transfer resting stages, or cysts, of HAB species to new areas from different regions of the ocean. It is still uncertain whether these factors are important in developing HABs in the Pacific Northwest.

Activity

1. All students bring in a newspaper article about a recent harmful algal bloom event.
2. Start in groups of four and designate one person as a recorder and one person as a spokesperson. Compare articles, and make a chart (use the example below) within your small group which summarizes the harmful algal blooms in the articles.
3. The instructor should create a large chart on butcher paper or a chalkboard which looks like the example below.
4. After 15 minutes in small groups, come together as a class and fill in the larger chart as a group. Discuss any possible causes or solutions to harmful algal blooms that were mentioned in the newspaper articles.
5. Discuss some possible sources of information about harmful algal blooms other than newspapers.
6. Are all HABs due to human factors?

Example Chart

Name of Harmful Algae	Geographic Location of blooms	Organisms impacted	Health Impacts	Economic Impacts	History of toxic events



Marine Food Webs



Estimated Time: 45 minutes
Grade Levels: 7-9

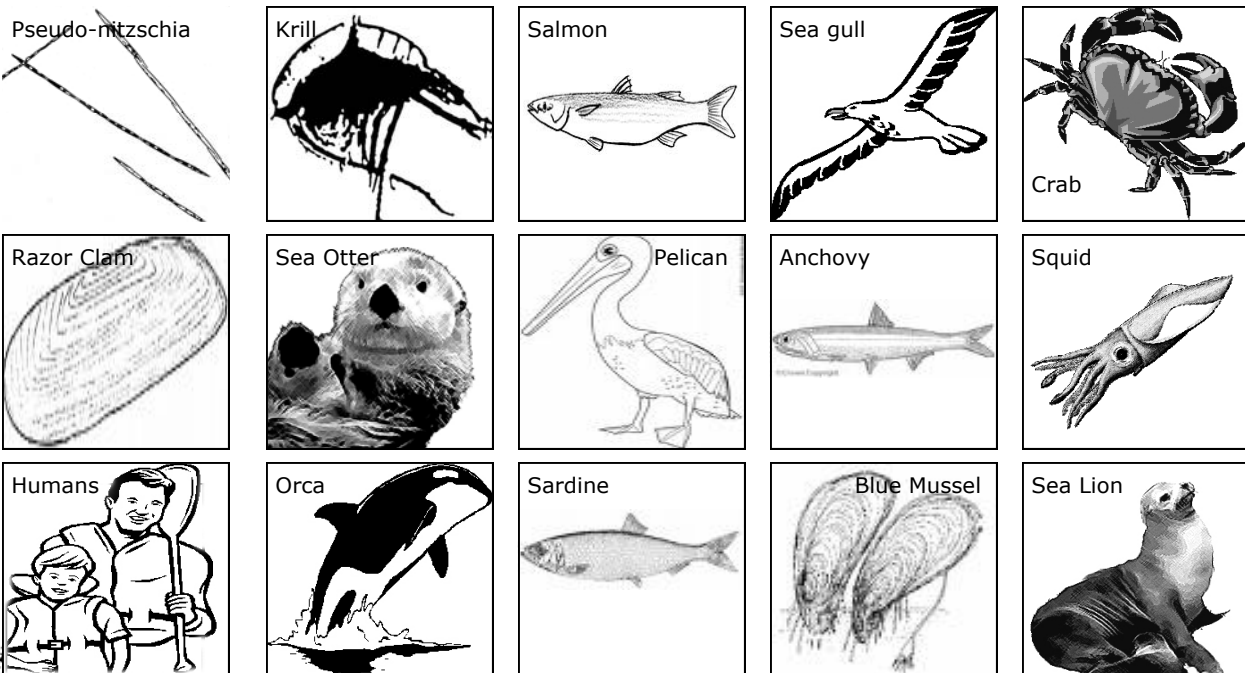
Materials

- Blank marine food web for each student or group
- Copies of Days 9 and 10 of Cruise Journal and Glossary for reference

Food webs: Food webs show the flow of energy through an ecosystem. Food webs depict energy flow and show the multiple interactions among the different types of organisms. So where does energy come from? The fundamental energy source for most of the environment is the sun. **Photoautotrophs** capture the sun's energy and use it to make organic compounds through **photosynthesis** (basically converting light energy into chemical energy). The process of photosynthesis transforms carbon dioxide and water into simple carbohydrates. The photoautotrophs then use the simple carbohydrates to build other more complex organic molecules (proteins, lipids and starches) that are either used as building blocks for their cells or are stored for later use. Photoautotrophs are often also called primary producers because they establish the basis for most other production; they create organic material from inorganic, or non-living, sources.

Trophic Levels: Each level of a food web is called a trophic or feeding level, and the organisms in the food web are classified by whether they are primary producers (autotrophs) or consumers. The consumers in food webs are called **heterotrophs** and they consume the organic material made by the autotrophs. Heterotrophs cannot make their own food, so they are dependent on the autotrophs for survival.

Domoic Acid & Bioaccumulation: **Domoic acid** is a **neurotoxin** that is naturally produced by some diatoms. Diatoms are single-celled plant-like organisms that live in the ocean and are food for many larger marine organisms like clams, oysters, krill, anchovies, and sardines. When these **filter feeders** consume toxic diatoms, the poison is accumulated in their bodies and can be passed up through the food web. When predators such as marine mammals, sea birds, and humans eat the toxic prey they can become sick and even die. Symptoms of domoic acid poisoning include vomiting, diarrhea, confusion, seizures, memory loss, coma, and death.

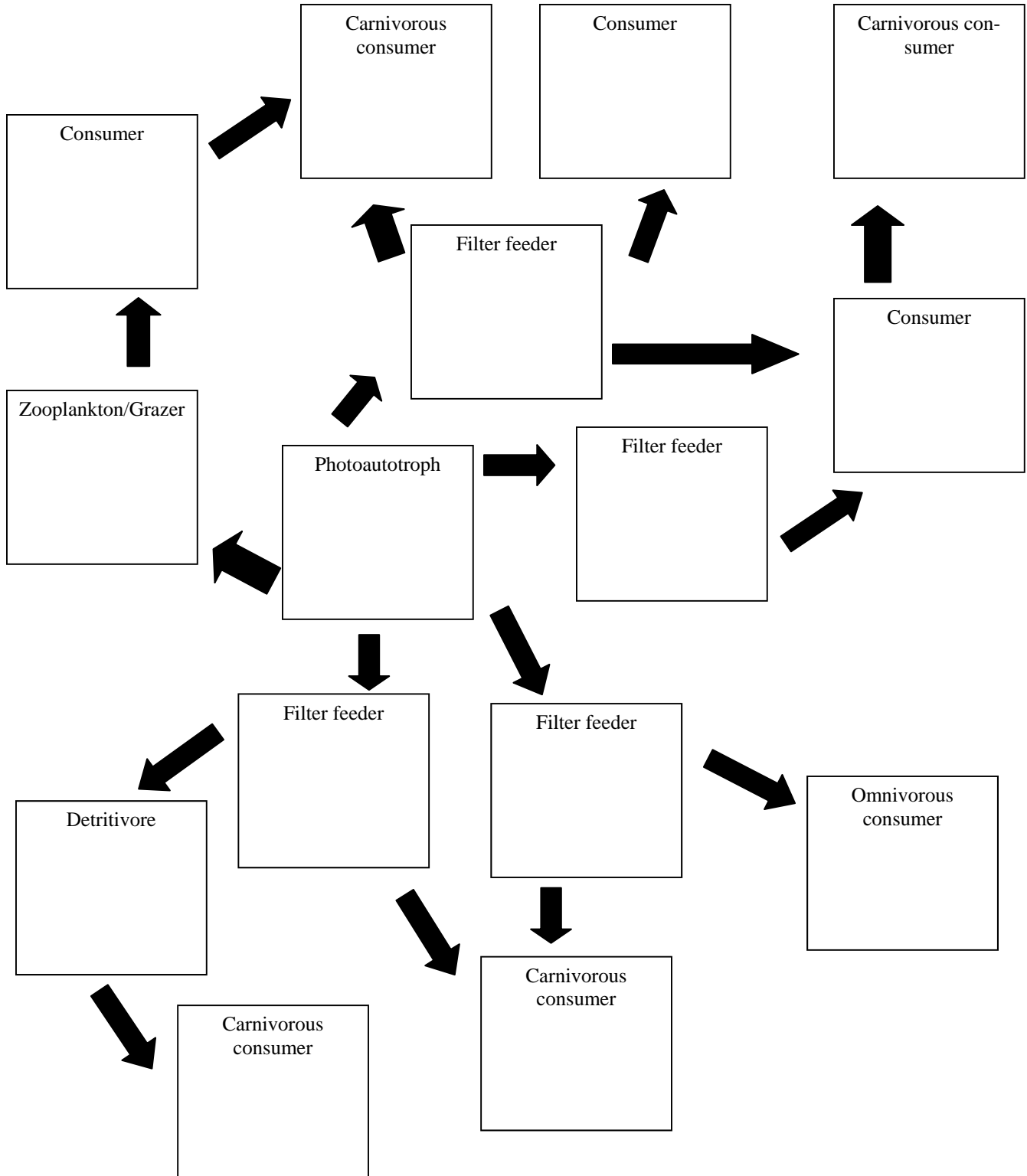


Marine Food Webs



Activity: Tracking Toxin in a Food Web

Cut out the pictures of the participants in this marine food web on the previous page, and create a web using the clues given in the boxes. You may also find the Glossary and Day 10 of the Cruise Journal helpful. (HINT: Top predators will be on the outside of the web.)



Tough Choices: HAB Closures



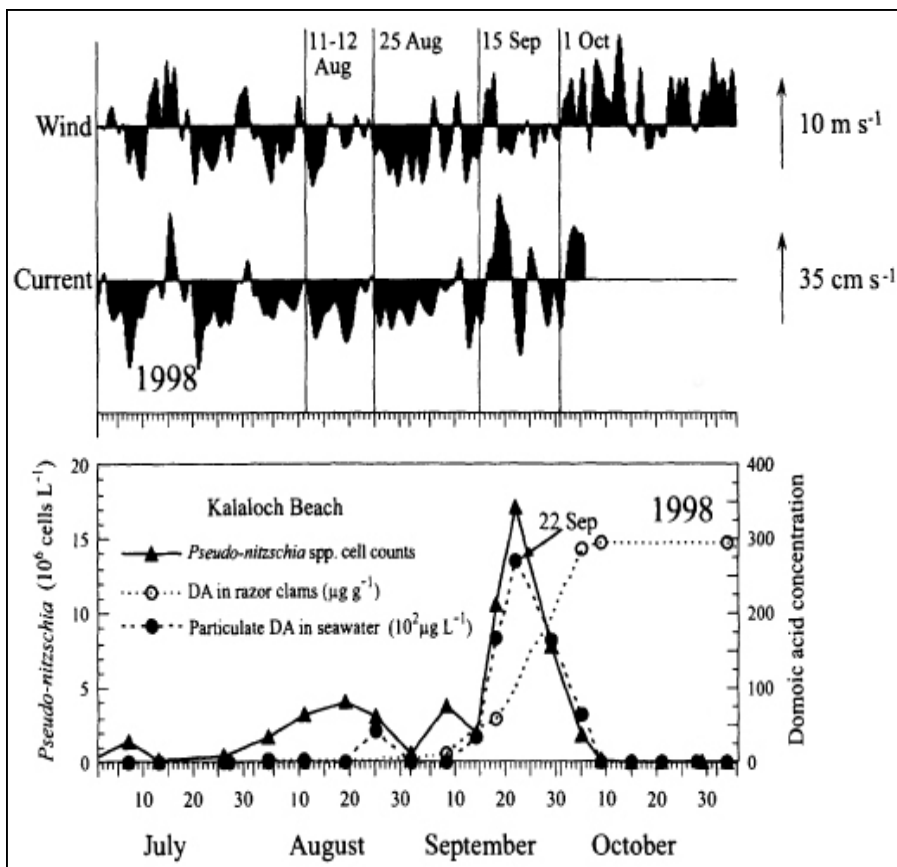
Estimated Time: 2-3 hours
Grade Levels: 8-11

Materials

- Newspaper articles about domoic acid (4 articles per group)
- Copies of Cruise Journal Days 4, 10, and 11
- Publishing tools: desktop publishing software, video cameras, voice recorders (optional)

Setup

1. Work in teams of four.
2. Read at least 2 newspaper articles and Days 4, 10, and 11 from the Cruise Journal (reading can be divided up among the group).
3. Examine the graph below showing wind and current conditions prior to a 1998 toxic event on the Washington Coast, and answer the questions about the graph as a group.



In October of 1998, Kalaloch Beach experienced record levels of domoic acid, leading to a year-long razor clam closure which cost commercial fisheries and local beach communities \$10-20 million.

The graph to the left (top) shows the direction of the wind and currents off of Kalaloch Beach from July to October of 1998.

The graph on the bottom shows numbers of Pseudo-nitzschia, domoic acid levels in seawater, and domoic acid levels of clams on Kalaloch Beach.

Analyzing Graphs

1. What is the relationship between wind direction and current direction?
2. What direction are the winds blowing throughout most of the summer? (lines going down are winds blowing to the south, lines going up are blowing to the north)
3. What is the wind and current doing just before the highest levels of domoic acid are seen at Kalaloch Beach?
4. Why might wind direction make difference to domoic acid levels at Kalaloch?



Tough Choices: HAB Closures



Activity—PART I: Making a decision about beach closure

Your team works for the Washington State Department of Health (WDOH) and are in charge of deciding whether beaches are closed because of danger from domoic acid. It is Thursday, and a razor clam opening is scheduled to start on Saturday. Thousands of people have booked hotel rooms, made dinner reservations at restaurants, and are planning a fun weekend with their family at the coast.

The regulatory level of the toxin, domoic acid, determined by WDOH, is 20 μg per gram of shellfish, meaning that if levels are above that the shellfish are unsafe to eat. Levels of domoic acid in razor clams have been at about 3 μg per gram for the past month, but jumped up to 10 μg per gram yesterday. It takes approximately 24 hours to test clams for domoic acid, so a decision to close cannot wait until the regulatory level is reached.

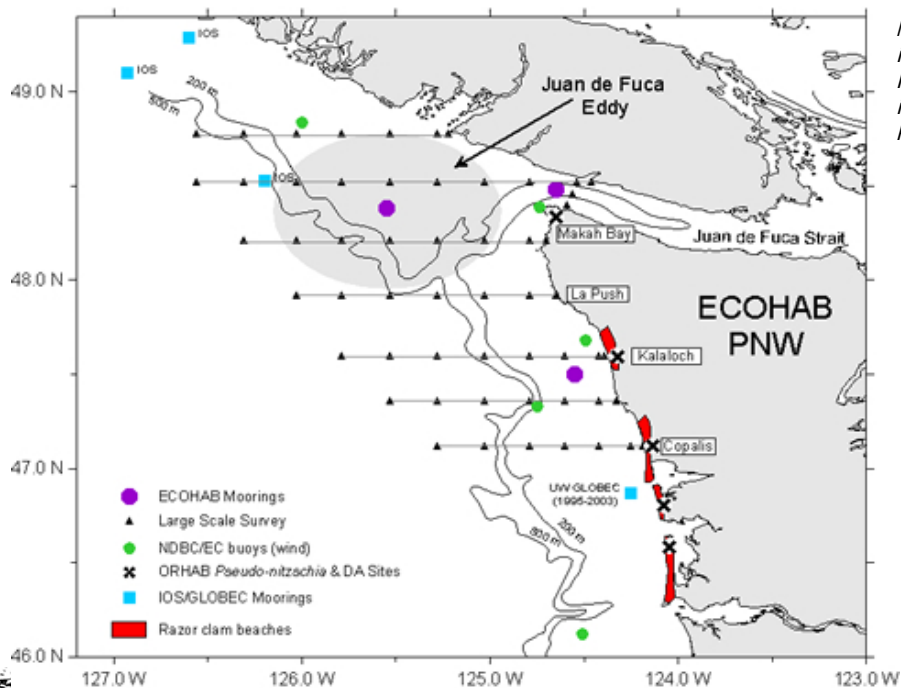
The water 10 km offshore was tested about three weeks ago, and showed low levels of domoic acid. The weather has been mostly sunny and nice for a few weeks with winds from the north, but a storm with winds from the south is predicted to come in tomorrow.

Will your group close the beaches or allow the dig to open as scheduled?

Activity—PART II: Communicating your decision

As a group, write a newspaper article, write a bulletin from the Department of Health, or make a 3-minute newscast about your decision. In the communication, be sure to answer the following questions:

1. Is the razor clam opening going forward or is it cancelled?
2. Why did you make this decision?
3. What are the possible consequences if you had made the other choice? Be sure to talk about impacts on human health, the economy, and to individuals (for example, a family heading to the beach that weekend)
4. Bring your report or article in the following day and share it with your class.



Map of razor clamming beaches in Washington and the Juan de Fuca Eddy, thought to be an initiation site for blooms of toxic *Pseudo-nitzschia*.



Cruise Journal

September, 2006: ECOHAB PNW



Day 1 - Welcome Aboard!

Sunday, 9/10/2006

My name is Christine Muir and I will be keeping the Teacher At Sea journal for the first leg of the ECOHAB-PNW cruise. I am a science teacher at the Woodside Priory School, in Portola Valley, CA (San Francisco Bay Area). My job on board the ship is to help scientists collect and process samples, as well as write a journal to allow people at home to understand what it is like to be on an oceanographic expedition. The purpose of this journal is to bring science to life in the classroom. The multidisciplinary field of oceanography is extremely exciting. Through reading this journal on a daily basis, you will get an inside perspective of conducting science at sea.

I arrived at the *R/V Thomas G. Thompson* at the University of Washington wharf in Seattle, WA. The ship is impressive, with a length of 274', beam 52.5', and draft of 19'. This vessel hosts the scientists of ECOHAB – Pacific Northwest (ECOHAB-PNW), which are a group of scientists from five different agencies/institutions to study the ecology and oceanography of harmful algal blooms. The ship carries a crew of twenty-two officers and crew, two marine technicians and up to thirty-six scientists.

The purpose of this cruise is to study the physiology, toxicology, ecology and oceanography of a toxic microscopic algae belonging to the *Pseudo-nitzschia* genus off the Pacific Northwest coast. This is the last cruise of this 5-year exciting, long term study!

Day 2 - Set Sail

Monday, 9/11/2006

N 47° 38'.9744

W 122° 18'.7899

Water temperature: 22.7°C

Salinity: 31.2 (on the practical salinity scale)

Today has been a busy day of scientists and crew setting up equipment and loading supplies. The agencies involved in this research expedition are San Francisco State University's Romberg Tiburon Center, University of Washington, NOAA's Northwest Fisheries Science Center, University of Maine, and University of Western Ontario, and following our progress and working up data are scientists from Canada's Dept. of Fisheries and Oceans at the Institute of Ocean Sciences. Each group of scientists onboard must set up their respective equipment in order to collect and analyze samples needed to fulfill their research objectives.

This evening we left the University of Washington dock at 7 PM, and from now on I will switch to the 24 hour clock as done on all ships at sea, so 1900 for you landlubbers. All scientists and crew went to the weather decks to watch us leave port. As we left the UW's marine facility we went under a series of bridges and draw bridges heading toward Lake Union, to Salmon Bay and through the Ballard Locks exiting into Puget Sound. Tomorrow morning we will begin sampling in Puget Sound near Port Madison.

Since leaving the dock, scientists and crew continue working to prepare for tomorrow's sampling. We had a safety meeting late this evening in which we listened to crew discuss safety practices and protocol, and finally a short science meeting outlining protocols. During the science meeting, we reviewed the sampling plan for the next day. Scientists worked late this evening, as we are anticipating a very busy day tomorrow! It is now 0030 and I am ready to go to my cabin and retire for the night!





Day 3 - Sampling Puget Sound

Tuesday, 9/12/06

N 47° 50'.0578

W 122° 25'.2756

Water temperature: 14°C

Salinity: 29.5 (on the practical salinity scale)

Topic: ECOHAB-PNW - Understanding Harmful Algal Blooms

The day began by our collecting water samples throughout the water column from the first station in Puget Sound just offshore of Seattle, WA. Today's sampling scheme will involve collecting from five stations in the Puget Sound before moving further out into the Juan de Fuca eddy where we will continue to sample into the Pacific Ocean.

The purpose of the ECOHAB-PNW project is to study the physiology, toxicology, ecology, and oceanography of toxigenic microscopic algae species belonging to the *Pseudo-nitzschia* genus. We have sampled off the Pacific Northwest coast twice a year since 2003 and this is our last cruise. The ECOHAB-PNW team has observed the conditions under which toxic cells are found offshore of British Columbia and Washington and then advected towards the coast of Washington where they contaminate shellfish.

One of the most fundamental objectives of the project is to collect and study local water masses to determine where, when, why, and how toxic diatom blooms occur in the Pacific Northwest. ECOHAB-PNW scientists are specifically looking for the diatom *Pseudo-nitzschia* (PN), and the presence of the neurotoxin domoic acid. Domoic acid is a nerve toxin which causes harm to members of the marine ecosystem. Algae such as these, which cause harm to members of the marine ecosystem, are called Harmful Algal Blooms (HABs). However, not all species of the genus *Pseudo-nitzschia* produce domoic acid and those that do produce this toxin, produce the toxin at variable levels. The factors that influence toxin production are one of the main questions being answered in this project.

The ECOHAB-PNW science team is made up of six main groups which each study a particular piece of the puzzle to determine which environmental factors trigger or enhance the toxigenic effects of *Pseudo-nitzschia* and how the bloom physically moves from the open ocean to the coast.

Each team of researchers is led by a principal investigator. The chief scientist is Dr. Barbara Hickey (University of Washington) who studies the physical oceanography of the area and the movement of the bloom. Dr. William Cochlan (Romberg Tiburon Center, San Francisco State University), Dr. Charles Trick (University of Western Ontario), and Dr. Mark Wells (University of Maine) investigate the ecophysiology of *Pseudo-nitzschia* diatoms. Drs. Cochlan and Wells also study the chemical oceanography of the water in which PN blooms grow. Dr. Vera Trainer (NOAA, Northwest Fisheries Science Center) studies the toxicology of domoic acid, while Dr. Evelyn Lessard (University of Washington) investigates the ecology of the diatom in relation to the planktonic food web.

This multidisciplinary approach to answering a question is the backbone of the field of oceanography. In this field, scientists must study all pieces of the puzzle – biology, chemistry, physics, and ecology on so many levels (macro and micronutrients, different levels of the food web, etc.)! Each scientist must collect, analyze and communicate with other members of their science team for this to proceed effectively. A research project of this scale and complexity is a humble lesson in teamwork and collaboration! The sampling design, collection of water, and experiments on board the ship are also incredibly complex and well-designed. Keep reading the journal in the upcoming days to learn more about each team of researchers and science at sea!





Day 4 - Sampling the Juan de Fuca Strait and Eddy

Wednesday, 9/13/06

N 48° 29'.6503

W 125° 09'.3269

Water temperature: 12°C

Salinity: 31.8 (on the practical salinity scale)

Topic: Physical oceanography - tracking water masses and blooms

Throughout the night, members of ECOHAB-PNW sampled as we passed the San Juan Islands and sailed out the Strait of Juan de Fuca hugging the northern (Canadian) side of the Strait. This morning we started sampling near Port San Juan on Vancouver Island. We are heading off the coast into a water mass called the Juan de Fuca Eddy. In the Eddy, we will continue to sample the water column, as well as release drifter buoys to track water movement within the eddy and the jets which separate from the Eddy.

The physical oceanography of the waters off the coast of Washington and British Columbia determine whether a bloom of toxic algae developing offshore will move toward the shoreline of Washington where it can impact shellfish, beaches, and people. Dr. Barbara Hickey (University of Washington) is the chief scientist on this cruise and her research group investigates the physical oceanography patterns that enable offshore water to come toward the coast. Her group is primarily studying the role of the Juan de Fuca Eddy in bringing toxigenic *Pseudo-nitzschia* blooms to the coast where they have the potential to cause detrimental impacts. They are also comparing and contrasting water movement and characteristics from the eddy water versus water in the coastal upwelling zone.

An eddy is a region of water moving within a circular pattern. The water rotates as a gyre and retains its individual characteristics for a period of weeks or months. Because of the circulation within an eddy, the water mass within the eddy does not mix much with surrounding water. Eddies can form at the surface as well as at depth, and can vary in size. The energy in an eddy gradually dissipates through friction causing the eddy circulation to slow down and eventually the eddy disappears. The Juan de Fuca Eddy persists seasonally from May to October on a yearly basis. This Eddy is formed by a number of factors which are still under investigation. It is currently thought that the Eddy forms due to a combination of coastal currents, local winds, water coming from the Strait of Juan de Fuca, tides, and topography of the seafloor (bathymetry). (There is a canyon under where the Eddy forms). The Eddy ranges from 12-36 nautical miles in diameter and is characterized by a steady supply of inorganic nutrients such as nitrate and silicate. The eddy reaches to depths of well over 100 m from the sea surface.

Today the Hickey research group released ten Brightwater drifters in different areas of the Eddy to follow the water patterns. Ocean drifters are devices that scientists use to follow patterns of water masses. The drifters can be placed in different areas to follow water circulation patterns as well as collect data on water temperature, salinity and other environmental parameters. Five of the drifters released today are drogued drifters, which means the floating buoy is attached to a large net (which acts like a sail) which is located at a certain depth below the surface. The net (or as scientists call it - a drogue) is attached to the surface buoy, which transmits its location and certain water characteristics to a satellite. This data is then downloaded through the internet onto a computer. The drogue enables the drifter to follow water circulation patterns at that particular depth. Today's drifters are following water circulation patterns at 25m depth. In addition to the drogued drifters, five surface drifters were deployed to follow surface circulation. All drifters were released in strategic locations to study the physics of the eddy, and will be collected again within the next few days to weeks depending on where they go. Additionally, four stationary (moored) buoys are deployed by Dr. Hickey's team in the Eddy area from May - October.

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Topic: Physical oceanography - tracking water masses and blooms (continued)

The deployment is done in association with the Canadian participants of the ECOHAB-PNW project based at the Institute of Ocean Sciences in Sidney, B.C. These buoys measure many variables in the water column – including currents, dissolved oxygen, temperature, salinity, amount of light etc – many of the factors which control currents and also phytoplankton growth.

Drifter studies as well as sophisticated computer modeling efforts help the Hickey research group understand how *PN* get transported to the coast. If wind condition predictions become more precise, the computer models may eventually permit prediction of water movement from the Juan de Fuca eddy to the surrounding coastlines.

Day 5 - Sampling the southernmost section of the grid

Thursday, 9/14/06

N 47° 4'.15

W 124° 14'.88

Water temperature: 13.6°C

Salinity: 32 (on the practical salinity scale)

Topic: *Pseudo-nitzschia* – a toxic diatom

Yesterday we had rough, rolling seas as we left the Strait of Juan de Fuca and proceeded seaward to the offshore waters of the Juan de Fuca Eddy. The science team has to work continuously and carefully, despite the almost constant pitching and rolling of the ship from side to side. We are now off the southwestern coast of Washington State near Pt. Brown and Pt. Chehalis on either side of Grays Harbor. We are starting the grid survey at the southernmost point of the grid. During each ECOHAB-PNW cruise, the same grid pattern is followed to sample the waters off the coast of Washington and British Columbia in a consistent manner to permit year-to-year comparisons. Each grid line has at least eight sampling stations, and there are a total of eleven grid lines (transects). Today we are following the GH transect - sampling from the coast to offshore. At each station we will deploy a CTD-equipped rosette which has a series of Niskin water sampling bottles attached to it. This rosette package allows us to collect water at many depths in the water column. In addition to the CTD cast, a plankton net is towed to collect phytoplankton, and special Go-Flo water bottles are used collect water for trace metal analysis at most stations.

Pseudo-nitzschia (*PN*) is a genus of diatoms. Diatoms are phytoplankton (microscopic algae) or literally "light-drifters." They may also be referred to as plant-like drifters. They are considered drifters because they cannot move to escape the effects of waves, tides, and oceanic currents. Phytoplankton are autotrophic and use photosynthesis to make their own food. They are extremely important primary producers in the ocean. Using the energy of the sun, they use dissolved carbon dioxide and water to create oxygen and carbohydrate and thus form the base of the marine food web.

Diatoms are one of the most important and abundant phytoplankton in the marine environment. They occur in all regions of the oceans, but are most abundant in polar and temperate areas, and particularly in coastal zones. Diatoms are single-celled microscopic organisms that have a shell or frustule composed mostly of silica (glass). They are usually divided into two taxonomic groups based on their shape. Centric diatoms are circular with radial symmetry from a central point, whereas the pennate diatoms are elongated ovals that have longitudinal symmetry. Diatoms can be solitary or united in colonies of various kinds. Cells in colonies may be linked by a variety of siliceous structures, mucus pads, tubes, or stalks, and/or threads of chitin.

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Topic: *Pseudo-nitzschia* – a toxic diatom (continued)

Diatoms of the *Pseudo-nitzschia* genus are pelagic, which means they are found in open water as opposed to being associated with the seafloor (benthic). They are found in the photic zone (0-200 m) of the water column and are most abundant in the upper 0-5 meters of water where sunlight is abundant. *Pseudo-nitzschia* cells are pennate and form chains which can be 30-40 cells in length. *PN* species are found all over the world, in a variety of temperature and salinity ranges. Blooms of *PN* tend to occur in coastal waters and are common along the coast of North America.

Dr. Vera Trainer (NOAA, Northwest Fisheries Science Center) and her research group are investigating the basic biology and toxicity of *Pseudo-nitzschia*. At each station the team collects water samples from various depths to use for whole *PN* counts, enumeration of *PN* size classes, and for species identification using scanning electron microscopy. A hand-held plankton net is also towed at each station to collect plankton from the surface water. The plankton net has a 20- μ m mesh which acts as a filter in the water and retains organisms greater than the mesh size. The scientists view the sample under a microscope and look for the presence or absence of *PN* in the plankton sample as well as relative abundance of *PN* compared to other species. There are many species of the *PN* genus and the Trainer research group focuses on learning why certain species of *PN* contain higher levels of toxin. The toxin produced by *PN* is a neurotoxin called domoic acid.

Read tomorrow to learn more about domoic acid!

Day 6 - Continued sampling on the survey grid

Friday, 9/15/06

N 47° 06'.43

W 125° 07'.42

Water temperature: 13.5°C

Salinity: 32.4 (on the practical salinity scale)

Topic: Domoic Acid Toxicity

Yesterday we finished sampling the Grays Harbor (GH) transect sampling line and steamed close to shore to collect water for an experiment. Today we are sampling along the Copalis Beach (CB) transect near Cape Elizabeth, Washington starting near the mouth of the Quinault River and proceeding offshore. At each station of the grid, we follow the same sampling protocol that I mentioned in yesterday's entry – including deploying a CTD-equipped rosette which has a series of Niskin bottle which collect water at a series of depths, a phytoplankton net tow, and Go-Flo water collection for trace metal analysis. The depth along our grid transects varies dramatically as we move from shallower coastal waters of only 30-60m to deeper waters offshore varying from 1200-2000 m in depth.

Domoic acid is a relatively new phytoplankton toxin that was first detected on the west coast of the United States and Canada about 15 years ago. It is produced by diatoms of the genus *Pseudo-nitzschia* and was first found in red macro-algae in Japan. Domoic acid was consequently named after the Japanese word for seaweed which is 'domoi'. Domoic acid (DA) is a nerve poison, which means it affects the nerves and brain. DA is specifically an excitatory amino acid which binds to glutamate receptors in the hippocampus, causing cell death and tissue degeneration in that region of the brain. DA can affect organisms on many levels of the food chain. Organisms that feed on toxic *Pseudo-nitzschia* (*PN*) species, or on species that have eaten toxic *PN* species, can accumulate DA in their tissues.

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Topic: Domoic Acid Toxicity (continued)

However the toxic effects of domoic acid vary accordingly to the position of the organism on the marine trophic food chain. For example, filter feeders such as clams, mussels, and scallops appear relatively unaffected by the toxin, whereas higher level trophic consumers such as planktivorous fish, birds, marine mammals and humans can be severely or marginally affected; it depends on the animal.

Domoic acid causes amnesic shellfish poisoning (ASP) in mammals including humans. Some common symptoms of domoic acid poisoning in marine mammals, such as the California sea lion, include unbalance, head-weaving, muscle tremors, and seizures. In humans, ASP symptoms include gastrointestinal problems within 24 hours of eating affected shellfish and neurological symptoms such as headache, dizziness, confusion, disorientation, and loss of short-term memory within 48 hours. Mammals may suffer permanent brain damage. Domoic acid is not destroyed by cooking or freezing.

In addition to studying basic biology/ecology of *Pseudo-nitzschia* species, Dr. Vera Trainer (NOAA – Northwest Fisheries Science Center) and her research team investigate the amount of DA present in certain species of the *Pseudo-nitzschia* genus. It appears that not all species of *PN* produce DA. Currently, four species of the *PN* genus on the West Coast are known to produce domoic acid. The Trainer group is interested in learning why only certain species of *PN* produce DA, what levels of DA are produced, and at what point in the growth cycle cells produce and release DA into the seawater.

To answer these questions the research group is sampling continuously and are conducting a variety of experiments. At each survey station, water is collected, using a CTD-equipped rosette with Niskin bottles, from 0, 5, and 10 m, and the amount of domoic acid present both in the water (dissolved DA) and in the cells (particulate DA) is determined. Concentrations of DA are measured by first filtering the samples and subsequently running sophisticated assays to determine both the presence and the relative concentration of DA in the samples. Plankton net tow samples containing *PN* are also collected for whole cell genetic assays which are used to determine which *PN* species are present, and to grow up unialgal cultures for use in growth experiments at sea and later ashore in the laboratory. Growth experiments measure the growth rate of *PN* species in an ideal environment with excess nutrients. The *PN* cells are grown for a series of days to weeks, and cells are sampled daily to determine the presence and concentration of DA.

Knowing the ambient seawater concentration of DA is key to determining whether a bloom of *PN* can be considered toxic. Species identification using whole cell epifluorescent probes, toxicity assays, and growth experiments enable Dr. Trainer and her research group to determine the link between different concentrations of DA toxicity and species of *Pseudo-nitzschia*. As the Trainer group is able to identify toxic species and measure levels of toxicity, they can identify toxic blooms and predict toxicity based on species.

Keep reading to learn more about the environmental factors that create bloom conditions and how scientists can manipulate factors to render a bloom toxic!





Day 7 - Survey sampling off Cape Johnson, Washington

Saturday, 9/16/06

N 47° 39'.65

W 125° 02'.78

Water temperature: 12.0°C

Salinity: 32.2(on the practical salinity scale)

Topic: Photosynthesis and Primary Production

Throughout the night, scientists finished sampling the Copalis Beach (CB) transect offshore and began the Kalaloch Beach (KB) transect from offshore toward the Washington coast. Today we will sample the entire Kalaloch Beach transect. The razor clam fishery at Kalaloch Beach is currently not open due to high concentrations of domoic acid. The Washington State Department of Health tests for high concentrations of domoic acid while the Department of Fish and Wildlife enforces closures. The razor clam fishery can not open when the concentration of domoic acid is higher than 20 µg/g (wet weight). After sampling the KB line, we are continuing our grid survey and will sample the La Push (LP) transect off Cape Johnson throughout the afternoon and evening.

Primary production is the amount of plant tissue built up by photosynthesis over time; the rate of this reaction is referred to as primary productivity. Phytoplankton are the major primary producers of the sea, converting inorganic materials such as nitrate and phosphate into new organic molecules such as lipids and proteins through the process of photosynthesis. Phytoplankton are thus classified as autotrophs, and since they utilize sunlight for their energy they are referred to as photoautotrophs. These organisms form the base of the marine food web.

Remember the equation for photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{CO}_2$. For this reaction to proceed, both electromagnetic energy from the sun (visible light) and light-catching pigments are needed. The process of photosynthesis converts radiant energy to chemical energy and requires special photosynthetic pigments such as chlorophyll a, b, c, and d plus accessory pigments, usually contained in the chloroplasts of algae. However, phytoplankton growth is affected by more than just the amount of light and nutrients. Temperature and salinity also must be considered.

As with plants, phytoplankton require both macronutrients and micronutrients in order to photosynthesize and create new biomass (grow). The macronutrients that phytoplankton need include nitrogen and phosphorus. Some algae such as diatoms also require dissolved silicon (silicate). Micronutrients such as iron and copper also have been found to be very important for growth. Too much of some micronutrients (such as copper) can be inhibitory for growth, whereas too little will limit their growth as well. In general, the concentration of macronutrients found in deep seawater is high and becomes depleted with sustained phytoplankton growth in the surface waters. Micronutrients are also generally elevated in deep waters, but their surface concentrations are highly variable. In some cases, low concentrations of micronutrients will limit phytoplankton growth, despite elevated macronutrients.

The physical and chemical characteristics of seawater change often, which impacts phytoplankton growth and reproduction. Dr. William Cochlan (Romberg Tiburon Center for Environmental Studies, San Francisco State University) and his research team study the characteristics of the water column (nutrients and light) which create the environmental conditions conducive to an algal bloom. The primary objective of the Cochlan group for ECOHAB-PNW is to examine the relationship between elevated concentrations of *Pseudo-nitzschia* and its toxin domoic acid in relation to concentrations of macronutrients in the water column and phytoplankton biomass.

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Topic: Photosynthesis and Primary Production (Continued)

To characterize the water column and quantify phytoplankton biomass, the RTC research team collects water at each station using Niskin bottles (attached to an instrumented rosette) for both nutrient and chlorophyll analyses. Water samples are filtered to collect phytoplankton using different pore-sized filters. The 0.7- μm filter collects all the phytoplankton greater than 0.7 μm in size, (which constitutes essentially all the natural phytoplankton community), whereas the 5- μm filter collects larger phytoplankton such as diatoms. Chlorophyll is then extracted from the phytoplankton using a solvent, and the concentration of chlorophyll per sample is determined using a fluorometer. Knowing the chlorophyll concentration enables scientists to estimate the biomass or the amount of cells in the water sample. Nutrients including nitrate, nitrite, phosphate, and silicate are determined using a sophisticated flow injection nutrient autoanalyzer. Ammonium concentrations are also determined onboard using a sensitive fluorometric method, while samples for urea concentration are collected and analyzed using a spectrophotometric technique. The scientists' goal is to analyze all these nutrients in near, real-time in order to optimize sampling strategies and more effectively design experiments to be conducted on the ECOHAB-PNW cruise.

One of the fundamental objectives of the ECOHAB-PNW project is to determine the environmental parameters that create and sustain *Pseudo-nitzschia* blooms that produce domoic acid. Dr. Cochlan's group is instrumental in quantifying the environmental conditions, including light and nutrients, which sustain such blooms. Using sensitive isotopic methods (both radioactive and stable tracers) these researchers are then able to accurately estimate the productivity of resident phytoplankton and bacteria. It is vitally important to characterize the ecophysiology (ecology and physiology) of *PN* in order to predict where, when and if toxigenic *PN* blooms may occur, and the possible role of anthropogenic factors in bloom development.

Read tomorrow to learn more about the importance of trace metals!

Day 8 - Continued survey sampling off Cape Alava, Washington

Sunday, September 17, 2006

N 48° 07'.96

W 124° 51'.00

Water temperature: 10.9°C

Salinity: 32.0 (on the practical salinity scale)

Topic: Photosynthesis and micronutrients – a domoic acid connection

It was windy and rainy last night as scientists continued to sample water along the La Push (LP) transect far west of Mt. Olympus (7,954ft). Afterwards we steamed to the offshore section of the Ozette Lake (OZ) transect and will continue to sample along this transect from offshore toward the shore near Cape Alava, Washington. Most of the survey grid is within the Olympic Coast National Marine Sanctuary and some of the coast in the area consists of tribal lands as well as Olympic National Park land.

In order for phytoplankton to photosynthesize and grow, they need both macronutrients and micronutrients. Of the principal nutrients in the sea that are required for phytoplankton growth, only a few may be in short supply. In general, the quantities of magnesium, calcium, potassium, sodium, sulfate, and chloride are all in sufficient quantities for plant growth, as are dissolved concentrations of carbon dioxide. Some essential inorganic substances such as nitrate, phosphate, silicate, (all termed macronutrients) and trace elements such as iron, copper, and manganese (termed micronutrients) may be present in low enough concentrations to limit phytoplankton productivity.

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Topic: Photosynthesis and micronutrients – a domoic acid connection (*continued*)

There may also be synergistic effects between essential nutrients needed for growth. For example, iron governs the ability of phytoplankton to utilize inorganic nitrogen substrates because iron (a metal) is needed in enzymes required for reduction of nitrate and nitrite to ammonium (thus we call these metal-containing enzymes metalloenzymes). The reduced nitrogen is then incorporated into amino acids and other macromolecules as part of phytoplankton growth (or, ... that make up a large part of the phytoplankton biomass that feeds higher trophic levels.)

The physical and chemical environment of seawater is not constant. Light, temperature and macro- and micronutrient concentrations all vary. Light and temperature vary both daily and seasonally, while nutrient levels vary for a variety of reasons such as surface circulation patterns, upwelling/downwelling patterns, and wind (aeolian) and riverine inputs.

In order to understand the development of massive blooms of algae such as *Pseudo-nitzschia*, scientists must determine the factors that enable one species to either outcompete or grow alongside other species. Unlike terrestrial ecosystems, where there may be patterns of succession of species leading to a climax community structure, the planktonic ecosystem has no analogous climax structure. The marine environment changes rapidly and is not stable long enough to evolve this type of 'permanent' structure. The question then is, what factors enable one species to bloom over another at certain times? Most algal blooms tend to be monospecific, meaning one species dominates over other species for the bloom or flowering period. There is evidence that micronutrients might be a key factor in determining which species are best able to use the macronutrients present in seawater and thus create a bloom.

Dr. Mark Wells (University of Maine) and his research team are investigating this mystery. To this end, they are studying the ecophysiology of *PN* in relation to micronutrients, specifically the trace metals - iron and copper. Both metals are found in very low concentrations dissolved in seawater, and they are important in nearly all metabolic processes, not just nutrient assimilation. Iron is particularly important for synthesis of amino acids and chlorophyll, neutralizing reactive (harmful) oxygen species, and for the basic electron transport chain used in photosynthesis, in addition to a number of other metabolic processes. Dr. Wells as part of his ECOHAB discoveries has found that *Pseudo-nitzschia* has a unique way of interacting with iron. *PN* appears to produce domoic acid when it is stressed from low amounts of dissolved iron and copper in seawater. Domoic acid appears to help *PN* acquire (i.e., take-up) the metals they need for growth. So in other words, this toxin is more than merely a toxin, but appears to have an important role in ensuring that this diatom is able to survive and even flourish in a micronutrient starved ocean.

Scientists do not really know why harmful algal species produce toxins. The two major possibilities are that phytoplankton produce toxins to deter predators (i.e., to stop from being eaten), or that they produce an accidental toxin – a molecule that is useful to the organism, but toxic to other organisms, even humans. This latter suggestion may be the case for domoic acid, but we are still not certain. The Wells research group is asking the question whether trace metals such as dissolved iron and copper are important triggers for the success of *PN*, and in particular their tendency to make domoic acid.

The primary objectives of the Wells research group are to collect seawater samples from the ECOHAB-PNW study area for trace metal analysis and to field-test a shipboard flow injection method for trace-metal analysis. Trace metal sampling and analyses are extremely difficult to do at sea because of the huge contamination problems. Remember we are on a big, sometimes rusting piece of iron (the ship) trying to collect seawater samples so that the scientists can measure minute concentrations of dissolved iron.....a task that was

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Topic: Photosynthesis and micronutrients – a domoic acid connection (*continued*)

impossible to do until fairly recently. Dr. Wells and his team use either a trace-metal clean FISH or special Go-Flo bottles. The FISH flies in the water at a depth of 5-10 m and can be flown continuously as the ship moves. The FISH must be towed from a boom off the ship, to ensure that the ship's metal hull itself does not contaminate the sample. Water is pumped up from depth to the ship through special tubing, to a trace-metal clean laboratory (the bubble room) for analysis. The other sampling technique uses a Go-Flo sampling bottle. This bottle collects discrete samples, and is a plastic container similar to a Niskin bottle that is sent down to any depth to collect a single water sample. By using both of these methods, the research team is able to provide onboard analysis of iron concentrations from throughout the water column; information which acts as a guide for designing deckboard incubation experiments where iron and copper concentrations are manipulated during physiological studies of *PN* and domoic acid production.

Keep reading to learn what organisms feed on *Pseudo-nitzschia*!

Day 9 - Survey sampling continues off the Strait of Juan de Fuca

Monday, September 18, 2006

N 40° 05'.78

W 125° 30'.42

Water temperature: 12.1°C

Salinity: 31.8 (on the practical salinity scale)

Topic: Phytoplankton ecology – *Pseudo-nitzschia* population dynamics

Winds, cold rain, and rough seas continued last night as scientists finished sampling the Cape Flattery (CF) transect offshore and began the La Perouse Bank (L) transects. All the L transects (LA, LB, LC, and LD) are monitored by the Canadian Institute for Ocean Sciences in Sidney, B.C. The La Perouse Bank is an important fishing ground off the west coast of Vancouver Island. Today we are sampling the LA transect from offshore toward the mouth of the Strait of Juan de Fuca just between Cape Flattery, Washington and Vancouver Island, Canada.

Phytoplankton are important primary producers. They are autotrophs, meaning they synthesize their own organic material. Heterotrophs are organisms that must eat other things to gain energy. Although most phytoplankton are microscopic, they are an important food source for grazers (heterotrophic organisms that feed on other organisms). Phytoplankton grazers can be separated into two categories based on their size. Microzooplankton are animal-like plankton (20-200µm) such as protists, while macrozooplankton include larger plankton (2-20cm) such as copepods and amphipods (microscopic crustaceans).

The trophic relationship between primary producers and their small herbivorous grazers (mostly zooplankton) can be complex. Intensive grazing can decrease the standing crop (the biomass of organisms present per unit volume or per unit area at a given time) even if the phytoplankton are rapidly growing (think of it like the well-fertilized lawns of golf courses that are continuously mowed, so they appear never to grow). Grazing rates often adjust to the magnitude of primary production to establish a balance between producer and consumer populations.

For a bloom of *Pseudo-nitzschia* to occur, not only do the physical and chemical conditions have to be just right (enough sunlight and macro- and micronutrients), but *PN* must out-compete other phytoplankton for nutrients and overcome grazing pressure. If *PN* are eaten by grazers at the same rate as they grow and reproduce, there is no bloom.

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Topic: Phytoplankton ecology – *Pseudo-nitzschia* population dynamics (continued)

In order to understand the population ecology of a harmful algal bloom, one must understand the trophic structure of the phytoplankton community.

Dr. Evelyn Lessard (University of Washington) and her research group are investigating the role of grazers in *Pseudo-nitzschia* population dynamics and domoic acid production. They are specifically using dilution techniques to experimentally alter the grazing rate and nutrient recycling to determine the effects of grazers on the net growth rate of the whole and size-fractionated phytoplankton community, specific species, groups of phytoplankton, and the production of dissolved and particulate domoic acid. These experiments provide *in situ* growth rates of *PN* compared to other phytoplankton species. The team also uses the Flo-CAM, an imaging flow cytometer onboard the ship to determine the abundance and species composition of natural phytoplankton communities. This special device allows for quick quantitative assessment of both *PN* abundance as well as phytoplankton and microzooplankton community structure at the surface and at depth.

Pseudo-nitzschia species don't easily fit into conventional plankton size categories (picoplankton, 0.2 – 2.0 μm , nanoplankton, 2.0 - 20 μm , and microplankton, 20-200 μm) because they are very long (>40 μm), but very thin (2-10 μm). Because they are long and skinny, they have a high surface area to body mass ratio. Diatoms such as *PN* are often harder to feed on than other phytoplankton groups due to their silica frustule and their shape. The primary grazers of *PN* appear to be microzooplankton.

The Lessard group studies the vertical profiles of planktonic assemblages in the sampling area by using microscopy and the Flo-CAM. Water is collected at various depths with Niskin bottles and is filtered into size classes. Then much time is spent using epifluorescence microscopy to identify the species of phytoplankton in the community. The Lessard team also works with the Trainer group to determine the importance of biotic versus abiotic factors in the degradation of dissolved domoic acid in seawater.

In nature, phytoplankton populations do not grow unchecked with unlimited growth rates. Their sizes are controlled by their tolerance limits to critical environmental factors including predators or by the availability of substances for which they have a need for sustained growth. Important limiting factors for phytoplankton biomass accumulation are grazing by herbivores and the availability of light and nutrients. The principal investigators in the ECOHAB-PNW project work together to learn the limiting factors for *PN* blooms. The Lessard research group focuses on the biotic grazing pressures on *PN*, while the Cochlan and Wells groups (see days 7 & 8 reports) investigate abiotic factors (such as macro- and micro-nutrients) that limit *PN* growth. Both "bottom-up" and "top-down" controls on *PN* abundance in the sea are covered by this collaborative ECOHAB project.





Topic: *Pseudo-nitzschia* in the food web – domoic acid impacts (continued)

Researchers from NOAA, Northwest Fisheries Science Center are investigating the dynamics and effects of DA transfer in the marine food web. Specifically, they are studying DA in copepods (macrozooplankton) and planktivorous anchovies. Dr. Stephanie Moore and Dr. Evelyn Lessard (both of the University of Washington) are working to determine whether copepods are vectors capable of transferring DA to higher trophic levels. Copepods may be feeding directly on toxigenic *PN* species or may be feeding on microzooplankton grazers that have eaten *PN*. For this study, a vertical plankton tow is used to sample water in the upper 100 m of the water column. The sample is then sorted by size into two categories: >850 μm (salps, krill) and 250-850 μm (copepods). Both size classes are then processed to determine concentrations of DA. Sub-samples are kept for identification of species.

Dr. Kathi Lefebvre (NOAA Northwest Fisheries Science Center) and her research group are conducting fish exposure studies to determine the effects of dietary exposure to toxic *PN* on planktivorous anchovies. This requires live anchovies to be brought onboard the research vessel and exposing them to *PN* blooms collected from the ECOHAB-PNW sampling stations. A unique attribute of this study is that fish are exposed to concentrations of *PN* found naturally in the ocean rather than being staged in a laboratory. The goal of this study is to determine how the toxin is distributed and metabolized in different tissues of the fish. There are three main components to this study: DA toxicity in fish tissues, anchovy behavior, and ecochemical conditions in the fish tanks.

This experiment uses two large tanks each containing 100 fish. One tank is a control tank with filtered seawater that contains no phytoplankton at all and so the fish are not feeding. The other experimental tank contains seawater with natural phytoplankton assemblages and relatively high concentrations of toxic *PN* collected from ECOHAB-PNW stations. Every 12 hours the seawater is changed in the tanks. Three fish every 24 hours are collected from each tank (control and experimental) for dissections. Scientists remove the heart, brain, muscle, kidney, bile, and gall bladder to measure the concentration of DA in the various tissues. Daily behavioral observations are performed in which fish are filmed to note any indications of impairment due to DA toxicity. Seawater samples are monitored at the beginning and end of every 12 hours (before water in the tanks is changed) for concentrations of nutrients (including urea and ammonium), and dissolved and particulate DA. Cell counts are also being taken for whole phytoplankton assemblage studies including the abundance of *PN*.

We know that anchovies are capable of transferring DA to other organisms higher in the food web such as pelicans and sea lions and therefore must accumulate toxin, but the anchovies themselves so far appear to be relatively resistant to the effects of DA. Scientists believe they may be either sequestering the toxin in certain tissues to protect other tissues, or they may be adding functional groups to the DA molecule which may make it less harmful to the fish. In either case, the anchovy demonstrates some level of DA resistance. What is this mechanism that provides anchovies with some level of resistance to DA, and why are marine birds and mammals that feed on the anchovies impacted so severely? The copepod and anchovy studies by NOAA and University of Washington researchers investigating DA toxin transfer through the marine food web are an important higher trophic level complement to the ecophysiological and physical investigations being conducted concurrently in the ECOHAB-PNW project.





Day 11 - Continued sampling on the La Perouse Bank

Wednesday, 9/20/2006

N 48° 30'.09

W 125° 28'.55

Water temperature: 11.6°C

Salinity: 32.6 (on the practical salinity scale)

Topic: ECOHAB-PNW Research - early warning of domoic acid events

We continued our sampling throughout the night on the LB transect starting offshore. Scientists are working today in the cold rain to complete this transect, but this is the Pacific Northwest so such weather is not uncommon. As we approach station LB1 will we be close to shore between Nitinat Lake and Pachena Pt., on Vancouver Island, Canada. This is the furthest north we have been thus far during our oceanographic cruise.

Toxigenic blooms of *Pseudo-nitzschia* are a cause of concern for those living and fishing in the Pacific Northwest coast of the U.S. and southwestern Canada. These blooms can result in significant loss of revenue for fisheries in coastal communities, as well as cause public health concerns. Many trophic levels of the marine food web are impacted during a bloom, including zooplankton, planktivorous fish, shellfish, finfish, marine birds, marine mammals, and even humans. Some higher level trophic consumers such as marine birds and marine mammals are severely affected by domoic acid. Human consumers of toxic shellfish may become ill or even die from ASP (Amnesic Shellfish Poisoning), but the only human fatalities to date in North America occurred in the Canadian Maritime province of Prince Edward Island.

Shellfish on the Pacific Northwest coast are of special concern, due to their consumption by humans. The Pacific razor clam is unique in that the clam can retain high concentrations of domoic acid for over a year without being negatively impacted itself. Razor clams seem to bind the toxin, but keep filter feeding *PN* from the water column and accumulating domoic acid during a toxigenic bloom. Because they bind the DA and retain it for so long, careful DA monitoring of the species must occur to protect the large number of recreational and tribal fishers. Razor clams are a huge part of coastal and tribal culture. The Quinault tribe even has a specific word meaning "clam hungry". Razor clams are a staple of their diet and an important part of tribal life. When ceremonial and sustenance digs aren't allowed, an important part of the native culture is lost. Coastal economies are very much tourist-based and razor clamming from Fall through Spring bring much needed revenue from the population centers out to the coast. When extended closures occur, small family-owned businesses literally close their doors and board up their windows permanently, and a traditional and family pastime is taken away from coastal society.

Other shellfish such as clams, oysters, mussels, and scallops do not bind domoic acid. These organisms will filter this microalgae and release the toxin in the time span of a few days or weeks. However, these fisheries are still closely monitored. The Department of Health has placed a regulatory level of 20µg of DA per gram of shellfish weight as the amount of domoic acid that can be safely consumed before beaches are closed to shellfish harvesting. Dungeness crabs are detritivore/scavengers which may feed on particles or pieces of dead shellfish. These crabs can also accumulate the toxin. The crab can be eaten however during toxic conditions, if it is cleaned properly and the consumer is careful not to eat any of the viscera (internal organs). Blue mussels are often used as an indicator species for a toxigenic bloom. These filter feeders process food quickly, which means they are able to accumulate DA quickly during an event and when tested can indicate a current bloom.

(continued)





Topic: ECOHAB-PNW Research - early warning of domoic acid events (*continued*)

Scientists from ECOHAB-PNW have published much information about the physical oceanography of *PN* blooms moving to the coast, the biology of *PN*, variable toxicity of DA, macro- and micronutrients needed for blooms, and how phytoplankton community structure changes during a bloom. They have also been invaluable in creating new, and adapting existing methods, to measure many of the eco-chemical factors thought to promote or sustain toxic blooms of *PN*. From this research, new patterns and ideas are emerging regarding the seasonality, duration, and magnitude of toxigenic *PN* blooms, which will be eventually utilized by managers and scientists worldwide to help predict and control the impact of such diatom blooms.

In 1999, academic, federal, tribal, and state managers and researchers in Washington State formed the Olympic Region Harmful Algal Bloom (ORHAB) partnership. The objectives of ORHAB were to investigate the origins of toxic algal blooms, monitor where and when the blooms occur, assess the environmental conditions conducive to blooms and toxicification of intertidal shellfish, and to explore methods to reduce HAB impacts on humans and in the environment. The ORHAB program currently monitors seven locations on the Washington coast where razor clam harvesting occurs. The program monitors two times a week to measure total *PN* cell counts using light microscopy and measures DA in the seawater. Researchers can take samples from the field or even use a cellular toxicity test strip in the field to measure DA concentrations. This monitoring provides important data for resource managers who must decide when and where to open fisheries. This data provides them with early warning of DA accumulation by shellfish.

The ECOHAB-PNW research provides valuable information to marine resource managers. Drifter studies tracking toxigenic *PN* blooms can be used to predict whether a toxic bloom will advect toward the coast. Computer modeling using physical, chemical, and ecological data collected at sea are being used to predict the magnitude and movement of blooms in the Pacific Northwest. The ECOHAB-PNW project maintains moored buoys during May-October in the Strait of Juan de Fuca and the Juan de Fuca Eddy, which can be used as an ocean observing system to follow, monitor and eventually predict bloom environmental conditions. One of the ultimate goals is to develop a U.S. West Coast HAB-forecaster using the scientific information gained from ECOHAB-PNW.

Effective HAB forecasting will likely need an integrated suite of sensors from both moored buoys and satellites. The buoys would measure ocean water properties such as temperature, salinity, light, macro- and micronutrients, currents, wind, *PN* cell number counts, and domoic acid concentrations, all of which could add real-time data to shore-based laboratory testing and monitoring. New and emerging technologies may allow *in situ* detection of phytoplankton at the species level, improved detection of phytoplankton biomass, measurement of macro- and micronutrient concentrations, and domoic acid (and other toxin) concentrations.

The relationship between ECOHAB-PNW research scientists and managers of coastal resources in the Pacific Northwest is unique. Anthony Odell is the coastal sampling coordinator and data manager of ORHAB and also participates in mooring servicing, drifter recovery, and yearly research cruises with ECOHAB-PNW. He acts as a real-time bridge between cutting-edge research at sea and integrating this research into monitoring programs that affect the culture, economics, and public health in coastal communities. Collaborative research efforts such as ECOHAB-PNW provide real results which help guide management of coastal resources.





Day 12 - Sampling the La Perouse Bank grid and searching for blooms in Barkley Sound

Thursday, 9/21/2006

N 48° 51'.53

W 125° 14'.58

Water temperature: 11.0°C

Salinity: 31.8 (on the practical salinity scale)

Topic: Experimental design - research at sea

We woke to rough seas and pods of Pacific white-sided dolphins and Dall's porpoises swimming in the waves about the ship. Today we are sampling along the LBC transect from offshore to onshore toward Cape Beale. After finishing the transect we are going to steam to Barkley Sound on Vancouver Island, Canada, where we hope to find a bloom of *Pseudo-nitzschia* cells to sample for deckboard experimentation.

The scientific method is a circular process designed to investigate phenomena while suggesting testable explanations for those phenomena. Observations and data collection often lead to complex questions, which can only be answered by careful experimentation. The ECOHAB-PNW grid survey sampling provides much data about the physical, ecological, and chemical conditions conducive to blooms of toxigenic *PN*. This information can then be used to design experiments on board the research vessel to learn more about the specific processes of *PN* growth and DA toxicity.

In addition to the survey sampling conducted on the ECOHAB-PNW research cruises, a suite of 'grow-out' experiments are conducted on board the vessel. Dr. William Cochlan (Romberg Tiburon Center for Environmental Studies, San Francisco State University) and Dr. Mark Wells (University of Maine), along with Dr. Charlie Trick (University of Western Ontario) and their respective research teams, offer their expertise to the *PN* growth experiments. These experiments are the heart and soul of finding answers to the perplexing questions of why *PN* produces DA, and what environmental conditions in the field initiate or sustain blooms of toxigenic *PN*? The purpose of the growth experiments, (or incubation experiments), is to elucidate the factors that influence the initiation, formation, and/or maintenance of *PN* blooms and DA concentrations (cellular or extra cellular).

There are two main types of 'grow-out' experiments where scientists are able to manipulate the amount and types of macro- and micro-nutrients (such as trace metals), add chemical chelators, and alter other environmental factors such as amount of light, temperature, or salinity. Scientists create different treatments and are able to measure biomass formation, nutrient drawdown, domoic acid production (dissolved and particulate), community structure changes, bacterial and phytoplankton productivity, and photosynthetic efficiency and capacity.

The grow-out experiments utilize two types of culture systems: batch mode culturing and continuous culturing. Batch cultures are enclosed bottle experiments where a community of phytoplankton, (in this case including *PN* cells) are placed in an incubation bottle which acts as a closed ecosystem. In batch cultures, the experimenter decides the treatment and at the beginning of the experiment, places natural seawater with phytoplankton into the bottle and adds an addition (the treatment may be additional nutrients, trace metals, etc.) at a certain concentration. The bottle is then closed and allowed to incubate for a certain period of time with temperature and light levels mimicking those of the natural system. At the end of the experiment (12 hours - few days), the experimenter analyzes the change in the ecosystem (bottle) from the beginning of the experiment to the end by again measuring biomass formation, nutrient drawdown, domoic acid production (dissolved and particulate), community structure changes, bacterial and phytoplankton productivity, and photosynthetic efficiency and capacity. Subsamples from the batches may also be taken on an hourly - daily time period for more in-depth analysis of changes over time.

(continued)





Topic: Experimental design - research at sea (*continued*)

In continuous culture experiments, a natural phytoplankton community collected from the sea is placed into an incubation bottle which acts as an ecosystem. This bottle is special however, with a small inflow and outflow tubes. The inflow and outflow tubes enable the experimenter to make an addition (treatment may be nutrients, trace metals etc.) continuously over time, rather than only once such as in the beginning of a batch culture. The treatment may be added or changed over a period of time by having small inflow tubes that flow directly into the ecosystem bottles. The bottles also have outflow tubes, which permits continuous flow over the entire period of the experiment (what goes in must come out), and scientists are able to take subsamples whenever they wish from the treatments to measure biomass, nutrient drawdown, domoic acid production, etc. Flow rates are kept constant for bottles and monitored closely. The bottles are completely closed except for the inflow and outflow tubes. The bottles are kept in an incubator which controls mixing, light, and temperature. These experiments can run for a longer period of time than batch cultures, due to the possibility of continuous additions over time. By using continuous culture methods, scientists are able to look at the change in phytoplankton community structure over time, as well as measure the entire suite of characteristics important when studying *PV* blooms.

ECOHAB-PNW is the first series of research cruises to use a sophisticated continuous culture incubator on the deck of a research vessel with precision-controlled flow rates. By using both batch experiments and continuous culture experiments at sea with natural seawater and phytoplankton community assemblages, scientists are breaking new ground. Using continuous cultures at sea is new to the field of oceanography, and only two continuous culture incubators currently exist in the world. By conducting complex growth experiments, in addition to survey sampling, and directed bloom sampling at sea, ECOHAB-PNW researchers have and are continuing to answer complex questions about *PV* physiology, domoic acid production, and the chemical factors that are conducive to *PV* blooms in nature.



Plankton Identification

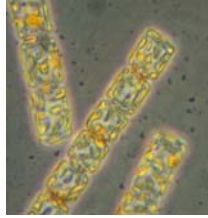
Diatoms



Asterionellopsis (1)



Attheya



Detonula



Guinardia



Odontella (1)



Odontella (2)*

Common Coastal Species

Puget Sound and Coastal Species



Chaetoceros (1)



Coscinodiscus



Rhizosolenia



Thalassiosira (1)



Thalassionema



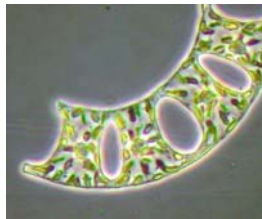
Ditylum



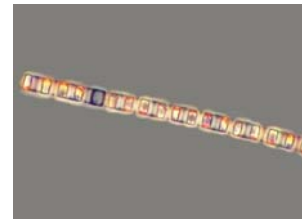
Chaetoceros (2)*



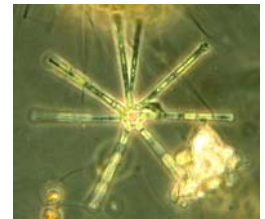
Thalassiosira (2)*



Eucampia



Skeletonema



Asterionellopsis (2)*

Dinoflagellates



Noctiluca



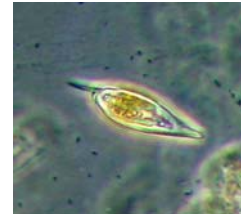
Dinophysis



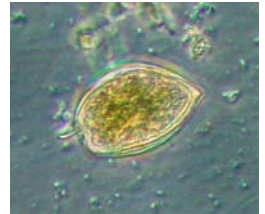
Protoperdinium



Ceratium

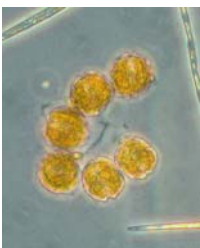


Prorocentrum (1)



Prorocentrum (2)*

Toxic Species Found in Washington



The dinoflagellate genus *Alexandrium* produces a variety of toxins which cause Paralytic Shellfish Poisoning (PSP). Shellfish filter feed, meaning they pump sea-water and eat phytoplankton. As they digest *Alexandrium*, toxin is released into their digestive system and then distributed into their tissues.



Domoic acid is produced by diatoms in the genus *Pseudo-nitzschia*, needle-like cells that form chains by overlapping their tips. It is the only diatom currently identified as producing a marine biotoxin. Not all species of *Pseudo-nitzschia* produce domoic acid, nor do they produce it consistently.



In addition to marine toxins, the salmon farming industry in Washington State has suffered large losses due to the golden-brown algae *Heterosigma*. *Heterosigma akashiwo* is a bloom forming organism associated with massive finfish deaths in temperate waters worldwide.

* Another example of the same genus of this organism.

Plankton Identification

Marine algae come in a variety of sizes and forms. The small, microscopic plant-like organisms are often referred to as microalgae or **phytoplankton**, which like land plants, contain **photosynthetic** pigments such as chlorophyll and need sunlight and inorganic **nutrients** to grow.

Diatoms

Perhaps the most varied, beautiful, and geometrically intricate of all the phytoplankton are the diatoms. Diatoms have a rigid **silica** shell (and hence require silicate as an essential nutrient) composed of two interlocking parts. Unlike dinoflagellates, diatoms do not propel themselves up and down in the water column, but are dependent on oceanic currents for transport. After diatoms die, their silica shells are either dissolved back into the seawater or sink to the bottom and eventually become diatomaceous earth. Diatoms can either be solitary or colonial (forming chains or groups of cells), and many have distinctive shapes or structures which help them stay afloat.

Dinoflagellates

Dinoflagellates typically have one or two **flagella** (whip-like tails) that can move them up or down in the water column. They are either naked or have complex outer shells or armor plating called **theca**, made of carbohydrate material in a variety of shapes and sizes. Dinoflagellates' ability to move up or down, called **vertical migration**, is thought to assist them in gaining access to nutrients or light as needed, and so they can optimize their position in the water column.

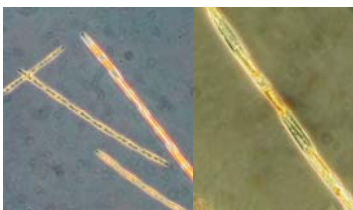
Why are some species toxic and others not?

Out of the thousands of phytoplankton species identified, only a few dozen can produce biotoxins. Toxins apparently benefit these algae in some way: some species produce toxin consistently, while some, like *Pseudo-nitzschia*, only appear to produce toxin under certain environmental conditions. Some of the most important questions that researchers face are determining the structure and function of toxic compounds in harmful species, and the conditions under which they produce toxins.

Why do the ones I see look different?

Answer One: Magnification

Your microscope may be set to a different magnification than the ones that took these pictures. Below are three sets of plankton magnified to 160x and 400x to show the difference that magnification can make. What is the magnification of your microscope?



Answer Two: Same genus, but different species

Phytoplankton are so small that we can't always tell the difference between species using a regular light microscope. Below are four different species of *Chaetoceros*—how are they similar? How are they different?



Answer Three: Size

Plankton size can depend on stage of life, growing conditions and food supply.

Glossary of Terms



Alga: singular of algae

Algae: any of various chiefly aquatic, photosynthetic organisms ranging in size from single-celled forms to the multi-cellular giant kelps

Anoxic: an environment lacking oxygen, often due to decomposition of large amounts of organic matter

Autotroph: organism which makes own source of food (usually in the form of sugar) using energy from the sun (a photoautotroph) or chemicals (a chemoautotroph)

Biological oceanography: the study of the microbes, plants and animals of the oceans and their ecological interaction

Carbon cycle: the circulation of carbon atoms through the ecosystem, e.g. via the processes of photosynthesis and respiration

Carnivore (carnivorous): animal with a diet mainly consisting of other animals, whether living (predator) or dead (scavenger)

Chemical oceanography: the study of the chemistry of the ocean

Chloroplast: an organelle found in the cells of green plants and algae which contains chlorophyll and are responsible for carrying out photosynthesis

Colonial diatom: diatoms which form chains or groups of cells

CTD: an oceanographic sensor lowered into the sea for measurement of conductivity (related to salinity), temperature and depth (related to hydrostatic pressure).

Density: mass per unit volume (e.g., grams/liter)

Diatom: microscopic, single-celled or colonial algae whose cell walls are made of silica and consist of two halves that fit together like a pill box (or Petri dish)

Dinoflagellate: microscopic single-celled or colonial algae having one or two flagella (whip-like tail) which allow them to move vertically in the water column. Structure is composed of plates or "theca"

Domoic acid: a nerve toxin produced by some *Pseudo-nitzschia* species that can adversely affect humans, marine mammals, and seabirds

Experimental manipulation: the process by which a single parameter is altered (e.g., the concentration of iron in seawater) to determine the influence of that parameter

Flagella: whip-like tail found on dinoflagellate plankton which allow some movement in the water column

Flo-CAM: an instrument used for rapid identification of algae in seawater

Flow cytometer: used for the simultaneous analysis of multiple physical and/or chemical characteristics of single cells flowing through an optical and/or electronic detection apparatus using laser technology

Grazer: an organism that feeds on algae



Glossary of Terms



Heterotroph: organism which cannot make its own food and must consume other organisms (dead or alive) for energy

Investigator: the person in charge of a research study

Neurotoxin: any toxin which impacts the organs of the nervous system—brain, spinal cord, or nerves

Nutrients: element or compound used by an organism for growth or reproduction; some of the nutrients important to phytoplankton include nitrate, nitrite, phosphate, and silicate

Omnivore (omnivorous): an animal which eats both plants and animals as primary food sources

Photosynthesis: process in organisms (e.g., green plants) by which carbon dioxide and water are combined to form carbohydrates using sunlight as the energy source. Oxygen is usually released as a byproduct of photosynthesis

Plankter: singular of plankton

Primary Productivity: the rate of production of organic carbon from carbon dioxide by plants and algae, usually through photosynthesis

Planktonic: organism whose movement is directed mainly by water currents

Physical oceanography: studies the ocean's physical attributes including temperature-salinity structure, waves, tides and currents)

Phytoplankton: usually microscopic, free-floating aquatic plant-like organisms

Positive pressure: a condition that exists when more air is supplied to a space than is exhausted

Profile: a graph showing the variation of an oceanographic parameter (e.g. temperature) with depth

Pseudo-nitzschia: the genus of pennate (pen-shaped) diatoms that can produce the toxin domoic acid

Salinity: a measure of the amount of dissolved salts in water

Toxin transfer: the passing of toxic compounds from one organism to another most often through feeding

Treatment: alteration of a single factor in an experiment (e.g., the concentration of iron in seawater) to determine its effect

Upwelling: process by which surface waters are drawn away from coastal areas and replaced by colder, denser water (and usually higher in nutrients) from below

Vertical migration: process of moving up and down in the water column in order to escape predation, gain access to sunlight or nutrients; dinoflagellates and zooplankton have the ability to vertically migrate, usually on a daily cycle

Zooplankton: usually microscopic, aquatic animals which consume phytoplankton and bacteria



Additional Sources of Information about HABs



Informational Websites

NOAA's Northwest Fisheries Science Center's Harmful Algal Bloom Program

http://www.nwfsc.noaa.gov/hab/habs_toxins/index.html

Ecology and Oceanography of Harmful Algal Blooms (ECOHAB Pacific Northwest)

<http://www.ecohabpnw.org>

Woods Hole Oceanographic Institute: The Harmful Algae Page

<http://www.whoi.edu/redtide/>

Washington State Department of Health: Office of Shellfish and Water Protection

<http://www.doh.wa.gov/ehp/sf/default.htm>

Olympic Region Harmful Algal Blooms (ORHAB) Partnership

<http://www.orhab.org/>

Interactive Websites

Click on the test tube to learn more about toxic algae species and how they can affect humans! <http://www.bigelow.org/hab/index.html>

The SEA Times <http://www.nwfsc.noaa.gov/hab/outreach/seatimes.html>

NOAA's Ocean Explorer <http://oceanexplorer.noaa.gov/>

Lesson Plans

Bad Algae!

http://www.oceanservice.noaa.gov/education/classroom/lessons/07_algal_algae.pdf

In Full Bloom!

<http://www.vims.edu/bridge/archive0402.html>

Oceanographic Data available for download

National Data Buoy Data: Near real-time wind, temperature, current, and salinity data for U.S. coastal waters <http://www.ndbc.noaa.gov/>

NOAA's Coastwatch: Near real-time maps of sea surface temperature, chlorophyll, surface winds for U.S. coastal waters http://coastwatch.noaa.gov/cw_index.html



Contribution to Washington State EALRs



EALR 1. SYSTEMS: The student knows and applies scientific concepts and principles to understand the properties, structures, and changes in physical, earth/space, and living systems.

Washington State Component	Scientific Discipline	Grade Level Indicators	Activities in this curriculum
1.2 Structures: Understand how components, structures, organizations, and interconnections describe systems.	<i>Physical Earth/Space and Living Systems</i>	1.2.1 (6) Explain how the parts of a system interconnect and influence each other. (8) Describe the interactions and influences between two or more simple systems.	<ul style="list-style-type: none"> ●Marine Food Webs ●Coastal Upwelling
	<i>Structure of Matter</i>	1.2.3 (4) Observe and describe that some particles can only be seen with magnification.	<ul style="list-style-type: none"> ●Phytoplankton Identification
	<i>Components and Patterns of Earth Systems</i>	1.2.4 (7) Describe the interactions among the components of Earth's systems (i.e., the core, the mantle, oceanic and crustal plates, landforms, the hydrosphere and atmosphere). (9) Correlate Earth's surface features to observable weather patterns (e.g., rain shadow, deserts, rain forest).	<ul style="list-style-type: none"> ●Coastal Upwelling ●Tough Choices: HAB Closures
		1.2.6 (3) Observe with a microscope and record that living things are made mostly of cells (i.e., plants, animals, and single-celled organisms). (3) Describe how plant and animal cells are similar and different.	<ul style="list-style-type: none"> ●Phytoplankton Identification
1.3 Changes: Understand how interactions within and among systems cause changes in matter and energy.	<i>Earth and Space Systems</i>	1.3.6 (7) Explain the causes of atmospheric circulation and oceanic currents (e.g., prevailing winds are the result of hot tropical regions, cold polar regions, and Earth's spin).	<ul style="list-style-type: none"> ●Density & Stratification ●Coastal Upwelling
	<i>Life Processes and the Flow of Matter and Energy</i>	1.3.8 (4) Identify sources of energy and matter used by animals to grow and sustain life (e.g., air, water, light, food, mineral nutrients). (5) Explain how plants and animals obtain food (e.g., plants make food from air, water, sunlight, mineral nutrients; animals obtain food from other living things).	<ul style="list-style-type: none"> ●Marine Food Webs
		1.3.8 (7) Describe the different sources of matter and energy required for life processes in plants and animals (e.g., seeds have energy for germination; green plants need light for energy). (7) Describe how organisms acquire materials needed for life processes. (7) Describe how systems interact to distribute materials and eliminate wastes produced by life processes. (7) Describe that both plants and animals extract energy from food but plants produce their own food from light, air, water, and mineral nutrients while animals consume energy-rich foods.	<ul style="list-style-type: none"> ●Marine Food Webs
		1.3.10 (3) Describe the role of an organism in a food chain of an ecosystem (i.e., predator, prey, consumer, producer, decomposer, scavenger). (5) Describe how an organism's ability to survive is affected by a change in an ecosystem (e.g., the loss of one organism in a food chain affects all other organisms in that food chain). (5) Describe the path of substances (i.e., air, water, mineral nutrients) through a food chain.	<ul style="list-style-type: none"> ●Marine Food Webs
		1.3.10 (9) Describe how matter and energy are transferred and cycled through ecosystems (i.e., matter and energy move from plants to herbivores/omnivores to carnivores and decomposers). (9) Describe the living and nonliving factors that limit the size and affect the health of a population in an ecosystem.	<ul style="list-style-type: none"> ●Types of Harmful Blooms ●Tough Choices: HAB Closures



Contribution to Washington State EALRs



EALR 2. INQUIRY: The student knows and applies the skills, processes, and nature of scientific inquiry.

Washington State Component	Scientific Discipline	Grade Level Indicators	Activities in this curriculum
<p>2.1 Investigating Systems: Develop the knowledge and skills necessary to do scientific inquiry.</p>	<p><i>Explaining</i></p>	<p>2.1.3 (6, 7, 8) Describe a reason for a given conclusion using evidence from an investigation. (6, 7, 8) Generate a scientific explanation of an observed phenomenon using given data. (6) Predict what logically might occur if an investigation lasted longer or changed.</p>	<ul style="list-style-type: none"> •Coastal Upwelling •Tough Choices: HAB Closures
		<p>2.1.3 (9, 10) Describe a reason for a given conclusion using evidence from an investigation. (9, 10) Generate a scientific explanation of an observed phenomenon using given data. (9, 10) Predict and explain what logically might occur if an investigation lasted longer or changed. (10) Revise a scientific explanation to better fit the evidence and defend the logic of the revised explanation.</p>	<ul style="list-style-type: none"> •Density & Stratification •Coastal Upwelling •Tough Choices: HAB Closures



Contribution to Washington State EALRs



EALR 3. APPLICATION: The student knows and applies science concepts and skills to develop solutions to human problems in societal contexts.

Washington State Component	Scientific Discipline	Grade Level Indicators	Activities in this curriculum
<p>3.1 Designing Solutions: Apply knowledge and skills of science and technology to design solutions to human problems or meet challenges.</p>	<p><i>Evaluating Potential Solutions</i></p>	<p>3.1.3 (3, 4, 5) Identify the criteria for an acceptable solution to a problem or challenge. (3, 4, 5) Describe the reason(s) for the effectiveness of a solution to a problem or challenge using scientific concepts and principles. (3, 4, 5) Describe the consequences of the solution to a problem or challenge (e.g., sharpening a crayon results in using up crayons faster). (3, 4, 5) Describe how to change a system to solve a problem or improve a solution to a problem. (3, 4, 5) Test how well a solution works based on criteria, and recommend and justify, with scientific concepts or principles and data, how to make it better (e.g., sharpen a crayon using sandpaper; one grit is better than another).</p>	<ul style="list-style-type: none"> • Tough Choices: HAB Closures
<p>3.2 Science, Technology, and Society: Analyze how science and technology are human endeavors, interrelated to each other, society, the workplace, and the environment.</p>	<p><i>Environmental and Resource Issues</i></p>	<p>3.2.4 (3, 5) Describe the effects of humans on the health of an ecosystem. (3, 5) Describe how humans can cause changes in the environment that affect the livability of the environment for humans. (3, 5) Describe the limited resources humans depend on and how changes in these resources affect the livability of the environment for humans.</p>	<ul style="list-style-type: none"> • Types of Harmful Algal Blooms • Tough Choices: HAB Closures



Instructor Guide Answer Key



Algae Hunters: Video Exercise

1. Domoic acid
2. Off of the West Coast of Washington State
3. Geology, Physics, Chemistry, Biology
4. Yes
5. 32
6. From the north to the south
7. A plankton net
8. Salinity, temperature, and depth
9. Inorganic nutrients: phosphate, nitrate, nitrite, silicate
10. Alteration of a factor in an experiment (for example, changing the concentration of iron)
11. *Pseudo-nitzschia* can be toxic to humans to the point of death, but more often results in permanent short-term memory loss. The algae are not always toxic, however, so the name is not entirely accurate.

Density and Stratification

1. The water forms layers because the differences in temperature and salinity between the two water masses mean they have different densities. Density is a function of mass (or weight), $Density = mass/volume$. The same way that disturbed sediment will form layers based on weight (for example, larger sand particles will form the bottom layer), water masses will form layers based on weight. The temperature and amount of salt in water determines its density. Cold, salty water has more mass/volume, therefore greater density, and will sink to the bottom.
2. Density is a function of mass [$Density = mass/volume$]. Salinity describes the amount of dissolved salts in a liquid.
3. As water becomes more saline it becomes more dense, and will sink below less dense water. Some places in the world where this occurs include the polar (increased salinity via formation of ice) and the equatorial regions (via evaporation).
4. The map on the left is Coastal, and the right is Puget Sound.
5. The map on the right has water of lower salinity on top, indicating the fresh water coming in from the river. The scale at the bottom of the maps is a good clue since a bay in Puget Sound would have smaller distances. The maximum depth of 40 m in the left-hand map reflects the greater depth of the ocean relative to the bay.
6. The water below would come to the surface, called "upwelling".

Coastal Upwelling

PART I: Graphing

1. Coastal upwelling should be occurring throughout the 48 period.
2. The water along the shore will be cooler as it is coming from below the surface before moving outward from the coast. When there is no upwelling, the water temperature should be about the same as offshore waters.
3. There will be high productivity due to the nutrient-rich waters being upwelled.

PART II: Mapping

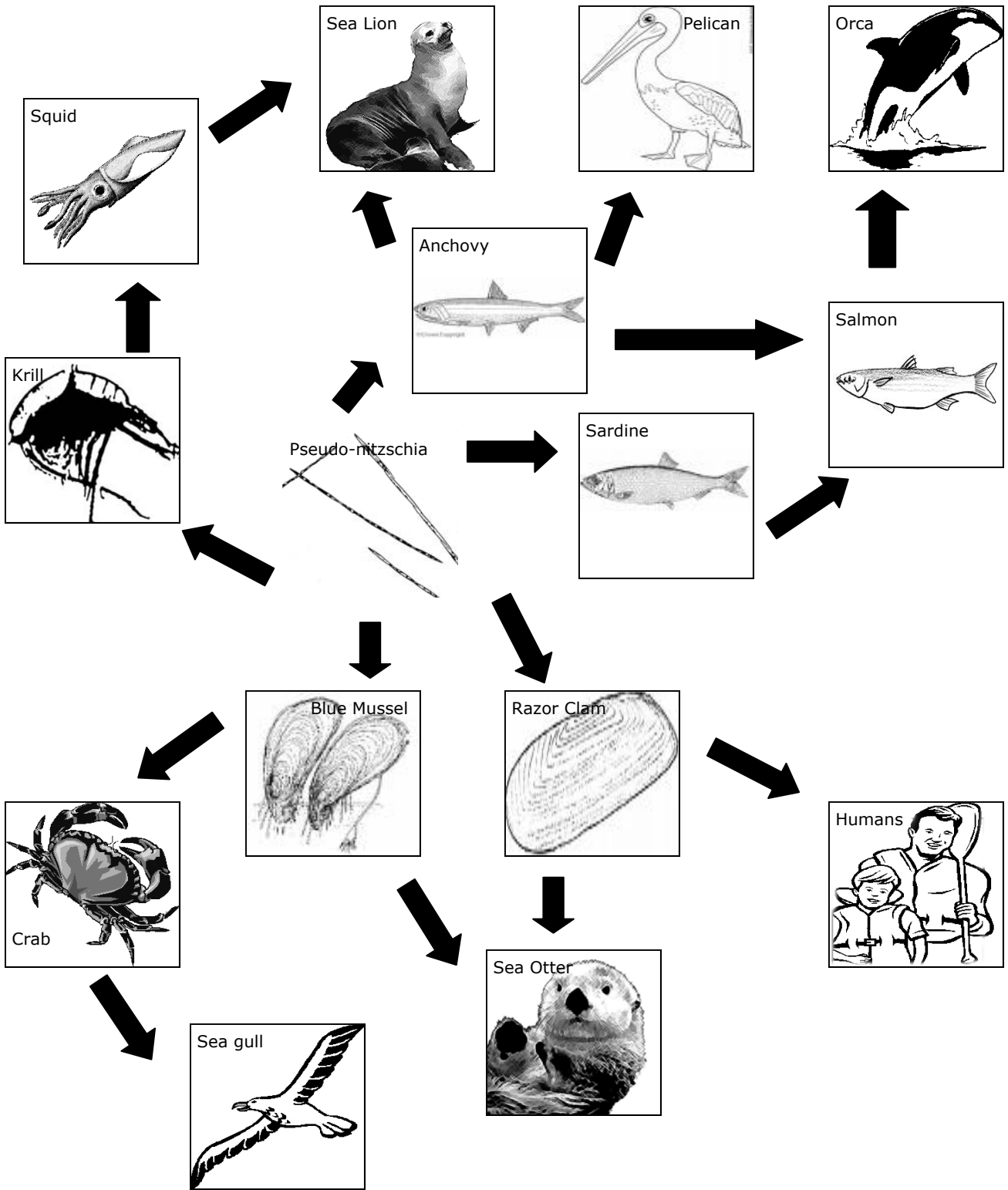
1. This map shows evidence of upwelling because the water close to the coast is cooler than the waters offshore.
2. The highest nutrients should be in the areas of cooler, upwelled water.
3. The width is approximately 40 nautical miles during this time period.
4. Sea surface temperatures for this area in the winter would probably be cooler overall, but coastal upwelling would probably be less evident.



Instructor Guide Answer Key



Marine Food Webs



Instructor Guide Answer Key



Tough Choices: HAB Closures

1. The direction of the current corresponds to the direction of the wind.
2. The wind blows from north to south for most of the summer.
3. The wind and current switch direction (very strongly) from southerly to northerly just before the high levels of domoic acid are seen at Kalaloch Beach.
4. Because the wind determines the direction of the currents which contain phytoplankton, if a body of water contains *Pseudo-nitzschia* which is producing toxic levels of domoic acid, this water can be pushed toward shore where it can impact razor clams.



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