LEARNING FROM AND ADAPTING TO CLIMATE VARIABILITY IN THE PACIFIC NORTHWEST

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In recent years, Pacific Northwest[1] (PNW) natural resource managers, planners, and policymakers have been increasingly utilizing climate information to prepare for and adapt to climate fluctuations on seasonal/interannual to decadal timescales. While some of this progress reflects improvements in climate forecasting, much can be attributed to efforts undertaken by the Climate Impacts Group (CIG) to increase regional resilience to climate fluctuations, including:

- developing regionally-specific integrated understanding of the consequences of climate fluctuations for PNW natural resources,
- developing seasonal to interannual forecast tools and climate change scenarios for integrating climate impacts into resource planning, and
- developing the strategies and relationships required to bring the academic research and the resource management/policymaking communities together for mutually beneficial interaction.

This paper describes the results and transferable lessons from eight years of sustained research and outreach undertaken by CIG (funded under NOAA's Regional Integrated Science and Assessments (RISA) Program). We show that the ability to adapt management processes in response to climate information is a complex function of: the nature of information available, characteristics of the institutions receiving and providing the information, and the methods by which the information is communicated.

The paper begins by introducing the crucial role climate service organizations, such as CIG and other RISA groups, play in making climate information not only *useful* for but *used* by regional stakeholders in planning and management. We describe the characteristics that influence the ability of resource management institutions[2] to adapt to climate variability and analyze institutional responses to new climate information. Finally, we show what these results imply for future and ongoing efforts to develop resilience to climate fluctuations on any timescale, from seasonal/interannual to centennial.

CLIMATE IMPACTS RESEARCH AND CAPACITY BUILDING IN THE PACIFIC NORTHWEST

CIG has been working since 1995 to increase the resilience of the PNW to fluctuations in climate, i.e., to provide resource managers and policy makers with the information and tools they need to improve their adaptability to climate fluctuations. To this end, CIG performs interdisciplinary research aimed at understanding the regional consequences of natural climate variability and anthropogenic climate change and works with PNW planners and policy makers to bring this information into regional decision making processes. In effect, CIG functions as a "pipe fitter", doing the work necessary to fit the outputs of climate research efforts (e.g., innovations in climate forecasting or advances in climate change projections) with the information needs and technological and institutional capacities of regional natural resource

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[1] The PNW: the combination of the Columbia River basin and the states of Washington, Oregon, and Idaho.

[2] "Institutions" refers to the formalized actions that underlie human social activity, including standards of behavior, formal decision rules and decision making procedures, and grants of authority to prescribe policy. "Law" or legal systems, for instance, are institutions.

management entities (Figure 1), thereby connecting two otherwise mostly independent (and often mismatched) institutions.

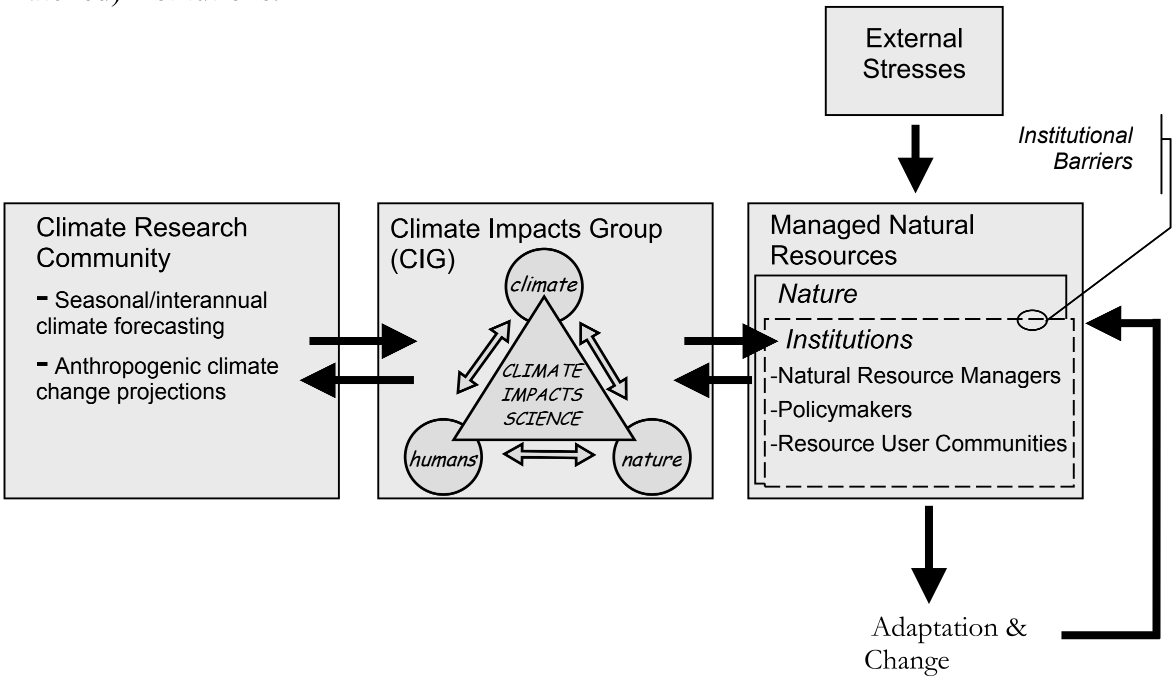

Figure 1. The Climate Impacts Group (CIG) translates climate information about natural climate variability and human-caused climate change into regionally-specific natural resource forecasts/projections for stakeholders in the Pacific Northwest (PNW). This translation is made possible by climate impacts research, a study of how climate, natural systems, and human socioeconomic systems and institutions interact to determine a region's sensitivity, adaptability, and vulnerability to climate fluctuations. Through outreach activities, such as specialized resource forecasting workshops, one-on-one consultancies, and high level policy and planning meetings, CIG works to tailor and provide this climate information to regional decision makers, with the aim of improving regional resilience to climate fluctuations. The institutional adaptation and change that could result in improved resilience is often impeded, however, by institutional barriers, which may also filter incoming information. (Note that institutional adaptation and change can also result from other external stresses on the management system.)

Making innovations in climate research relevant to regional stakeholders requires basic and applied research on the linkages between changes in climate and changes in natural resources. CIG's strategy is to develop an assessment of the implications of past climate variability for natural resources as a basis for projecting impacts and proposing adaptation strategies for future climate variability and change. Our research focuses on identifying the environmental parameters to which each natural resource system is sensitive and delineating the links between (a) regional climate and key environmental parameters (e.g., changes in snowpack due to changes in winter temperature), (b) environmental parameters and natural resources (e.g., changes in summer streamflow as a result of changes in snowpack), and (c) planetary and regional scale climate (e.g., changes in PNW winter climate associated with El Niño conditions). This work draws on process-based quantitative models (as in the case of climate impacts on water resources), empirical models (drawing on observed historic patterns of climate and resource variation), and conceptual models (based on hypothesized connections between climate and impacts) at a variety of timescales. CIG's research also includes an analysis of the characteristics and adaptive capacity of human institutions involved in natural resource management.

CIG's research on linkages between large scale climate variations (e.g., the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)) and regional climate,[3] combined with improving skill in monitoring and predicting these variations, provides opportunities to forecast future PNW climate. Our research on regional climate and natural resources has demonstrated that even subtle changes in PNW precipitation and temperature like those associated with variations in ENSO and PDO have noticeable impacts on the region's snowpack, streamflows, floods, likelihood of summer droughts, forest productivity and fire risk, salmon abundance, quality of coastal and near-shore ocean habitat, and risk of coastal hazards (Mantua et al. 1997; Hamlet and Lettenmaier 1999a,b, 2000; Mote et al. 1999, 2003; Peterson and Peterson 2001; Peterson et al. 2002; Gedalof 2002; Gedalof et al. 2003).

Together, these developments provide opportunities to develop regionally specific climate-based natural resource forecasts a few seasons to years in advance. CIG has developed climate, streamflow, and water demand forecast applications for water resources management (Hamlet and Lettenmaier 1999a, 2000; Hamlet et al. 2002). Potential additional applications include: climate-based forecasts for the weather derivatives market (energy demand projections, natural gas storage requirements, energy market analysis); streamflow, water quality, and stock-level salmon abundance forecasts for fisheries; forest fire risk and forest growth projections for forestry managers; and coastal hazard (flooding and erosion) forecasts for disaster planning.

Studies in the 1990s (Changnon et al 1995; Golnaraghi 1997; Pulwarty and Redmond 1996), consistently showed that climate forecasts were not then being widely used in either the public or private sectors. Similarly, in initial contacts with stakeholders in the PNW (Callahan 1997; Callahan et al. 1999), CIG found that translation of new climate forecast technologies into water resource forecasts in an academic setting would not stimulate forecast use by water managers. A coordinated outreach effort was also required to (1) introduce the water management community to the potential role of climate forecasts in management and (2) facilitate the transfer of information from the research to the resource management context (Gamble et al. 2003).

Building regional capacity to adapt to climate fluctuations required significant effort communicating with the public, private, and North American tribal groups responsible for managing and directing the management of regional natural resources. An outreach approach that has been particularly successful has been sectorally-focused climate workshops. At these workshops, CIG (1) interprets current climate forecasts, (2) translates these forecasts into regional climate outlooks and climate-based resource forecasts, and (3) discusses forecast products proposed or in development. These workshops are valuable for both CIG and the participants. CIG teaches interpretation of seasonal forecasts in terms of regionally-relevant, sectorally-specific impacts. Stakeholders identify their needs and, by implication, useful products CIG might develop. Overall, these workshops have proved to be highly successful; a group of "early adopters" (Seattle Public Utilities (SPU), the National Resources Conservation Service, Seattle City Light (SCL), the Bonneville Power Administration (BPA), and the Columbia River Intertribal Fisheries Commission (CRITFC)) have constructed and are beginning to use their own climate-based streamflow forecasting systems in their decision support systems. Several of these systems (SCL, BPA, CRITFC) are based on methods developed by CIG; all rely on CIG's climate-water resources research.

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[3] Analysis of past ENSO and PDO events shows that warm (cool) phases of ENSO and PDO increase the odds for below (above) normal precipitation and above (below) normal temperatures in the PNW, particularly during the cool season months (Mote et al. 2003). (The warm (cool) phase of ENSO is often called El Niño (La Niña).)

INSTITUTIONAL RESPONSES TO CLIMATE VARIABILITY: INHERENT ADAPTIVE CAPACITY

Understanding the nature of linkages between human institutions and climate variability is essential for understanding the vulnerability of human systems to inter-annual and decadal changes in climate, and, by extension, their vulnerability to changes in climate at longer time scales (Gray 1999; Callahan et al. 1999; Miles et al. 2000). The inherent capacity of institutions to adapt to, or prepare for, climate variations is a function of several factors, including: the time scale(s) of climate variations relevant for management of a particular resource, the structure and historical development of existing institutions, and the complexity of the management domain.

Management Timescales. Differences in the time scales of climate variation considered in resource management have important implications for the perceived importance, and ultimately the use, of climate information.

- Forest managers have historically assumed that climate is essentially stationary over the 60-80 year timeframe of bringing plantings to maturity and harvest. Only very recently have the changing patterns of disturbances (e.g., fire, disease, insect damage) that vary from year to year and decade to decade begun to be considered in the context of management, policy, and long-term planning (Mote et al. 2003).
- For fisheries management, the role of climate variability has been masked by the complexity of the biological systems involved. In the absence of a clear relationship between variations in the resource and variations in climate, fisheries management systems have evolved without explicit linkages to formal information about climate variability. Instead "real-time" indicators (such as salmon jack[4] returns) have been used to monitor variability. Only recently have explicit linkages to climate variations been identified (Mantua et al. 1997; Hare and Mantua 2000; Logerwell et al. 2003).
- Water resources management systems, although frequently informed by observed climate variability (via historic streamflow records), have been relatively unresponsive to decadal and longer climate variations. Water allocation policy and expansion of irrigated acreage in Washington's Yakima basin, for example, followed relatively short-lived variations in water availability without recognition that these changes could be cyclical (e.g., associated with variations in the PDO) and therefore unsustainable on a long term basis (Gray 1999).

Characteristics of Existing Management Systems. The specific characteristics of existing management systems in different natural resource sectors imply differing vulnerabilities to climate change.

- Forests and fisheries may be vulnerable to gradual changes in climate because their management systems are either unresponsive to climate variations (e.g., traditional management of forest plantations) or unable to project future resource changes, due to insufficient understanding of the extremely complex linkages between climate variations and the resource (e.g., fisheries management (Mantua and Francis 2003)).
- In water resources, where the relationships between climate and the resource are largely physical in nature (and therefore easier to project forward in time with models), linking climate information and planning is practically feasible (Hamlet and Lettenmaier 1999a,b, 2000; Snover et al. 2003). However, political and institutional actions are predominantly informed by information on relatively short time scales (e.g., driven by crisis or the short time frame of political decision processes). There are few adaptive models for responding to problems that evolve gradually over a long time period.

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[4] Salmon jacks are males that return to their spawning ground prior to their year of maturity.

Management Domain and Jurisdiction. The fragmented management systems often associated with large management domains can hinder effective management and planning. In the Columbia River basin, for example, Miles et al. (2000) showed that important differences between vulnerability to high or low flows result from a high degree of management centralization on the high flow side (resulting in low vulnerability) and fragmentation on the low flow side (where vulnerability is high). Transboundary considerations (e.g., cultural, ideological, and institutional conflicts at intra-state, inter-state and international levels of governance) are also important in the PNW (Miles et al. 2000; Mote et al. 2003; Hamlet 2003). Climate related examples include ocean fisheries management conflicts between Canada and the US and conflicts between upstream water use for irrigation in Idaho and downstream efforts to reserve water for fish in the lower Snake and Columbia Rivers.

Historical Development of Management Institutions. The historical development of management institutions, combined with past patterns and consequences of climate variability, can also determine vulnerability to future changes in climate. Participatory management systems that have had to cope with frequent conflicts associated with climate variability or other drivers (e.g., water management institutions that allocate Snake River water for irrigation) may be better positioned to adapt to future climate shifts than centralized systems in less conflict-prone areas. The management "train wreck" in the Klamath basin in 2001, for example, is partly attributable to the fact that large irrigation shortfalls were essentially unprecedented prior to Endangered Species Act listings in the basin. Management systems for dealing with water allocation in times of shortage depended on US Bureau of Reclamation (USBR) administration rather than arrangements created by the participants over time (Slaughter, in preparation).

INSTITUTIONAL RESPONSES TO CLIMATE FORECASTS: WHEN DOES NEW INFORMATION STIMULATE CHANGE?

In this section we move from an examination of institutions' inherent capacity to adapt to climate variability to a discussion of institutional barriers to the use of climate forecasts. An understanding of these barriers has been developed from an analysis of the institutional context of resource management (Gamble et al. 2003; Hamlet et al. 2002; Hamlet 2003; Snover et al. 2003) and from sustained interaction with regional stakeholders.

The ability of a particular management agency to bring climate forecasts to bear on specific decision processes is a complex function of having sufficiently accurate, spatially-relevant forecast information at the right time in the decision process (Ray 2003); adequate incentives; technical capacity to access, interpret, and use forecasted information; and the ability and will to manage the benefits and risks associated with use of the forecast.

The varying degree to which ENSO/PDO based streamflow forecasts have been incorporated into PNW water management decision processes illustrates some of these factors. Early adopters of CIG's streamflow forecasting innovations were private and public sector hydropower operating and marketing agencies (SCL, BPA) and small centralized water supply management agencies (SPU and PWB). Hydropower marketing entities (particularly in the private sector) have a strong economic incentive to improve system performance and are relatively technically advanced, with access to sophisticated tools for managing risk using probabilistic information (hydropower companies routinely use short term weather forecasts, for example). Small, progressive water supply management entities have centralized control over relatively small systems, inherently flexible management policies, and can adapt their decision processes to incorporate forecast innovations without incurring high costs (Gray 1999).

The “second wave” of adopters of forecast innovations may prove to be larger irrigation water supply systems east of the Cascade Mountains (e.g., USBR in the Yakima River basin and Idaho Department of Water Resources (IDWR)) where reasonably strong incentives for management improvement exist, but institutional barriers impede rapid change. Barriers include high costs of changing operating guidelines, rigid procedures for allocating water, and the high management complexity of the larger management domain.

Extraordinarily risk-averse institutions (e.g., those responsible for flood control) may be the slowest to utilize forecast innovations because of the associated professional risks, limited incentives for change, reluctance to trade benefits in other sectors for short term risks to the primary objective (preventing floods), and fragmented management. When those responsible for flood control are not responsible for other water management objectives, for example, they have little incentive to take risks to benefit other aspects of system operation.[5,6]

In some cases developing useful forecasts to guide management decision processes may prove to be impossible, either because of practical considerations or because there is actually no predictability to be exploited. Examples include long-range management of fisheries stocks where development of accurate multi-year forecasts may be prevented by the unpredictable nature of the system (Mantua and Francis 2003). In such cases, it may be more valuable to focus on decreasing the vulnerability of the managed system. Basing adaptive water allocation decisions on markets (rather than specific regulatory mandates) is a way of designing an institution that is not informed by predictions of future conditions, but will nonetheless change over time in response to changing conditions (e.g., Slaughter et al. 2003).

CLIMATE CHANGE OUTREACH AND CAPACITY BUILDING

CIG has been working to stimulate regional preparation for anthropogenic climate change since 1997. We began by using our understanding of linkages between climate and natural resources to construct scenarios of projected future changes in regional natural resources. These scenarios focused on the 2020s and the 2040s, i.e., timeframes appropriate for the planning horizons of many resource agencies.

Outreach was targeted at technical managers in an attempt to capitalize on their developing interest in seasonal/interannual climate forecasts. After learning that managers at this level lack the authority to set their own agendas on this issue, CIG convened senior water resource managers and policy makers for a “Climate Change and Water Policy Workshop” (CIG 2001). Most workshop participants recognized climate change as a potentially significant threat to PNW water resources. Several upper-level managers stated that they would use data on climate impacts in their planning if it were accessible.[7] While few participants wished to take up the specific mantle of planning for climate change, most wanted to know how it would affect their primary issues of concern, i.e., drought and growing water scarcity. This represented a significant step

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[5] During a presentation at a CIG workshop on inter-annual streamflow forecasts a prominent official for the US Army Corps of Engineers described in some detail the disciplinary measures that would befall her if flood damages were to occur on her watch. Afterwards a member of the audience asked what would happen if fish flow targets were missed as a result of her actions. There were no important professional consequences that the Corps official could cite in this instance.

[6] In agencies that manage both for flood control and other objectives, jurisdictional issues may be less prominent. This is true for USBR management of dams in Idaho for both irrigation and flood control.

[7] In response to this request, CIG now provides climate change streamflow scenarios via the web (www.ce.washington.edu/~hamleaf/climate_change_streamflows/CR_cc.htm) to support simple and inexpensive evaluation of water resources systems’ vulnerability to climate change (Snover et al. 2003).

forward from 1997, when climate change was not recognized as a serious issue affecting the region (Snover et al. 1998).

More recently, CIG has engaged in partnerships with individual planning agencies interested in incorporating climate change into their planning, including PWB (Palmer and Hahn 2002), SPU, IDWR, and The Pacific Northwest Power Planning Council (Snover et al. 2003).

LESSONS LEARNED FROM STUDYING CLIMATE VARIABILITY: HOW CAN WE ENHANCE REGIONAL CAPACITY TO ANTICIPATE AND ADAPT TO CLIMATE VARIABILITY AND CHANGE?

ASSESSING CLIMATE IMPACTS AND INSTITUTIONAL ADAPTABILITY

1. A complete assessment of the impacts of climate change must address:
   - both direct (e.g., resulting directly from changes in temperature and precipitation) and indirect (occurring via changes in, e.g., the hydrologic cycle and in ocean conditions) impacts of climate fluctuations,
   - the asymmetry of climate impacts (e.g., the PNW's asymmetric vulnerability to droughts vs. floods),
   - the limits to predictability and the skill of climate change projections, and
   - the potentially confounding influences of climate variability and human activities.

   A vigorous climate science research effort is a critical part of the regional climate impacts assessment enterprise; without such research, development of forecast applications will be limited.

2. Answering the real world natural resource questions raised by regional stakeholders requires an integrated, interdisciplinary research approach. In the PNW, fish, water, trees, and coastal watersheds are tightly interconnected on different space and time scales. Understanding horizontal integration (i.e., the relationships among these sectors) is far more complicated and difficult than understanding vertical integration (i.e., climate impacts and society's response capacity within a single sector).

3. Information about the nature of future climate variability (which is currently unavailable) is crucial for making useful climate change related resource projections. In water resources, for example, the inter- and intra-annual sequencing of climatic events determines the nature of impacts.

4. Most technical managers operate at watershed and sub-watershed rather than regional space scales. This accentuates the downscaling challenge for regional climate change impact research teams.

FACTORS CONTRIBUTING TO INSTITUTIONAL ADAPTABILITY

1. Institutional change is facilitated by stress, sometimes to the point of crisis. If stress is below a critical threshold, innovation is unlikely, even if everyone knows that a crisis will eventually occur.

2. Successful innovation is facilitated by structures in which those subject to institutional rules have a prominent voice in determining the rules. Stakeholder ownership is far more conducive to innovative capacity than political processes that attend the commons.

3. The ability of a particular user to make use of forecasts hinges on his/her ability to manage risks (calculate and hedge) on the timescale of the forecasted changes.
    - Few know how to manage risks on the decadal to centennial timescale of climate change.
    - Use of deterministic forecasts does not ensure an ability to adopt probabilistic (e.g., ENSO-based) forecasts.
    - Those who cannot manage risks may be best served by developing institutional resilience to climate fluctuations.

4. Because of the different timescales associated with climate variability (seasons to years, relevant for short-term tactical decision making) and climate change (decades to centuries, relevant for long-term, strategic planning), information about these two climate drivers will be useful to different types of organizations and to different people within an organization.

INSTITUTIONS FOR FORECASTING AND/OR COMMUNICATING FORECASTS

1. An ongoing relationship between forecasters and the user community is required. Without direct communication between forecasters and users of climate forecasts, minimal feedback and dialog occur. Without monitoring by forecasters of forecast accuracy and impacts on users' behavior, users will have little reason to trust forecast accuracy and utility.

2. Establishing credibility with user groups requires a sustained effort over a long period of time.

3. Partnerships and technology transfer are the primary mechanisms for moving forecasts from research and experimental activities into operations. NOAA has not yet provided mechanisms under which RISA teams can systematically transfer successful experimental products to the operational community.

COMMUNICATING CLIMATE INFORMATION

1. Policy makers' decision processes are often narrowly focused on specific problems. Therefore, information about the impacts of climate change should be shaped to add information rather than complexity.

2. A policy maker's risk is frequently asymmetrical. The costs of getting it wrong can be significantly greater than rewards of getting it right or just doing nothing. The policy maker must be fully informed about the probabilities of error in climate change projections. Only then will s/he feel comfortable incorporating climate information in the decision process.

3. High credibility can be gained by grounding information about the future in examples from the past. Stakeholders can apply their understanding of the consequences of past climate events to "calibrate" likely impacts of projected future events and to justify action. Generating the capacity to respond effectively to near-term challenges such as drought in the PNW, for example, is more politically viable than (but in many ways equivalent to) generating the capacity to adapt to climate change.

4. Fruitful engagement of the stakeholder community requires simultaneously targeting the entire hierarchy: operations, planning, and policy levels within municipalities, states, regional and federal organizations, and Congress. For example, even though Congress requested that coastal states address the potential impacts of sea level rise, little sea level rise planning has been done in Washington because it has not been mandated at the state level.

5. The spatial and temporal scales and focus of climate information must match the spatial and temporal scales and perspective of decision makers. CIG's efforts to provide water resources managers with climate change information, for example, has demonstrated that, while agencies are now incorporating climate change considerations in planning, they want information that interfaces with their models, not more academic climate sensitivity studies.

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