



Well, Well, Well

SUMMARY

In this activity students investigate the relationship between winds, surface currents, sea surface temperature and upwelling and downwelling off the coast of OR and WA. Students analyze data to make predictions on today's upwelling or downwelling conditions.

OBJECTIVES

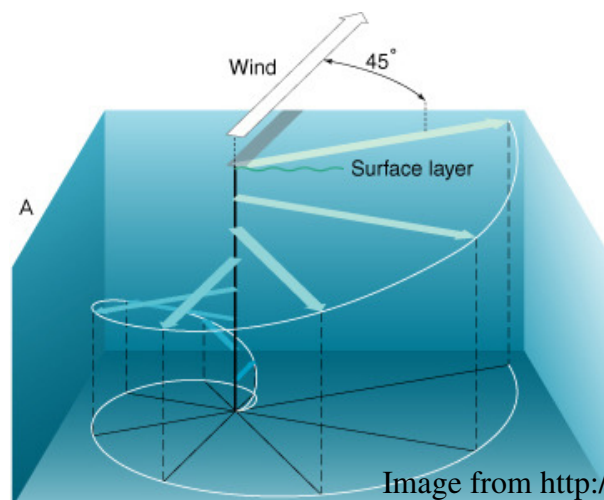
- Students will be able to explain the process of upwelling and downwelling.
- Students will be able to analyze the relationship between wind, surface currents and sea surface temperature to make predications on water conditions.

MATERIALS

- Computer lab with Internet access or projection screen

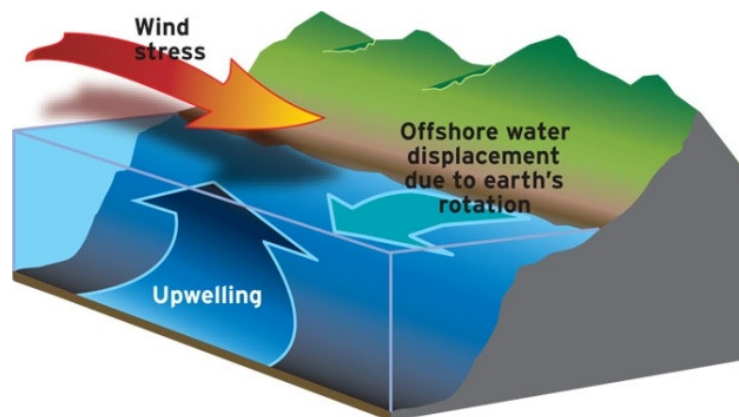
BACKGROUND

As wind blows across the ocean, it moves ocean water due to friction at the ocean surface. The influence of the wind to move ocean water decreases with ocean depth, until at some depth, usually between 100 and 150 meters, there is little motion created directly by wind. The layer of water from the surface to the depth where wind has little direct influence on the ocean movement is called the mixed layer. The Coriolis effect, which is that anything moving over the surface of the earth (and not frictionally coupled to it) will be deflected to the right in the northern hemisphere, and to the left in the southern hemisphere due to Earth's rotation comes into play. In the case of wind blowing over water, the Coriolis effect causes surface water to move to the right of the wind direction in the Pacific Northwest. As we go down in depth through the mixed layer, water under the surface is moved by the wind even more to the right. The result is a spiral of moving water called an Ekman spiral that runs through the mixed layer. The direction of water flow over the entire mixed layer net transport is about 90 degrees to the right of the wind, this is called Ekman transport. In some areas such as shallower waters, a complete Ekman spiral cannot develop, and the net Ekman transport may be less than 90 degr



PNW Upwelling: For Oregon and Washington coastal areas, when northerly winds (winds coming from the North) blow along down the coast, thanks to Ekman transport, these winds drive surface waters offshore from the coastline. This offshore transport of surface waters is balanced by the ascent of cool, high-salinity, nutrient-rich deep waters that flow upward to replace the surface water moving offshore. This process is called upwelling. Conversely, when winds are blowing southerly along the coast, surface waters are moved onshore, driving bottom waters away from the coast, and this process is called downwelling.

Every summer, from about April to September, the Oregon and Washington coast are dominated by upwelling favourable northerly winds. The upwelled waters, cold and rich in nutrients like nitrogen and phosphorus, in combination with the sunlight available at the shallower depths, promote primary production, or the growth of phytoplankton. The phytoplankton, the base for marine food webs, provide food for zooplankton, which are in turn are food for larger fish. Oregon and Washington's productive ocean ecosystem is due in a large part to this upwelling.



Teaching Notes:

There is an introductory demonstration which shows how “wind” moving water can bring water from depth to the surface. This simple demonstration does not demonstrate the Coriolis effect. For a more in-depth demonstration of the Coriolis effect see:
http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/21_2/21.2_hands_on.pdf

Introductory Activity, Upwelling

Objective

- Demonstrate the process of upwelling and downwelling

Materials

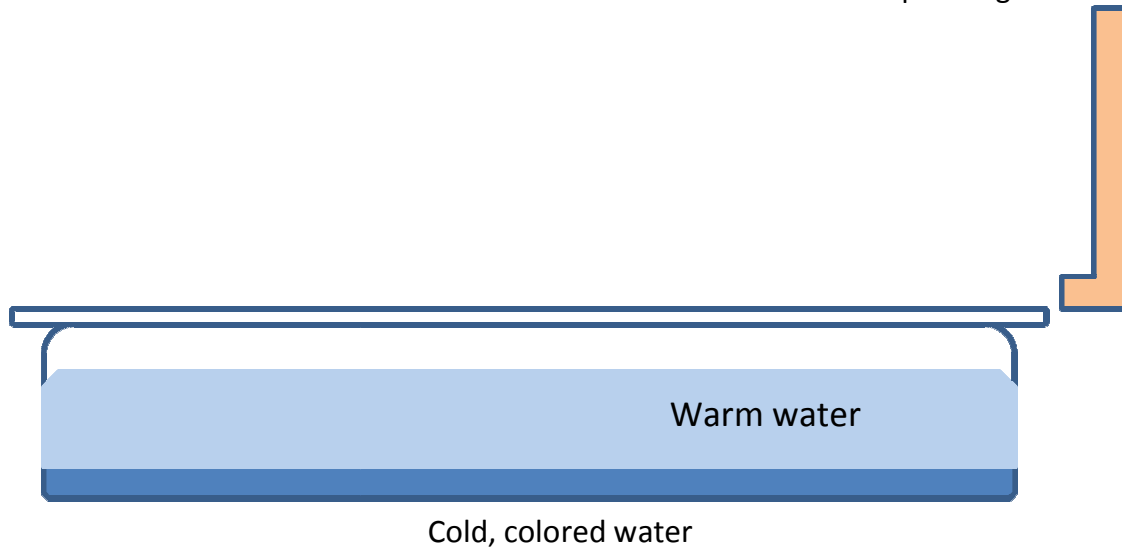
- Pitcher
- 2 pans
- Small container
- water
- Food coloring or dye
- Large eye dropper, syringe or similar
- Drinking straw
- Ice

Procedure

1. Divide students into small groups to perform the following exploration.
2. Using the pitcher, fill both pans with room-temperature water to about 1/2 inch from the top. One pan will be a control.
3. Let the pans sit undisturbed until the water is quiet, about 5 minutes.
4. Prepare colored ice water in the small container.
5. Slowly release a cold, colored water at the bottom (near one end) of each pan. This will represent nutrient-rich water. Record observations.
6. Rest the straw on the end (opposite the colored water) of one pan. Gently blow across (not into) the water, creating offshore waves.
7. Compare the results with the control pan. Record your observations.
8. Have one person in each group report the observations. Compare these results. What happens to the "nutrient-rich" water when the surface water is moved away by the wind? What happened to the warmer surface water at the opposite end of the pan?
9. Ask the students what happens to the cold, deep water when the surface waters are pushed away from the shore by the wind? What happens when the surface waters are pushed towards shore by the wind? Have students draw a side view of what they

observed in the pan. Allow students to compare drawings until the majority of the class agrees on a drawing that accurately represents what happened. Introduce the terms “upwelling” and “downwelling at this point.

10. Review the process of upwelling, explaining how the movement of surface waters away from shore causes deeper, colder waters to rise. Ask the students what would be carried to the surface with the colder, deeper waters? How would this movement of nutrients affect the phytoplankton? If phytoplankton are blooming, what other organisms would be affected? What information can students use to determine if upwelling or not?



Upwelling Data Scavenger Hunt

Objective

- Use real time data to determine if it is upwelling or downwelling on the coast Of OR and WA

Procedure

1. What information can students use to determine if upwelling or downwelling is occurring?
2. Students work in pairs or small groups on NVS to find data. Have students follow the Data Scavenger Hunt or walk students though navigating of NVS and have them determine which variables to use to come to their own conclusions.



Northwest Association of Networked Ocean Observing Systems

Upwelling Data Scavenger Hunt

SUMMARY

Seasonal upwelling is a very important process not just to the Pacific Northwest but to many coastal regions in the world.

During the summer in the Northern Hemisphere, upwelling is driven by winds blowing **from** the North **to** the South (Northerlies) that, combined with the Coriolis effect, push surface water off-shore and out to sea. This pulls deep ocean water up to the surface making the surface coastal ocean more salty, cold, and nutrient rich. The added nutrients in the sunny surface waters trigger fast phytoplankton growth and reproduction, which is the base of the food web and supports the important fisheries along the West Coast of the US.

Is upwelling currently happening? Follow this scavenger hunt to see if you can find the clues and signs of upwelling in the data!

GET STARTED

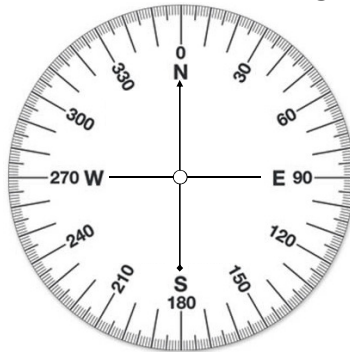
- 1) Go to www.nanoos.org
- 2) On the left side under “Data Explorer”, click on “NVS”
- 3) Click on the “Click here to view all assets” button
- 4) Orient yourself to the buttons in the left-hand column:
 - a. Map – the map layer is always on
 - b. Filters – find assets that meet all the checked criteria
 - c. Assets – select data based on Asset type: Cruises & Gliders or In-Situ Assets
 - d. Overlays – select a map overlay of Observation or Forecast data
 - e. Regions – select a region to zoom in to with one click
 - f. Legend – understand the various icons used in NVS

FIND THE SIGNS

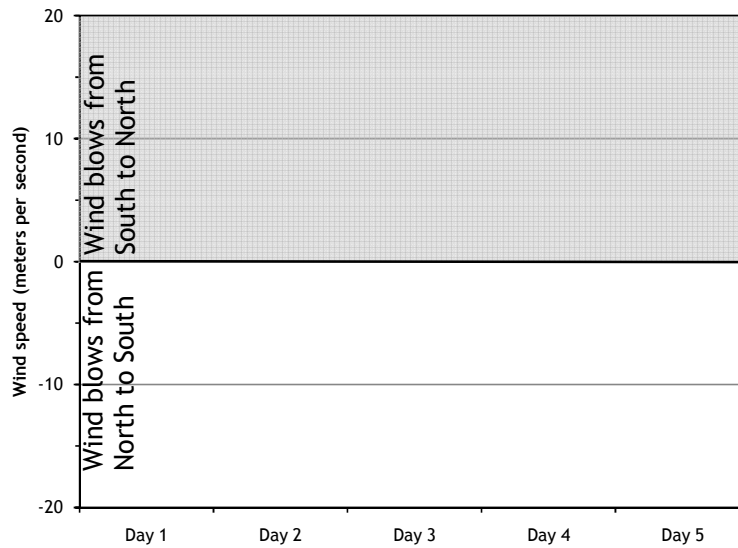
Indicator #1: Wind direction

Wind direction is most important. Winds blowing from the _____, as indicated as **0 or 360 degrees** on NVS, start the upwelling process.

Find an asset in WA that measures wind direction. On the compass rose below, draw in the general direction wind has been blowing **to and from** for the past 7 days:



Find the OSU buoy that measures wind direction and speed and *Explore the Asset*. Using the arrow graph that combines wind direction and speed, draw one line for each of the past 5 days of the general wind speed and direction **the wind is blowing to** for that day.



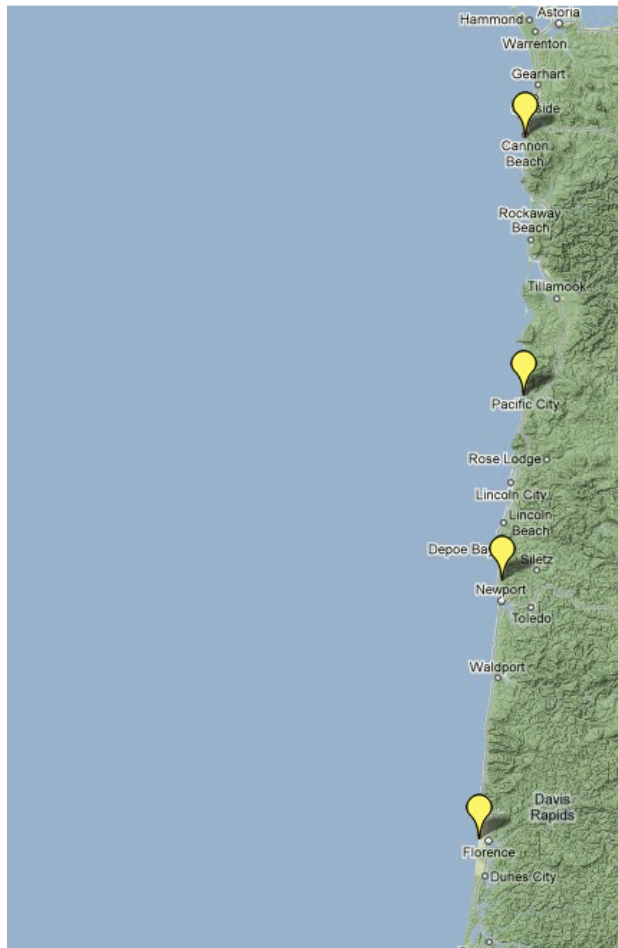
		Yes	No
Indicator #1	Wind direction from is within 50 degrees on either side of 0 or 360 degrees		

Indicator #2 Surface Currents

Wind directly affects the surface currents of the ocean. Because of the Coriolis effect, south-blowing, upwelling favorable winds move surface waters towards

_____.

Find the overlay that shows surface current data (*NOTE: don't forget to turn off any checked Filters*). Turn on the overlay by clicking the double boxes next to "Surface Currents". Using the Region tool, zoom in to the North and Central Oregon Coast to find and examine the surface currents at 4 locations: Cannon Beach, Pacific City, Newport, and Florence. For the 4 locations, on the map below mark the surface current direction 1) next to the shore and 2) the farthest out to sea the current was measured.



		Yes	No
Indicator #2	Surface currents moving south and/or west		

Indicator #3: Water temperature and salinity

During upwelling, water temperature and salinity along the coast are next to show a change. Predict how these will change during upwelling: water temperature will (fill in the correct arrow) \uparrow \downarrow and the salinity of water will \uparrow \downarrow .

Find the OSU buoy that measures both temperature and salinity (NOTE: don't forget to turn off any checked Filters or Overlays). Do you see a change in temperature or salinity of the surface water (-2m) in the past 7 or 30 days? How about in deeper water (-60m or -73m)? Record data below:

↑↓ Change in **surface** water temperature:

↑↓ Change in **surface** water salinity:

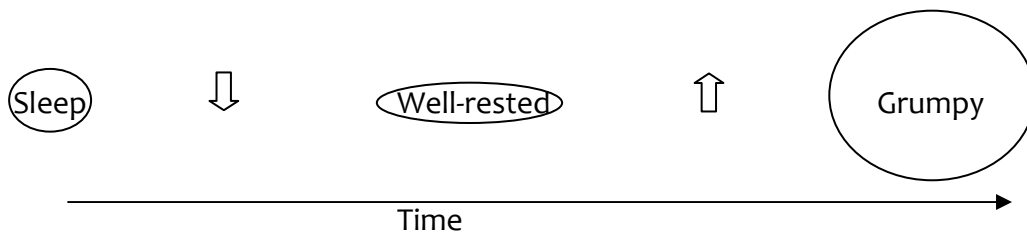
↑↓ Change in **deep** water temperature:

↑↓ Change in **deep** water temperature:

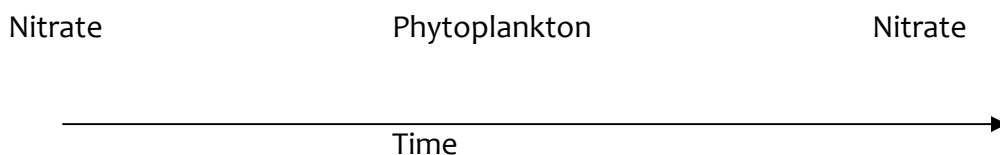
		Yes	No
Indicator #3	There was a decrease in surface temperature in the past month		
	There was an increase in surface salinity in the past month		

Indicator #4: Nutrients

are brought to the surface through upwelling, and one of the most abundant nutrients in the coastal ocean is **nitrate**. Nitrate fertilizes the sunny surface water causing phytoplankton to bloom which (circle one) produces/uses nitrate. Using the example as a guide, draw the relationship between nitrate and phytoplankton.



Example relationship reads: A small amount of sleep will decrease how well-rested you are in the morning which will increase how grumpy you are throughout the day.



The nitrate/phytoplankton relationship reads:

Find the LOBO buoy in Yaquina Bay in Newport, OR and select the nitrate graph (*NOTE: don't forget to turn off any checked Filters or Overlays*). Ocean water has about 30 umol nitrate per liter of water (umol/L), so on the 30 day graph upwelling should look like pulses of nitrate up to 30 umol/L that last for a few days (a umol, or micromole, is 10^{-6} moles or 0.000006 mol).

In the 30 day graph, if there is a upwelling pulse, how many days are between the start of the pulse and the end of the pulse?

Why does the nitrate decrease after a few days?

What do you think the other pulses that happen twice a day are?

		Yes	No
Indicator #4	A nitrate pulse up to 30 umol/L lasted for more than 2 days		

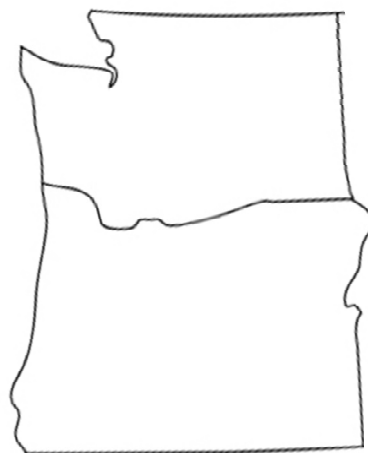
Indicator #5: Phytoplankton

The abundance of phytoplankton, the base of the coastal ocean's food web, is measured by **chlorophyll**, a photosynthesizing pigment in plant cells. As mentioned previously, phytoplankton need, like all plants, _____ and _____ to grow and reproduce.

Use the NOAA CoastWatch MODIS Overlay to find out if the phytoplankton are blooming (*NOTE: don't forget to turn off any checked Filters or Overlays, and zoom back out to the NANOOS region*). Click the double boxes next to "Chlorophyll a" to turn on the overlay, and using the pull-down menu in the lower right corner, select 1 Month.

What is the highest concentration of chlorophyll (mg of chlorophyll per cubic meter of water (mg/m^3)) next to the coast?

How are the other composites different than the 1 month? Do you see different chlorophyll patterns? Draw on the map below where the highest chlorophyll concentrations typically are.



		Yes	No
Indicator #5	Chlorophyll concentrations are above 25 mg/m ³		

PUTTING IT ALL TOGETHER

Now that you have sleuthed through the data for clues, your final task is to determine if upwelling is in fact happening.

Remember there is a time lag between when the winds start upwelling to when we see the resulting chlorophyll increase so all of the indicators may not be in the yes category yet. If that is the case, check back in a few days to see if anything changed! The faster the winds are, the faster the ocean will respond to the upwelling conditions.

		Yes	No
Indicator #1	Wind direction from is within 50 degrees on either side of 0 or 360 degrees		
Indicator #2	Surface currents moving south and/or west		
Indicator #3	There was a decrease in surface temperature in the past month		
	There was an increase in surface salinity in the past month		
Indicator #4	A nitrate pulse up to 30 umol/L lasted for more than 2 days		
Indicator #5	Chlorophyll concentrations are above 25 mg/m ³		

EXTENSION ACTIVITY

**What role does upwelling play in coastal hypoxia?
What role does upwelling play for salmon in the PNW?**

In the News:

At the end of this document are newspaper articles from 2008-2010 from Oregon and Washington which report on on salmon, hypoxia and ocean acidification. Each of these issues is linked to upwelling – how?

Have students work in groups to come up with a diagram of how each of these issues is affected by upwelling.

Alternatively, students can investigate on line:

1. On www.nanoos.org select “Learning Tools:
2. Select “Lack of Oxygen?”
3. Select the “coastal hypoxia” tab and view the animation
4. For more information view the video:
<http://www.piscoweb.org/research/science-by-discipline/coastal-oceanography/hypoxia/pisco-hypoxia-research-video>
5. To learn more about research to understand this emerging issue:
NSF Special Report: Dead Zones
http://www.nsf.gov/news/special_reports/deadzones/climatechange.jsp
6. Go to NOAA’s NW Fisheries Science Center informational page on oceanic ecosystem indicators for Pacific Northwest Salmon:
<http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm> and select “coastal upwelling”
7. How does upwelling impact salmon runs?
8. Using NVS, or other products available on www.nanoos.org, what can we say about oxygen conditions off the coast right now?



Carbon emissions, carbon-rich waters drive up ocean acidity

Published: Thursday, May 22, 2008, 11:02 AM

Updated: Thursday, May 22, 2008, 12:08 PM

Shelby Wood, The Oregonian

Manmade carbon emissions and the seasonal upwelling of naturally carbon-rich waters are driving up the acidity of the shallow ocean just off the West Coast, a team of researchers from Oregon and elsewhere has found, posing a threat to shellfish, sea urchins and smaller shell-forming creatures that serve as food for young salmon.

Their study, published **online today in the journal Science Express**, for the first time documents high acidity in the shallow nearshore waters of the West Coast's fruitful continental shelf, the researchers said. It expands on global research into ocean acidification, which has tied increasing acidity levels to the ocean's absorption of manmade carbon dioxide emissions and warned that it could decimate coral reefs.

The acidity the researchers documented along the coast from Canada to Oregon to Mexico last spring is at levels that scientists expected to see in 50 to 100 years, the researchers said, and is likely high in nearshore waters worldwide that get seasonal upwelling of deeper waters.

Those deeper waters were last at the surface 50 years ago but show clear signs of higher carbon content and acidity because of manmade emissions, the researchers said. Given steep increases in carbon dioxide emissions since the 1950s, the long-term cycle means spring and summer acidity levels are likely to rise for another 50 years off the West Coast no matter what steps are taken to reduce carbon emissions now.

The research team used an Oregon State University boat and included researchers from Oregon, Mexico, Canada and the U.S. National Oceanic and Atmospheric Administration. **Burke Hales**, an OSU professor of chemical oceanography and a member of the research team, said the year to year changes in acidity are small and more study needs to be done on their biological effects. Some organisms could adjust to higher acidity levels.

But West Coast waters are naturally up to the brink of acidity levels hospitable to many shellfish and other ocean organisms. And the researchers documented acidified water within 20 miles of the coast.

"The natural system has put us close to the edge," Hales said. Manmade emissions "are starting to push us over."

-- *Scott Learn*; scottlearn@news.oregonian.com

SUMMER DEAD ZONES OFF OREGON COAST HERE TO STAY, OSU RESEARCHERS SAY

Published: Thursday, October 08, 2009, 5:44 PM

Updated: Thursday, October 08, 2009, 8:06 PM



Scott Learn, The Oregonian



Dungeness crabs washed ashore at Cape Perpetua as the ocean off Oregon experienced "dead zone" conditions in the summer of 2004. Researchers said today such dead zones will likely occur every summer.

The waters off Oregon's coast experienced low-oxygen conditions for the eighth consecutive year in 2009, Oregon State University researchers said Thursday, an indication that late summer "hypoxic" conditions that can kill crabs and other sea creatures near the ocean floor are here to stay.

"We've been looking hard at this problem for eight years now, and each year we've seen hypoxia," said **Jack Barth**, an OSU oceanography professor. "I really think we're in a new pattern offshore here. I would expect hypoxia to show up to some degree every year now."

The increase in persistent, strong winds and in ocean surface temperatures that are helping drive the phenomenon are consistent with changes predicted by climate change models, Barth said, meaning the problem could worsen if global warming projections pan out.

This summer, the winds that fuel annual upwelling died down in August and September, when oxygen levels are usually lowest. That allowed Oregon to avoid the severe hypoxia and significant biological "dead zones" that appeared in force in 2006, OSU researchers said.

But it was a close call in some spots: In early August, the oxygen level got as low as 0.5 milliliters per liter off Newport and Cape Perpetua, which is at the cusp of being classified as "severe," before the winds eased and oxygen levels rose. Crabs, anemones, sea stars, sea cucumbers and other creatures can die off when oxygen levels get too low.

The hypoxia area near the ocean floor, stretching from Oregon into Washington, was about average in size and duration in comparison with recent years, the researchers said.

It was less severe than 2006, when strong and steady winds led to zero-oxygen, or "anoxic" conditions, and caused alarming die-offs of crabs and other creatures, Barth said.

The low-oxygen areas are typically labeled "dead zones." But Barth and **Francis Chan**, a senior research professor in OSU's Department of Zoology, said that's an oversimplification. Ocean monitoring has increased dramatically with the help of crabbers and fishermen, but not enough to determine changes in ocean life beyond limited areas.

Creatures closer to the surface and those adapted to lower oxygen levels aren't as vulnerable. Some can escape to higher oxygen areas; crabbing in more oxygenated bays was "phenomenal" in 2006, Chan said, as many crabs appeared to take refuge there. Some densely populated reefs also appear to fare better than others.

But the steady rise of low-oxygen waters in the summer does appear to have decimated sea cucumber populations on the most severely affected reefs, the researchers said. It's also a significant change in how nature operates near the coast.

"We can't prove that it's a disaster right now, but we're affecting a lot of pieces of the marine food web," Barth said. "It comes down to how big (the change is), how severe and how long-lasting."

Unlike hypoxic areas in the Gulf of Mexico and along the East Coast, which are caused by agricultural runoff and pollution, the low-oxygen waters off Oregon are triggered by summertime upwelling -- the wind-driven mixing of cold, nutrient-rich deep water with surface waters.

The upwelling generates large phytoplankton blooms. As the plankton dies, it sinks to the bottom and decomposes, lowering the oxygen level of the water just off the seafloor.

Summertime upwelling is normal off the coast. But Chan said ocean oxygen records dating to the 1950s indicate the low oxygen levels off Oregon's coast since 2002 are "unprecedented."

In the past, winds would blow at the coast for a week or so, then settle down, Barth said, easing

the upwelling and allowing low-oxygen waters to be washed away. Now strong winds may last 20 to 30 days.

Climate change is likely playing a role already, Barth said. Warmer ocean surface temperatures in the North Pacific are decreasing the amount of oxygen descending to the same deep ocean waters that well up in the summer. That pattern seems clearly tied to climate change, he said.

It's less clear if the stronger, more persistent winds in recent years are tied to climate change, Barth said. But global warming models predict more winds off Oregon's coast if temperatures rise. Warming would increase the temperature differential between land and ocean, he said, a key driver of wind.

That would mean more windy and cold summer days at the beach, Barth said, as the strong winds blow across summertime's cooler coastal waters.

"You'll notice it," he said. "You won't be able to wear your shorts."

-- **Scott Learn**

COLD WATER REJUVENATES OREGON OCEAN, SALMON

by Michael Milstein, The Oregonian

Monday September 08, 2008, 10:30 PM

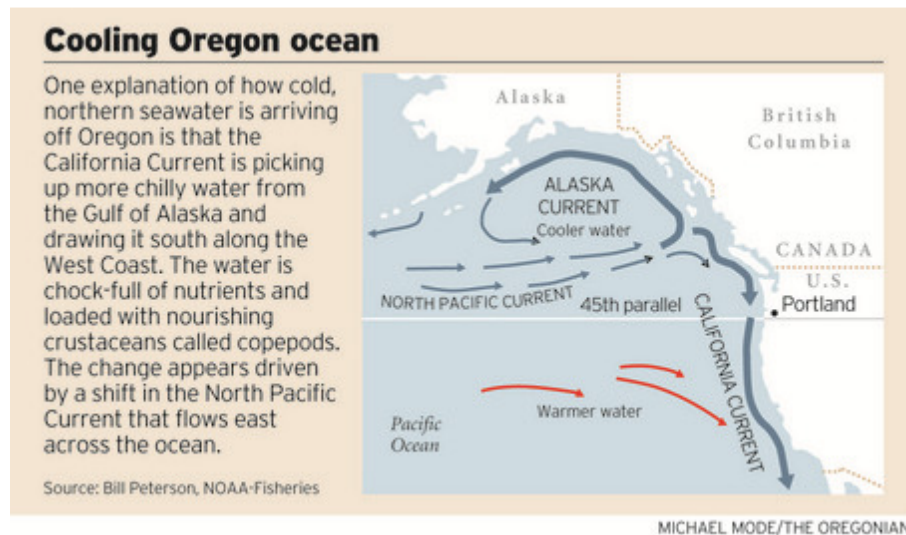


Bill Peterson, NOAA

Fisheries Service A fat copepod called *Neocalanus cristatus* is filling Oregon's ocean with food.

Cold currents are pumping in masses of the small crustacean, about a third of an inch long and three times the size of the more southerly species that would otherwise dominate.

NEWPORT -- As fishing communities suffer through the first nearly complete closure of ocean salmon catches, some good news is surfacing off the coast: The Oregon ocean is once again booming with life.



A flush of cold northern water, rich with food, is nurturing a dramatic turnaround in ocean conditions this year, marine experts say. The situation contrasts with poor offshore conditions in recent years that left fish and birds desperate for food and probably contributed to the collapse of Sacramento River salmon, a keystone of Oregon's salmon fishery.

"This will be the year that saves a lot of fisheries," said Bill Peterson, an oceanographer based at Newport's Hatfield Marine Science Center with the [NOAA-Fisheries](#), the federal agency that monitors oceans.

The dose of chilly water from the Gulf of Alaska may also be what is bringing an odd mix of sea creatures onto Oregon's shores this summer. They include young salmon sharks -- a relative of the great white that feeds on salmon -- and a robust clubhook squid, the third-largest squid in the ocean, measuring up to 13 feet long.

Also, the eerie "dead zones" that suffocated marine life along the coast in recent summers have been less pronounced this year, Oregon State University scientists said.

But the biggest payoff could come in the form of rebounding salmon stocks.

It will take some time, though, especially for Sacramento River salmon, which plummeted sharply in recent years, leading to a nearly complete closure of West Coast salmon fishing this summer. Unusually warm conditions, especially off Northern California in 2005, delayed the upwelling of nutrients, and the ocean food chain collapsed -- leaving young salmon little to eat.

That hammered the Sacramento fish so hard they might need more time to rebuild, Peterson said.

Because salmon live at sea for more than a year, fish benefiting from this year's resurgence won't return to their home rivers in California and Oregon right away, Peterson said. Next year, though, coho salmon returns should be strong, followed by chinook returns in 2010.

"All the signs are there for a recovery of salmon stocks," he said, describing his outlook as "guardedly optimistic."

The ups and downs in salmon numbers have underscored how little scientists know about factors that can dramatically affect one of the West Coast's most valuable fish during its time at sea. Different salmon stocks use different parts of the ocean, which may explain why some flourish even as others plummet.

Sacramento River fish make up about 80 percent of fish caught off the Oregon coast in summer, so they are heavily influenced by conditions here.

Peterson has identified a series of ocean and climate conditions -- such as temperature, salinity, upwelling and food supply -- that affect salmon. He has combined them into a [system of indicators](#) that he hopes will provide better advance signals of salmon declines or upsurges.

The system is now signaling more positive salmon returns than it has in more than 10 years.

The undersea current of cold water from the Gulf of Alaska is pumping Oregon's ocean full of fat little copepods, tiny crustaceans that form the base of the marine food chain, Peterson said. The main species of copepod from the north is about three times the size of more southern species that would otherwise dominate, which adds an extra dose of nutrition to the offshore ecosystem.

"You get this kind of river of animals fed to everything that's here," Peterson said.

Offshore netting surveys in June turned up more juvenile salmon, including three times more spring chinook, than ever before in the 11 years crews have done the surveys, Peterson said. That often presages strong salmon returns in coming years.

The inflow of northern water has kept the Oregon ocean around 46 degrees, colder than any year since 1999, Peterson said. This may signal a new cool phase in an ocean temperature pattern known as the Pacific Decadal Oscillation. Cold water is generally good for salmon because it tends to hold more nutrients.

Tuna, on the other hand, favor warmer water. Last year fishermen caught tuna within 15 miles of shore, a sign the water was warm, said William Hanshumaker, a public marine education specialist at the Hatfield Marine Science Center. This year, tuna are staying around 50 miles offshore, an indication the near-shore waters have gone cold.



Bill Hanshumaker, Hatfield Marine Science CenterA giant robust clubhook squid washed ashore just north of Yachats earlier this summer. The squid rarely appear on Oregon beaches. A public dissection of the squid will take place at the Hatfield Marine Science Center Jan. 10.

Odd fish have washed ashore this summer, perhaps influenced by the changing conditions. Hanshumaker said the creatures include lancetfish, which resemble barracudas. He has heard of seven baby salmon sharks washing up in the past two weeks.

The sharks get attention because they resemble young great whites.

The northern water arriving off Oregon is especially rich because La Nina climate conditions, characterized by lower water temperatures, helped mix the water, said Jack Barth, a professor of oceanography at Oregon State University. That helped draw more nutrients up from the depths.

"The source water is better than average," he said.

The cold, sub-Arctic water holds less oxygen, which could prove negative for ocean life if compounded by the appearance of dead zones. Dead zones have appeared unusually close to shore along the Oregon coast in recent years, often driven by strong local upwelling of nutrient-rich water that causes explosions of tiny marine organisms.

The decay of those organisms then sucks oxygen from the surrounding water, suffocating marine life such as starfish and crabs -- though fish seem to move fast enough to escape.

There was some evidence of hypoxia -- a deadly lack of oxygen -- early in the summer, said Francis Chan, a marine ecologist at OSU. But moderate summer weather punctuated by cool periods appears to have kept the upwelling from going into overdrive and creating more severe hypoxic conditions, he said.

But he cautioned that the summer's not over and that there's still time for hypoxic conditions to appear. Federal crews will conduct offshore surveys to better measure how oxygen conditions influence fish.

--Michael Milstein; michaelmilstein@news.oregonian.com

<http://oregonstate.edu/dept/ncs/newsarch/2008/Apr08/salmondecline.html>

4-4-08 **Media Release**

Salmon Decline Linked Mostly to Ocean Conditions, Scientists Says

NEWPORT, Ore. – The finger of blame for declining runs of Pacific Northwest salmon has been pointed broadly: habitat loss from logging and development, an abundance of predatory sea lions, power-generating dams, terns and other coastal birds that prey on juvenile fish, and over-fishing by commercial and sport fishermen.

But no factor is more critical to salmon prosperity than ocean conditions, experts say, and the complex interaction between biologically distinct groups of salmon and changing ocean habitats has created a nightmare for resource managers.

At the same time a projected huge run of spring chinook salmon are entering the Columbia River, fishing on one of its major tributaries – the Willamette River – has been closed because of a shockingly low estimate of returning fish. And offshore salmon seasons are in jeopardy along the entire West Coast this spring and summer because of a projected historic low return of fish to the Sacramento River basin.

The common denominator in the good and bad runs is the ocean.

Bill Peterson, a fisheries biologist with NOAA who is based at Oregon State University's Hatfield Marine Science Center, says this year's salmon debacle can be traced back to unusual ocean conditions in 2005. A delay in the ocean upwelling caused ocean conditions "to collapse."

"The delayed upwelling off the Oregon coast meant that in the critical time when juvenile salmon were entering the ocean, there was nothing for them to eat – and most of them died," said Peterson, who is a courtesy professor in OSU's College of Oceanic and Atmospheric Sciences. "But you don't see the impact until two or three years later, when the fish should first begin returning as adults."

Wind-driven upwelling brings nutrients from deeper water to the surface and fuels phytoplankton blooms. Lipid-rich copepods and other zooplankton feed on the tiny plants, and in turn are consumed by anchovies, sardines, herring and other small fish that are staples in the diet of salmon and other fish. The delay in upwelling was caused by late arrival of seasonal winds, according to researchers at OSU, who published their findings in the [Proceedings of the National Academy](#).

<http://oregonstate.edu/dept/ncs/newsarch/2007/Feb07/pnasstudy.html>

PNAS: Ocean Upwelling Delay Gives Scientists Sneak Preview of What Future May Hold

CORVALLIS, Ore. – A one-month delay in the annual spring “upwelling” of the California current in 2005 provided scientists with a sneak preview of what conditions may be like if global climate change models prove accurate.

And those results, published this week online by the Proceedings of the National Academy, include numerous anomalies affecting West Coast marine ecosystems.

Though the scientists stop short of saying the upwelling delay and its associated impacts were caused by global warming, they acknowledge that the changes are consistent with what most climate change models predict will happen.

“Delays in the onset of upwelling and strong late-season upwelling are consistent with regional climate change models and that’s exactly what we saw in 2005 off the West Coast of the United States,” said Jack Barth, a professor in the College of Oceanic and Atmospheric Sciences at Oregon State University and lead author on the study. “The winds were late in arriving by one month, resulting in the lowest upwelling-favorable ‘wind stress’ in the region during the past 20 years.

“The winds eventually picked up and triggered strong upwelling late in the season, but for some species that depend on those nutrients being there, it was too late,” Barth added. “The juvenile recruits for both barnacles and mussels, for example, were down considerably.”

Mussel recruits were down 83 percent, while barnacle recruits were only 66 percent of normal, the study pointed out.

During the spring of 2005, upwelling didn’t begin until June – a month later than usual. During that time, nearshore waters were two degrees (Celsius) warmer than normal, while chlorophyll levels in the surf zone were only half of normal, and nutrient levels were about 30 percent lower.

Barth said the one-month delay was associated with 20- to 40-day wind oscillations that accompanied a southward shift of the Jet Stream in 2005. In recent years, the Jet Stream has experienced “wobbles” that can warm the waters of the Pacific Ocean of the Northwest coast and hamper upwelling when the shift is to the south, or it can accelerate upwelling when it shifts northward.

What causes these shifts isn’t clear to scientists, but the influence of the enormous mountain ranges in Asia and North America on wind patterns may play a role.

“One major change has been the appearance of persistent wind patterns of 3-5 weeks overriding what used to be patterns that lasted more like two to five days,” Barth said. “The shorter time frame was healthy for the upwelling system; the winds could trigger upwelling and when they died down the shelf would be a great incubator for growth.

“With wind patterns lasting a month or more, you can get a major delay in upwelling,” Barth pointed out, “or you can long windy periods that result in super-charged upwelling like we had in 2006, when the ocean production was so great it created a major hypoxic event along the Pacific Northwest coast.”

Although the researchers’ PNAS study focused only on the 2005 delay, the last decade has seen significant variability outside the norm. The swing began in 1997-98 with one of the most powerful El Niño episodes on record, as ocean waters off the West Coast grew warmer, nutrients decreased, biological production was reduced, and species from zooplankton to salmon disappeared, were drastically reduced or moved from their typical habitats. The El Niño capped what had been a series of years through the 1990s characterized by warm waters and weak upwelling.

That regime ended abruptly in late 1998, and the California Current system entered a four-year period of cold ocean conditions that led to strong phytoplankton and zooplankton productions and a rebound in salmon runs. The final hurrah of that cold-water period came during the summer of 2002, when the system received an influx of sub-arctic water that triggered massive phytoplankton production in the surface waters. As the organisms decayed and sank to the bottom, they sucked oxygen out of the lower water column, leading to hypoxia and marine die-offs of crabs and other species that were unable to move out of the area.

And though the ocean waters warmed over the next four years, the West Coast has experienced hypoxia events every summer, according to Francis Chan, a senior research assistant professor at Oregon State University and one of the authors of the PNAS study.

“When it comes to upwelling and phytoplankton production, there can be too much of a good thing,” Chan said. “Although the low-oxygen zone has varied in intensity from year to year, 2006 saw an unexpected expansion and degradation in oxygen conditions. At least 3,000 square kilometers of the continental shelf along the Oregon coast were affected.”

OSU’s Jane Lubchenco, who organized a symposium on West Coast variability for the annual American Association for the Advancement of Science meeting, said the bottom line is that the dramatic events of the past few years have shown how vulnerable our oceans are to changes in overall climate – and how quickly ecosystems respond.

“Wild fluctuations in the timing and intensity of the winds that drive the system are wreaking havoc with the historically rich ocean ecosystems off the West Coast,” Lubchenco said. “As climate continues to change, these arrhythmias may become more erratic. Improved monitoring and understand of the connection between temperatures, winds, upwelling and ecosystem responses will greatly facilitate capacity to manage those parts of the system we can control.”

Researchers in the study included Barth, Chan and Lubchenco, as well as OSU colleagues Bruce Menge, Anthony Kirincich and Stephen Pierce; John Bane, of the University of North Carolina at Chapel Hill; Margaret McManus, University of Hawaii at Manoa; Karina Nielsen, Sonoma State University; and Libe Washburn, University of California at Santa Barbara.

The delayed upwelling can explain why most fish runs are plummeting, yet fisheries managers are predicting a huge number of spring chinook bound for the Columbia River this year. Why? The answer, Peterson says, can be found by tracing where juveniles from different river systems go once they enter the ocean.

For the past 10 years, Peterson has participated in a research project funded by the Bonneville Power Administration that analyzes the distribution of juvenile salmon off the West Coast and uses genetic tracking to determine their river origin <http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm>. Juvenile fish from many of Oregon's coastal rivers, along with those from the Willamette River and the Sacramento River, congregate just off the Oregon coast once they leave their river systems.

When the ocean collapse came in 2005, most of those fish starved.

“But Columbia River spring chinook don't stay off the Oregon coast,” Peterson said. “In our 10 years of sampling, we've only caught a few Columbia River juveniles just off our coast, so it's obvious they go somewhere else. If you look this year at chinook salmon in Alaska, they're doing well. So it's possible that Columbia River juveniles head to the same place as Alaska juveniles.”

Peterson speculates that perhaps young Columbia River salmon may migrate toward a unique ecosystem several hundred miles off the Northwest coast. In that deep, cold water, lipid-rich fishes known as myctophids, or “lantern-fish,” provide a bountiful diet for a variety of marine life. These fishes are “very abundant” in the mesopelagic zone, he added, and could provide a rich forage base for young chinook salmon.

“It's just a theory at this point,” he said. “We need to go out there and sample for juvenile salmon. But the situation this year underscores how fascinating research on salmon can be. We used to have a lot more genetic diversity in our salmon runs. They used to spawn at different times and hang out offshore at different times. We may be paying for the loss of that diversity.”

Ocean conditions off Oregon in 2006 and 2007 were somewhat better for salmon survival, but still were less than ideal. The good news, Peterson says, is that the influence of La Niña over the winter has created what appear to be excellent ocean conditions thus far in 2008. But, he added, it's premature to celebrate.

“The system can't recover from a near-complete collapse in one year,” Peterson warned. “There may not be enough adults in the streams to repopulate the runs. We need three or four years of good conditions before we can breathe a little easier.”

<http://oregonstate.edu/terra/2008summer/departments/earth/ocean.php>

Acid Ocean

New study finds increasing acidification along the West Coast



Burke Hales, OSU College of Oceanic and Atmospheric Sciences (Photo: Don Frank)

Water that upwells seasonally along the West Coast of North America is growing increasingly acidic, according to a survey conducted in 2007 by an international team of scientists. In June, they reported finding acidified ocean water within 20 miles of the shoreline, raising concern for marine ecosystems from Canada to Mexico.

Deep-ocean currents take years to transport acidified water to upwelling regions, say members of the research team, which included Burke Hales, an associate professor in the College of Oceanic and Atmospheric Sciences at Oregon State University. Thus it is likely that increasingly acidic water will continue to upwell along the West Coast in the future, they add.

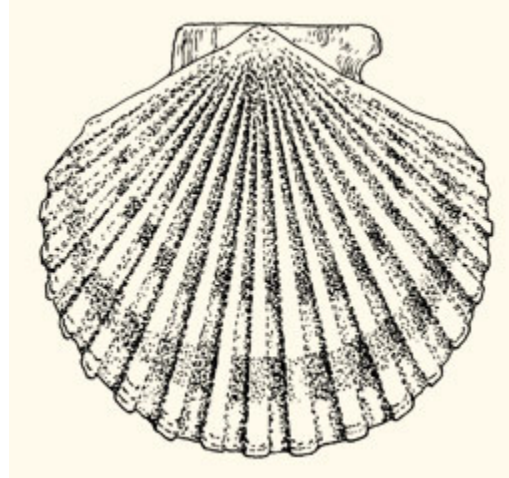
“The coastal ocean acidification train has left the station, and there not much we can do to derail it,” says Hales, an author of a report published in *Science*. The research was funded by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA).

In their survey, the researchers used the *Wecoma*, an OSU research vessel owned by the National Science Foundation, to collect water samples at pre-determined points off shore. They found indications that acidified water in upwelling regions had previously been at the ocean surface about 50 years ago. At that time, atmospheric CO₂ levels were roughly 310 parts per million.

Since then, CO₂ levels have risen in the atmosphere by about 20 percent. When it reacts with water, CO₂ generates carbonic acid, which, at high enough concentrations, can harm shell-building organisms such as corals, clams, snails and oysters. Scientists call such water “corrosive” because it can weaken shells and coral reefs.

The study was the first in a planned series of biennial observations of the carbon cycle along the West Coast. In addition to Hales, principal investigators included Richard A. Feely and Christopher Sabine of the NOAA Pacific Marine Environmental Laboratory; J. Martin Hernandez-Ayon, the University of Baja California in Mexico; and Debby Ianson, of Fisheries and Oceans Canada, Sidney, B.C.

Shells at Risk



Pink scallop (Illustration courtesy of Oregon Sea Grant)

“When the upwelled water was last at the surface, it was exposed to an atmosphere with much lower CO₂ levels than today’s,” Hales points out. “The water that will upwell off the coast in future years already is making its undersea trek toward us, with ever-increasing levels of carbon dioxide and acidity.”

Scientists have become increasingly concerned about ocean acidification in recent years, as the world’s oceans absorb growing levels of carbon dioxide from the atmosphere. Carbonic acid has a corrosive effect on aragonite, the calcium carbonate mineral that forms the shells of many marine creatures.

Certain species of phytoplankton and zooplankton, which are critical to the marine food web, may also be susceptible, the scientists point out, although other species of open-ocean phytoplankton have calcite shells that are not as sensitive.

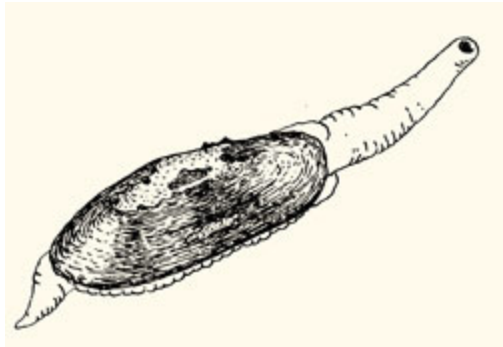
“There is much research that needs to be done about the biological implications of ocean acidification,” Hales says. “We now have a fairly good idea of how the chemistry works.”

Atmospheric CO₂ levels form the beginning baseline for carbon levels in ocean water. As water sinks away from the surface and moves toward upwelling areas, CO₂ levels also rise from the normal process of respiration by plants and animals. As that nutrient-rich water is upwelled, it triggers additional phytoplankton blooms that continue the process.

Dead Zones and Acidification

There is a strong correlation between recent hypoxia events off the Northwest coast and increasing acidification, Hales says.

“The hypoxia is caused by persistent upwelling that produces an over-abundance of phytoplankton. When the system works, the upwelling winds subside for a day or two every couple of weeks in what we call a ‘relaxation event’ that allows that buildup of decomposing organic matter to be washed out to the deep ocean.



Razor clam (Illustration courtesy of Oregon Sea Grant)

“But in recent years, especially in 2002 and 2006, there were few if any of these relaxation breaks in the upwelling, and the phytoplankton blooms were enormous,” Hales adds. “This decomposition puts more CO₂ into the system and increases the acidification.”

The researchers found that the 50-year-old upwelled water had CO₂ levels of 900 to 1,000 parts per million, making it “right on the edge of solubility” for calcium carbonate-shelled aragonites, Hales says.

“If we’re right on the edge now based on a starting point of 310 parts per million, we may have to assume that CO₂ levels will gradually increase through the next half century as the water that originally was exposed to increasing levels of atmospheric carbon dioxide is cycled through the system. Whether those elevated levels of carbon dioxide tip the scale for aragonites remains to be seen.

“But if we somehow got our atmospheric CO₂ level to immediately quit increasing,” Hales adds, “we’d still have increasingly acidified ocean water to contend with over the next 50 years.”

Variation is the Rule



Mussel (Illustration courtesy of Oregon Sea Grant)

Hales says it is too early to predict the biological response to increasing ocean acidification. There is already a huge seasonal variation in ocean acidity based on phytoplankton blooms, upwelling patterns, water movement and natural terrain. Upwelled water can be pushed all the way onto shore, he says, and barnacles, clams and other aragonites have likely already been exposed to corrosive waters for a period of time.

They may be adapting, or they may already be suffering consequences that scientists have not yet determined.

“You can’t just splash some acid on a clamshell and replicate the range of conditions the Pacific Ocean presents,” Hales says. “This points out the need for cross-disciplinary research. Luckily, we have a fantastic laboratory right off the central Oregon coast that will allow us to look at the implications of ocean acidification.”