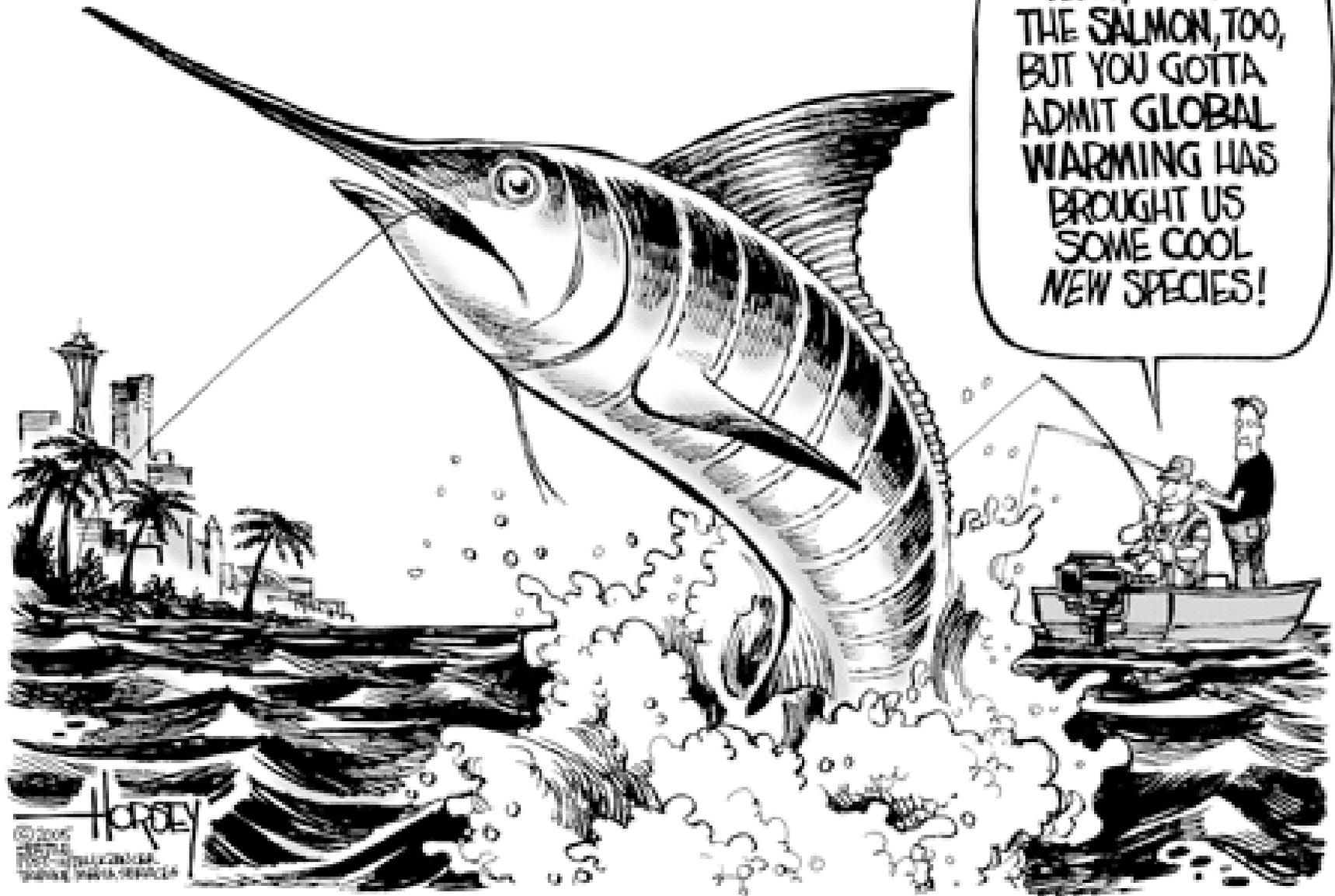
A photograph of an orca breaching the surface of the ocean. The orca is captured mid-leap, with its body arched and its tail fluke visible. The water is splashing around the orca, and the background shows a dark, forested coastline under a cloudy sky. The text is overlaid on the image in a bright yellow color.

Marine Productivity and Influences on Fish

Dr. Nate Mantua
University of Washington
Climate Impacts Group

Puget Sound, 2045...



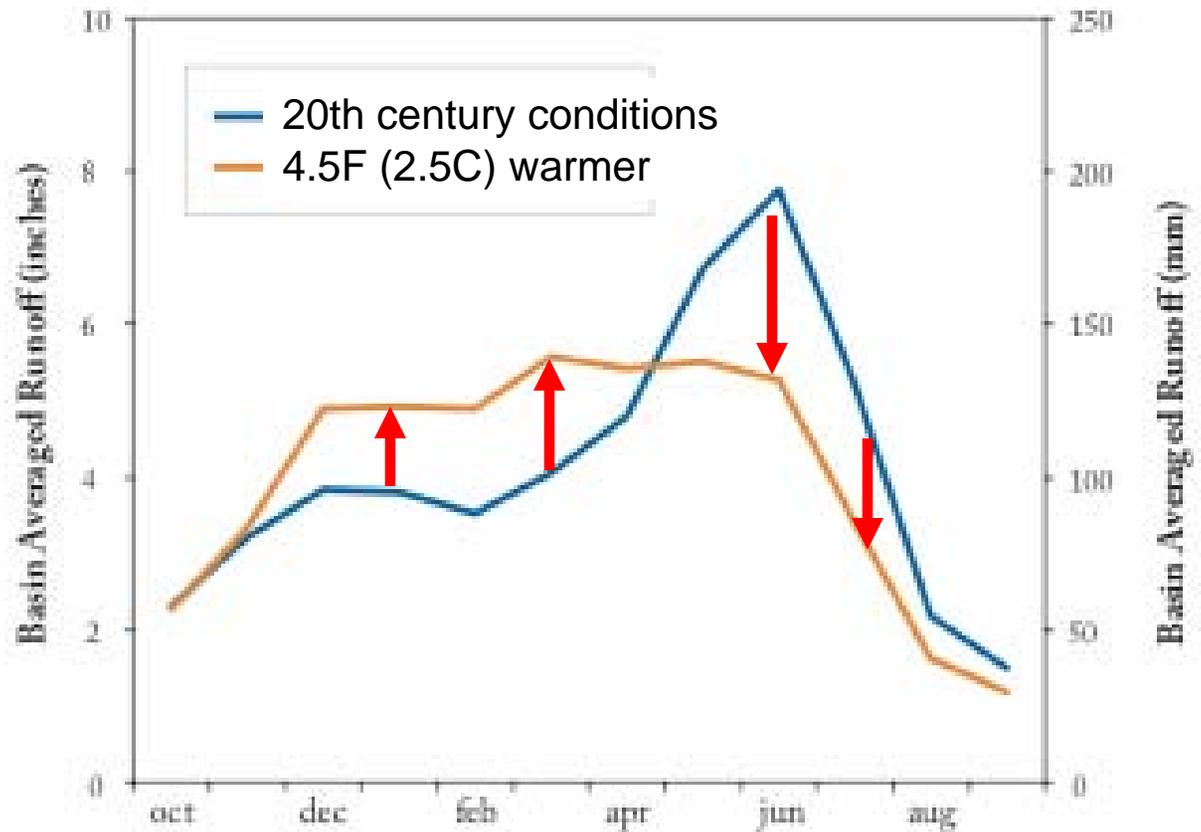
From the Seattle Post-Intelligencer, October 20, 2005

Some consequences of a warmer climate

- Timing shifts in Puget Sound freshwater inflows
- Warmer water temperatures, especially near the surface
 - tend to increase stratification in lakes, estuaries, and the ocean
 - cause sea level rise and a loss of wetlands and salt marshes where dikes or levees restrict shoreline retreat
 - cause species distribution changes
 - cause life history timing shifts
- A key unknown for our coastal ocean is how upwelling winds will change in the future

Simulated Average Freshwater Inflow Into Puget Sound

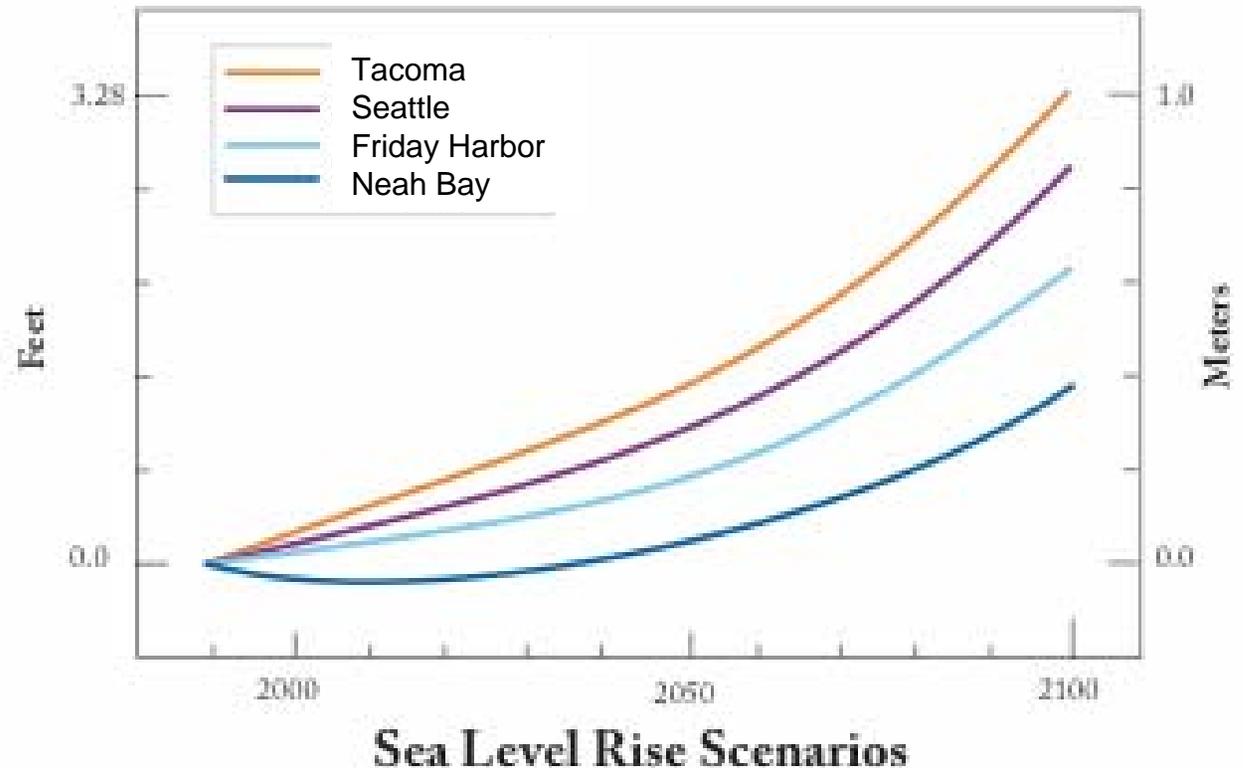
- **Warmer temperatures will reduce inflows in late spring and summer, and increase inflows in winter**



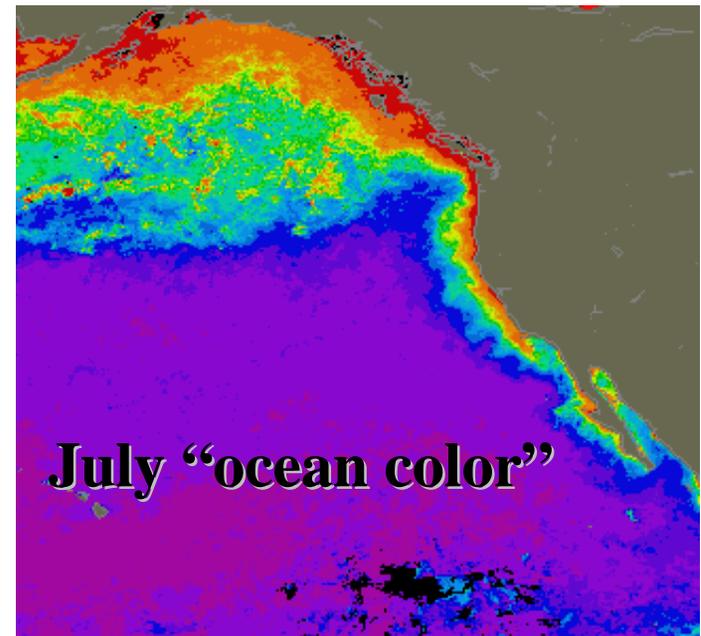
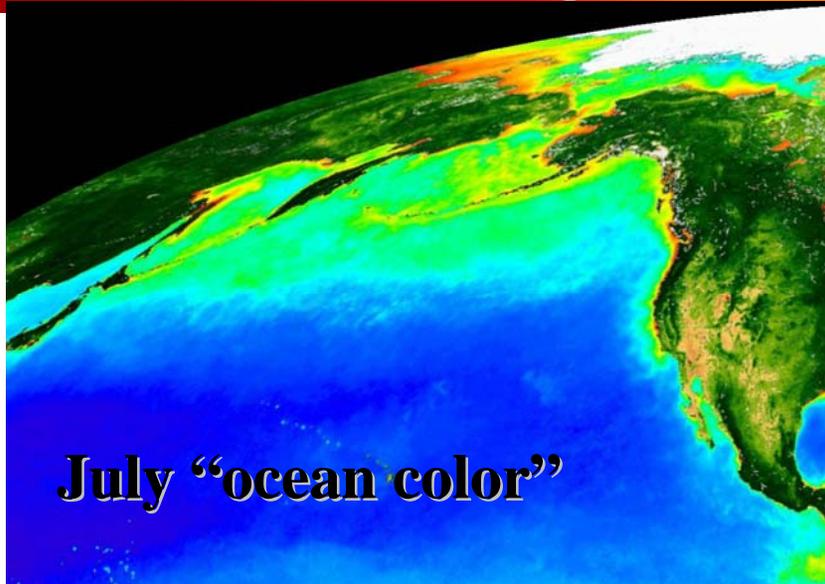
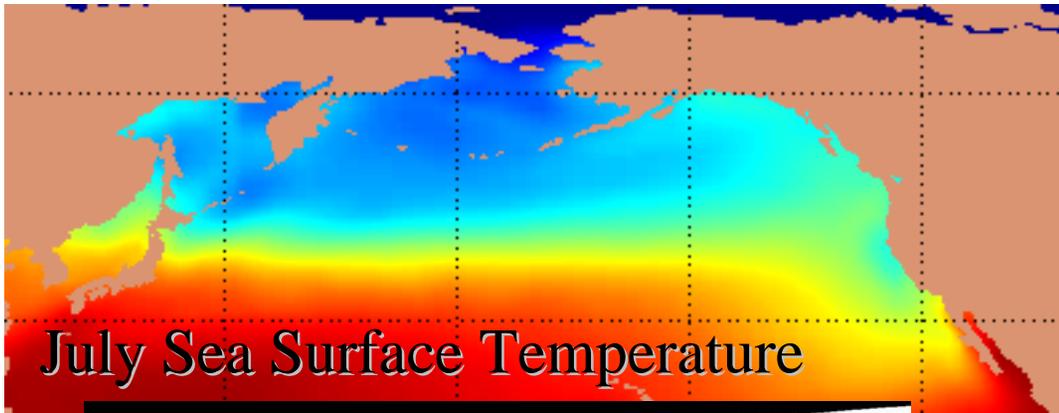
PSAT 2005

Sea Level Rise

- sea level rise is projected to be most rapid in south Puget Sound where land is sinking most rapidly



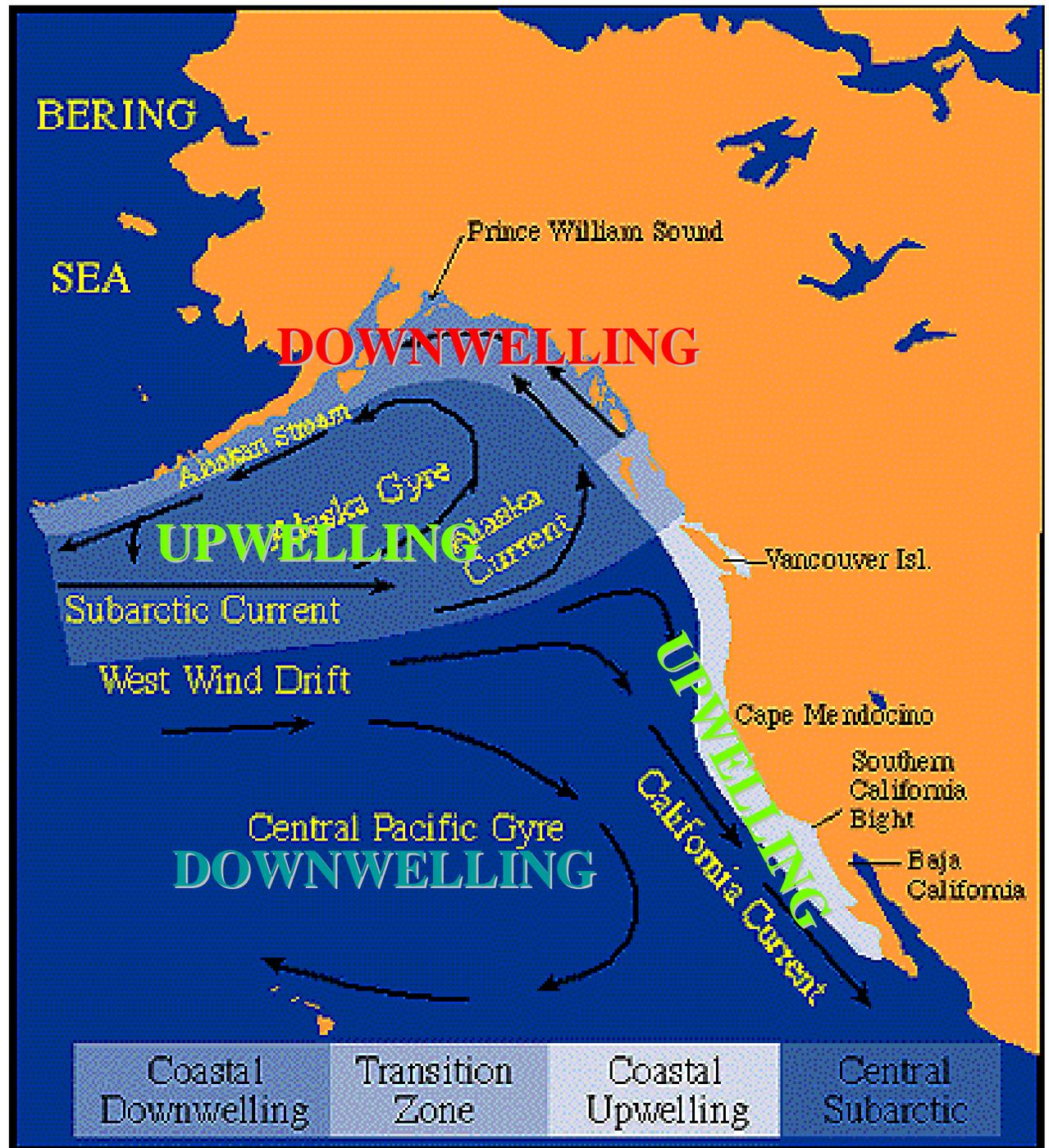
Pacific salmon habitat: **productive sub-arctic (cool-fresh-nutrient rich) waters from Japan to California -- coastal upwelling extends this habitat south to S. Cal.**



SeaWiFS images from NASA's Goddard Space Flight Center
<http://seawifs.gsfc.nasa.gov/SEAWIFS.html>

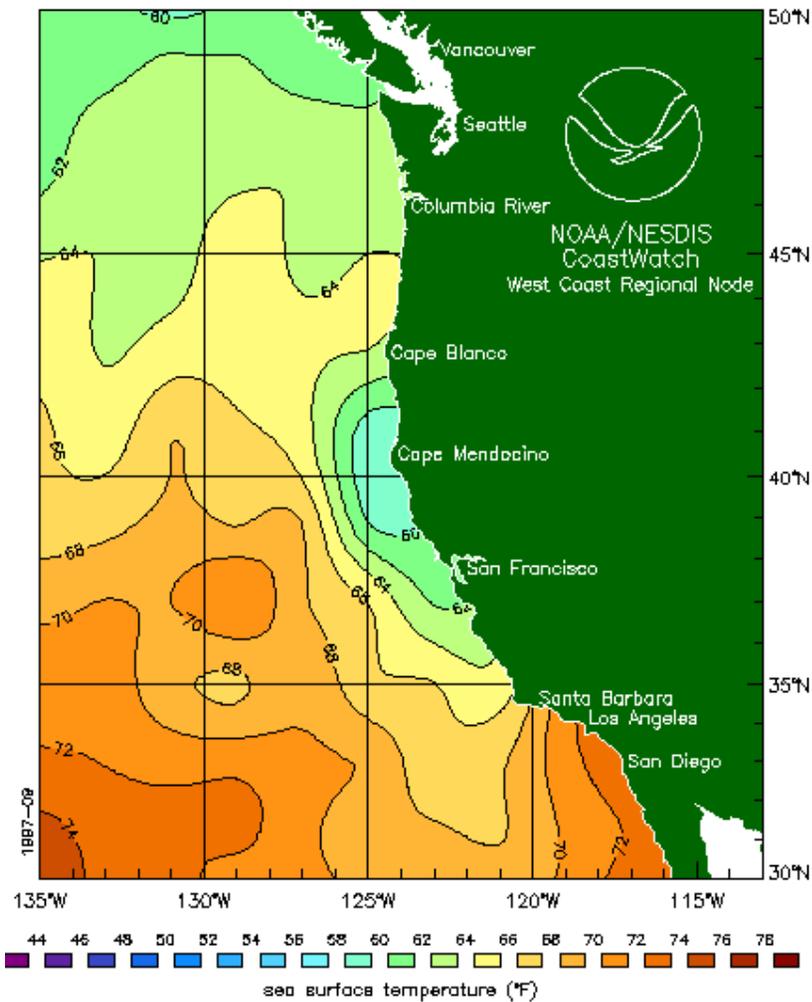
Ocean habitat domains are closely linked to wind and current patterns

(from Ware and McFarlane, 1989)

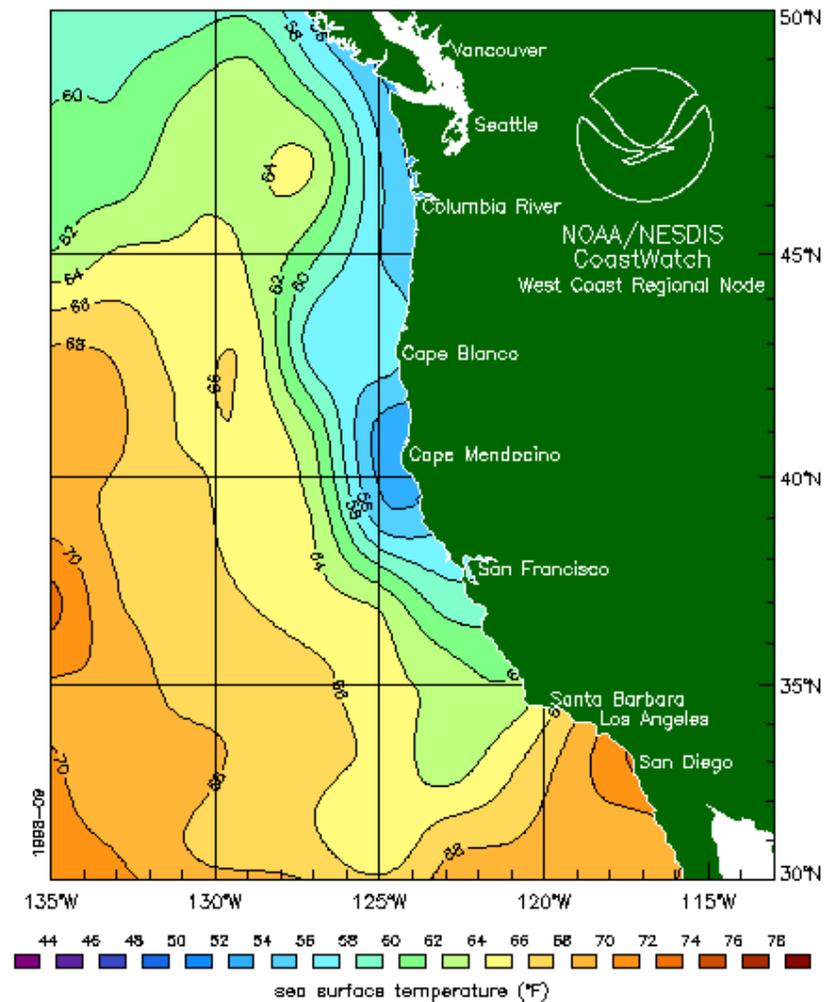


West-coast sub-arctic habitat is dynamic and sensitive to changing wind patterns (El Niño, La Niña, the Pacific Decadal Oscillation (PDO), and other)

Sept 1997 El Niño



Sept 1998 La Niña

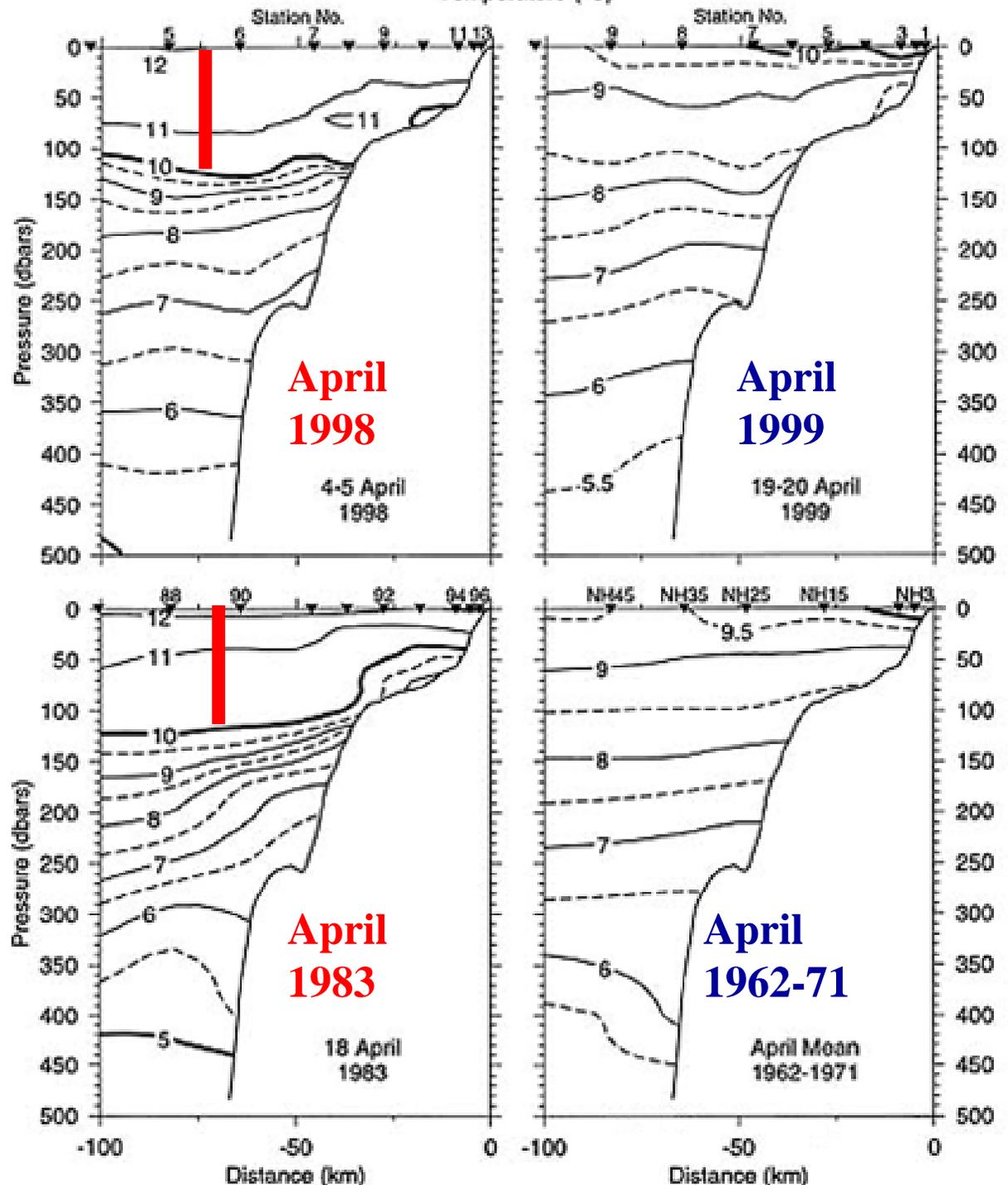


Newport Line temperatures at depth

A thick layer of warm (low density) water at the surface can cut off the nutrient supply...

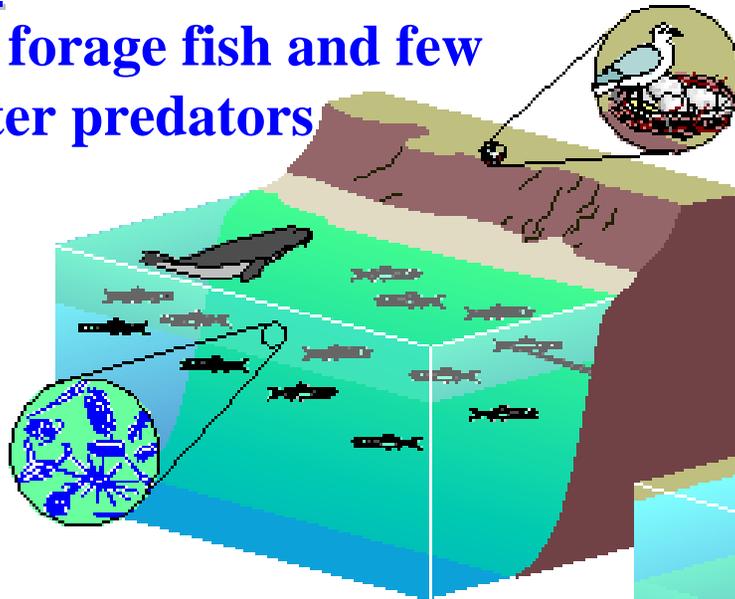
Upwelling without nutrients yields no benefits to phytoplankton!

Figure obtained from:
<http://ltop.coas.oregonstate.edu/~ctd/>

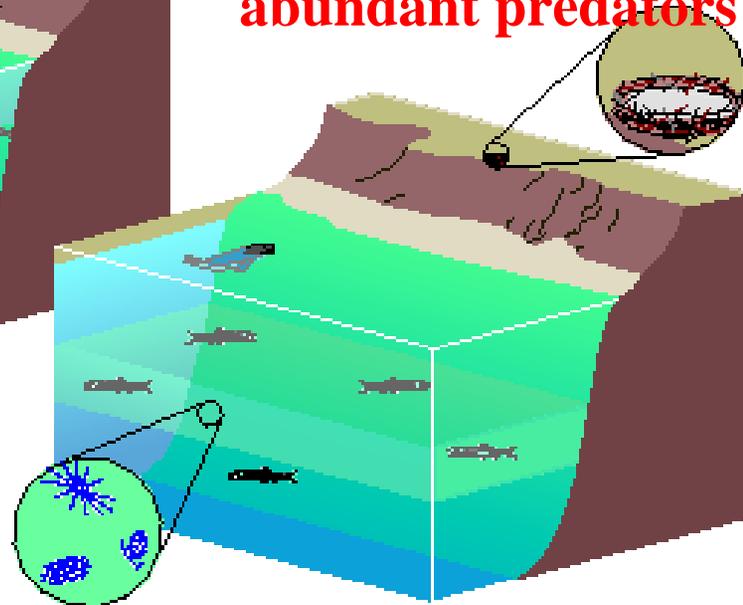


upwelling food webs in our coastal ocean

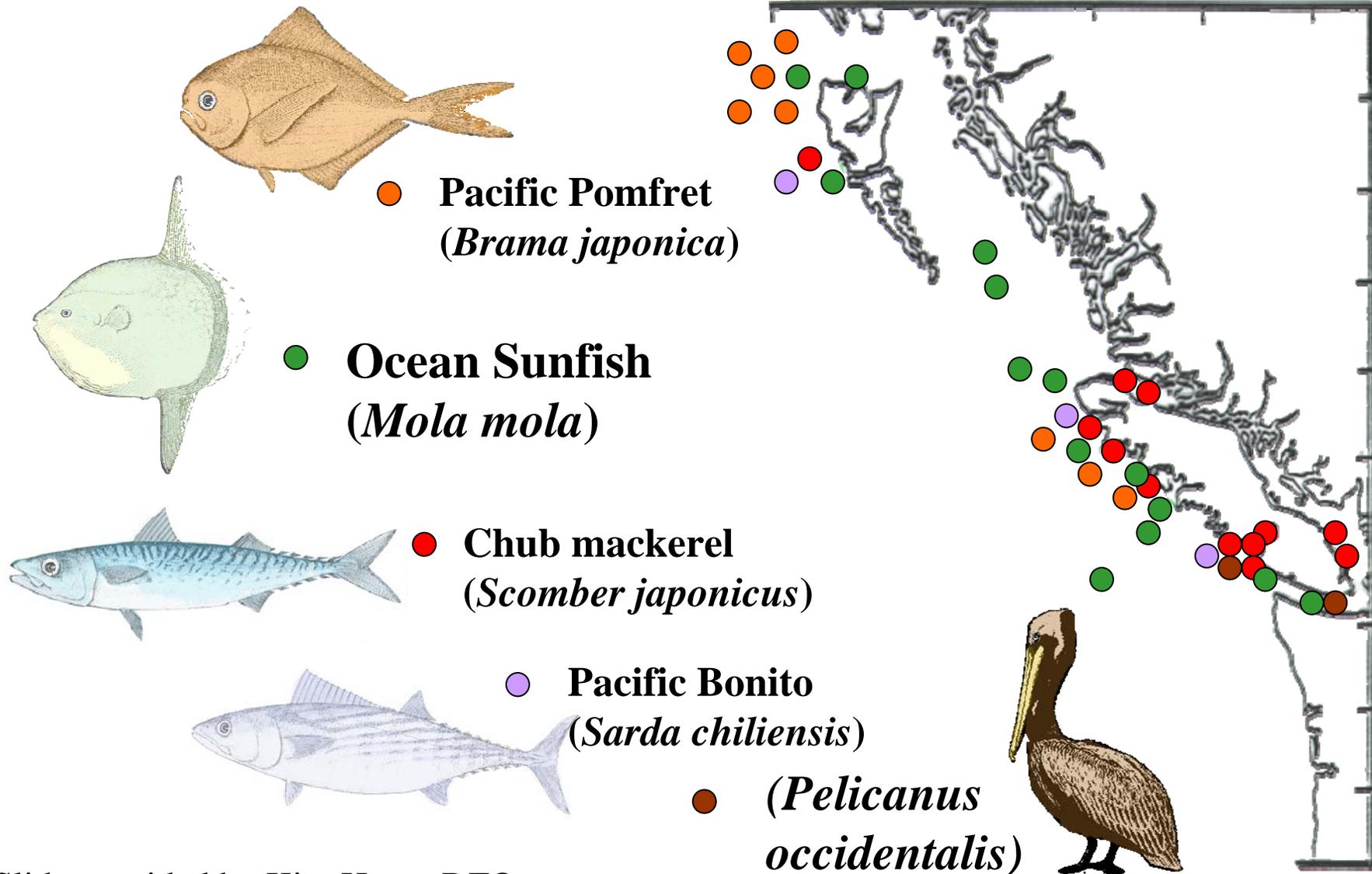
Cool water, weak stratification
high nutrients, a productive
“subarctic” food-chain with
abundant forage fish and few
warm water predators



Warm stratified ocean, few
nutrients, low productivity
“subtropical” food web, a
lack of forage fish and
abundant predators



Exotic Species Sightings off the BC Coast During 1983, an extreme El Niño year (J. Fulton, P.B.S.)



Slide provided by Kim Hyatt, DFO

Marlin in Washington aren't a joke!

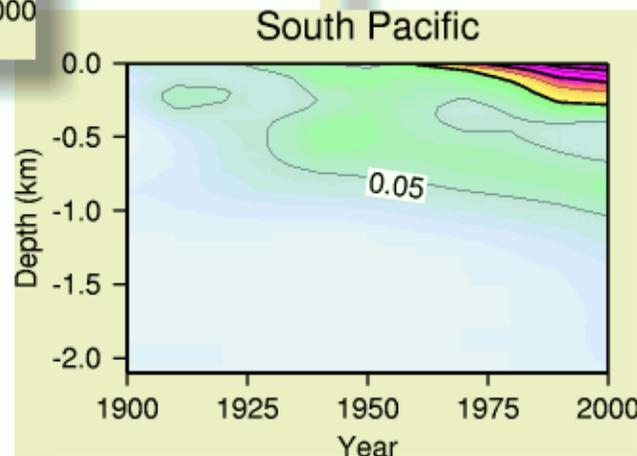
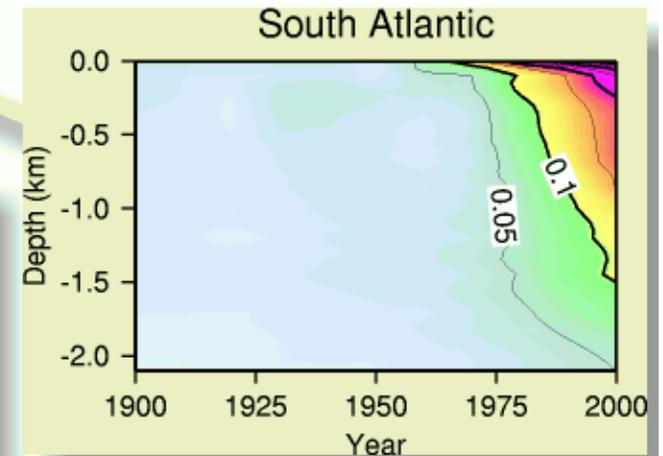
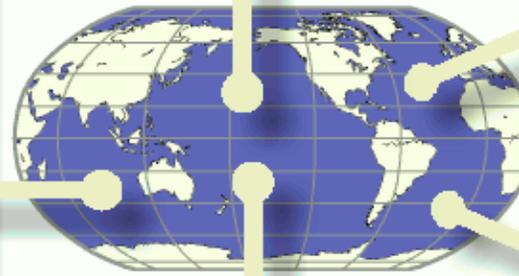
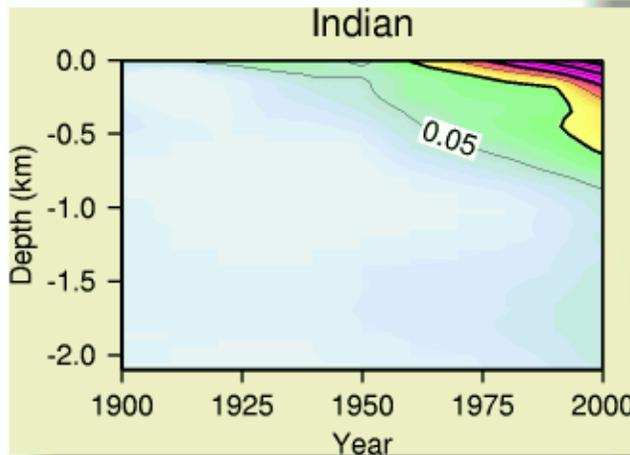
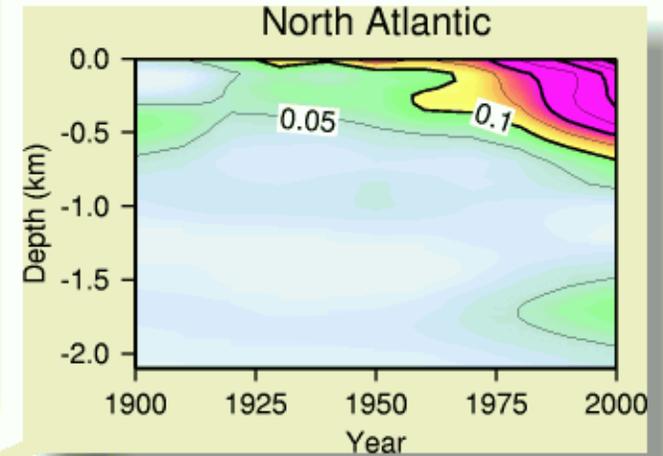
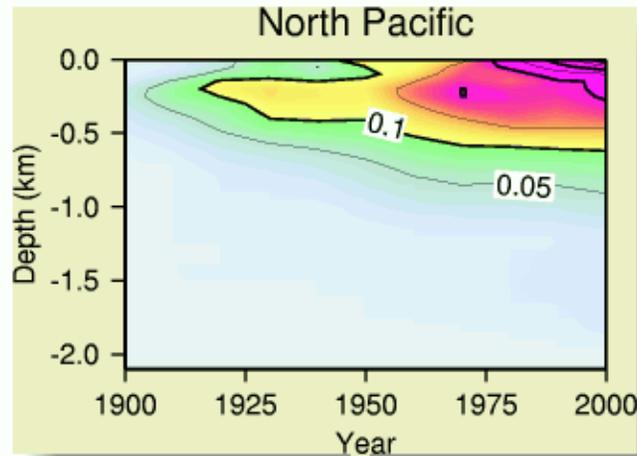
- This 134lb striped marlin was caught 40 miles off Westport Sept. 2, 2005



Photo obtained from the Seattle Times web-archives

World Ocean Warming ($^{\circ}\text{C}$), 1900 to 2000

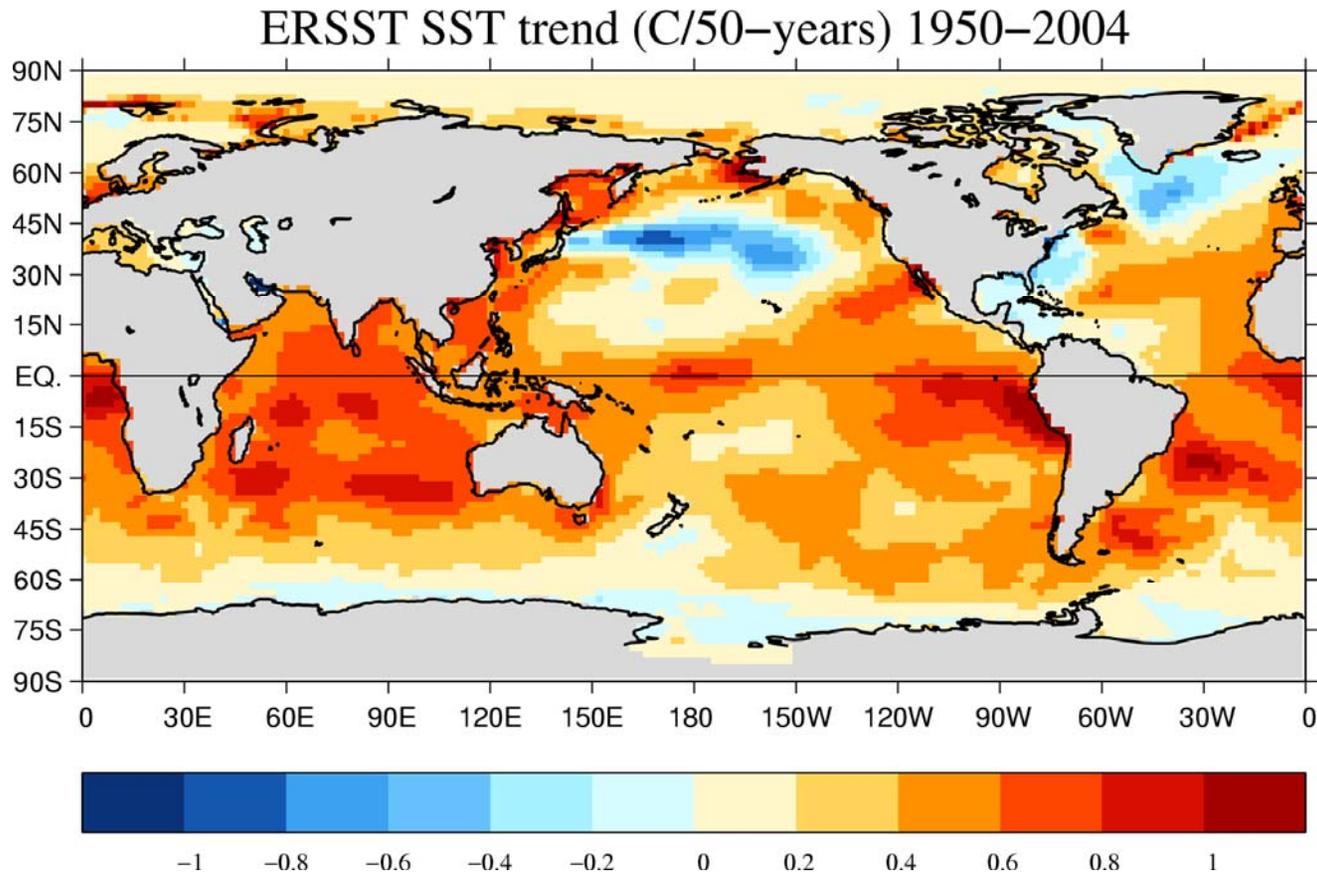
Observed upper ocean temperature trends



Most warming was near the surface

Barnett et al., *Science*, 2001

55yr trends in Pacific SSTs



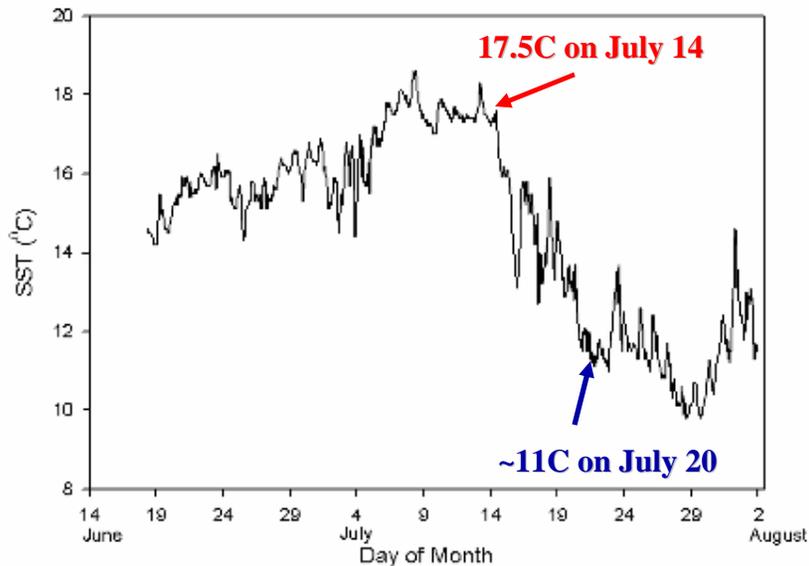
Between 1950 and 2004 there was a near-global warming of SSTs
*subarctic N. Pacific SSTs have a cooling trend because of
increased wind speeds*

(Figure created by Todd Mitchell, UW-JISAO)

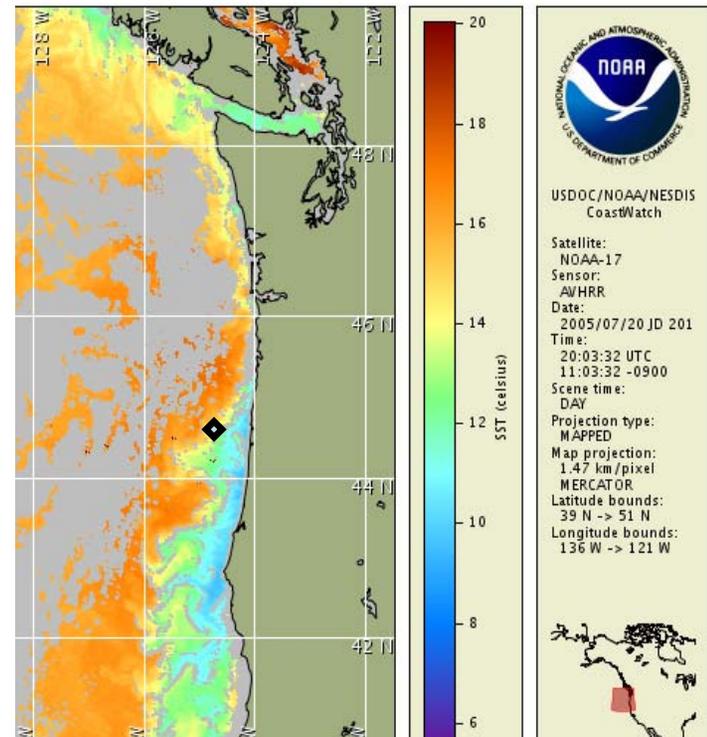
Upwelling winds are a dominant source of coastal ocean temperature changes

- **Newport buoy ocean temperature dropped 6.5C in one week this summer! The future of upwelling winds for the OR/WA coast is not clear**

**Stonewall Banks Buoy SST
18 June - 2 August 2005**



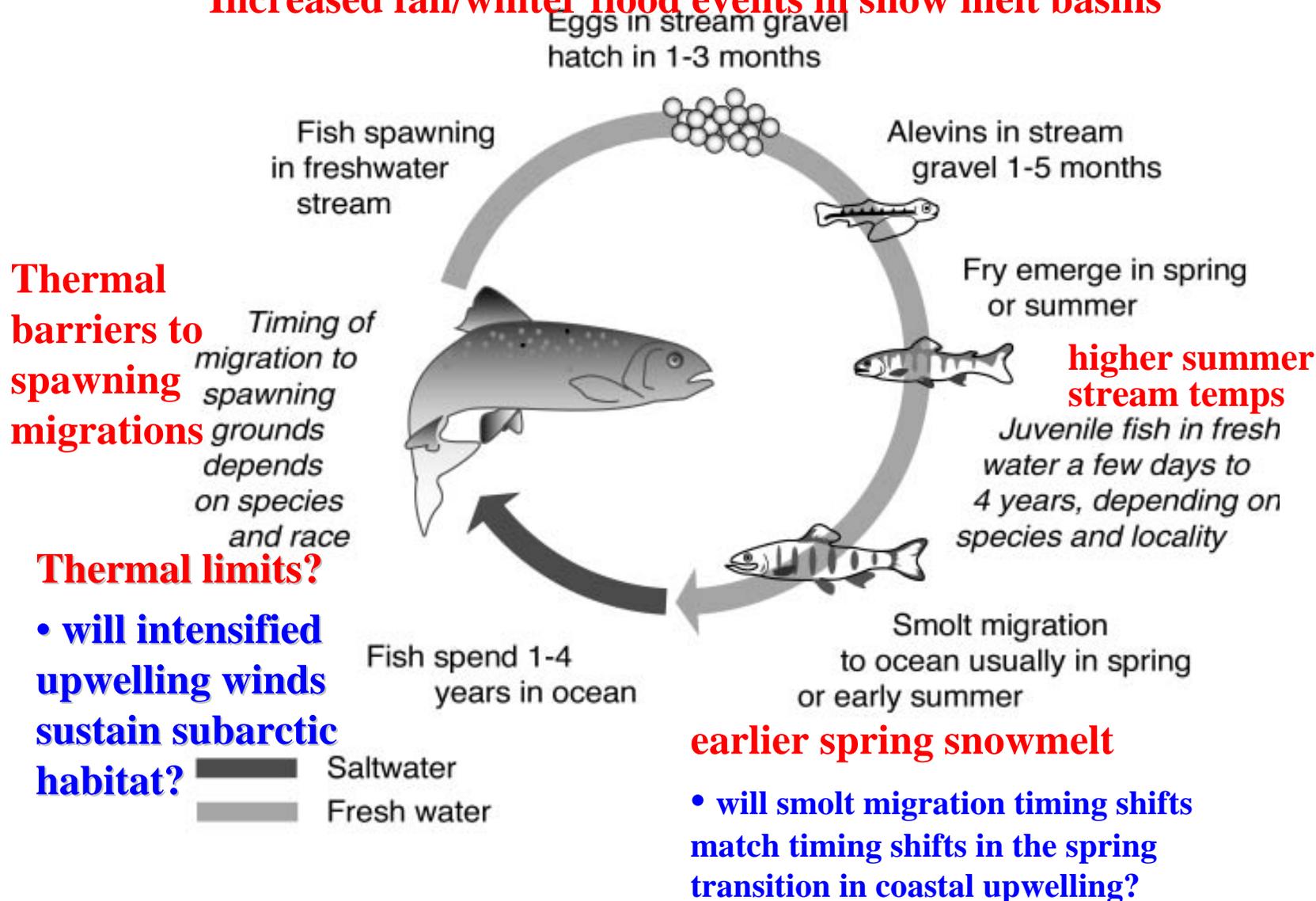
Buoy SST plot courtesy of Pete Lawson, NOAA (Newport)



20 July 2005 NOAA CoastWatch image

The salmon life cycle and climate warming

Increased fall/winter flood events in snow melt basins



summary

- The regional impacts of global warming will likely alter estuaries with warmer water temperatures, increased stratification, sea level rise, and changes in freshwater inflows
- A warmer upper ocean will likely favor a trend away from subarctic toward subtropical zooplankton and fish communities
 - A major wildcard for our coastal ocean is the future behavior of coastal upwelling winds; if winds increase substantially they may counteract or even overwhelm local surface warming that is directly caused by an increase in the greenhouse effect

Impacts on PNW salmon

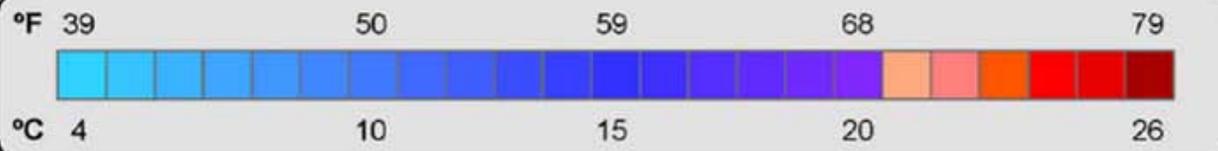
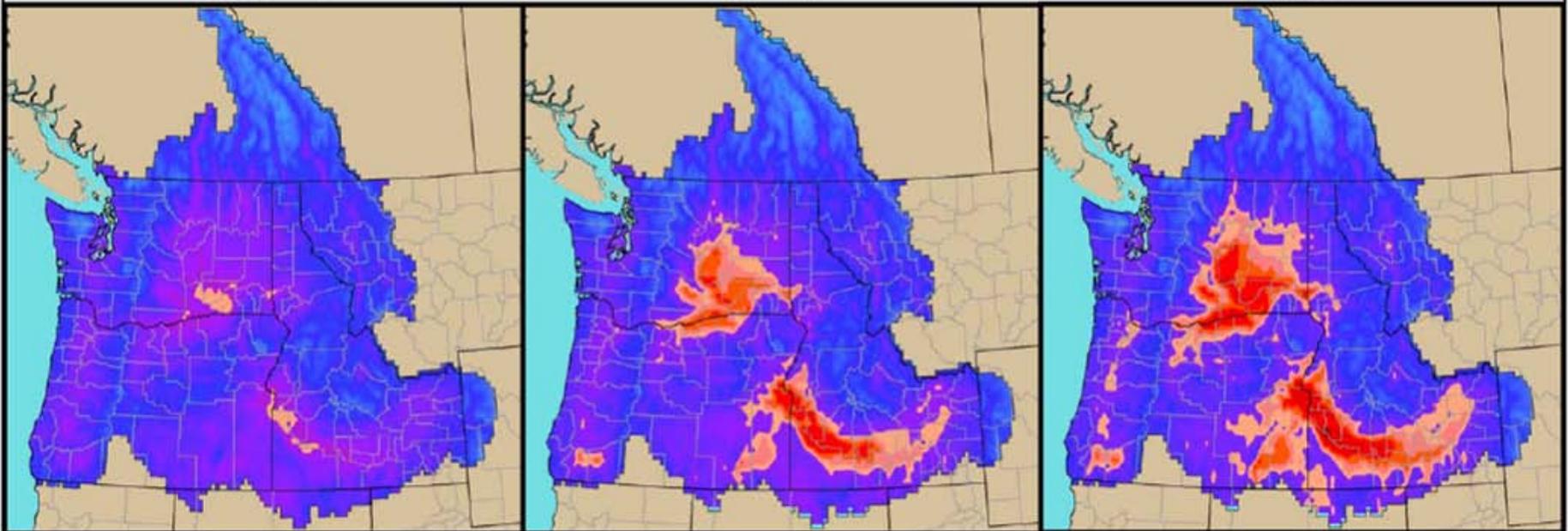
- The regional impacts of global warming are likely to increase stresses on many PNW salmon populations
 - In order to protect PNW salmon, steelhead, trout and other cold water fish from the negative impacts of global warming, existing stresses will need to be alleviated and thermal refugia will need to be protected

August Mean Surface Air Temperature

1980-97

2020s

2040s



Climate Impacts Group
University of Washington

Runoff patterns are temperature dependent

