Impacts of Climate Change on the Marine Environment of the Pacific Northwest

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The Climate Impacts Group

Goal: to increase the region’s resilience to climate variations and climate change

Areas of study:
- Water resources
- Salmon
- Forests
- Coasts

The past is the key to the future.

Featuring work by: Edward Miles, Nathan Mantua, Philip Mote, Dennis Lettenmaier, Alan Hamlet, Doug Canning and others.

Interdisciplinary research team at UW
Defining the “marine environment”

According to the Oceans Act:

- The **marine environment** includes the oceans, including coastal and offshore waters, and the continental shelf.

- **Ocean and coastal resources** include any living or non-living natural resource found in the marine environment.

  Define **marine environment** to include the terrestrial (upland) component of coastal watersheds, in addition to the open ocean and coastal zone.
The role of climate in the marine environment

1. Terrestrial systems
2. Coastal zone
3. Open ocean

Let’s begin with a look at the past...
Natural climate variability

Pacific Decadal Oscillation (PDO)  El Niño/Southern Oscillation (ENSO)

Mantua et al. 1997
Variability in the Pacific Ocean (especially the Pacific Decadal Oscillation and El Nino-Southern Oscillation) exerts an important influence over winter and spring climate in the PNW. Warm-phase ENSO and PDO tends to split the storm track, so that our winters tend to be slightly warmer and drier than normal. Under these conditions snowpack tends to be smaller than normal, streamflow in snowmelt-driven basins is reduced, and (for PDO) salmon production and forest growth (except at high elevations where deep snow limits early summer growth) tend to be reduced, and there is a higher likelihood of drought conditions which can lead to wildfires.
Terrestrial Issues: freshwater habitat

**ENSO**

- Warm ENSO
- Cool ENSO
- Long Term Mean

**PDO**

- Warm PDO
- Cool PDO
- Long Term Mean

Flow (cfs)
Coastal Issues: Hazards & Habitat

- Landslides
- Flooding and inundation
- Coastal erosion
- Habitat

Three hazard regions:
N Pacific coast, S Pacific coast, Puget Sound

The southwest coast of Washington now faces a net loss of coastal lands, reversing a long term trend of sediment buildup. Beachfront erosion now threatens an area that represents more than 10% of Ocean Shores’ tax base. Ocean Shores also has a wastewater treatment plant that’s currently threatened by erosion and flooding.

A study of the Oregon Coast found that the amount of armored shoreline increased in dramatic pulses following El Nino winters in the past few decades. El Nino’s tend to alter Pacific winds in ways that raise sea levels coast-wide, and also produce large waves from a more southerly than usual direction, a combination that is especially good at eroding beaches.

Wet winters and heavy rainfall events frequently cause coastal flooding, especially when high flows coincide with high tides.

Because the land mass of South Puget Sound is subsiding, the risk of inundation is especially large in low-lying parts of Olympia.
Seasonal-Interannual sea level variations: +/- 1 foot at SF
due to persistent winds and coastal ocean temperature changes
• Location: West Point Brown, Ocean Shores, Grays Harbor County

• Time; Date: 1641; 2 February 1998

• Caption: Aerial view east of Brisas del Mar condominium. Note the end effect erosion caused by the armored beach fill.

• Photography by: Douglas J. Canning, Olympia, Wash.
COASTAL UPWELLING
Coastal Habitat: Upwelling Food Webs

Cool water, weak stratification abundant nutrients, and a productive “subarctic” food-chain

Warm stratified ocean, few nutrients, low productivity “subtropical” food web

Recipe for biologically effective upwelling: sunlight, nutrients and weak-to-moderate stratification in the upper ocean

Reports to the Nation: El Niño and Climate Prediction
Ecosystem impacts of recent changes in coastal ocean conditions

Open Ocean

Key aspects of climate-induced variability include:

- availability and types of food
- abundance and type of competitors & predators
- direct links between ocean temperature and metabolic rates
An Inverse Production Pattern

Hare et al. 1999
what happened in Alaska after this PDO phase shift in 1976.

These photos are from research trawls along the Alaska Peninsula. Within a few short years over this time span catches changed from primarily shrimp and capelin to cod, pollock, and flatfish.

Not just climate change! Also saw changes in Canadian geese, NW salmon, dungeness crab, Pacific sea birds numbers, Washington Oyster growth … all captured by a composite 40-member ecosystem state variable.
### Summary: Natural Climate Variability

<table>
<thead>
<tr>
<th>El Niño/wPDO</th>
<th>Impact Drivers</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Winter temperature, precipitation</td>
<td>salmon freshwater habitat, coastal flooding, landslides, estuarine nutrient supply &amp; mixing processes</td>
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<tr>
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<td>Sea level</td>
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<td>+ (El Niño)</td>
<td>Upwelling winds, sea surface temp.</td>
<td>coastal ecosystem structure and productivity</td>
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<tr>
<td>-</td>
<td>Storm direction</td>
<td>erosion</td>
</tr>
<tr>
<td>+</td>
<td>Ocean circulation</td>
<td>structure and productivity of open ocean ecosystem</td>
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<tr>
<td>S/SW</td>
<td></td>
<td></td>
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<tr>
<td>EN: ??</td>
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Coastal ocean conditions are the net result of essentially random combinations of independent processes.
The role of climate in the marine environment

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Turning to the future...
Temperature Projections

• The global average surface temperature is projected to increase by **2.5 to 10.4°F (1.4 to 5.8°C)** over the period 1990 to 2100. These results span the full range of scenarios used in the TAR (35 SRES scenarios).

• The projected temperature increases are greater than those in the SAR (top end of the range is nearly doubled), which were **1.8 to 6.3°F (1.0 to 3.5°C)**. The revised higher estimates of projected warming are due primarily to the lower projected sulphur dioxide emissions in the TAR scenarios relative to the SAR scenarios (less of a cooling effect); i.e., a result of the assumption that we will produce fewer pollutants when producing electricity.

• The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be unprecedented for at least the last 10,000 years. The magnitude of the warming at the upper end of the range is of the same order as the warming the earth experienced emerging from the depth of the last ice age 20,000 years ago to the warmth of the present interglacial beginning about 10,000 years ago.
PNW temperature to 2100
We looked at 8 scenarios produced by several different general circulation models from climate modeling centers around the world. We averaged the results for the Pacific northwest and compared them with the “control” climate from long runs with fixed CO2. In the table above I’ve highlighted the average values (red), broken down into the warm half and cool half of the year. The bottom line: warmer and wetter.

Some details:
• using just June-July-August, most of the models project a decrease in precipitation.
• The 2C warming exceeds the 20th century warming (0.8C in the Northwest)
• There is no difference in warming rate between winter and summer. Globally, we expect winter warming to exceed summer warming. I’m not sure why that isn’t the case in the PNW.
The main terrestrial impact: Less snow
Hydrologic Changes

Less snow, earlier melt:
- More water in winter
- Less water in summer

- Increased winter flooding
- Increased spring/summer water temperature
- Decreased spring/summer flows for salmon
- Increased competition with other uses

Climate change is in the “wrong” direction, given current conflicts and lack of adaptability, ESA listings, population growth...
Sea-Level Rise Projections

• Global average sea level is projected to rise by **4 to 35 inches** (9 to 88 cm) between 1990 and 2100 (projections from full range of SRES scenarios). This is due primarily to thermal expansion of the oceans and the melting of glaciers and ice caps.

• Despite higher temperature change projections in the TAR, the projected rise in sea level is slightly lower than the range presented in the SAR (6 to 37 inches). This is due mainly to the use of improved models, which give a smaller contribution from glaciers and ice sheets (some snow and ice will be added to ice sheets because of increased precipitation, but this effect will likely be small compared to the loss of mass from melting).

• It should be noted that global temperatures will continue to increase and sea level will continue to rise for thousands of years after stabilization of greenhouse gas concentrations (even at present levels) due to the long time scales on which the deep ocean and ice sheets adjust to climate change.
Vertical Land Movement

- Tectonic forces move the land
- Rising sea levels add to the land movement
  - Current rise: 1.0-2.5 mm/yr
  - Projected rise: 2.0-8.6 mm/yr
  - Shoreline change ~10 mm/yr

Komar 1992
Canning 1991
Climate change impacts in the coastal zone

- Coastal erosion
  - ↑ Rising sea levels
  - ↑/↓ Changing wave climate
- Landslides
  - ↑ With increased winter rainfall
- Flooding and inundation
  - ↑ Due to sea level rise and increased winter stream flows; Olympia perhaps most vulnerable
- Coastal ocean productivity
  - ↑ ↑/↓ Changing wind climate; altered estuarine conditions

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Sea water intrusion, coastal water table rise (ag soils, floods, storm drainage, haz materials)
Potential sea level rise in Olympia by 2100

City of Olympia, 1993
Climate change impacts in the open ocean

Requires knowledge of
  – Future changes in large-scale ocean and atmosphere circulation
  – How climate changes affect the marine food web

Insufficient knowledge precludes projection of impacts
### Summary: Climate Change

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Conclusions

- 20th century variations in PDO and ENSO have had significant consequences for the marine environment of the PNW
  - Main drivers: wintertime air temperature and precipitation, sea level, coastal (upwelling) winds, storm direction, ocean circulation
  - Main impacts: salmon habitat, coastal and open ocean ecosystem structure and productivity, coastal hazards
- 21st century climate is very likely to be warmer than the 20th century (1-4°F by 2040s)
- Regional warming likely to be faster than global warming (3-6°F by 2040s)
Conclusions

• The impacts of climate change for the PNW are best understood for the terrestrial environment:
  – Seasonality of projected regional climate changes will have significant impacts on PNW water resources
  – Warmer, wetter winters → decreased snowpack, summer streamflow; increased winter streamflow
  – Negative consequences for PNW salmon

• Impacts are least understood for the open ocean:
  – How will climate change affect upwelling winds? Storm direction? Ocean circulation?
Conclusions

- Climate variability and change are important issues for the National Ocean Commission to consider as part of their charge to...
  - protect life and property against natural and manmade hazards
  - promote responsible stewardship and use of fishery resources and other ocean and coastal resources
  - expand human knowledge of the marine environment including the role of the oceans in climate and global environmental change