El Niño

For centuries, the human inhabitants of the Pacific Northwest have endured extreme natural variations in weather and oceanic conditions. Some years have brought devastating floods to the region, whereas others have produced severe droughts. For example, in 1957, areas extending from northern California to Washington experienced intense drought conditions and unusually warm waters off the coast. Only seven years later, the same region fell under a cold spell that resulted in high snowpack and frigid coastal waters.

Are these variations in conditions mere vagaries of Mother Nature, or do they occur in cycles and exhibit some type of predictable pattern? Available evidence increasingly suggests that the Pacific Northwest is a region dominated by the interaction of different types of climatic cycles that can greatly affect the organisms that inhabit ocean waters. One of the best understood sources of variations is the El Niño-Southern Oscillation, a phenomenon that originates in the equatorial Pacific Ocean, thousands of miles away from the Pacific Northwest. It is the culprit behind a variety of extreme weather conditions ranging from severe droughts in Indonesia to floods in Florida. To understand how the El Niño-Southern Oscillation exerts its powerful force, we must first examine the oceanic and atmospheric conditions that normally persist in the Pacific Northwest.

Sea Grant Oregon

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The Pacific Northwest: a Region of Transitions

The unusual oceanic and atmospheric conditions of the Pacific Northwest create a remarkable and dynamic setting unlike any other in the world. Situated between cold, subarctic waters to the north and warm, equatorial waters to the south, the Pacific Northwest is characterized by stormy winters and mild, warm summers (figure 1).

***Figure** 1. Oceanic currents off the Pacific Northwest. The oceanic region of the Pacific Northwest is characterized by two large currents, the North Pacific and Subarctic Currents. As these two currents approach the coast, they divide into two coastal currents: the northward-flowing Alaska Current and the southward-flowing California Current. The point at which the Subarctic and North Pacific Currents divide varies annually between 45 °N in the winter and 50 °N in the summer.*

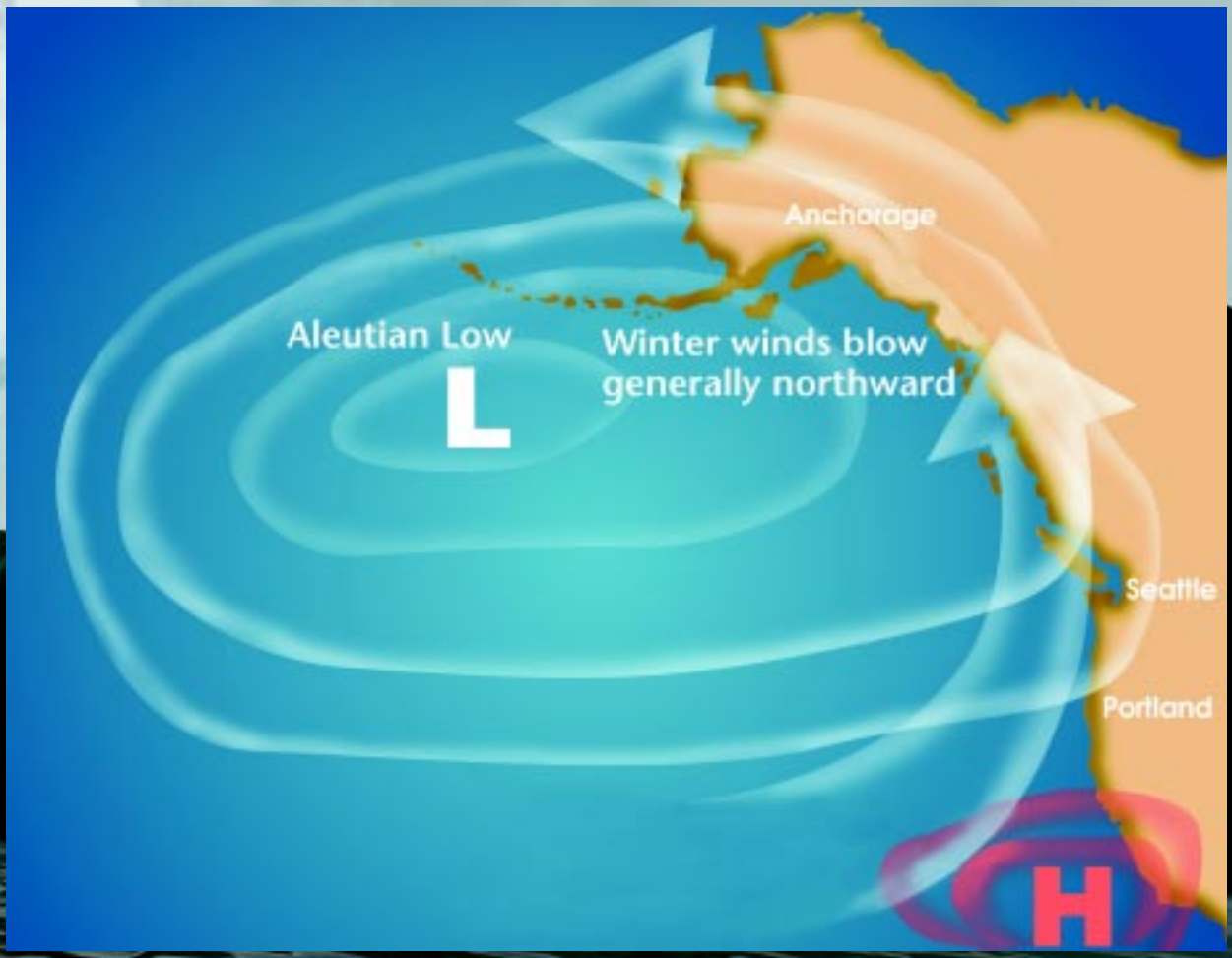

***Figure** 2. Winter location of pressure systems off the Pacific Northwest. The large Aleutian Low is the primary driving force of winter winds along the Pacific Northwest coast. In winter these winds generally flow northward.*

The Atmosphere

The atmosphere plays a central role in regulating weather patterns and oceanic conditions in the Pacific Northwest. Under normal conditions, a large, powerful, low-pressure system known as the Aleutian Low sits off the Aleutian Islands and brings cool Arctic air to the Pacific Northwest (figure 2). Atmospheric conditions change abruptly during the summer months as the Aleutian Low decreases in intensity and migrates to the west. At the same time, a subtropical, high-pressure system, usually located over the coast of California, increases in strength while a smaller, low-pressure system forms over North America. These pressure systems affect the winds along the Pacific Northwest. During the winter months, for example, the winds along the Oregon coast blow generally northward. However, in the spring, as the positions of the pressure systems change, the winds switch direction. This switch, known as the *spring transition,* has important consequences for the organisms that inhabit coastal waters.

The Ocean

Surface winds generated by these pressure systems are the main force driving coastal currents off the Pacific Northwest. During the spring and summer, as winds along the coast blow generally toward the south, the surface waters near the coast flow southwards. Although it's not what we might expect at first, this southward flow of water results in the offshore movement of the upper surface waters. As this water moves offshore, cold, nutrient-rich water from below the surface flows upward to replace it (figure 3).

This process, known as *upwelling*, is ultimately responsible for Oregon's rich fisheries. This is because the cold waters are laden with nutrients vital to tiny plants known as phytoplankton that inhabit the ocean. During the upwelling period, phytoplankton flourish and provide ample food for the animals that live in ocean waters. In addition, when the cold water comes in contact with warm, moist surface air, it causes the familiar phenomenon of cool, summer fog along the coast.

The opposite of upwelling, known as *downwelling*, occurs in the fall and winter months when the winds blow generally toward the north and surface water is forced shoreward. Tiny perturbations in oceanic or atmospheric conditions can greatly affect the timing and duration of the upwelling season.

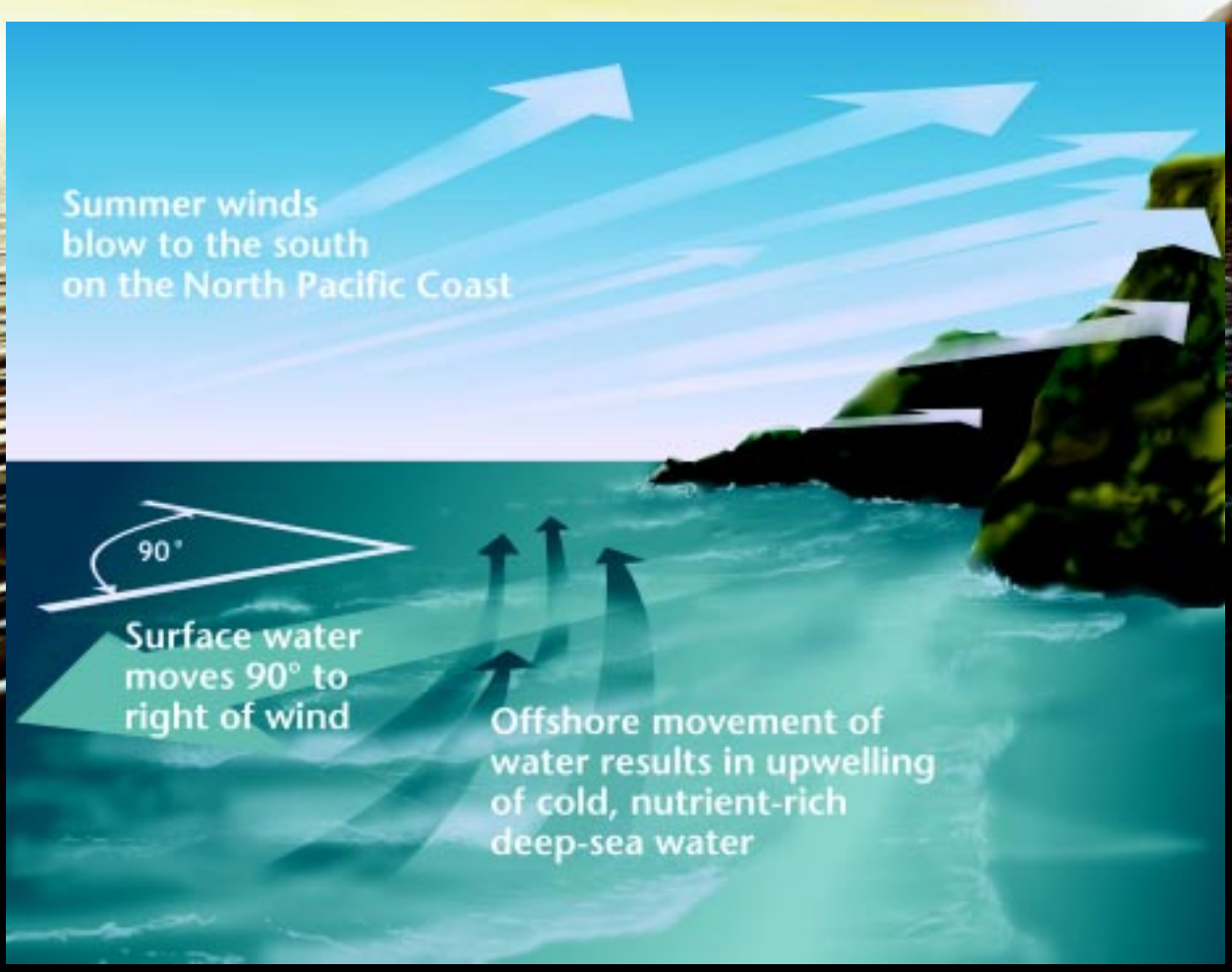

***Figure 3**. Coastal upwelling off of Oregon. Southward-blowing winds are associated with a net transport of surface waters away from the coastline, resulting in intermittent upwelling. This offshore transport of water, known as Ekman transport, is largely due to the Coriolis force, which arises from the rotation of the Earth and acts to deflect motion to the right in the Northern Hemisphere. The wind exerts a force on the top layer of water with subsequent, deeper layers of water being deflected to the right, resulting in a net transport of a surface layer of water 90° to the right of the direction of the wind. As this water is moved offshore, nutrient-rich water upwells to the surface.*

Oceanic Variability and the Pacific Northwest

The normal conditions of the Pacific Northwest are frequently undermined by variations in atmospheric and oceanic conditions. These fluctuations take many forms and are usually characterized by the magnitude, or scale, of their effects. For example, winter storm systems, which bring precipitation and high winds to the Pacific Northwest, usually persist for a short period of time (a few days) and affect relatively small areas. In contrast, large-scale variations tend to persist for a longer period of time and affect larger areas. The El Niño-Southern Oscillation is one example of such a large-scale variation: its effects persist for approximately 12 months, and it has a simultaneous impact on many areas across the globe.

What is the El Niño-Southern Oscillation?

In the late 1800s, South American fishers first noticed the appearance of unusually warm water off Ecuador. The fishers named the phenomenon El Niño (Spanish for "the Christ Child") because of its tendency to occur in December or January, around Christmas. Far from a festive occasion, El Niño caused anchovetta populations in coastal waters off Ecuador and Peru to decline, temporarily shutting down the valuable fishing industry. Now known to be part of a disruption in the oceanic-atmospheric system in the equatorial Pacific, El Niño has global repercussions. To understand this phenomenon, we must first learn why conditions at the equator are unique.

Atmospheric-Oceanic Interactions at the Equator

The trade winds are the main driving force of ocean currents at the equator. For centuries, trade ships have used these powerful and persistent winds to move across the equatorial ocean (hence their name). Normally, the trade winds blow from east to west, causing surface water to flow in the same direction (figure 4). As the surface waters are transported along the equator, they are continually heated by the sun. By the time the water arrives in the west Pacific, it is over 7°C warmer. This constant movement of water causes sea level off the coast of Indonesia to be about 1/2 meter (or 1.5 feet) higher than sea level off the coast of Ecuador. As surface water moves westward, deeper water flows upward to replace it. This upwelling of cold, nutrient-rich water off Ecuador and Peru supports huge populations of anchovettas and sardines. These fish form the basis of the multimillion dollar South American fishing industry.

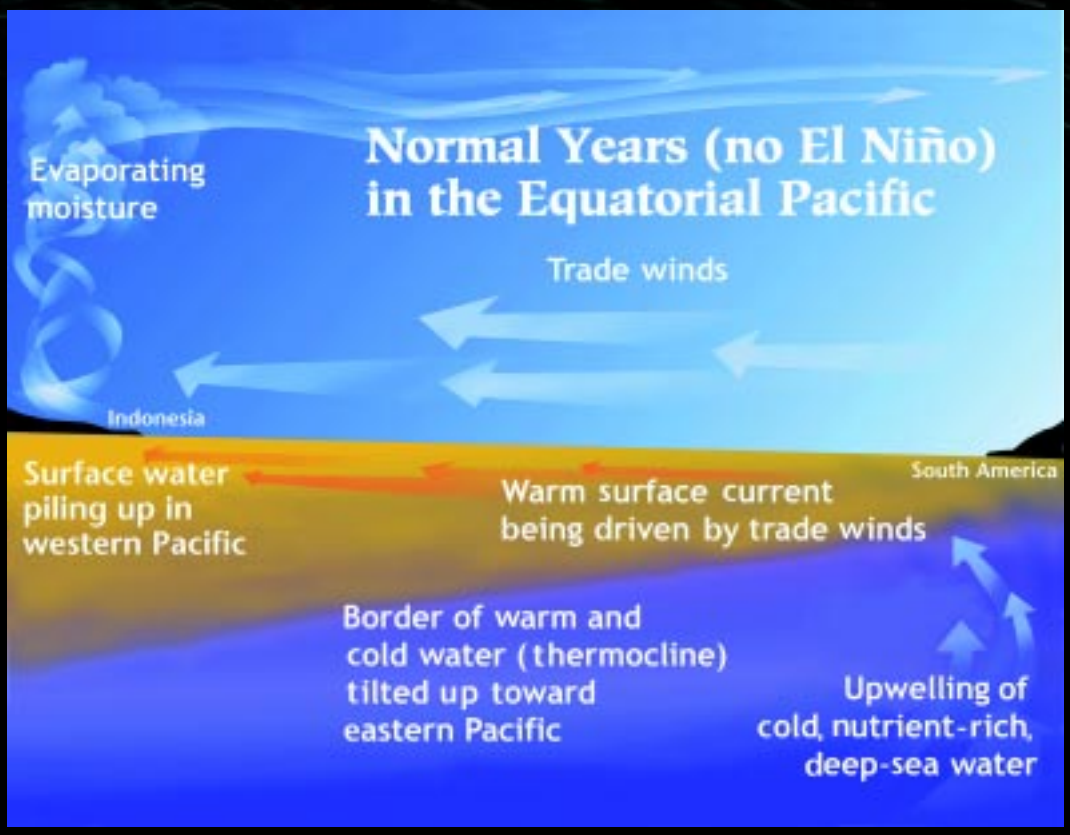

Figure 4. *Equatorial conditions during non-El Niño years. Strong and persistent trade winds result in a pool of warm water that accumulates in the western Pacific Ocean. This causes a compensatory tilt in the thermocline, with upwelling along the eastern Pacific Ocean.*

Figure 5. *Equatorial conditions during El Niño. Changes in the pressure system result in a decrease (or even reversal) of the trade winds. This releases the warm pool of water from the western Pacific, which then flows back toward South America and accumulates off the coast. Excess evaporation associated with the warm pool also migrates to the east and disrupts the jet stream, thereby substantially altering weather patterns.*

The Southern Oscillation: a Seesaw of Atmospheric Pressures

El Niño is generally used to refer to the oceanic component of the larger El Niño-Southern Oscillation. The term *Southern Oscillation* refers to changes in atmospheric pressure that tend to occur every two to seven years. Sir Gilbert Walker, a British scientist, first noticed that sea level air pressures in the equatorial Pacific seesaw between two extremes. He observed that in the *high index phase* of this pattern, pressure is higher in the eastern equatorial Pacific near Tahiti than farther to the west near Darwin, Australia. These two pressure systems are linked so that when pressure increases in the east, it falls in the west, and vice versa. Since air flows from a region of higher pressure to a region of lower pressure, the seesawing pressures have an important effect on the direction of wind flow. In the high index phase, surface winds (that is, the trade winds) blow in their normal direction, from east to west. However, in the *low index phase*, the pressure difference between Darwin and Tahiti decreases or even reverses, causing the trade winds to diminish.

It is this weakening of the trade winds that initiates El Niño. No longer held in place by the winds, the pool of water off Indonesia flows eastward as a wave of warm water and brings El Niño conditions to the coast of South America (figure 5). This wave of warm water causes a decrease in upwelling off Peru and Ecuador and sends certain fish populations crashing.

El Viejo: El Niño's Counterpart

El Niño has a cold cousin, often referred to as *El Viejo* (Spanish for "the Old One" and also referred to as *La Niña*), which is characterized by intensified trade winds and unusually cold surface waters in the equatorial Pacific. Conditions at the equator can swing back and forth between these two states; often an El Niño event is followed a few years later by an El Viejo event. Together, these variations influence the weather and oceanic conditions off the Pacific Northwest.

Impacts on the Pacific Northwest: the Role of Teleconnections

El Niño can affect the Pacific Northwest through two primary pathways: the oceans and the atmosphere. The atmosphere and ocean can link the conditions in two areas that are thousands of miles apart, by forming *teleconnections* (or connections that act over considerable distances) between these areas. Noticeable changes in oceanic conditions off the Pacific Northwest have been reported to occur as rapidly as one month after El Niño conditions were first spotted off Peru. These initial effects are transmitted by coastal waves that originate off South America and that bring warmer water to areas off the Pacific Northwest.

The atmospheric forces associated with El Niño tend to occur later, generally in the fall or early winter. Some of the more pronounced atmospheric changes that have been observed in the Pacific Northwest involve variations in the intensity and position of the winter Aleutian Low. During certain El Niño events, the winter Aleutian Low strengthens and migrates southwards or westwards or both, often altering the course of the jet stream and intensifying northward-blowing winds. These changes generally result in drier conditions, warmer temperatures, and lower precipitation and streamflow throughout the Pacific Northwest (such as during the 1991 to 1993 El Niño). *However, not all El Niños have the same effect.* The strong El Niño of 1982 to 1983, for example, brought winter floods to Oregon and Washington.

El Viejo events can also affect the Pacific Northwest. These events are generally associated with higher precipitation and streamflow throughout the region.

Variations in the Aleutian Low: Regime Shifts

El Niño events are not the only large-scale phenomena that affect the Pacific Northwest. In addition to the temporary fluctuations associated with El Niño, the Aleutian Low exhibits longer-term fluctuations in intensity and location that are believed to be responsible for different climatic regimes in the Pacific Northwest. These climatic regimes are generally characterized by either warm-and-dry or cool-and-wet winter conditions that tend to persist for approximately a decade. The relatively quick shifts from one climatic regime to the other are known as *regime shifts*.

The most recent climatic regime, extending from 1976 to 1988, was characterized by an intensification and eastward migration of the winter Aleutian Low, which forced storm tracks northward, bringing more precipitation to Alaska and less to Oregon. These changes in the Aleutian Low caused the persistent droughts in Oregon and Washington that occurred in the late 1980s. In addition, during this regime the currents off the Pacific Northwest shifted, bringing warmer waters to the west coast of North America, and El Niño events were more frequent.

In contrast, when the Aleutian Low is weak (during a cool-and-wet period), the surface waters off the Pacific Northwest are generally cooler and the area receives more precipitation.

Variations in Fish Populations: The Role of Oceanic Conditions

Because of the economic and social value of fishery resources to the Pacific Northwest, it is important to understand the effects of oceanic conditions on fish populations. Fluctuations in populations of certain fish often coincide with changes in conditions caused by El Niño events and climatic regimes. Salmon, a particularly important species to the Pacific Northwest, may be especially susceptible to such changes. For example, salmon harvest off Oregon declined dramatically during the El Niño events of 1958 and 1983 (figure 6).

Salmon are unique because they spend part of their life in freshwater and part in the ocean. Most salmon enter the ocean when they are relatively young. Because the first four months of ocean life are the most dangerous for juvenile salmon, abrupt changes in oceanic conditions may prove fatal to them.

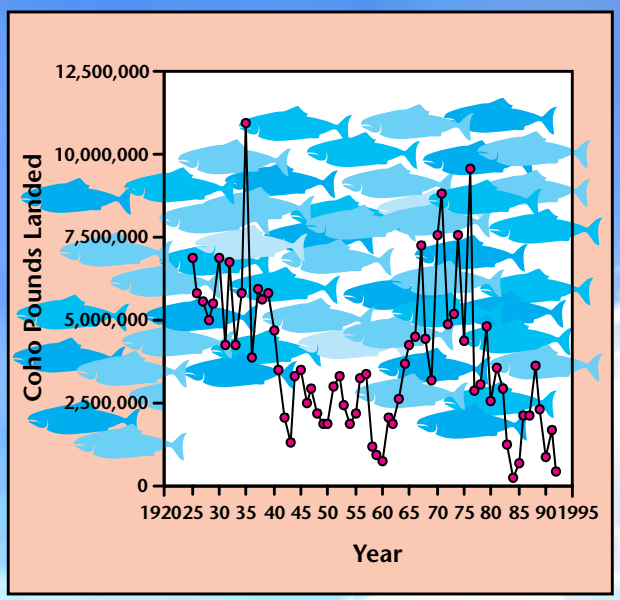

Figure 6. *Pounds of coho landed in Oregon, 1925-1992. Strong El Niños occurred in 1932, 1940-41, 1957-58, 1972-73, 1982-83, and 1992. However, not every strong El Niño has a noticeable effect on Oregon coho fisheries.*

Scientists do not yet fully understand how changes associated with El Niño affect salmon. It is likely that the changes in oceanic conditions associated with El Niño and other events interact and, in doing so, serve to decrease a young salmon's chance of survival.

There are currently several hypotheses as to why El Niño events might affect coastal organisms along the Pacific Northwest. One hypothesis is that El Niño conditions, by affecting the timing and effectiveness of upwelling, result in a diminished supply of nutrients to surface waters. Fewer nutrients adversely affect phytoplankton growth, which, in turn, means that there is less food for small animals (known as zooplankton) that feed on phytoplankton. During the El Niño event of 1982 to 1983, the average spring and summer density of zooplankton off Newport, Oregon, decreased by 70 percent. This effect can reverberate up the food web, threatening the survival of juvenile salmon that eat the zooplankton.

El Niño conditions can also reduce the movement of water away from the coast. Juvenile salmon, too small to swim against the currents, rely on the offshore transport of water to whisk them away from the coast. In El Niño years, juvenile salmon may get trapped near the shore and fall prey to seabirds and other coastal predators.

In addition, changes in the direction of coastal currents and in water temperatures can directly determine the types of fish found off the Pacific Northwest. During the El Niño of 1982 to 1983, fish that normally inhabit tropical and subtropical waters migrated northwards, following warmer waters. For example, two warmer-water species, the Pacific and jack mackerel, were unusually abundant off the coasts of Oregon and Washington. These voracious predators consume the same types of food as salmon and may have diminished the supply of phytoplankton and zooplankton; in addition these fish may have snacked on juvenile salmon.

Salmon aren't the only creatures affected by fluctuations in oceanic conditions. Other important commercial species such as the Dungeness crab are also susceptible to these changes. Crab are so small they depend heavily on ocean currents for transport. Changes in water movement along the Pacific Northwest that are associated with El Niño may dramatically affect survival of these larvae and have important ramifications for adult populations.

Future Directions

Although we have made great advances in our understanding of the effects of oceanic fluctuations on fisheries resources, there are still many unanswered questions. For example, we do not fully understand how changes in oceanic conditions affect organisms along the coast. Many fundamental questions also remain regarding El Niño events, variations in the Aleutian Low, and the interaction between these two events. These questions and many others will fuel scientific endeavors in the years to come, and their answers will provide important clues to the mystery of variations in the Pacific Northwest.

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