Climate and Oceans Think Tank 2009

Proceedings - Day 1

LIVING OCEANS SOCIETY

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CLIMATE AND OCEANS THINK TANK 2009

PROCEEDINGS

DAY 1- THE SCIENCE

These proceedings provide a summary of the presentations that were given at the Climate and Oceans Think Tank, hosted by the Living Oceans Society in March 2009.

The purpose of the Think Tank was to provide the conservation community in B.C. with the opportunity to explore the known science behind potential climate change impacts to the ocean and to generate policy ideas for addressing the likely consequences of such changes.

To that end, the Think Tank provided the opportunity to: (i) hear from scientists about the known and potential impacts climate change will have on our coast, (ii) allow them to highlight aspects and factors we know much less about, and (iii) brainstorm policy that will help deal with potential impacts of climate change on our ocean ecosystem.

Several marine based groups were represented at the Think Tank including Canada Parks and Wilderness Society, David Suzuki Foundation, Forest Ethics, Georgia Strait Alliance, Greenpeace Canada, Living Oceans Society, North Coast Skeena First Nations Stewardship Society, Raincoast Conservation Foundation, Sierra Club of British Columbia and World Wildlife Fund - Canada.

The science presented focused on the impact of climate change on upwellings and currents, sea level rise, ocean acidification, marine ecosystems, and species and freshwater runoff. For more information on any of the subjects please see:
www.livingoceans.org/programs/energy/climate_change/resources.html

Presentations by Scientists

1. **Bill Crawford,** Ph.D., Oceanographer **- *Climate Change Impacts on Upwelling and Currents in the Pacific North-West***

2. **Dr. Stephane Mazzotti,** Research Scientist, Natural Resources Canada **- *Sea Level Records and Projections for the B.C. Coast***

3. **Dr. Richard Feely,** Oceanographer, Professor, University of Washington School of Oceanography **- *Ocean Acidification – The Other CO_2 Problem***

4. **Dr. Paul Whitfield, -** Senior Manager, Environment Canada - ***Changing Freshwater Runoff a Global Issue at Local Scales***

5. **Dr. Nathan Mantua -** Research Associate Professor in the School of Aquatic and Fishery Sciences, University of Washington - ***Climate Change Impacts on Marine Ecosystems***

Living Oceans Society would like to acknowledge the assistance of Mountain Equipment Co-op, the Vancouver Foundation and the Ocean Management Research Network for funding the Climate and Oceans Think Tank.

MOUNTAIN EQUIPMENT CO-OP
environment fund
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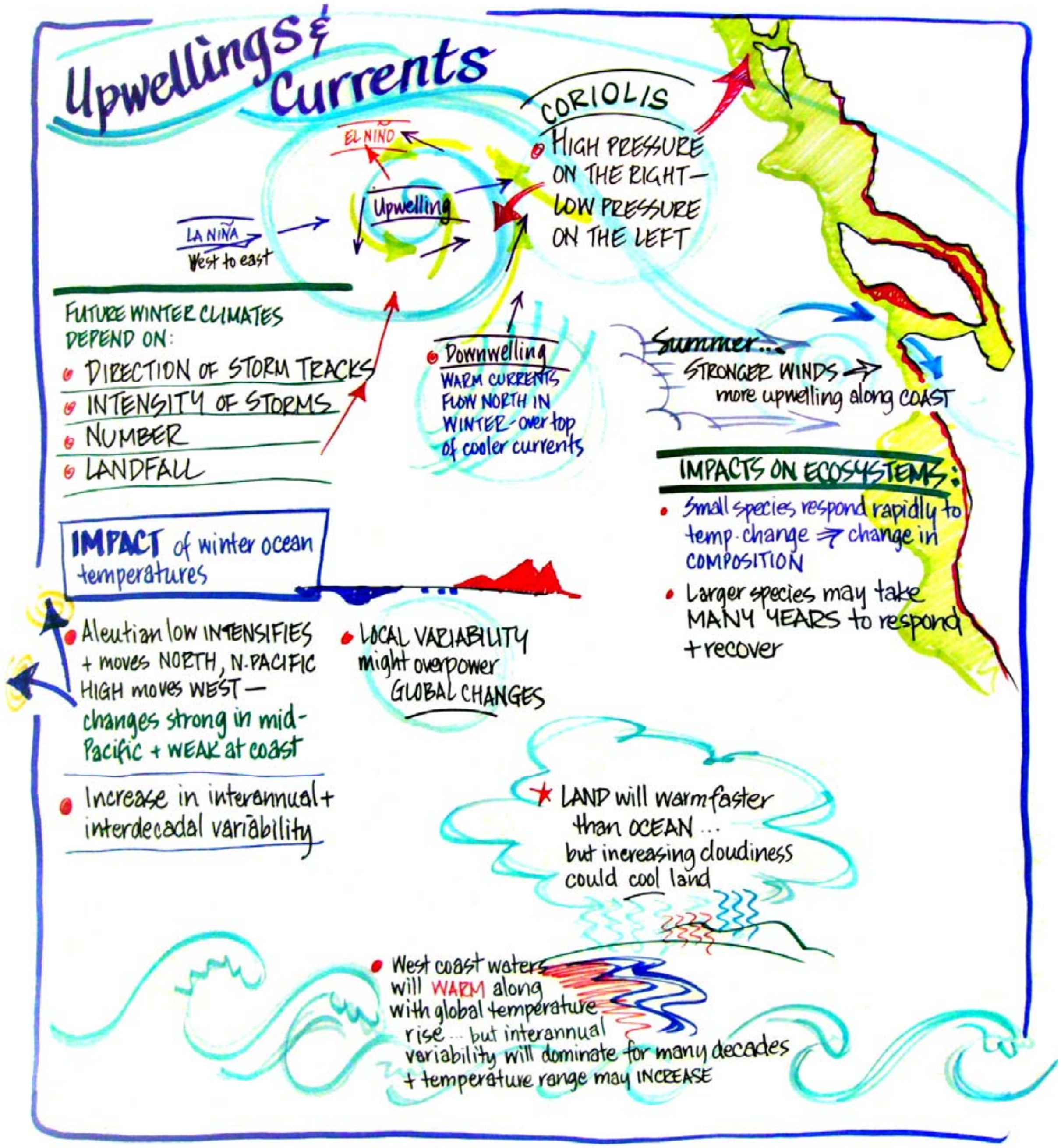
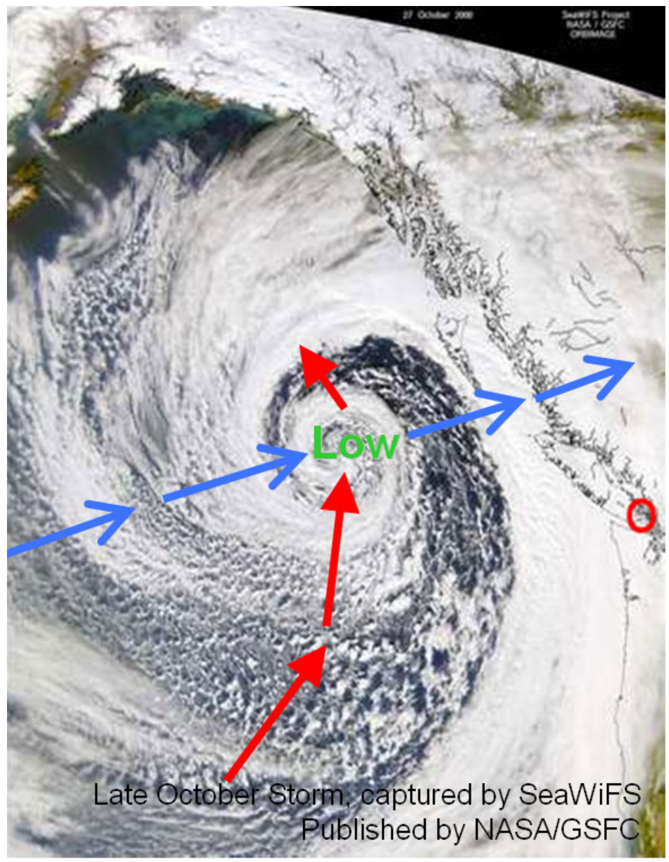


Upwellings & Currents
CORIOLIS
HIGH PRESSURE ON THE RIGHT— LOW PRESSURE ON THE LEFT
EL NIÑO
Upwelling
LA NIÑA
West to east
FUTURE WINTER CLIMATES DEPEND ON:
DIRECTION OF STORM TRACKS
INTENSITY OF STORMS
NUMBER
LANDFALL
Downwelling
WARM CURRENTS FLOW NORTH IN WINTER - over top of cooler currents
Summer...
STRONGER WINDS
more upwelling along COAST
IMPACTS ON ECOSYSTEMS:
Small species respond rapidly to temp. change ⇒ change in COMPOSITION
Larger species may take MANY YEARS to respond + recover
IMPACT of winter ocean temperatures
Aleutian low INTENSIFIES + moves NORTH, N. PACIFIC HIGH moves WEST — changes strong in mid-Pacific + WEAK at coast
LOCAL VARIABILITY might overpower GLOBAL CHANGES
Increase in interannual + interdecadal variability
LAND will warm faster than OCEAN ... but increasing cloudiness could cool land
West coast waters will WARM along with global temperature rise ... but interannual variability will dominate for many decades + temperature range may INCREASE

Presentation 1 - Bill Crawford, Ph.D., oceanographer
Climate Change Impacts on Upwelling and Currents in the Pacific North West

The winds of summer and winter along the British Columbia coast determine most of the features of our marine life. Winter winds blowing from the south bring warm air and ocean currents, and winds from the north in summer provide oceanic nutrients for marine growth. B.C. lies at a latitude where changes in storm tracks from one winter to the next can change ocean temperatures by several degrees. Low marine growth rates in a spring and summer of weak northerly winds can kill off many juvenile fish and seabirds. The next few pages illustrate these features, and show how climate change might affect the coast.

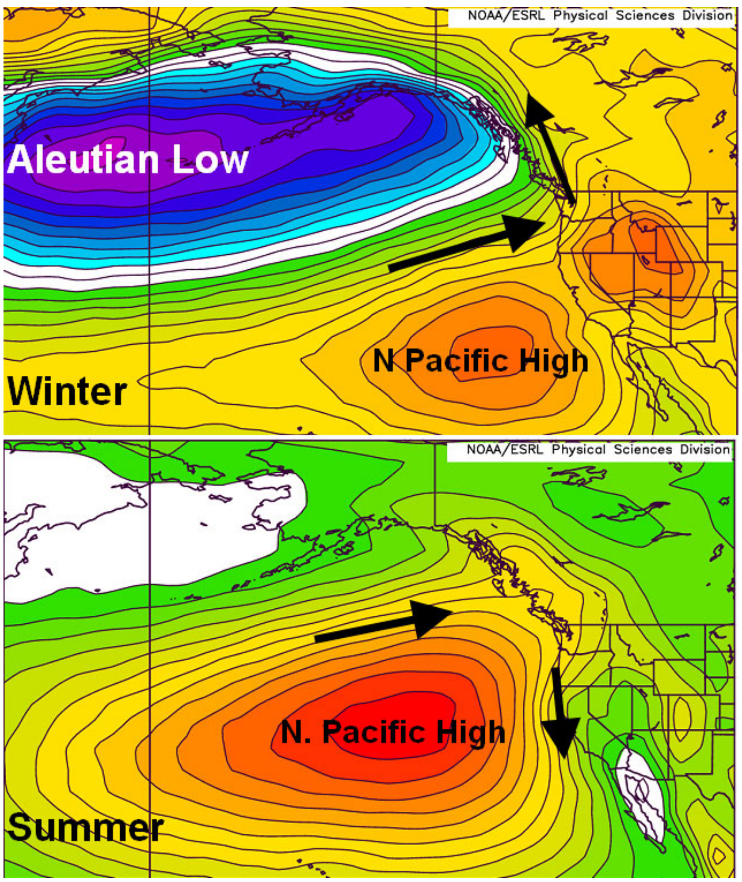


The image shows clouds of an autumn storm passing over the ocean west of B.C. (The red circle encloses Victoria and Vancouver.) These storms blow from mid autumn to the end of winter and determine the weather along the coast. Winds blow clockwise around the centre of the storm (marked "Low") in the image.

Winter weather is determined by whether these storms hit land. In addition, if they do pass over B.C. the point of landfall can determine the amount and degree of wind and rain.

During El Niño, winter storms are more likely to follow the path of the red arrows, with warm winds from the south warming the coast. In La Niña winters these storms often follow the blue arrows, bring cooler air. These La Niña storms are more likely to pass right over land, with stronger winds.

Annual-average ocean temperatures in B.C. have cycled back and forth by one to two degrees over the past decade, due to alternating El Niño and La Niña winters and shifts in North Pacific winds, and we can expect these cycles of temperature to continue in the future. In addition, we will see a rise in ocean temperatures with global warming. A recent study by James Overland and Muyin Wang (2007) suggests that by mid 21st Century, global ocean warming off our coast will exceed the one to two degree cycles of temperature that we have seen over past decades.



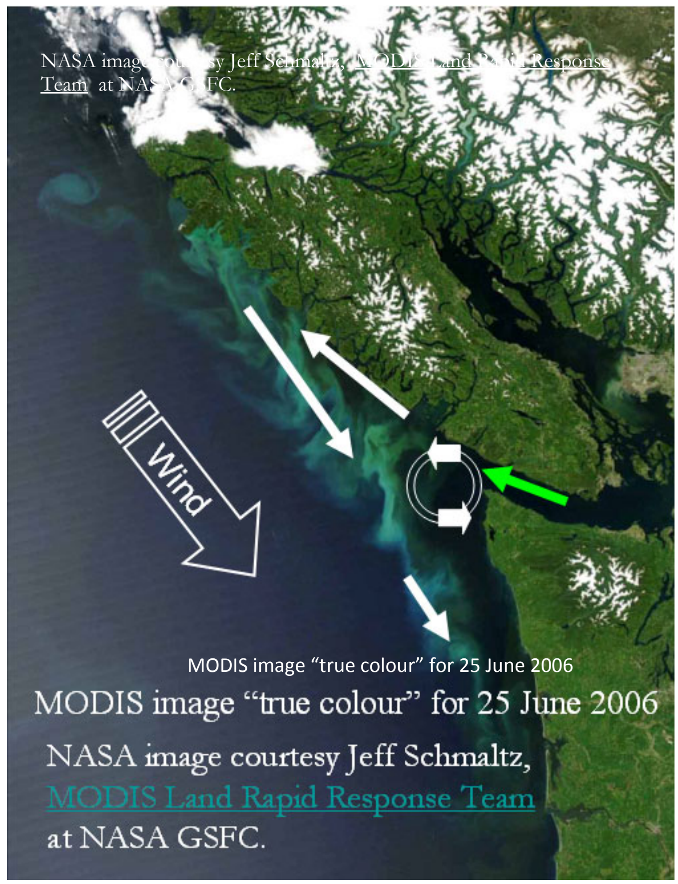
The maps at left show average winter and summer pressures. They were prepared from a web site of the U.S. National Oceanic and Atmospheric Administration.

Black arrows show typical winds of these seasons, blowing along lines of constant air pressure. (Due to the Earth's rotation, winds blow along these lines, with low pressure on their left.) The air pressure systems are called Aleutian Low and North Pacific High. B.C. is in a region where a small movement these systems will change the speed and direction of winds.

Global climate models of the Intergovernmental Panel on Climate Change (IPCC) indicate that air pressures of the Aleutian Low in **winter** will become lower through this century, so winter storms might be more intense and the ocean temperature changes from El Niño to La Niña years might increase.

These same IPCC models indicate that winds of future **summers** will blow with increasing strength from the north along the B.C. coast, perhaps due to more summer warming over land than over the nearby Pacific Ocean. With stronger winds from the north, we can expect more upwelling of nutrients in colder waters along the coast, and our coastal waters might warm more slowly than the global average. However, year-to-year variations will be big.

The image at right was captured by the American MODIS satellite. It shows the coast of Vancouver Island in green and white, the Pacific Ocean in blue, and a few white clouds over northern Vancouver Island. The green-blue in the ocean is a long patch of billions of tiny, free-floating oceanic plants called coccolithophores, one of many that provide food to other marine life. These plants are a normal feature of late spring and summer, although this particular patch was especially large.



Near the coast, winds from the northeast push coastal surface waters offshore (due to Earth’s rotation and Coriolis force), with deep nutrient-rich waters upwelling to take their place. Additional nutrients flow out of Juan de Fuca Strait and swirl around Juan de Fuca Eddy. This eddy and the wide continental shelf prevent coccolithophores and other tiny floating marine life from flowing out to the deep sea. These oceanic features create the richest marine life of any region of the west coast of the US and Canada.

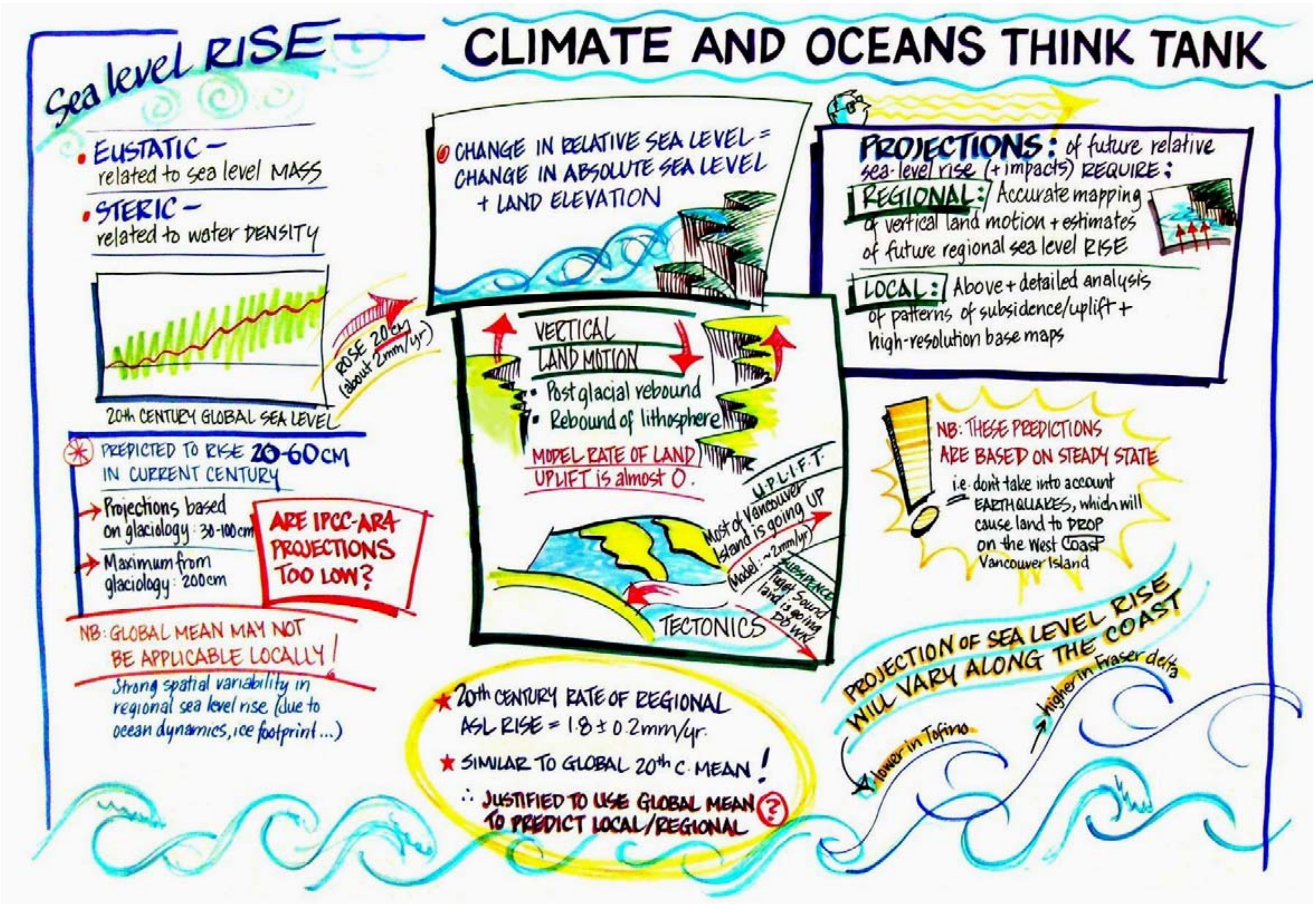
With climate change, we might see stronger summer winds, with more nutrient input, but also more export of marine life into Washington State.

When ocean temperatures cycled through a degree or so over the past decades, we saw a shift from northern to southern species of zooplankton (these are the smallest animals in the ocean and serve as prey for fish). Scientists suspect that southern species of zooplankton have fewer rich oils needed by our native fish, so warmer ocean temperatures due to global warming might reduce this food supply. Warmer temperature might also bring more southern marine predators such as Humboldt squid to feed on native fish.

Winds blowing from the north also upwell deep, oxygen-poor waters onto the bottom of the continental shelf. With increasing summer wind speeds, we could see these already-low oxygen levels drop even more. Oregon waters have already seen lowest-ever levels early in this century.

Conclusions:

1. Climate change will increase ocean temperatures, and likely increase the interannual variability of winds that modify these temperatures. Rather than a steady rise in ocean temperature, we can expect alternating years of warm and cool, with a slow background warming.
2. Much of this interannual variability in winds is due to changes in winter storm tracks and storm intensity, predicted for climate warming.
3. Summer winds from the north are essential for coastal upwelling. We might expect stronger winds in summer in a future climate.
4. Upwelling brings deep-ocean nutrients to the surface, stimulating oceanic plant growth that feeds many marine species.
5. Our native fish might see their preferred prey decline, as warmer waters bring more southern species of zooplankton to our coast.



Sea level RISE
CLIMATE AND OCEANS THINK TANK
EUSTATIC – related to sea level MASS
STERIC – related to water DENSITY
20th CENTURY GLOBAL SEA LEVEL
ROSE 20cm (about 2mm/yr)
PREDICTED TO RISE 20-60CM IN CURRENT CENTURY
Projections based on glaciology: 30-100cm
Maximum from glaciology: 200cm
ARE IPCC-AR4 PROJECTIONS TOO LOW?
NB: GLOBAL MEAN MAY NOT BE APPLICABLE LOCALLY!
Strong spatial variability in regional sea level rise (due to ocean dynamics, ice footprint...)
CHANGE IN RELATIVE SEA LEVEL = CHANGE IN ABSOLUTE SEA LEVEL + LAND ELEVATION
VERTICAL LAND MOTION
Post glacial rebound
Rebound of lithosphere
MODEL RATE OF LAND UPLIFT is almost 0.
U.P.L.I.F.T.
Most of Vancouver Island is going UP
Model: ~2mm/yr
SUBSIDENCE
Puget Sound land is going DOWN
TECTONICS
PROJECTIONS: of future relative sea-level rise (+ impacts) REQUIRE:
REGIONAL: Accurate mapping of vertical land motion + estimates of future regional sea level RISE
LOCAL: Above + detailed analysis of patterns of subsidence/uplift + high-resolution base maps
NB: THESE PREDICTIONS ARE BASED ON STEADY STATE
i.e. don't take into account EARTHQUAKES, which will cause land to DROP on the West Coast Vancouver Island
PROJECTION OF SEA LEVEL RISE WILL VARY ALONG THE COAST
lower in Tofino
higher in Fraser delta
20th CENTURY RATE OF REGIONAL ASL RISE = 1.8 ± 0.2mm/yr.
SIMILAR TO GLOBAL 20th C. MEAN!
∴ JUSTIFIED TO USE GLOBAL MEAN TO PREDICT LOCAL/REGIONAL ?

Presentation 2 - Dr. Stephane Mazzotti, Research Scientist, Natural Resources Canada

Sea Level Records and Projections for the B.C. Coast

Predictions of global average sea level rise due to thermal expansion and glacial and ice cap melt are about 50 to 150 cm over the next 100 years; with a possible extreme maximum of 200 cm. Over the 20th Century the global mean sea level rose 20 cm, or 2 mm per year. Since 1991 the trend has been about 3 mm per year. This is a possible indication of acceleration.

A challenge in making predictions is that different studies have varying projections. For example, there are concerns that IPCC projections may be too low. From 1993 to 2006, model projections have been lower than actual amounts shown through tracking over the same period.

Sea level rise can be defined in different ways:

- *Eustatic* sea level is the mean elevation of global ocean surface due to water mass;
- *Steric* sea level is the mean elevation of global ocean surface due to water density (temperature and salinity);
- *Absolute* sea level is the global ocean surface relative to the Earth's centre of mass, and;
- *Relative* sea level is the mean elevation of ocean surface relative to land.

Note: Relative sea level is what matters most for impact planning and mitigation as it represents local changes of sea level with respect to local vertical land motion.

Projections for the West Coast of Canada are different from those of other geographical areas such as the East Coast of Canada, due to variability in regional relative sea level rise. This is caused by a number of factors such as land movement and regional oceanic processes. Over the 20th Century, the absolute sea level rise on the West Coast was 1.8 mm to 2 mm per year, similar to the global mean.

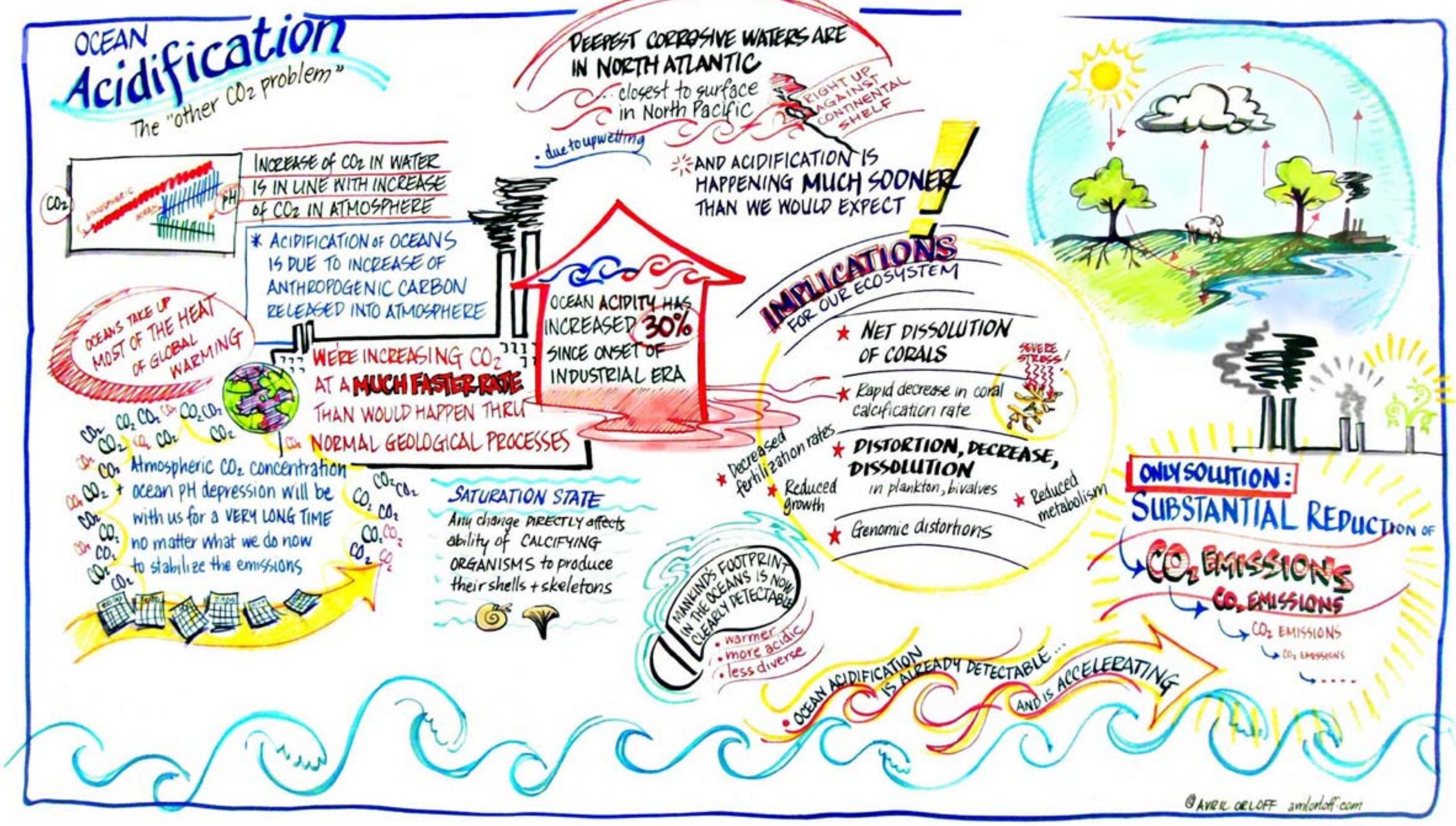
In the Pacific Northwest, land motion has a large impact on relative sea level rise due to the (oceanic) Juan de Fuca plate moving under the (continental) North American plate. The tectonic uplift varies between 0 and 2 mm per year and can offset the rise in sea level (depending on specific locations). For example, in Tofino, measurements for the 20th century showed about a 1 mm per year relative drop in sea-level. This is because the land rise was 2 to

3 mm per year in this particular spot. In contrast to the West Coast is the Fraser River Delta, where the land is actually dropping 2 to 10 mm per year, resulting in a 50 to 100 percent increase in relative sea level rise over the next century. It is important to note that currently the connection between the oceanic plate and the continental plate is locked. This is why the land motion is upward and not downward. Should it release, a massive earthquake would change all predictions.

On the coast of B.C. the relative sea level rise is expected to be 75 cm in Tofino, 100 cm in Vancouver, and 150 cm in the Fraser Delta over the next 100 years. What is needed for best preparation is accurate mapping on vertical land motion on a regional and local scale and detailed analysis of local patterns of uplift.

Conclusions:

1. Sea level in B.C. rose at a rate of about 2 mm/year during the 20th Century.
2. On the west coast of Vancouver Island, the land is rising at a rate of 2 mm/year due to plate tectonics, and has kept sea level rise neutral. This will not be the case into the next century as the sea level is rising more quickly than it did in the past century.
3. Projections of relative sea-level rise vary between about 75 and 150 cm in western B.C., depending on local land motion.
4. In one notable area, the Fraser Valley, the elevation is dropping thus increasing relative sea-level rise.
5. A very large earthquake could change this and result in large relative sea level rise, especially on western Vancouver Island.


OCEAN Acidification
The "other CO_2 problem"
INCREASE OF CO_2 IN WATER IS IN LINE WITH INCREASE OF CO_2 IN ATMOSPHERE
* ACIDIFICATION OF OCEANS IS DUE TO INCREASE OF ANTHROPOGENIC CARBON RELEASED INTO ATMOSPHERE
OCEANS TAKE UP MOST OF THE HEAT OF GLOBAL WARMING
WE'RE INCREASING CO_2 AT A MUCH FASTER RATE THAN WOULD HAPPEN THRU NORMAL GEOLOGICAL PROCESSES
OCEAN ACIDITY HAS INCREASED 30% SINCE ONSET OF INDUSTRIAL ERA
DEEPEST CORROSIVE WATERS ARE IN NORTH ATLANTIC
closest to surface in North Pacific
due to upwelling
RIGHT UP AGAINST CONTINENTAL SHELF
AND ACIDIFICATION IS HAPPENING MUCH SOONER THAN WE WOULD EXPECT
IMPLICATIONS FOR OUR ECOSYSTEM
NET DISSOLUTION OF CORALS
SEVERE STRESS!
Rapid decrease in coral calcification rate
Decreased fertilization rates
DISTORTION, DECREASE, DISSOLUTION in plankton, bivalves
Reduced growth
Reduced metabolism
Genomic distortions
Atmospheric CO_2 concentration + ocean PH depression will be with us for a VERY LONG TIME no matter what we do now to stabilize the emissions
SATURATION STATE
Any change DIRECTLY affects ability of CALCIFYING ORGANISMS to produce their shells + skeletons
MANKIND'S FOOTPRINT IN THE OCEANS IS NOW CLEARLY DETECTABLE
warmer
more acidic
less diverse
OCEAN ACIDIFICATION IS ALREADY DETECTABLE ... AND IS ACCELERATING
ONLY SOLUTION:
SUBSTANTIAL REDUCTION OF CO_2 EMISSIONS
CO_2 EMISSIONS
CO_2 EMISSIONS
©AVRIL ORLOFF

Presentation 3 - Dr. Richard A. Feely

Ocean Acidification – The Other CO_2 Problem

"Corrosive waters are getting on to the continental shelf and are affecting our ecosystems right now."

What is Ocean Acidification?

Under normal conditions, oceans absorb huge amounts of CO_2. Since the start of the Industrial Revolution however, the oceans have absorbed more than 550 billion tonnes of carbon dioxide from the atmosphere. This is due to the increasing atmospheric concentrations of CO_2 associated with industrial activity. When the anthropogenic CO_2 is absorbed by seawater, chemical changes occur that increase the carbonic acid (H_2CO_3) concentration, reduce seawater pH and carbonate ion (CO_3^{2-}), and reduce the saturation states of the biominerals calcite (Ω_{cal}) and aragonite (Ω_{arag}) in a process commonly referred to as "ocean acidification." Since the beginning of the industrial era, the pH of open-ocean surface waters has decreased by about 0.1 pH units, equivalent to an overall increase in the hydrogen ion concentration or "acidity" of about 30 percent. By the end of this century, surface ocean pH is expected to decline by another 0.3–0.4 pH units.

Ocean acidification is believed to threaten many marine organisms. An immediate concern is that it will make shell formation and maintenance very difficult for organisms that produce calcium carbonate skeletons or shells. Many important marine invertebrates, including corals and molluscs, have calcium carbonate shells. These shells do not dissolve in surface ocean waters because those waters are supersaturated with respect to calcium carbonate. However, carbonic acid—which is created when excess CO_2 dissolves in seawater—combines with carbonate in a chemical reaction. For this reason, carbonic acid reduces carbonate concentrations, and if surface seawater becomes under-saturated with respect to carbonate minerals, the seawater will literally begin to dissolve calcium carbonate shells. Even if marine organisms with calcium carbonate shells are not fully dissolved by under-saturated seawater, they will at least have to spend more energy producing and maintaining their shells which may have devastating effects on their survival. Since many organisms with calcium carbonate shells are critical to marine ecosystems (they often form the base of entire marine food webs) ocean acidification is a threat to many marine ecosystems.

Effects of Ocean Acidification

The work of the IPCC has revealed that over the last 200 years, 160 billion metric tonnes of carbon has been released into the atmosphere from land use and an additional 348 billion metric tonnes from fossil fuel consumption. Twenty-five percent of the total carbon release has been taken up by the oceans, or 127 billion metric tonnes. It was thought during that period, that the uptake of carbon by the ocean was largely a positive process since it decreases atmospheric carbon and reduces global warming. We are now seeing the consequences of that process play out in the oceans for species and for human use.

Since the industrial age there has been about a 0.1 decrease in pH in the surface oceans, which translates into about a 30 percent increase in acidity over the pre-industrial value. By the end of this century, surface ocean pH is expected to decline by another 0.3–0.4 pH units.

Very little is known about the effects of acidification on ecosystems. Lab experiments examining impacts of various levels of CO_2 on species found a dramatic effect on calcification for coral and shell species. For coral, when the CO_2 level reaches a level of 560 to 840 ppm, a net dissolution occurs rather than calcification. Drilling into coral like tree rings in a study of 328 samples of Porites corals from 69 sites along the Great Barrier Reef, scientists have found a rapid decrease of calcification by 14 percent since the 1990s.

Other laboratory experiments studying the effects of acidification on coccolithophores (marine phytoplankton) resulted in a 9 to 45 percent decrease in calcification. Foraminifera can have a 4 to 14 percent decline in calcification. When placed into corrosive under-saturated waters, pteropod shells begin to dissolve while the animal is still alive. Clams, mussels and oysters are all subject to decreased calcification as well. For clams, the juvenile species undergo dissolution within 24 hours and are most vulnerable to mortality within two weeks.

Lab studies on sea urchins show a decrease in the genomic response and the metabolic component of the development of calcification ability. This means that over time the species may lose its ability to calcify.

Efforts are being made to map out surface waters to create a model for the future. It can already be seen that some regions of the Arctic Ocean become under saturated for shell formation by 2030, and portions the North Pacific by 2090. The Arctic Ocean will become acidified faster because of the lower seawater temperatures and more freshwater ice melt which is low in carbonate ions.

Ecosystem changes are now dramatic, having an effect on a number of species, most are negative (calcification and reproduction), some are positive (such as for photosynthesis). Some species are facing no impact, and others fluctuate over time and changing circumstances. The food chain is a very important consideration. For example, when we look at juvenile salmon, 60 percent of their diet is pteropods; if pteropods disappear the salmon might follow. Salmon make an immense contribution to the food chain, and so on.

New research is showing that most of the anthropogenic CO_2 is in the upper part of the water column where the corrosive acidic water comes onto the continental shelf through the upwelling process and is affecting organisms (Feely et al., 2008). Corrosive water is moving closer to the surface as we add anthropogenic CO_2 from the top. In the north eastern Pacific the corrosive water is closest to the surface (100 to 200 meters) and if no mitigation occurs, carbonate ions will be reduced to 50 percent of pre-industrial concentrations by the end of the century.

Thus far, the laboratory experiments have been simple with abrupt pH changes over short times. We still need to consider the slower changes and possible adaptations. There are still many things we do not know; genetic responses, effects on other stress factors, ecosystem responses and how the changes in the ocean will impact the climate change process through its dynamic relationship with the atmosphere.

CO_2 emissions need to be reduced by about 80 percent over the next 50 years to make an impact. Even if the atmospheric CO_2 levels are stabilized, it will take many thousands of years for the surface ocean CO_2 levels to get back to the pre-industrial levels.

Conclusions:

1. Since the beginning of the industrial age surface ocean pH and carbonate ion concentrations have been decreasing (by ~0.1 and ~16% respectively) because of the uptake of anthropogenic CO_2 by the oceans, i.e., ocean acidification.

2. By the end of this century pH could have a further decrease by as much as 0.3-0.4 pH units.

3. Ocean acidification affects the development of calcium carbonate shells and skeletons in plants and animals, such as coccolithophorids, foraminifera, molluscs, and corals and has the potential to affect the

entire food web. More research on impacts and vulnerabilities is needed.

4. CO_2 emissions need to be reduced by 80 percent over the next 50 years in order to curtail this problem.

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson, and B. Hales (2008): Evidence for upwelling of corrosive "acidified" water onto the Continental Shelf. *Science*, *320*(5882), doi: 10.1126/science.1155676, 1490–1492.


Freshwater RUNOFF
Reflected energy
OUTGOING ENERGY
INCOMING ENERGY
Energy trapped by greenhouse gases
2020-29 Land + high latitudes will rise FASTEST
THE CHOICES WE MAKE NOW WILL MATTER!
WARMER springs + falls
PERIODS THAT ARE WET WILL GET WETTER
DRY PLACES WILL GET DRIER
HYDROLOGIC CHANGE
GLACIERS ARE RETREATING
Snow cover is disappearing in North America
If climate changes, what might we see in BC?
If we're looking for a needle in a haystack, we'd better recognize the needle!
STATISTICAL PROOF THAT SNOW MELT IS STARTING E·A·R·L·I·E·R
Comparison of seasonal data between PERIODS between PLACES
COMPARING 1976-85 TO 1986-95 1996-2005
BARKERVILLE: 1976-2005
Temperatures haven't changed significantly
Earlier snow melt
Significant changes in PRECIPITATION
We are seeing these same patterns across northern BC
COMOX: 1976-2005
Significant increases in rainfall in WINTER
1976-2005 SOUTH THOMPSON:
Climate changes are mitigated by effects of PINE BEETLE
CHANGES IN PATTERNS ⇒ CHANGES IN CHEMISTRY OF THE WATER
CHANGES in CLIMATE ⇒ CHANGES in FRESHWATER INPUT

Presentation 4 - Paul Whitfield

Changing Freshwater Run-off: a Global Issue at Local Scales

"The choices we make now will matter."

Global mean temperatures are increasing, average sea level is increasing and snow cover is decreasing in the Northern Hemisphere. According to the IPCC, 11 of the last 12 years have been ranked among the warmest years in the instrumental record of global surface temperature (1995-2006).

Variations in climate have been having hydrologic consequences, as a portion of incoming solar energy is reflected and trapped in the atmosphere, creating greenhouse gasses. For the ocean, the main considerations are ice-melt and its contribution to the rising sea level and acidification through freshwater input.

The Western Canada Cryosphere Network conducted an ice study that demonstrated that the lengths of glacier tongues are decreasing and glaciers are retreating. The tongue of the Toboggan Glacier in Alaska was measured in 1909 and then in 2000. It showed significant retreat of about six km in distance. In the Northern Hemisphere, there are now three million square km that do not have snow on them in March and April where they did in previous years (measurements beginning in 1920).

Although the entire globe is warming, different parts are behaving differently. Land is going to warm more than water, and most quickly at high latitudes. Some continents will warm at different rates. Overall, if anthropogenic CO_2 ceased to be produced there would still be another degree of temperature rise over the next 100 years. The Arctic will be warming twice as fast as other areas because of the high latitudes.

There are some uncertainties in IPCC research; globally we have high confidence in the overall results; locally, it gets very complicated because at this scale there are many factors (such as changes to land use) that contribute to changes in hydrology. For example, stream flow measurements in a provincial park show statistically significant earlier snowmelt. This tendency towards earlier snowmelt results in lower fall stream-flow than prior years. Some originally thought that this variation was a product land-use change but this example demonstrates variation in a park where there has been no forestry, in fact no change has occurred except for climate variations.

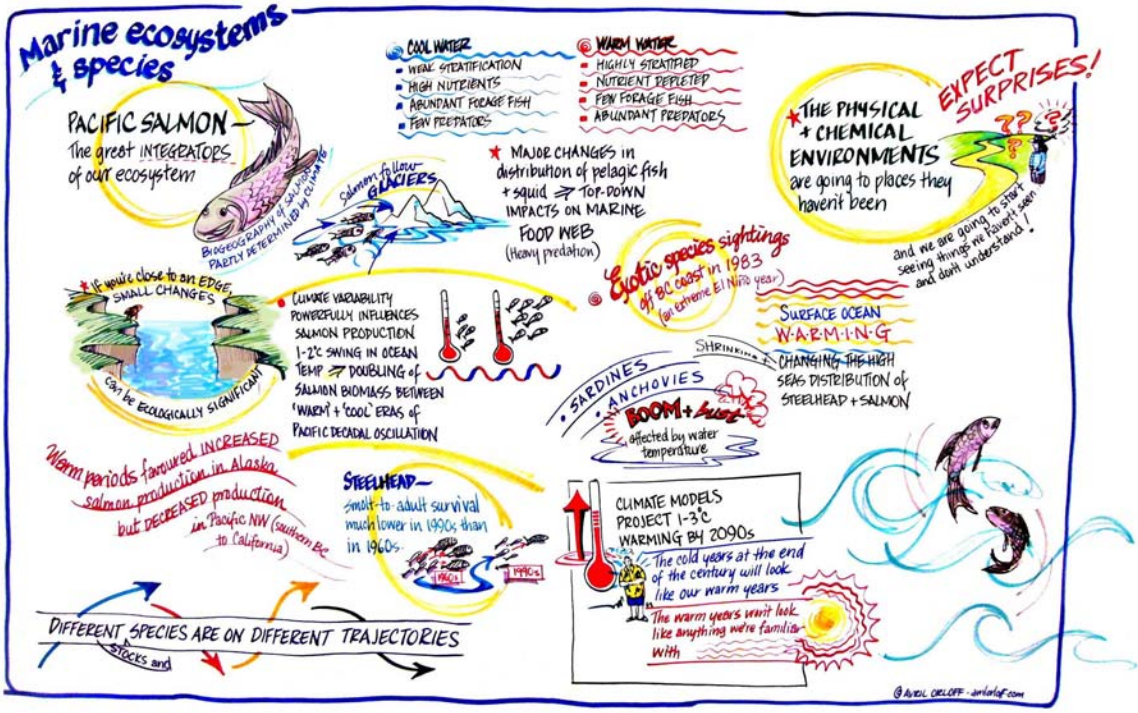
Using sub-monthly stream-flow series to compare the seasonal cycles, it can be observed that in B.C. we may see changes such as earlier spring melt and lower flow in the summer and through the fall. Spring and fall warming trends are most evident. Precipitation as rain can be expected to be much higher in the fall as it shifts to warmer conditions. The spatial distribution of observation locations has a large influence on local variations within the province.

The mountain pine beetle has had a drastic effect on the pine forests. In the interior parts of the province, the pine beetle effect on hydrology is as large as direct climate change impacts. Flows are increasing during summer months because bare landscapes are delaying snowmelts. When there is no forest the snow does not lose water through transpiration to the forest. The climate is pushing melts one way (quicker melt) and the pine beetle pushes it back in the other (delayed melt). The pine beetle is somewhat neutralizing the climate effect on hydrology in that region at least in the short term.

Conclusions:

1. On Vancouver Island and the South Coast, significant increases in flow are expected in the fall, winter and spring, but not in the summer. Rain is significantly increasing in the winter, on a day by day basis. There are increases in stream-flow in winter and decreases in summer flow (much longer dry period).

2. Coastal areas are particularly important to the ocean because when the hydrology changes in the coastal zone there is higher runoff, which changes the level and timing of freshwater input into the ocean.


Marine ecosystems & species
PACIFIC SALMON — The great INTEGRATORS of our ecosystem
BIOGEOGRAPHY of SALMON PARTLY DETERMINED by CLIMATE
COOL WATER
WEAK STRATIFICATION
HIGH NUTRIENTS
ABUNDANT FORAGE FISH
FEW PREDATORS
WARM WATER
HIGHLY STRATIFIED
NUTRIENT DEPLETED
FEW FORAGE FISH
ABUNDANT PREDATORS
Salmon follow GLACIERS
MAJOR CHANGES in distribution of pelagic fish + squid ⇒ TOP-DOWN IMPACTS ON MARINE FOOD WEB (Heavy predation)
THE PHYSICAL + CHEMICAL ENVIRONMENTS are going to places they haven't been
EXPECT SURPRISES!
and we are going to start seeing things we haven't seen and don't understand!
If you're close to an EDGE, SMALL CHANGES can be ECOLOGICALLY SIGNIFICANT
CLIMATE VARIABILITY POWERFULLY INFLUENCES SALMON PRODUCTION 1-2°C SWING IN OCEAN TEMP ⇒ DOUBLING of SALMON BIOMASS BETWEEN 'WARM' + 'COOL' ERAS of PACIFIC DECADAL OSCILLATION
Exotic species sightings off BC coast in 1983 (an extreme El Niño year)
SURFACE OCEAN W·A·R·M·I·N·G
SHRINKING + CHANGING THE HIGH SEAS DISTRIBUTION of STEELHEAD + SALMON
SARDINES
ANCHOVIES
BOOM + bust
affected by water temperature
Warm periods favoured INCREASED salmon production in Alaska but DECREASED production in Pacific NW (southern BC to California)
STEELHEAD — smolt-to-adult survival much lower in 1990s than in 1960s.
1960s
1990s
CLIMATE MODELS PROJECT 1-3°C WARMING BY 2090s
The cold years at the end of the century will look like our warm years
The warm years won't look like anything we're familiar with
DIFFERENT SPECIES ARE ON DIFFERENT TRAJECTORIES
STOCKS and
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Presentation 5 - Dr. Nathan Mantua

Climate Change Impacts on Marine Ecosystems

More and more discussion is beginning to happen with decision makers about climate change and its anticipated impacts. Under a conservative greenhouse gas emissions scenario (conservative being a middle of the road scenario where there is a plausible reduction in emissions), climate models project an additional atmospheric warming of 1 to 6 °C by 2090. For perspective, note that year-to-year fluctuations are only about 2 °C. Cold years at the end of the century will be like the hottest years now, and the hot years will be like nothing we have ever experienced.

For species of the ocean there are changes at the base of the food web as well as at multiple levels throughout. For the coastal waters from Vancouver Island south, periods having relatively cool surface water results in weak stratification (different levels of density layered in the ocean) and high nutrients making a productive sub-arctic food web with abundant forage fish and few warm water predators. In the same region, periods with relatively warm surface water results in a more stratified ocean, fewer nutrients, and lower productivity in a subtropical food web. This produces an environment with a lack of forage fish and abundant predators.

About half of this presentation focuses on Pacific salmon. The modern salmon species have lived in the Pacific for millions of years, through tremendous geological and climate changes. The evolutionary history of salmon has been forged, in part, by dramatic glacial/interglacial climate cycles. They are excellent colonists and opportunists, and show remarkable resilience to dramatic environmental changes.

The good news is that the salmon populations in B.C. are more stable than those in some other areas because B.C. lies in the heart of the distribution for Pacific salmon. In the recent past, Pacific salmon used to be in streams in southern California and even Baja California. The acceptable geographical range of distribution is largely determined by temperature preference. Salmon are thermally limited, and there are a number of physiological and ecological constraints that limit their habitat to relatively cold waters. Near the southern and interior edges of the distribution range there are likely ecologically significant temperature thresholds where small changes have the potential to eliminate a stock. In the middle of the range where B.C. lies, there is more stability. The glacier streams found in B.C. and Alaska are cold and typically very productive for salmon stocks.

Studying Pacific Decadal Oscillation (PDO) patterns has revealed that there are naturally-occurring warming and cooling trends in the North and South Pacific that reverse every few decades. This trend appears to be the result of ocean-atmosphere interactions similar to (and including) El Niño (warming) and La Niña (cooling) climate patterns.

Climate variability has a powerful influence on salmon production. Just a 1 to 2 °C swing in ocean temperatures has been associated with a doubling of total Pacific salmon biomass between warm and cool eras of the PDO.

North Pacific climate patterns parallel the history of salmon production with higher productivity in warm periods. In Alaska, marine productivity (total abundance) was much lower in the middle of the 20th Century during cool periods. High productivity can be seen in the 1930s and 1940s and then in the last couple decades during warm periods. This was only observed in Alaska and the opposite scenario has been observed for coho and chinook in B.C. and south, with decreasing populations during warm periods. Marine survival rates for southern stocks during low productivity years have plummeted.

One reason for this increase in salmon productivity during warm years in Alaska may be that salmon feed on phytoplankton, and phytoplankton feed on nutrients that move up from the depths of the ocean where they are abundant. In order for that to happen the nutrients need to make it to the surface where phytoplankton resides, and the phytoplankton need to remain in the light-rich surface layers in order to utilize the abundant nutrients.

If the ocean is too stratified in coastal waters from Vancouver Island south, nutrients cannot make it to the light-rich surface waters, and a lack of nutrients limits productivity for phytoplankton. In Alaska, as water temperatures rise and stratification increases, phytoplankton are forced close to the surface where there is sunlight, which is a good thing for feeding salmon. In southern areas, phytoplankton are unable to get the nutrient levels they need and have reduced productivity.

Data on steelhead show catch rates that peak at certain surface temperatures in the ocean (this is also true for sockeye, chum and pink). There are relatively narrow bands of surface temperatures where they are found. It appears that fish populations coincide with areas on the gradient where productivity is high. Most salmon species (all but chinook) are surface oriented at sea; some scientists have hypothesized that they are metabolically constrained by surface temperatures, and ocean surface warming will force salmon (sockeye, chum, pink, coho and steelhead) out of the Pacific and into cooler northern oceans (the Bering and Chuckchi Seas, and perhaps the Arctic Ocean).

From a human perspective, the current problem is not a lack of salmon in the Pacific, but that they are not where humans want them to be for our use. This is particularly the case from southern B.C. south into California. Modelling that looks at 2 x CO_2 (doubled from pre-industrial age) scenarios, show that salmon would be moving into the Bearing Sea and the Arctic in the future. This is bad news for Pacific salmon because the geography of their range will shrink as they are squeezed northward, possibly making them more vulnerable to ecosystem changes.

Another southern B.C. collection of species that will have difficulty with productivity in warm years are seabirds. Seabirds in the California Current System (that part of the coastal ocean from Vancouver Island south to Baja California) typically do well in the sub-arctic food web with prey and nutrients closer to the surface. Declines in seabird productivity have been well documented in many past warm years, and can be expected in warm years of the future.

Pacific sardine populations crashed in the 1940s, then recovered in the 1980s and 1990s. Observations showed that in warm years the spawning region expands greatly and shifts north. Development of sardine larvae is favoured between 14 and 16 °C and they were very temperature dependent. Interestingly, the abundance of anchovies and sardines in the California Current System have typically fluctuated in opposite directions with one taking over from the other; as one increases the other decreases along with temperature fluctuations.

Predicting climate impacts on species can be complicated by changes in distribution as warm water species move north with the warming water.

Typically warm water exotic species cause changes to the food web when they arrive and begin competing for resources. There were sightings of exotic species off of the B.C. coast during 1983, an extreme El Niño year. Pacific pomfret, ocean sunfish, chub mackerel, Pacific bonito and brown pelicans have been spotted in northern waters. B.C. is at the edge of faunal boundaries for fish like the Pacific hake which is at the northern edge of its boundary on Vancouver Island. Humboldt squid have been spotted off the coast of Oregon and Washington since 1997. They are warm water species moving with the temperature and are a major predator for northern ecosystems.

The rapid changes in the ocean are affecting many species through food-web interactions. There are some changes we can predict and other we cannot. The most difficult aspect to look at is how the various species in an ecosystem interact and what that will look like over time.

Conclusions:

1. Changes in ocean temperatures affect the distribution of marine species, such as the preferred foraging habitat for salmon moving northward, or the northward and inshore expansion of typically subtropical species during past periods of weak upwelling and warm surface temperatures. This will result in changes in how humans manage/harvest these species.

2. Synergistic effects of ocean acidification and upper ocean warming trends will very likely lead to a breakdown in historic patterns, so in this sense we might expect that past climate-ecosystem relationships will increasingly become less useful for predicting future climate change impacts on marine ecosystems.

3. Change in sea temperature could see an increase in southern species moving northwards.

4. Salmon and steelhead are facing rapid rates of environmental change in freshwater, estuarine, and marine habitats and they will need to adapt—reducing existing stresses (like degraded stream and estuary habitat, over-harvest, degradation of coastal ocean habitats and ecologically harmful hatchery practices) is one way to foster adaptability and resilience in salmon and steelhead populations.

5. As the primary drivers of change in salmon ecosystems, our actions will shape their potential for adaptation.

6. Relieving existing stresses is an obvious option for increasing the adaptive capacity for salmon and many other species.

GLOSSARY

PROCEEDINGS

OCEANS AND CLIMATE CHANGE THINK TANK – DAY 1

Listed as appears in proceedings (as opposed to alphabetically)

Intergovernmental Panel on Climate Change (IPCC) – A scientific body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The panel reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide and provides the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. (http://www.ipcc.ch/organization/organization.htm) Nov. 23, 2009.

Coccolithophores – a type of phytoplankton (one-celled marine plants that live in large numbers throughout the upper layers of the ocean). Unlike any other plant in the ocean, coccolithophores surround themselves with microscopic plates made of limestone (calcite). These plates, known as coccoliths, are shaped like hubcaps and are only three one-thousandths of a millimetre in diameter. (http://earthobservatory.nasa.gov/Features/Coccolithophores/) Nov. 23 2009.

Upwelling – An oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water. (http://en.wikipedia.org/wiki/Upwelling) Nov. 23 2009.

Tectonics uplift - A geological process most often caused by plate tectonics which increases elevation. (http://en.wikipedia.org/wiki/Tectonic_uplift) Nov. 23 2009.

Plate tectonics - A theory that describes the large scale motions of Earth's lithosphere. The theory builds on the older concepts of continental drift, developed during the first decades of the 20th century. The lithosphere is broken up into what are called tectonic plates. In the case of Earth, there are currently eight major and many minor plates. These plates move in relation to one another. (http://en.wikipedia.org/wiki/Plate_tectonics) Nov. 23 2009.

Anthropogenic CO_2 - Refers to carbon dioxide that has been produced as a result of human activity.

Carbonic acid (H_2CO_3) – a weak acid. Also a name sometimes given to solutions of carbon dioxide in water, which contain small amounts of H_2CO_3. The salts of carbonic acids are called bicarbonates (or hydrogen carbonates) and carbonates. (http://en.wikipedia.org/wiki/Carbonic_acid) Nov. 23 2009.

pH - A measure of the acidity of a solution. It is defined as the cologarithm of the activity of dissolved hydrogen ions (H+). Hydrogen ion activity coefficients cannot be measured experimentally, so they are based on theoretical calculations. The pH scale is not an absolute scale; it is relative to a set of standard solutions whose pH is established by international agreement. Pure water is said to be neutral. The pH for pure water at 25 °C (77 °F) is close to 7.0. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are said to be basic or alkaline. (http://en.wikipedia.org/wiki/PH) Nov. 23 2009.

Carbonate ion – a salt or ester of carbonic acid, characterized by the presence of the carbonate ion, CO_{2-3} or a carbonate functional group O=C(O-)$_2$. (http://en.wikipedia.org/wiki/Carbonate) Nov. 23 2009.

Biominerals - minerals that often form structural features such as sea shells and bones in mammals and birds. Examples include: silicates in algae and diatoms, carbonates in invertebrates, and calcium phosphates and carbonates in vertebrates. (http://en.wikipedia.org/wiki/Biomineralisation) Nov. 23 2009.

ppm – Parts per million. Two years ago, after leading climatologists observed rapid ice melt in the Arctic and other frightening signs of climate change, they issued a series of studies showing that the planet faced both human and natural disaster if atmospheric concentrations of CO_2 remained above 350 parts per million. (http://www.350.org/) Nov. 23 2009.

Foraminifera – a type of protozoa, mostly marine, with a shell of lime, silica or agglutinated sand grains. Their shells form an important part of chalk, and of many deep-sea oozes. Fossil foraminiferans are usually less than 1 mm across, although some were up to 100 mm in diameter. (http://museumvictoria.com.au/dinosaurs/glossary.html) Nov. 23 2009.

Pteropods – Sea Butterflies or flapping snails, are a taxonomic suborder of small pelagic (open ocean) sea snails. They are planktonic for their entire life cycle. The word pteropod applies both to the sea butterflies in the clade Thecosomata and also to the sea angels in the clade Gymnosomata. The

Thecosomata have a shell, while the Gymnosomata lack a shell. (http://en.wikipedia.org/wiki/Pteropod) Nov. 23 2009.

Genomic response - the reaction of an organism's genome (hereditary material e.g. DNA) to a stressor

Metabolic component – Refers to the development stage (or component) of the organism's metabolism (i.e. the set of chemical reactions that happen in living organisms to maintain life. These processes allow organisms to grow and reproduce, maintain their structures, and respond to their environments. (http://en.wikipedia.org/wiki/Metabolic) Nov. 23 2009.

Hydrologic consequences – impacts to the water cycle.

Stratification – the building up of layers. Stratified is an adjective referring to the arranging of layers. It is also the past form of the verb stratify i.e. to separate or become separated into layers. (http://en.wikipedia.org/wiki/Stratification) Nov. 23 2009.

Forage fish – small fish which are preyed upon by larger predators for food. Predators include other larger fish, seabirds and marine mammals. Typical ocean forage fish feed near the base of the food chain on plankton, often by filter feeding. They include herrings, sardines, and anchovies. (http://en.wikipedia.org/wiki/Forage_fish) Nov. 23 2009.

Pacific Decadal Oscillation (PDO) – a pattern of Pacific climate variability that shifts phases on at least inter-decadal time scale, usually about 20 to 30 years. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N. During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs. (http://en.wikipedia.org/wiki/Pacific_Decadal_Oscillation) Nov. 23 2009.

Metabolically constrained – limited by metabolism.

Faunal boundaries – an ecosystem boundary where species groups are abundantly represented on one side but poorly, if at all, on the other.