GLOBAL CLIMATE CHANGE AND MARINE POLICY: PLANNING FOR IMPACTS, ADAPTATION, AND VULNERABILITY

by

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ABSTRACT

The dominant message of this paper is that marine policy analysts need to enlarge their primary agendas to include the impacts of climate change as a priority issue requiring attention. This message is of considerable importance to South East Asia now and will be for the next two centuries at least. It must be treated in the context of moving towards sustainable use of the oceans and their resources. The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (TAR, 2001) has documented an average rate of global warming over the last century on the order of 0.6 ± 0.2 degrees C (or 1.1 degrees F). This rate of increase has been the largest in the last 1000 years. The IPCC has also identified the natural and anthropogenic earth-based systems that are either most sensitive or most vulnerable to climate change. In order to plan effectively to increase adaptability and reduce vulnerability of these systems, marine and other environmental policy analysts must decrease the space scale of integrated assessments of the likely impacts of climate change from the global level to the level of large ecological regions. The paper concludes with a detailed example of how this kind of analysis has been done for the Pacific Northwest region of the United States and suggests the applicability of the approach to other regions.

Introduction

My paper contains a simple, dominant message which is that marine policy analysts need to enlarge their primary agendas to include the issue of impacts of climate change. This message is of particular importance to South East Asia for the next century or two. In effect, then, proceeding from the title of the Conference, I am arguing that three issues need to be joined. These include sustainability, traditional marine policy, and climate change. We must move in this direction if we are to understand and plan for impacts, adaptation, and vulnerability.

At the SEAPOL (1997) Workshop in Rayong, I summarized at the end of my paper the policies the world community needed to pursue, and the priorities to be attached to these policies, if we are to achieve sustainability. This summary, slightly amended, is reproduced in Fig. 1. The third policy in the Priority 1 category is "Reduce and control emissions of greenhouse gases." Now, however, I think that formulation too narrow. There should have been an addendum to read ". . . and plan for impacts, adaptation, and vulnerability."

The reasoning underlying my current thinking can be stated as follows. No matter what solutions may be eventually arrived at with respect to mitigation, the world is already committed to a certain amount of climate change. This commitment stems from the long atmospheric residence times of several of the greenhouse gases (the range being 12-50,000 years), and particularly of the dominant one, carbon dioxide (CO_2—50-200 years). It also stems from the various timescales on which the atmosphere couples with the ocean operating as both a sink and a source of $C0_2$, i.e. from 4-1000 years.

Once climate change has been set in motion, as it already has (IPCC 1995, 2001), it will generate impacts on natural systems and human social systems. Accordingly, we need to plan for increasing adaptability and decreasing vulnerabilities.

Specifically, IPCC 2001 (WG. 1) has documented the following changes:

a) Global average surface temperature has increased by about 0.6 ± 0.2^{o} C (1.1^{o}F) since 1900. This increase has been the largest in the last 1000 years.

b) About 10% of permafrost and glaciers have melted in the Northern Hemisphere since the late 1960's.

c) Arctic ice has been reduced by 10-15% since the 1950's.

d) Global sea level has been increased on average by 0.1-0.2m in the 20th century.

The rate of warming which has been observed, especially since 1990, is highly unusual over the last 1000 years (Mann et al., 1999). It also cannot be explained as a result of natural factors alone. Both the rate and magnitude of warming are consistent with the basic physics of greenhouse gas exchanges, i.e., a 30% increase since the 1850's with half the increase occurring since 1960. Taken together, these reasons point unambiguously to humans as being responsible.

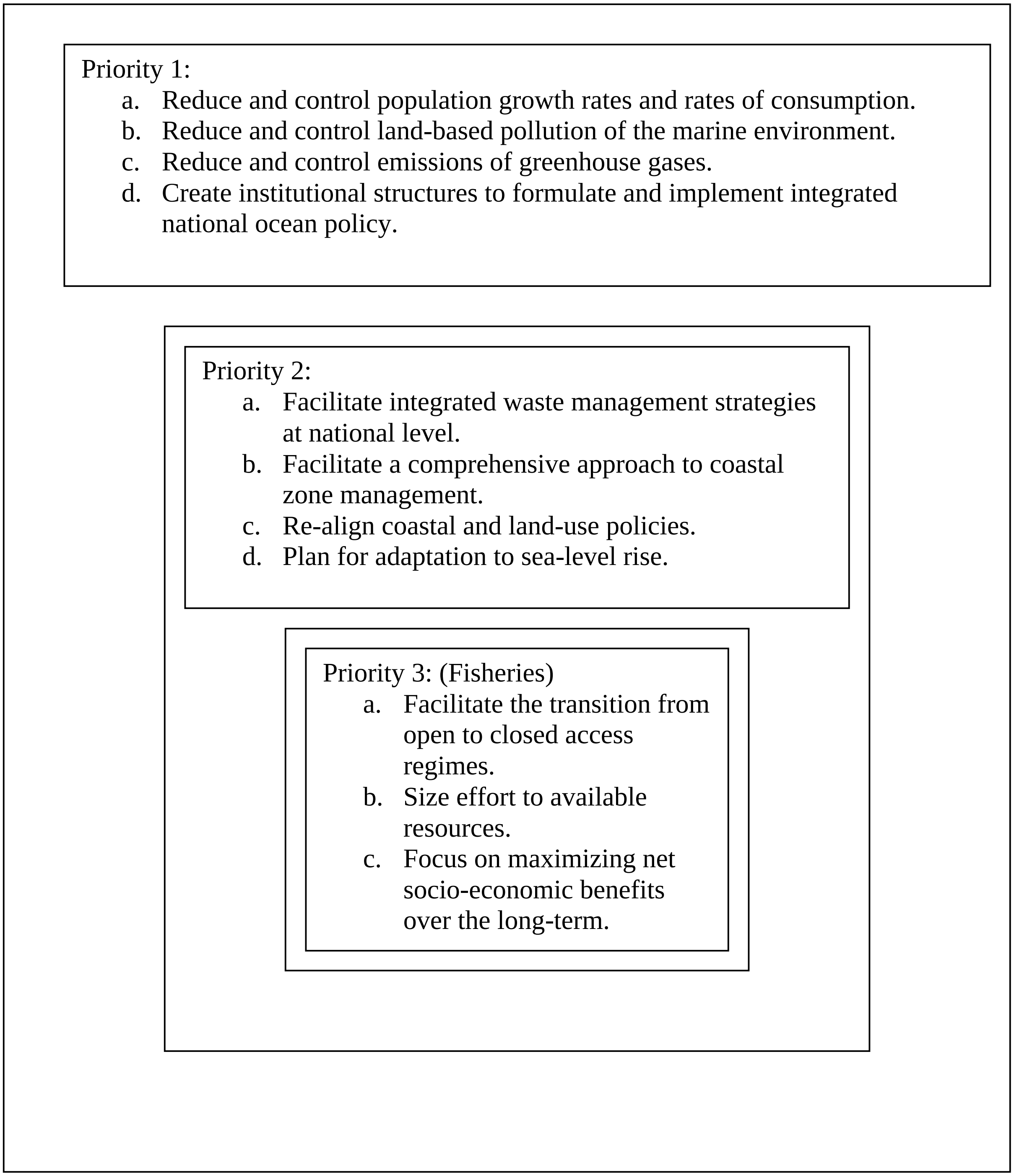
According to IPCC Working Group II, (2001), the following earth-based systems, both natural and human, are the most sensitive to global climate change: water resources, agriculture and forestry, coastal zones and marine systems, particularly fisheries, human settlements, energy, industry, insurance and financial services, and human health.

Sensitivity means that these systems will change in various ways as the climate changes. On the other hand, if we define vulnerability as the lack of capacity to adapt, or to cope with either the rate or the magnitude of change (or rate and magnitude), the following natural systems are the most vulnerable: glaciers, coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and remnant native grasslands (IPCC 2001, WG. II).

Having said that, however, it is obvious that impact analyses on the global space scale, while useful as an indicator of broad trends, cannot yield information useful for planning and policy formulation. To seek such utility from integrated assessments of the impacts of climate change, we must decrease the space scale down to a level of ecological regions, i.e., on the order of large river basins or at least watersheds. I present in this paper one approach from an ongoing effort in the Pacific Northwest of the United States and will suggest at the end that you in Southeast Asia need to mount a similar effort, perhaps starting with the Mekong River basin. Remember that it takes on average 25 years to change water supply systems and 50 years to change energy systems. By the year 2020 the climate change signal should be unmistakable and impacts will be readily apparent. It would be better to begin planning to increase adaptability and decrease vulnerability sooner rather than later.

From Rayong (1997) Workshop

Figure 1: Changes in Policy direction as a Nested Set of Solutions (Focus on Sustainability)



Priority 1:

a. Reduce and control population growth rates and rates of consumption.
b. Reduce and control land-based pollution of the marine environment.
c. Reduce and control emissions of greenhouse gases.
d. Create institutional structures to formulate and implement integrated national ocean policy.

Priority 2:

a. Facilitate integrated waste management strategies at national level.
b. Facilitate a comprehensive approach to coastal zone management.
c. Re-align coastal and land-use policies.
d. Plan for adaptation to sea-level rise.

Priority 3: (Fisheries)

a. Facilitate the transition from open to closed access regimes.
b. Size effort to available resources.
c. Focus on maximizing net socio-economic benefits over the long-term.

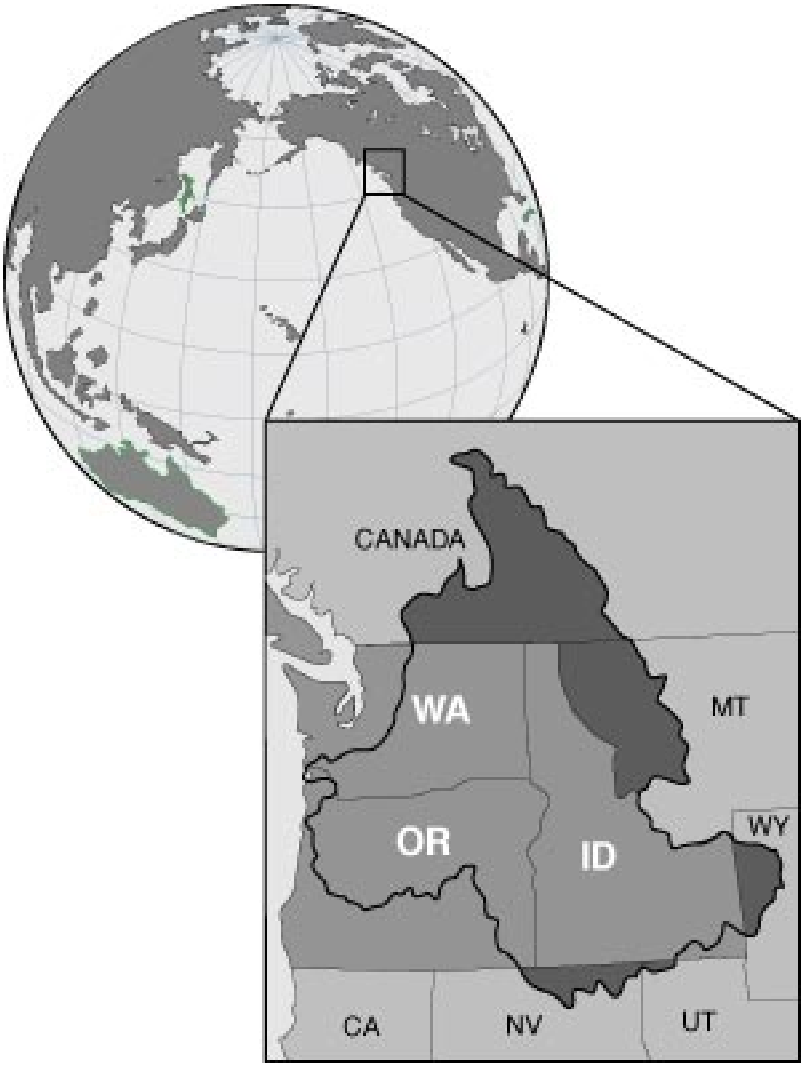
The Methodology of Climate Impact Assessment at the Regional Level: the Climate Impacts Group (CIG) at the University of Washington and the Pacific Northwest Assessment.

The effort that I shall describe is sponsored by the Office of Global Programs (OGP) of the U.S. National Oceanic and Atmospheric Administration (NOAA). Within the University of Washington, its hosts are the Joint Institute for the Study of Atmosphere and Ocean (JISAO) and the School of Marine Affairs (SMA). It consists of a research team which is fully integrated between the natural and social sciences and law. Students and faculty from six academic units participate in this team: Department of Atmospheric Sciences, the School of Marine Affairs, the Department of Civil and Environmental Engineering (Hydrology), the School of Aquatic and Fisheries Sciences, the College of Forest Resources, and the School of Public Health and Community Medicine.

Beyond the University of Washington, the CIG is a regional entity since it includes as research collaborators the Washington State Departments of Health and Ecology (human health and coastal zone), Battelle's Pacific Northwest National Laboratory (hydrology), the University of Idaho (on water markets), and Oregon State University (forestry and coastal zone). In addition, as part of the original grant application, the CIG is obligated to maintain close working relationships with a large number of state, federal and regional agencies which constitute the actual and potential user community for the information and analyses we produce. The relationship works exceedingly well and profitably in both directions and the team's research agenda has been substantially moulded by the desires and needs of the user community.

The region we have chosen for study is an amended version of the Columbia River Basin. It is depicted in Fig. 2. The Official Columbia basin is the bounded area from British Columbia in the north to northern Nevada in the south and from coastal Washington/Oregon in the west to western Montana and Wyoming in the east. There is a Canadian team at the University of British Columbia in Vancouver which does the assessment for British Columbia. We collaborate closely with that group but we have eliminated western Montana, eastern Wyoming, and northern Nevada from our study area, while we include all of Washington, Oregon, and Idaho. We depict the entire North Pacific Ocean as relevant for our study because Equatorial dynamics determine El Niño/Southern Oscillation (ENSO) events which have a signal over the Pacific Northwest (PNW). And the location and intensity of the Aleutian low-pressure area, dominated by the Arctic Oscillation, is critically important for the Pacific Decadal Oscillation (PDO). The PDO signal, as we shall see, is quite pervasive in its impacts on PNW climate.

Figure 2:



The scope of the assessment is bounded by two foci:

1). Climate variability:
    a). past variations and their impacts.
    b). ability of institutions to rebound, particularly to extremes of variability.
2). Climate Change:
    a). regional consequences of global warming; and
    b). societal sensitivity, adaptability, and vulnerability.

The sectors to which we pay particular attention include: water resources, aquatic ecosystems, particularly salmonids, the coastal zone, human health, and irrigated agriculture. The last two have only recently been added to the menu and are not yet fully developed.

The work of the IPCC, and more importantly the regional focus of NOAA/OGP, has in fact spawned a new sub-field of science which we may call climate impact science. This subfield has as its focus how climate, natural resources, and human socioeconomic/political systems affect each other. The basic analytical approach is a progression of the following steps:

1). Understanding <u>regional</u> climate dynamics and patterns of variability on seasonal/interannual to decadal timescales;
2). Observing and evaluating impacts on specified sectors as identified above through the use of posterior climate analysis;
3). The analysis involves regional or mesoscale climate models which are initialized against the global models for the boundary conditions. The regional climate models are then linked to and drive a variety of applications models, the most important of which are hydrology and reservoir operations models.

Having completed steps 1-3, we then shift the focus from the physical processes to their ecosystem and socioeconomic/political impacts by sector. The purpose of doing so is twofold: first, to assess their sensitivity and vulnerability to climate variability; and, secondly, to assess societal capacity to reduce vulnerabilities and increase adaptability to climate variability on seasonal-interannual (SI) to decadal timescales. Finally, we use the patterns of variability and the impacts produced on S-I/decadal timescales as the baseline for projecting sensitivity, adaptability, and vulnerability on decadal-centennial timescales.

It should be noted that the reliability of all models used is a major issue to be WRESTLED WITH, which requires that much time be spent checking. Since vertical or end-to end assessment calls for integrated teams doing problem-focussed interdisciplinary work through a chain of issues, how integration is achieved within the assessment team is another major issue. Finally, since the instrumental record is only 120 years long, paleoclimatological studies are critical to regional assessments because they represent our only pathway to extending the instrumental record significantly.

We should emphasize here that while we focus on understanding the role that climate variability and change play in relation to natural ecosystems, resources, and human activities, climate is not the only, nor is it the most important, element in the story. *The real story is about climate in a world of multiple stresses* in which the footprint of anthropogenic effects on the natural environment is very large. In the PNW this means that assessments of adaptability and resilience in the face of change need to pay considerable attention to population growth, rising demands for water and energy, expanding urbanization, growing pollution and habitat destruction. In this story, patterns of land use by humans play a very large part.

A Brief Summary of Results[1] Understanding the Present Climate

Our first step in seeking to understanding the dynamics underlying the variability observed in the present climate over the course of the last 120 years (the instrumental record) was to perform an empirical orthogonal functional (EOF) analysis of climate division data for the PNW. EOF analysis, sometimes referred to as principal component analysis, is a computational, pattern tracing tool which, in this case, showed two principal "drivers" of PNW climate. The more powerful driver, on a decadal timescale, was the Pacific Decadal Oscillation (PDO), which has reversed polarity from warm phases to cool phases over two to three decades several times in the 20th century. The other driver also appears in warm and cool phases but on a seasonal to interannual (SI) timescale. This is the ENSO phenomenon in which the warm phase is popularly known as "El Niño" and the cool phase as "La Niña." The patterns generated by these two drivers in the PNW are shown in Fig. 3. Clearly, in both phases, the most important variation concerns the amount of winter snowpack which largely determines both streamflow and soil moisture in spring and summer. Further analysis of the El Niño pattern (Miles, Mantua, and Mote, 1998) showed that it was principally moderate El Niños (i.e., 0.5-1.5 sigma) which characteristically yielded the "warm-dry" winter pattern. Strong El Niños (>1.5 sigma) generated a pattern which combined normal or near normal precipitation with significantly elevated temperature.

Combining all patterns, as shown in Table 1, we see a four-part "rhythm" to present climate variability in the PNW. This rhythm consists of the PDO in two phases and ENSO in two phases, but on different timescales, non-ENSO years on a S-I timescale, and strong El Niño events with their split personality.

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[1] This section of the paper briefly summarizes research results reported previously in two of the team's publications. For more detail, the reader is referred to: Philip Mote et al. 1999. Impacts of Climate Variability and Change: Pacific Northwest (Seattle, WA: The JISAO/SMA Climate Impacts Group, University of Washington), (November); and Edward L. Miles et al. 2000. "Pacific Northwest Regional Assessment: The Impacts of Climate Variability and Climate Change on the Water Resources of the Columbia River Basin", Journal of the American Water Resources Association, Vol. 36, No. 2 (April) pp. 399-420.

Figure3.

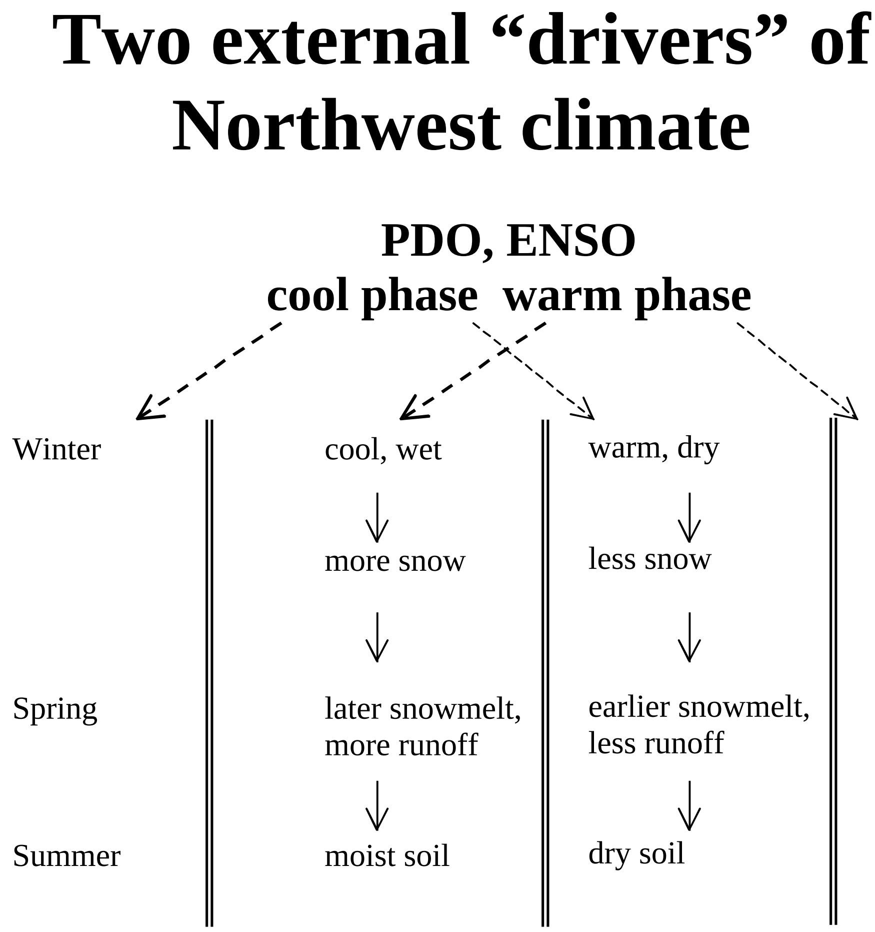

Two external "drivers" of Northwest climate
PDO, ENSO
cool phase
warm phase
Winter
cool, wet
warm, dry
more snow
less snow
Spring
later snowmelt, more runoff
earlier snowmelt, less runoff
Summer
moist soil
dry soil

Table 1: The “Beat" of the PNW Climate System

1) PDO—Decadal Timescale—Most Pervasive Climate-Driven Impacts.

2) ENSO—S/I in two phases:
    a) .La Niña
    b). El Niño

Non-ENSO Years—Interannual Timescale

3) Very strong El Niños (>1.5 sigma):
    --Split personality—S/I:
        a). Normal/Near Normal P.
        b). Highly elevated T.

Mindful of the fact that the story we are telling is one of climate in a world of multiple stresses, the CIG put equal emphasis on the extent to which humans have transmogrified the natural environment of the PNW. Moreover, since we are ultimately concerned with assessing both the impacts of climate variability and change in the region and the sensitivity, adaptability, and vulnerability of natural ecosystems and human social systems to these impacts, we must self-consciously follow at all times two pathways of change: a). one pathway in which climate variability is the principal source of change; and b). another in which human intervention is the principal source of change.

This procedure has led us to represent the climate system of the PNW as shown in Fig. 4. One fact of critical importance represented in Fig. 4 is that, because the PNW is a snowpack/snowmelt system, the regional hydrology is the critical mode in the system that translates climate variability into impacts. All other sectors with which we are concerned are linked to the regional hydrology and, through that link, to each other. Only the coastal zone has, in addition, an independent driver in the sea level rise factor.

Characterizing the regional climate system in this fashion leads us to identify the dominant pathway through which impacts make themselves felt. This pathway is shown in Fig. 5. For impacts, winter season is always the most important because temperature and precipitation combine to create snowpack. In the spring, as temperature increases, the snow melts creating larger streamflow. But not all snowmelt becomes streamflow. Some, in the form of run-off, goes into groundwater recharge, intensifying soil moisture and enlarging the potential evapotranspiration (PET). PET, in turn, is extremely important for generating terrestrial effects for forests and agriculture. What is left in the streams is available for water supply in which the criteria of quantity, quality, and timing are critical.

Given these characterizations of the climate system and dominant impact pathway of the PNW, let us now describe some of the principal impacts.

We begin with the regional hydrology as noted previously in Fig. 4. However, we should note that the context in which the regional hydrology is a critical component has been much changed by human beings, particularly in three respects. First, streamflow is now substantially different from what it was originally as a result of the more than 200 dams built on the river. These dams or reservoirs, and the ways in which they are operated to facilitate a variety of human activities (flood control, hydropower production, irrigation, recreation, etc.), are now the dominant features of the river system.

Secondly, because the river has been changed so substantially, it has become a chain of lakes in which the ecosystems are different from what they once were. Fish access to habitat, fish migration to and from the ocean, water temperature, and water quality have all been adversely affected by anthropogenic activities. Thirdly, the land is different as a result of logging, agriculture, mining, and increasing urbanization. These

Figure 4:

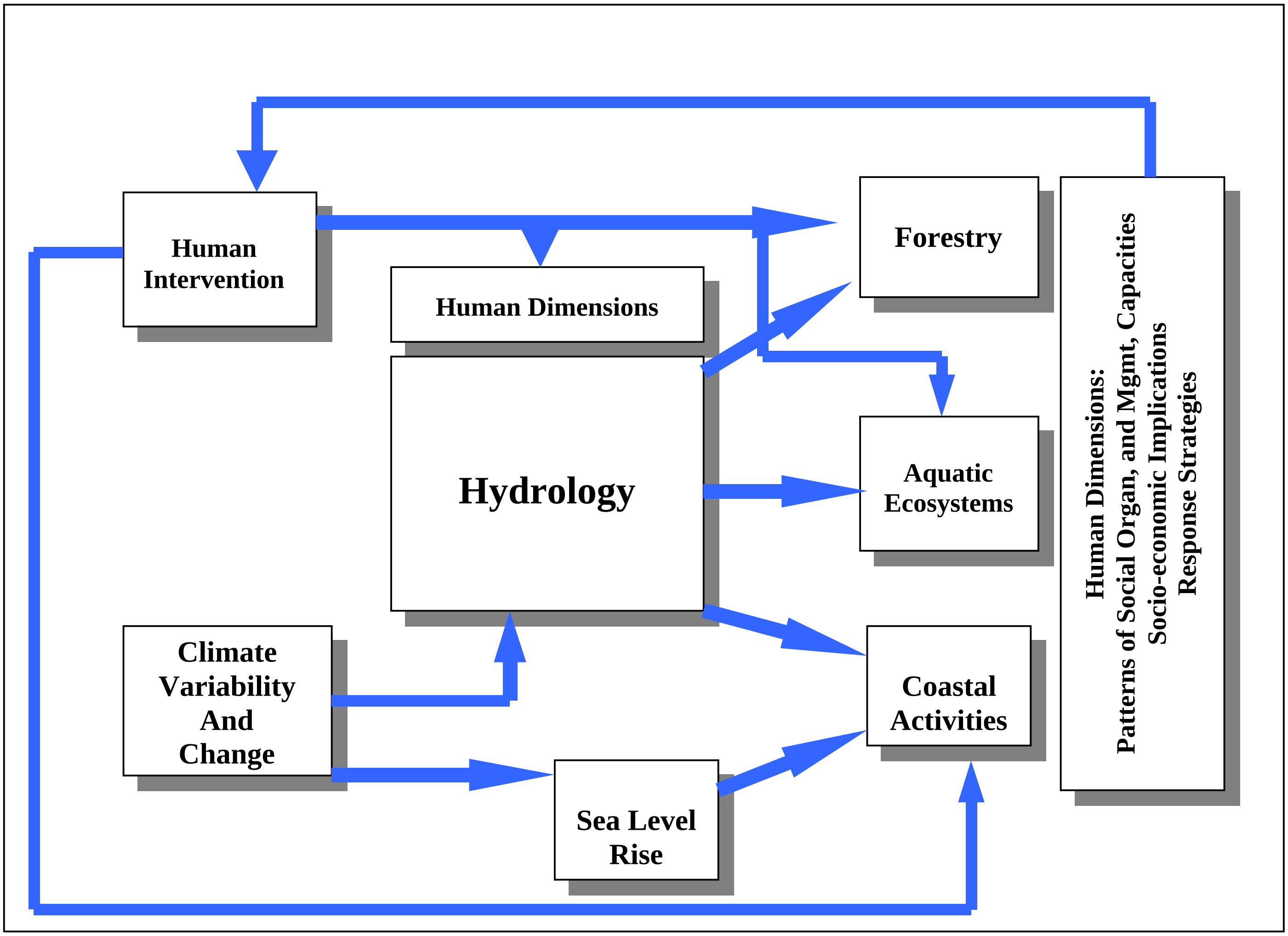
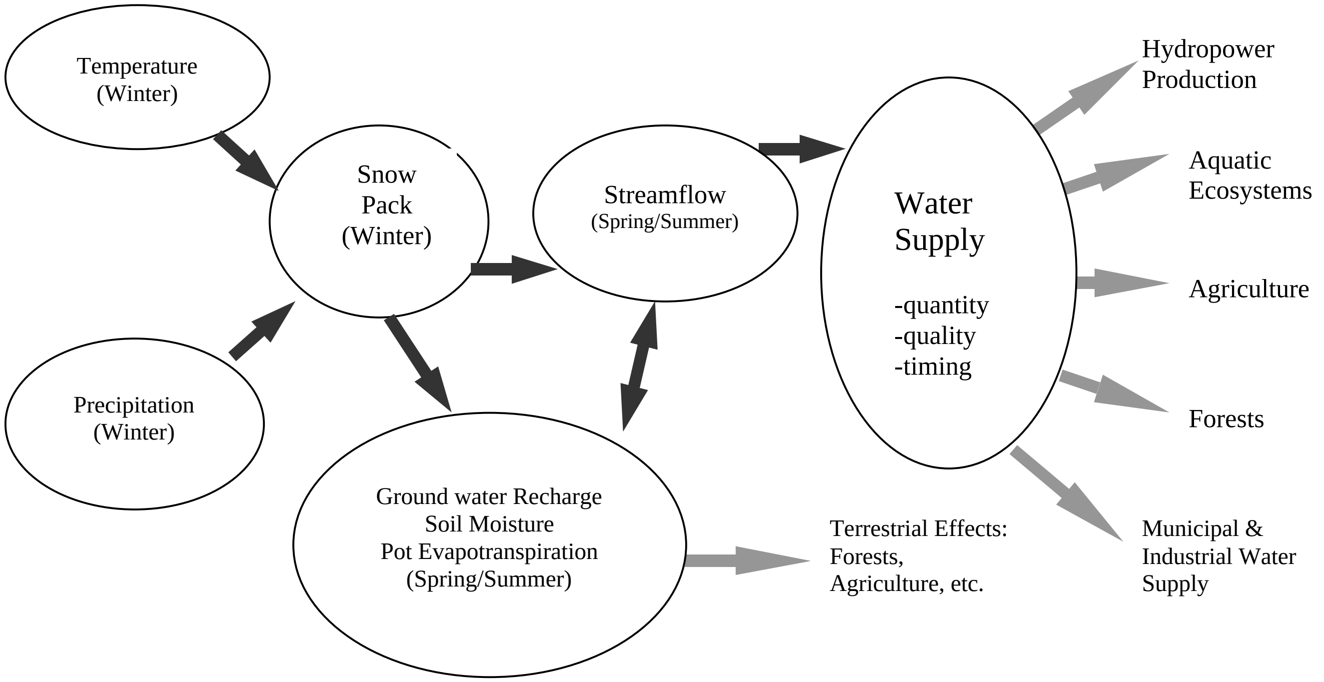
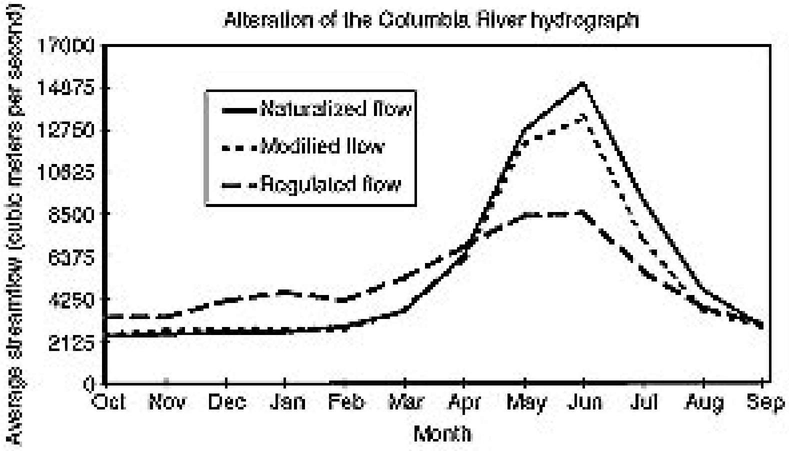

Human Intervention
Human Dimensions
Forestry
Hydrology
Aquatic Ecosystems
Climate Variability And Change
Coastal Activities
Sea Level Rise
Human Dimensions:
Patterns of Social Organ, and Mgmt, Capacities
Socio-economic Implications
Response Strategies

Figure 5



Temperature (Winter)
Precipitation (Winter)
Snow Pack (Winter)
Streamflow (Spring/Summer)
Ground water Recharge
Soil Moisture
Pot Evapotranspiration
(Spring/Summer)
Water Supply
-quantity
-quality
-timing
Hydropower Production
Aquatic Ecosystems
Agriculture
Forests
Municipal & Industrial Water Supply
Terrestrial Effects: Forests, Agriculture, etc.

Figure 6


Alteration of the Columbia River hydrograph
Average streamflow (cubic meters per second)
17000
14875
12750
10625
8500
6375
4250
2125
0
Naturalized flow
Modified flow
Regulated flow
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Month

activities not only adversely affect water quality and fish habitat, but they substantially decrease the capacity of the soils to hold water and they increase both run-off and sedimentation from precipitation events.

The ways in which human activities have affected water quantity is shown in Fig. 6. This curve shows the characteristic hydrograph of the Columbia River in phases of its planetary life cycle. The curve at the top shows a reconstructed version of the "virgin" river before the large influx of human settlements in the second half of the nineteenth century. Peak flows begin extending from May to August (four months) with the month of June containing usually the highest flows from snowmelt. The second curve represents the beginning impacts of population growth evident from the 1880's with increased diversions for agriculture and, consequently, increased evaporation. June peak flows have been reduced from c. 550,000 cubic feet per second (cfs) to less than 500,000 cfs. and the magnitude of peak flows has been reduced from a 4-month period to at best two months.

Not surprisingly, this proliferation of human activities dependent on the river as a resource, and the major reductions in water supply that they entail, have generated intense conflicts over reservoir operations and patterns of water supply. The conflict can be characterized as lining up combatants on either side of the "spill" vs. "fill" divide (Callahan, Miles, and Fluharty, 1999). Those users of the river whose interest favor reservoir storage for hydropower, irrigation, municipal and industrial water supply, recreation, and navigation all line up on the "fill" side of the divide. On the other hand, those users whose interests favor instream flows for fisheries and higher water quality for fish, but also those who favor recreation and navigation, all line up on the spill side of the divide. The clear trade-offs, therefore, are between those who favor hydropower, irrigation, and municipal and industrial (M&I) water supply vs. those who seek to protect fisheries. Since hydropower can, at least theoretically, compete with withdrawals for irrigation and M&I water supply, the dominant trade-off is between hydropower and fisheries.

The sociopolitical situation is even more complex because the dominant driving force for the construction of most dams was flood control. Hydropower has been second in priority and both flood control and hydropower (firm energy)have been operated at 100% reliability in the system since the beginning. In the 1980's fish preservation was declared to be at the same level of priority as hydropower, but this objective has been achieved in only one part of the river called the Hanford Reach.

The connections to climate variability and change lie in the pattern of impacts generated by the climate drivers of ENSO and PDO and the ways in which authority has been distributed. With respect to managing for flood control, there is but a single player in charge, the U.S. Army Corps of Engineers, and the full panoply of technical infrastructure and expertise is in place. This is definitely not the case in managing to respond to drought. No one is in charge and there are severe limits on system capacity to respond since most of the region's storage capacity is in snowpack and there is no possibility of building new storage on the river. The region's greatest vulnerability to both climate variability and climate change therefore, lies on the drought end of the precipitation variable. Drought then means snowpack (storage) is reduced while demands exceed supply possibilities and the legal system underlying the use of water is based in the 19th century when supply was great and demand was very low.

Climate Impacts on the Regional Hydrology, Salmon, and the Coastal Zone

On the basis of the existing instrumental record from 1878 to the present, we can say that the climate system of the PNW is highly sensitive to the amount, type, and timing of precipitation and the form in which that precipitation occurs, i.e., rain vs. snow. More specifically, because the PNW climate system makes the region highly dependent on winter snowpack, sensitivity to ENSO/PSO is combined with topography, primarily elevation, and aspect, i.e., east vs. west of the Cascades. Snowmelt rivers, the more important ones in the system, are high elevation rivers; rain-dominated rivers, in contrast, are low-elevation rivers.

Two additional factors come into play in determining the relationship between the climate drivers and their impacts on the regional hydrology. The first is the difference that moderate El Niños (0.5-1.5 sigma) exert vs. strong El Niños (1.5 sigma). Moderate El Niños are warm-dry events; strong El Niños are warm-wet events since the region receives normal or near-normal precipitation combined with significantly increased surface temperature. The second factor is whether ENSO and the PDO are in phase, since in-phase combinations roughly double the intensity of the event. More significantly, four of the top five streamflow years occurred in cool-phase PDO/ENSO combinations, while five of the five lowest streamflow years occurred in warm-phase PDO/ENSO combinations. One can conclude from this that climate variability in the PNW affects not only the means of the distributions but also the extremes to a significant extent.

We can therefore summarize the impacts of climate variability on PNW hydrology in the following way. La Niña vs. moderate El Niño years produce roughly ± 10% streamflow over/under the long-term average (1878-to present) on the mainstem Columbia. That variability produces mixed impacts on salmonids, forest and coastal zones. The reduction in streamflow experienced during moderate El Niño events, results in lower soil moisture in summer and higher evapotranspiration. Less water is available to support salmonid migrations and, given the competition with human activities, this water is of lower quality.

Because La Niña events generally produce more precipitation than usual, there is more water available for all uses and water is of a higher quality. Significant differences also exist in ocean productivity of salmonids (Mantua et al., 1997). In warm-phase PDO years salmonid productivity off Alaska increases significantly while productivity off Washington, Oregon, and California decreases significantly. The reverse is the case in cool-phase PDO years. El Niño/warm-phase PDO combinations significantly increase not only the probability of drought, but also the probability of multiyear drought with severe horizontal effects on the other sectors (Miles, et al., 2000, Table 1, p. 404). In contrast, La Niña/cool phase PDO combinations increase the probability of winter flooding in addition to providing a more abundant water supply for all users of the river.

Once again, however, it is necessary to reiterate that while climate variability affects salmonids in both the terrestrial and marine phases of their life cycle, humans are the major drivers of multiple stresses for salmon in the terrestrial and estuarine environments. This is so because:

- The adverse impacts of natural erosion are enhanced when clear cutting is permitted. Clear cutting increases sedimentation in run-off, burying the stream beds (redds) which salmon need for spawning;
- Clear cutting also removes riparian forests so that woody debris is not continuously replaced after winter flooding;
- Pond habitat is adversely affected by loss of riparian forests and woody debris;
- Altered hydrology as a result of building so many dams on the river decreases summer streamflows and increases water temperature.
- Other pollutants from land use, combined with the loss of riparian forests, decrease water quality;
- Dams reduce the sediment load transported to the estuarine and coastal ocean, thereby severely reducing the size of the plume at the mouth of the river in which the migrating smolts feed during their first month of life at sea;
- Reducing the sediment load also reduces severely the amount available for replenishing beaches after winter storms. This reduction in availability increases the rate and magnitude of coastal erosion in winter;
- The magnitude of production of hatchery-reared fish leads to genetic deterioration of wild stocks whose numbers are further reduced as a result of harvest practices; and
- Estuarine pollution from urban and rural land use, combined with systematic degradation and destruction of wetlands adversely affect smolt survival in migration.

The point here is that salmonids have to be managed on the basis of whole life cycle considerations which couple terrestrial and marine phases. This whole life cycle focus has to include both the effects of climate variability and the anthropogenic impacts on salmon survival.

With respect to the coastal zone, one must distinguish three drivers of variability: eustatic sea level rise; ENSO-related events; and variability in streamflow and nutrient input from coastal rivers. Eustatic sea level rise occurs on centennial to millennial cycles and is mediated through regional tectonic movements of subsidence and uplift. ENSO-related events generate short-term, high frequency (though sometimes long-lasting) local effects on a seasonal-interannual timescale. On the decadal scale, the PDO attenuates the ENSO effects if they are out of phase, or magnifies them if PDO and ENSO are in phase.

In La Niña/cool-phase PDO periods the tendency for increased winter precipitation and coastal flooding increases substantially (Miles et al., 2000). In El Niño/warm phase PDO periods, the most intense coastal erosion occurs as a result of higher than usual sea level in the N.E. Pacific after the Trade Winds die and a shift occurs in the pattern of winter storms from the S.W. to the N.E. The intensity of the erosion varies directly with the strength of the El Niño event. The amplitude of the sea level anomalies during El Niño events as measured by NOAA tide gauges from 1899-1992 at Seattle is shown by Field (1997) in Fig. 7. The range in this curve varies from 5 cm to 25 cm above normal. Twenty-five centimeters above normal, in this record, occurred only once, that is during the 1982-1983, El Niño, the most intense event in the instrumental record up to 1992.

There are some who would question the use of tide gauges located outside major cities on the basis of the argument that an amplification bias arises out of a combination of subsidence caused by the weight of cities and the urban heat island effect. However, during the 1997-1998 El Niño, which was more intense than the 1982-1983 event, the NOAA TOPEX-POSEIDON satellite system shows sea level off the State of Washington, and in Puget Sound, ranging form 20-25 cm. The 25 cm reading is characteristic of Puget Sound as a whole (NOAA Laboratory for Satellite Altimetry, Sea Level from TOPEX: Nov. 28-Dec. 7, 1997).

During the 1997-1998 event, also, Kaminsky et al. (2000) provide the first systematic measurements of the magnitude of coastal erosion in the Pacific Northwest during an intense El Niño event. They demonstrate conclusively that strong events generate the most coastal erosion and that the greatest erosional impacts are caused by significantly increased wave height when storms occur at high tides. The authors say:

> The largest wave event occurred on January 17, when the Grays Harbor wave gage (sic) reported a significant wave height of 14.52 m and significant period of 22 sec (reported at 0332 PST). Prior to this event peak, significant wave heights were above 7 m with 20 sec periods for the previous 6 hours and remained between 7.4 m to 8.5 m for 5 hours following the event peak, although wave periods dropped to about 11 sec, except for a 22 sec period reported at 0832 PST. Still, the extreme wave height appeared suspect, and the authors requested quality control checks on the data through personnel at the Scripps Institution of Oceanography. Their investigation suggested the reported significant wave height may be correct but the wave period should be on the order of 40 sec, the longest period the wave buoy could record. An independent analysis of the time series done at Scripps confirmed a wave height greater than 11 m and a peak period of 35 sec. During the same time, the wave buoy at the Columbia River entrance, maintained by the National Data Buoy Center, recorded a significant wave height of 7.8 m with a peak period of 17.4 sec. This wave event may have been a “squall-line surge”, a resonant coupling of a free surface wave with a moving pressure front that results in large waves (e.g.Thieke et al., 1993; Sallenger et al., 1995). The abrupt drop in wave periods from 22 sec to 11 sec following the peak in the storm support the likelihood of the passage of a major frontal system.

Figure 7

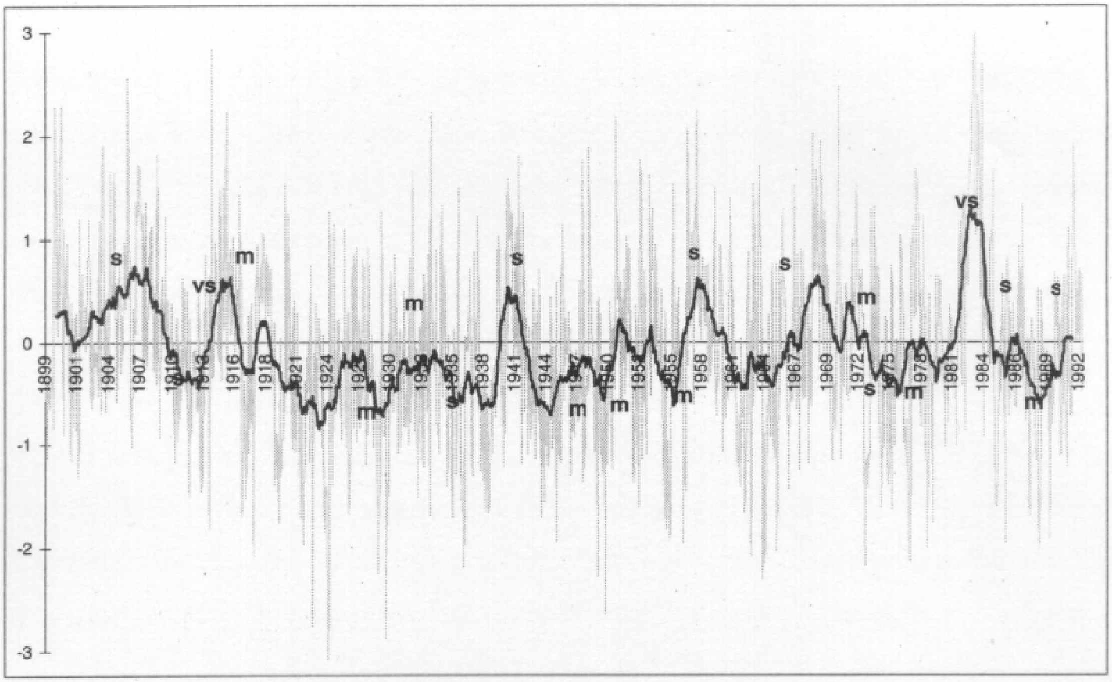


Figure 3: Sea level anomalies (in standard deviations) and running two year mean from Seattle tide gauge station (1899-1993); with major El Niño and La Niña events flagged as very strong (vs), strong (s), or moderate (m).

We can therefore conclude that present patterns of climate variability typically produce the following impacts in the coastal zone:

1) Eustatic sea level rise combines with seasonal-interannual variations in atmospheric pressure, along shore windstress, storms, winter precipitation, and run-off in coastal river basins to enhance coastal erosion and occasionally coastal flooding and loss of wetlands;
2) ENSO augments coastal erosion, bluff landsliding, and coastal flooding:
    a) storm-driven erosion is greatest at high tides;
    b) increased landslides and river flooding occur in unmanaged rivers in La Niña years; and
    c) hazards produce property damage;
3) Patterns of climate variability produce biological effects in estuaries as a result of the physical and chemical changes produced in the coastal ocean. Physical changes in the ocean include changes in water column density, i.e., temperature plus salinity, stratification, primary productivity, and dissolved oxygen content. These changes create important consequences for all estuaries and coastal ecosystems.

The Oyster Condition Index (OCI) which measures the "plumpness" of oysters commercially produced in Washington and Oregon has declined over the 45 years prior to 1997 (Field, 1997), but a cause has not yet been determined. However, it has been demonstrated that the pattern of climate variability which we have described for the Pacific Northwest, does facilitate the growth of some invasive species like Spartina alterniflora (cordgrass) in Willapa Bay (Feist & Simenstad, 2000).

We can summarize the heartbeat of the present climate system of the Pacific Northwest as shown in Fig. 8. Looking first at PDO effects by themselves, we note that very small changes in temperature (+0.2°C to-0.2°C) and precipitation (+02% to -4%) exert fairly large changes in snowpack (+17% to –15%), streamflow (+7% to –9%), salmon abundance and distribution in Alaska vs. Washington/Oregon/California (+19% to –16%), and in the frequency of forest fires (+65% to –49%).

Moving now to what we know are the critical variables in the climate system, i.e. snowpack and streamflow, we show separately and combined the effects of ENSO and the PDO. By itself, ENSO results in a range of +9% to –15% for snowpack, which increases to +26% to –30% when ENSO/PDO are in phase. The values for streamflow are +8% to –12% for ENSO and +14% to –17% for ENSO/PDO in phase.

Everything we have described so far is observable and is based on the instrumental record. There is very little uncertainty here. We now move to project the impacts of climate change on the region by 2020 and 2045/2050. There is more uncertainty in these projections because our regional climate model is initialized against the global models, so that the uncertainty inherent in each GCM is transferred to all those we have used in our ensemble. Secondly, the projections are based on what we understand of the climate dynamics underlying the present climate. We assume that ENSO/PDO dynamics will not change, whereas they might but we do not know how.

Our projection therefore is not a prediction but a reasonable scenario elaborated out of the conservative default option.

Fig. 9 shows our temperature projection. The average projection, which is the one we use, is in fact a linear extrapolation from the observed temperatures of the 20th century. This is bounded by the warmest scenario in our model runs, using the Hadley Centre model (HadCM$_3$), and the coolest scenario, the National Center for Atmospheric Research (NCAR) parallel climate model (PCM). We also show the results of the Canadian model (CGCM1) because the other model results are slices in time. The CGCM1 provides a transient simulation from 1900-2100 comparing the rate of warming in the 20th Century with what was observed.

Figure 8:

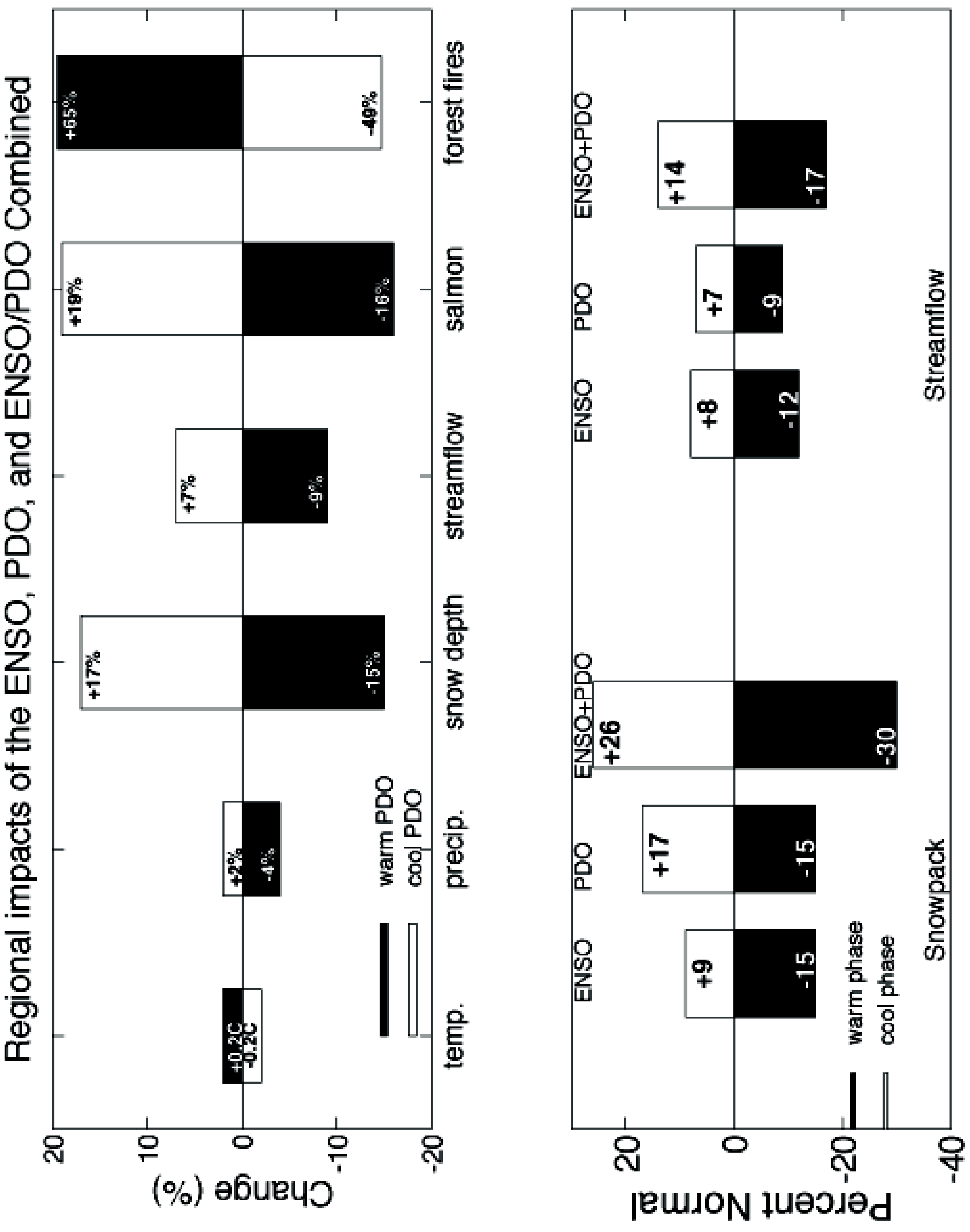
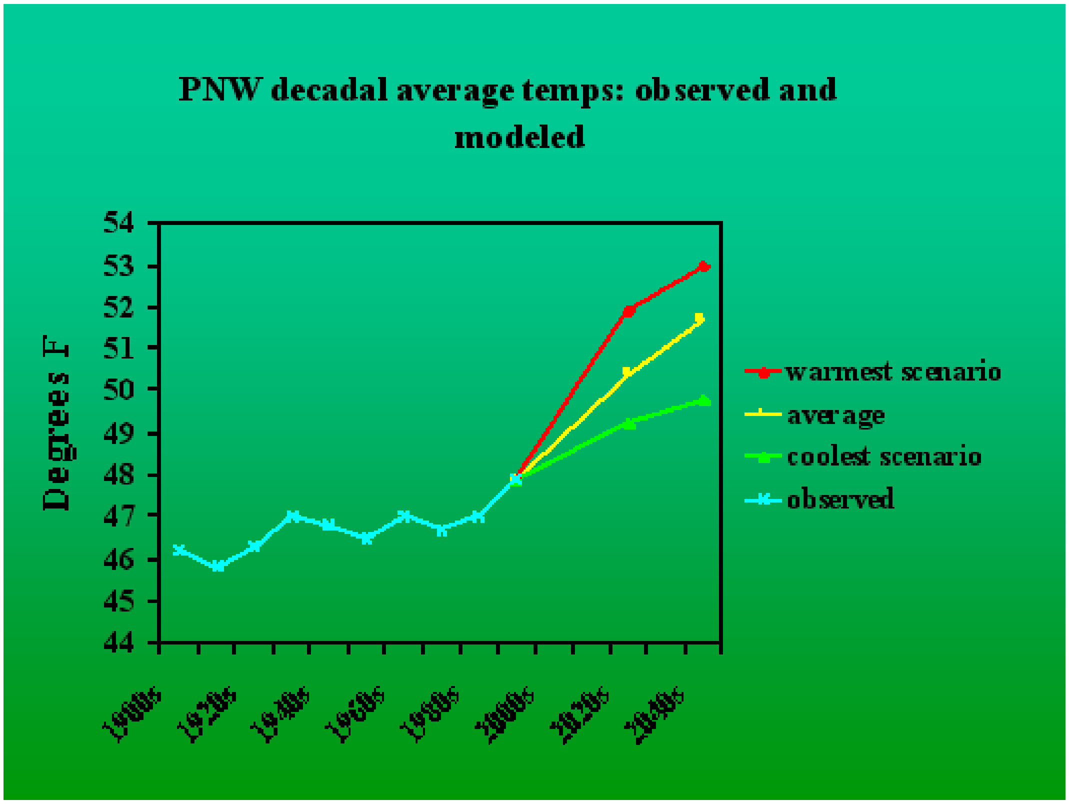

Regional impacts of the ENSO, PDO, and ENSO/PDO Combined
Change (%)
20
10
0
-10
-20
+0.2C
-0.2C
+2%
-4%
+17%
-15%
+7%
-9%
+19%
-16%
+65%
-40%
warm PDO
cool PDO
temp.
precip.
snow depth
streamflow
salmon
forest fires
Percent Normal
20
0
-20
-40
ENSO
PDO
ENSO+PDO
+9
-15
+17
-15
+26
-30
+8
-12
+7
-9
+14
-17
warm phase
cool phase
Snowpack
Streamflow

Figure9


PNW decadal average temps: observed and modeled
Degrees F
54
53
52
51
50
49
48
47
46
45
44
1900s
1920s
1940s
1960s
1980s
2000s
2020s
2040s
warmest scenario
average
coolest scenario
observed

What are the likely impacts of increasing regional temperature up to 5.3°F (°C) by 2050? As shown in Fig. 10 by 2025, with a temperature increase of 2.0°C, the region is projected to lose between 16-27% of the lower elevation snowpack. This increases to 37-46% by 2045.

Loss of snowpack does not necessarily imply decreases in precipitation. On the contrary, the physics of warming imply a modest intensification of the hydrological cycle as a result of increased evapotranspiration. This results in a projected 5% precipitation increase. But, with a significant increase in the regional average winter temperature, more of the precipitation falls as rain rather than snow. These physical changes then change the basic hydrograph of the Pacific Northwest as shown in Fig. 11. Snowmelt occurs earlier than normal so that the peak flows occur two months earlier than normal, producing a summer dry period of four months, not two.

This projection means higher rates of energy production will be possible in winter which can be translated into increased sales but at an environmental price of increased flooding and landslides. Less water for longer periods imply sharper trade-off conflicts between hydropower, fisheries, and irrigation in summer. Eventually, we will have to add municipal and industrial supply to the trade-off list as a function of population growth. Since are dealing with climate impacts in a world of multiple stresses, we need to note that the official projections of population growth in the region *from 2000 to 2020* range from an increase of 39% to an increase of 125% as shown in Fig. 12. The smallest increase for the State of Washington, that is utilized by the Office of Financial Management in the Governor's Office (Fig. 12a), still calls for an increase equivalent to three new Seattles.

Fig. 13 summarizes our projections under the climate change scenario we use. A 5˚F increase in regional temperature would result in a 5% increase in precipitation, a 33% reduction in snow pack in warm-phase PDO periods, an 11% reduction in streamflow, a much bigger reduction in salmon abundance, although the magnitude is at present unknown, and a larger increase in forest fires beyond the 65% increase currently observed.

We conclude therefore, that the greatest potential vulnerabilities climate change will imply for the Pacific Northwest are likely to occur in warm-phase PDO regimes. This expectation is even clearer when we note that all of the multiyear droughts of the 20th century have occurred in warm-phase PDO periods, especially when El Niños have been present simultaneously (four out of five events).

What then are the likely consequences of such a future for salmonids and the coastal zone, apart from the intensification of social conflicts over water supply for contending uses of the river? This question has another dimension to it as well: What do we need to plan for?

Planning for the Future: Water Supply, Salmon Management, and the Coastal Zone

As was made clear at the beginning of this paper, the central objective of planning is to increase adaptability and decrease vulnerabilities. On the cool-wet side of the ledger, planning should assume an increased probability of flooding. Responses will require understanding the seasonal-interannual climate forecasts, interpreting what impacts these forecasts imply, and coupling the forecasts plus interpretations to actual user communities and their operations. The actual infrastructure of reducing flood risk in managed rivers, as we have said before, is at an advanced stage of readiness. Problems will occur in the unmanaged rivers. In addition, institutional shortcomings will be hard to compensate for with respect to land-use practices in the face of increased risk of damage to housing developments unwisely located in the 100-year flood plains of rivers, landslides, and bluff failures.

On the warm-dry side of the ledger, we can easily see that societal response capacity will be heavily constrained by the extreme fragmentation of authority, by the applicable law as defined in the Prior Appropriation doctrine, i.e. first come, first served with seniority rights, by unrestrained population growth, and by the increasing severity of conflicting uses of the river on the east side of the Cascades and increasing conflict between hydropower, fisheries, and municipal/industrial water supply on the west side.

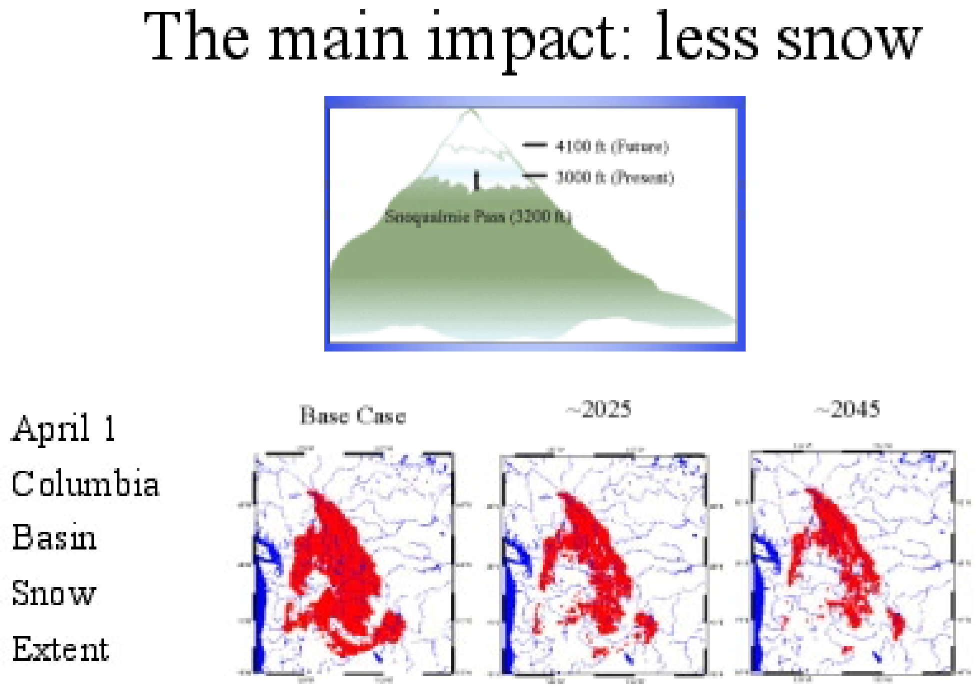
As far as salmonids are concerned, in their terrestrial phase, they will be affected by the increased frequency of winter flooding and the intensification of the summer/fall drought occurring in the same year. During warm-phase PDO periods, the increased probability of multiyear drought will add to their stresses. Since egg survival is in part a function of in-stream temperature, we would project increased mortality in the egg and larval stage. The shift in the hydrograph to the left would imply adverse effects on survival given the timing of spring smolt migration and the summer/fall return of adults. As temperature increases and streamflow declines, further deterioration is likely in in-stream and estuarine water quality.

In the marine phase of the salmonid life cycle, increasing sea surface temperatures (SST's) will seriously affect both different species of salmonids and their prey. Walsh et al. (1999) argue that there is physiologically a temperature envelope for sockeye which they cannot go beyond, and that increased SST's in the Gulf of Alaska/Bering Sea area, for instance, if they pass the 30°C threshold would place a large part of the foraging area of salmonids off limits to them. These SST's would also greatly affect the distribution of salmonid prey. Therefore natural mortality of salmon, and coincidentally of seabirds, will increase. Pronounced size/age differences are also likely to emerge given the reductions in food sources.

In the coastal zone, we can expect increased erosions as a function simply of the thermal expansion of seawater even without El Niños. Rising sea level will imply a changing wave climate. Combined with increased winter streamflows, we would project an increased probability of inundation and flooding.

The Pacific Northwest is highly sensitive to variability in temperature, precipitation, storm surges, water quantity and quality. It is vulnerable to droughts and floods, but more to the former than to the latter. According to the CIG's projections, the region has about two decades to plan and implement plans for reducing their major vulnerabilities. Whether there will be the leadership, skill, and political entrepreneurship to achieve this objective is not yet so clear.

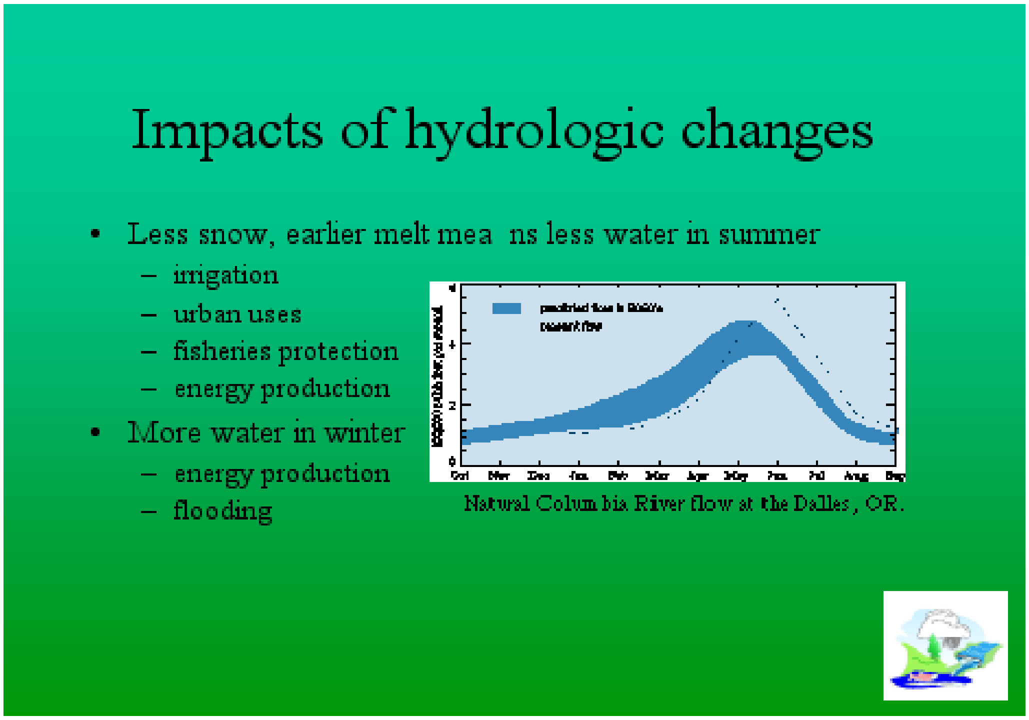
Figure 10



The main impact: less snow

April 1 Columbia Basin Snow Extent

Figure 11A



Impacts of hydrologic changes

- Less snow, earlier melt means less water in summer
  - irrigation
  - urban uses
  - fisheries protection
  - energy production
- More water in winter
  - energy production
  - flooding

Natural Columbia River flow at the Dalles, OR.

Figure 11 B

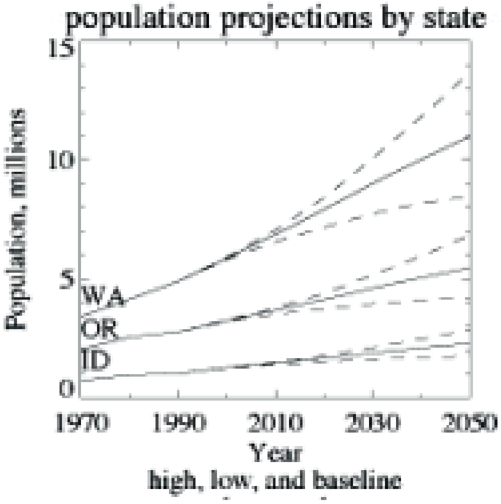

population projections by state
Population, millions
15
10
5
0
WA
OR
ID
1970
1990
2010
2030
2050
Year
high, low, and baseline

Figure 12:

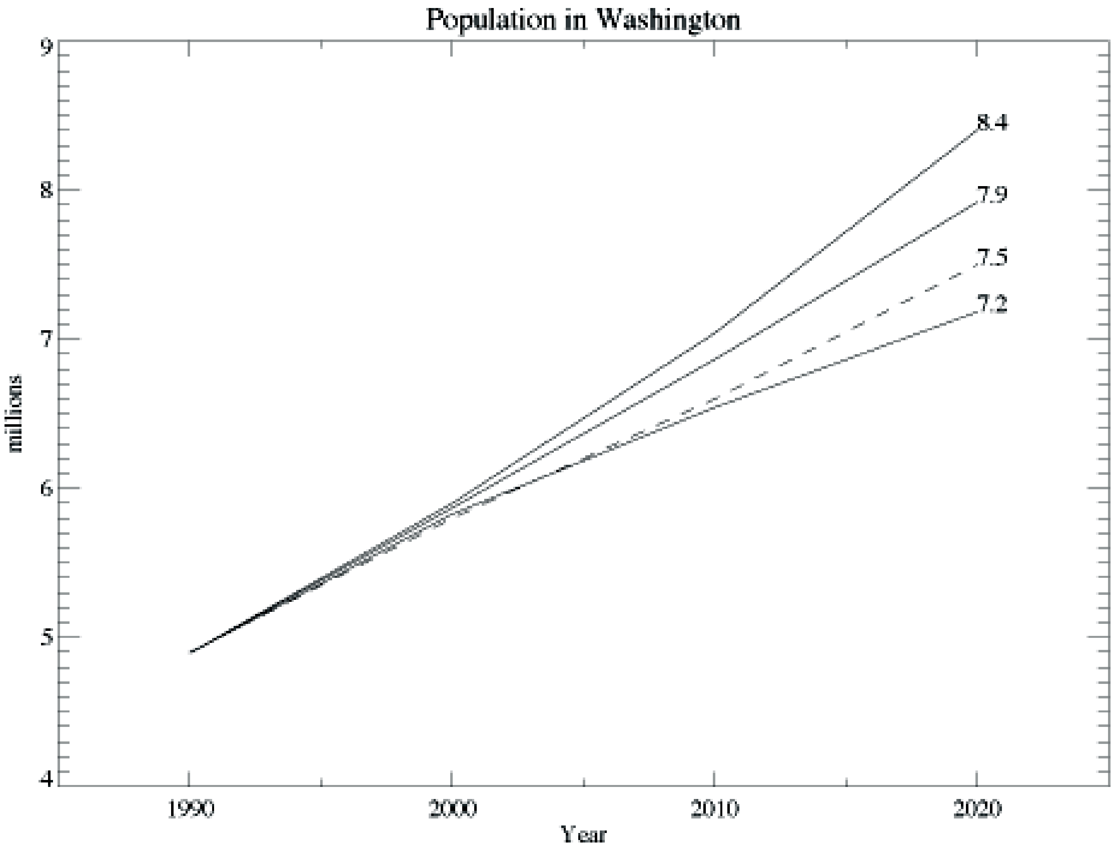
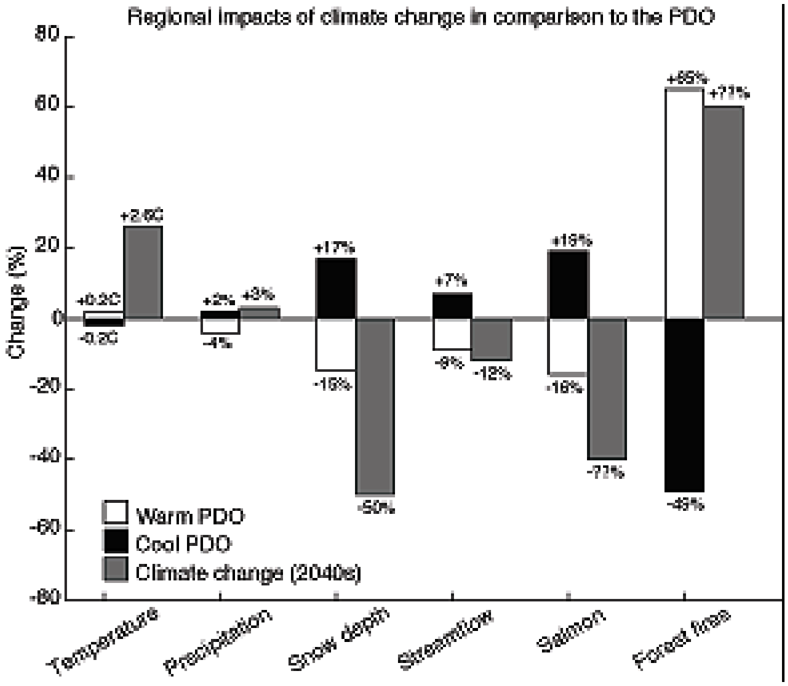

Population in Washington
millions
9
8
7
6
5
4
1990
2000
2010
2020
Year
8.4
7.9
7.5
7.2

Figure 13:


Regional impacts of climate change in comparison to the PDO
80
60
40
20
0
-20
-40
-60
-80
Change (%)
+0.2C
-0.2C
+2.6C
+2%
-4%
+3%
+17%
-15%
-50%
+7%
-9%
-12%
+19%
-16%
-71%
+65%
-49%
+71%
Warm PDO
Cool PDO
Climate change (2040s)
Temperature
Precipitation
Snow depth
Streamflow
Salmon
Forest fires

The Implications for South East Asia

The IPCC third assessment conducted by Working Group II concluded that among the key concerns of vulnerability and adaptive capacity, the following characterizations would apply (IPCC 2001, WG II, Table SPM-2):

- Adaptive capacity of human systems is low and vulnerability is high in the developing countries of Asia; the developed countries of Asia are more able to adapt and less vulnerable.
- Extreme events have increased in temperate and tropical Asia, including floods, droughts, forest fires, and tropical cyclones (high confidence).
- Decreases in agriculture productivity and aquaculture due to thermal and water stress, sea level-rise, floods and droughts, and tropical cyclones would diminish food security in many countries of arid, tropical, and temperate Asia; agriculture would expand and increase in productivity in northern areas (medium confidence).
- Runoff and water availability may decrease in arid and semi-arid Asia but increase in northern Asia (medium confidence).
- Human health would be threatened by possible increased exposure to vector-borne infectious diseases and heat stress in parts of Asia (medium confidence).
- Sea level rise and an increase in the intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia; increased intensity of rainfall would increase flood risks in temperate and tropical Asia (high confidence).
- Climate change would increase energy demand, decrease tourism attraction, and influence transportation in some regions of Asia (medium confidence).
- Climate change would exacerbate threats to biodiversity due to land-use and land-cover change and population pressure in Asia (medium confidence). Sea-level rise would put ecological security at risk, including mangroves and coral reefs (high confidence).
- Poleward movement of the southern boundary of the permafrost zones of Asia would result in a change of thermokarst and thermal erosion with negative impacts on social infrastructure and industries (medium confidence).

This information, by itself, is an insufficient basis for planning. We had earlier suggested an experiment in which we would seek to increase the utility for planning of ecologically-based regional assessment. The idea was to link three places which were very much affected by the combination of ENSO and the PDO in a comparative, trans-Pacific mode. The three places chosen were the Columbia Basin, the Murray-Darling Basin in Australia, and the Mekong River Basin in South East Asia. Fig. 14 shows the global reach of ENSO events in which both S.E. Asia and Australia clearly evidence a much stronger signal than the Pacific Northwest.

With respect to the PDO, Garreaud and Battisti (1998) and Dettinger et al. (2001) have shown that ENSO-like climate variations on a decadal time scale exist and importantly affect the climate patterns of the Southern Hemisphere in a fashion opposite to that exhibited in the Northern Hemisphere, as one would expect. Positive-phase variations then produce higher precipitation levels in the sub-tropics and negative-phase variations produce lower precipitation levels.

Both Australian colleagues in the Ecosystem Dynamics Group at Australian National University, and the Climate Impact Group at the CSIRO Division of Atmospheric Research responded enthusiastically. Intensive talks were then held with the hydrological community in Singapore, who were equally enthusiastic and who undertook to organize a representative selection of Chinese and S.E. Asian scientists to conduct the assessment of the Mekong River Basin. Sadly, the events in East Timor aborted these plans because funds on the Australian side had to be shifted for far more urgent purposes. We wish here to raise once again our invitation for our S.E. Asian colleagues to work with us in this common enterprise.

Figure 14:

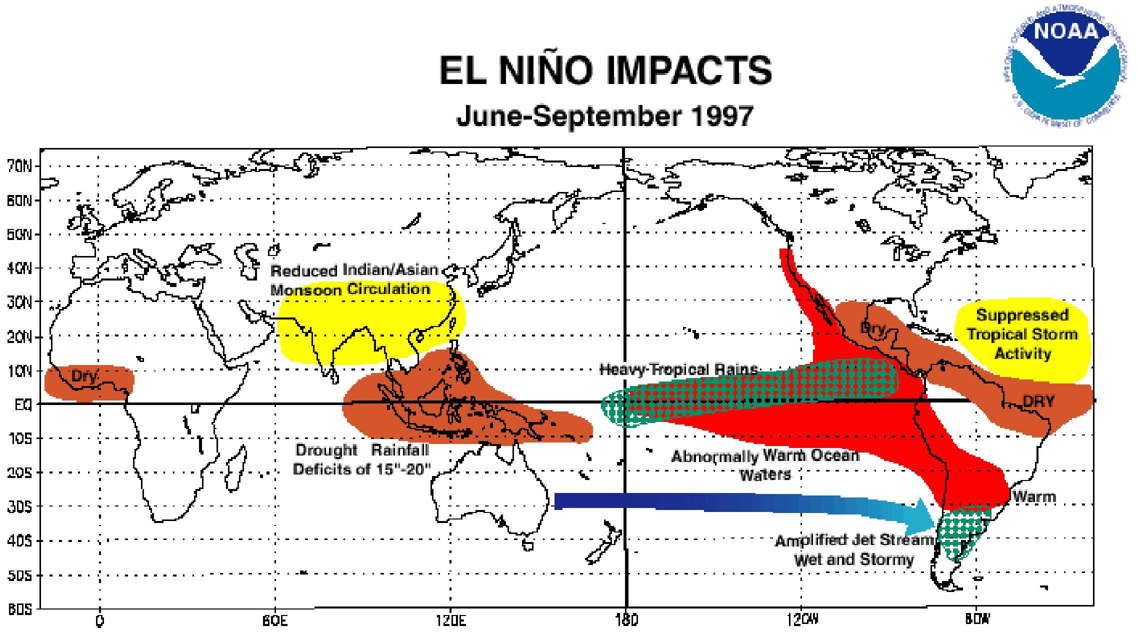


Figure 1. Schematic representation of major El Niño impacts during June-September 1997. The largest impacts thus far have been in the tropics and subtropics, and over the middle latitudes of the South Pacific and South America. The major impacts on the United States are not expected until the winter season.

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