# VIII. NEXT STEPS

In 2011 and 2012, National Wildlife Federation (NWF), in partnership with the University of Washington Climate Impacts Group (CIG), will convene six expert focus groups to confirm, augment, and disseminate the findings of this report. Leveraging NWF's existing efforts in outreach and stakeholder engagement and CIG's expertise conducting similar focus groups, NWF will utilize a participatory, integrative approach to engage experts in focus group discussions of climate change effects and adaptation strategies in freshwater aquatic and riparian ecosystems in the NPLCC geography.

Similar to the review process used to produce this final draft report, information gathered during focus group meetings will be incorporated into this report and reviewed by focus group participants as well as others. Focus groups will address climate change at both the local- and landscape-level, incorporating expert knowledge on the major effects resulting from climate change in freshwater ecosystems, the implications for biological communities across taxa and trophic levels, and adaptive approaches to address impacts into this report to produce the first picture of landscape-wide climate change effects in these ecosystems. Further, focus groups will confirm and revise the adaptation options described in the draft reports to produce a menu of policy and management options that respond to climate change in these ecosystems, and are therefore useful and relevant to management needs across the NPLCC landscape. The final product will be the first compilation of landscape-wide climate change impacts and adaptation approaches for the NPLCC region's freshwater aquatic and riparian ecosystems.

# IX. APPENDICES

## 1. KEY TERMS AND DEFINITIONS

## A

**Adaptation:** adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[1922]

**Adaptive capacity:** the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

**Adaptive management:** an experimental framework composed of management actions that specifies the research and monitoring information needed to evaluate management success and stipulates how and when information will be used to revise management action.[1923] It is similar to scenario-based planning, but does not build management experiments into a model.[1924]

**Aerosol:** highly dispersed solid or liquid particles suspended in a gas

**Anoxia:** a water column devoid of oxygen

**Aquatic** (habitat or ecosystem): habitats or ecosystems dominated by water

**Autotrophic:** the capacity to perform primary production; self-feeding; able to use $CO_2$ as a source of carbon using chemical (chemoautotrophy) or light (photoautotrophy) energy[1925]

## B

**Baseflow:** the level of stream discharge in the absence of recent storms[1926]

**Benthic community:** the community of organisms living on or near the bottom of a water body such as a river, a lake, or an ocean.[1927]

## C

(Date of) **Center of mass** (of streamflow): the date at which roughly half of the mass of annual streamflow has occurred

(Date of) **Center of volume** (of streamflow): the date at which roughly half of the volume of annual streamflow has occurred

**Climate:** Climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO).[1928]

**Climate change:** Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines 'climate change' as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.[1929]

**Climate change adaptation:** a dynamic management strategy that involves identifying, preparing for, and responding to expected climate change in order to promote ecological resilience, maintain ecological function, and provide the necessary elements to support

[1922] *IPCC. *Climate Change 2007: Impacts, Adaptation and Vulnerability: Introduction.* (2007, p. 6)
[1923] Gregg et al. (2011); Peterson, Cumming and Carpenter. (2003)
[1924] Peterson, Cumming and Carpenter. (2003)
[1925] Dodds & Whiles. (2010)
[1926] Dodds & Whiles. (2010)
[1927] Parry et al. (Eds.) (2007, p. 870)
[1928] Parry et al. (Eds.) (2007, p. 871)
[1929] Parry et al. (Eds.) (2007, p. 871)

biodiversity and sustainable ecosystem services.[1930]

**Climate shift:** a rapid change in relatively stable physical ocean properties that affects biota and ecosystems

**Climate threshold:** The point at which external forcing of the climate system, such as the increasing atmospheric concentration of greenhouse gases, triggers a significant climatic or environmental event which is considered unalterable, or recoverable only on very long time-scales, such as widespread bleaching of corals or a collapse of oceanic circulation systems.[1931] *See also Threshold.*

**Climate variability:** Climate variability refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).[1932]

# D

# E

**Ecosystem:** The interactive system formed from all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems cover a hierarchy of spatial scales and can comprise the entire globe, biomes at the continental scale or small, well-circumscribed systems such as a small pond.[1933]

**Ecosystem-Based Management (EBM):** an integrated approach to management that considers the entire ecosystem, including humans. EBM emphasizes the protection of ecosystem structure, function, and key processes; focuses on a specific ecosystem and the activities affecting it; explicitly accounts for the interconnectedness within systems (e.g. between species); acknowledges interconnectedness among systems (e.g. air, land and water); and integrates ecological, social, economic, and institutional perspectives.[1934]

**El Niño:** the warm phase of ENSO; characterized by stronger than average sea surface temperatures in the central and eastern equatorial Pacific Ocean, reduced strength of the easterly trade winds in the Tropical Pacific, and an eastward shift in the region of intense tropical rainfall

**El Niño-Southern Oscillation (ENSO):** the major source of inter-annual climate variability in the Pacific Northwest (PNW). ENSO variations are more commonly known as El Niño (the warm phase of ENSO) or La Niña (the cool phase of ENSO)

**Evapotranspiration:** water evaporation from soils, plant surfaces, and water bodies and water losses through plant leaves.[1935]

**Exposure (to climate change):** the nature and degree to which a system is exposed to significant climatic variations

**Extinction (of species):** the state of a species that no longer exists anywhere on Earth (includes wild and captive species)

**Extirpation (of species):** native species that no longer exist in the wild in any part of their original distribution area, although they may exist elsewhere

# F

**Firn:** Old snow that has become granular and compacted (dense) as the result of various surface metamorphoses, mainly melting and refreezing but also including sublimation (i.e. the physical process by which a solid transforms

[1930] Glick et al. (2009, p. 8)
[1931] Parry et al. (Eds.) (2007, p. 872)
[1932] Parry et al. (Eds.) (2007, p. 872)
[1933] Parry et al. (Eds.) (2007, p. 874)
[1934]. West Coast EBM Network. (2010)
[1935] Brooks et al. *Hydrological Processes and Land Use.* (2003)

to a gas without going through a melting stage)[1936]

**Flux:** the rate of flow of energy or particles across a surface

**Freshet:** the annual spring rise of streams in cold climates as a result of melting snow; a flood resulting from rain or melting snow, usually applied only to small streams and to floods of minor severity; a small freshwater stream[1937]

**Freshwater ecosystem:** Freshwater ecosystems are aquatic systems which contain drinkable water or water of almost no salt content. Freshwater resources include lakes and ponds, rivers and streams, reservoirs, wetlands, and groundwater.[1938]

# G

**Glacier:** A mass of land ice, formed by the further recrystallization of firn, flowing continuously from higher to lower elevations.[1939]

**Gyre:** a spiral oceanic surface current moving in a clockwise direction

# H

**Habitat:** the locality or natural home in which a particular plant, animal, or group of closely associated organisms lives.[1940]

**Heterotrophy:** metabolic energy and growth from degradaton of organic molecules; carnivory, detritivory, herbivory, microbial decay, and omnivory[1941]

**Hydric soils:** soils with characteristics related to constant water inundation[1942]

**Hydrologic cycle:** the existence and movement of water on, in, and above the Earth; composed of sixteen components: water storage in oceans, evaporation, sublimination, evapotranspiration, water in the atmosphere, condensation, precipitation, water storage in ice and snow, snowmelt runoff to streams, surface runoff, streamflow, freshwater storage, infiltration, groundwater storage, groundwater discharge, springs; the processes and pathways involved in the circulation of water from land and water bodies to the atmosphere and back again[1943]

**Hydrologic year:** generally, 1 October to 30 September in the Northern Hemisphere, 1 July to 30 June in the Southern Hemisphere; the annual cycle that is associated with the natural progression of the hydrologic seasons. It commences with the start of the season of soil moisture recharge, includes the season of maximum runoff (or season of maximum groundwater recharge), if any, and concludes with the completion of the season of maximum evapotranspiration (or season of maximum soil moisture utilization)[1944]

**Hydrology:** the science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground

**Hypolimnion:** the bottom layer of a stratified lake; below the metalimnion[1945]

**Hypoxia:** a water column largely deficient of dissolved oxygen; generally, a water column with less than 2.0 milligrams of oxygen per liter of water dissolved within it

# I

**(climate change) Impacts:** the effects of climate change on natural and human systems.[1946]

# J

[1936] American Meteorological Society. *Glossary of Meteorology (website).* (n.d.)
[1937] Farlex. *Freshet (website).* (2011)
[1938] U.S. EPA. *Aquatic Biodiversity: Freshwater Ecosystems (website).* (2010)
[1939] American Meteorological Society. (n.d.)
[1940] Parry et al. (Eds.) (2007, p. 876)
[1941] Parry et al. (Eds.) (2007, p. 876)
[1942] Parry et al. (Eds.) (2007, p. 876)
[1943] Brooks et al. (2003, p. 21)
[1944] American Meteorological Society. (n.d.)
[1945] Dodds & Whiles. (2010)
[1946] Parry et al. (Eds.) (2007, p. 876)

# K

# L

**La Niña:** the cool phase of ENSO; characterized by the opposite – cooler than average sea surface temperatures, stronger than normal easterly trade winds, and a westward shift in the region of intense tropical rainfall.

**Lake:** a very slowly flowing or nonflowing (lentic) open body of water in a depression and not in contact with the ocean (the definition includes saline lakes but excludes estuaries and other mainly marine embayments)[1947]

**Littoral zone:** shallow, shoreline area of a water body; the portion of benthos from zero depth to the deepest extent of rooted plants[1948]

# M

**Marsh:** continuously or usually inundated wetland with saturated soils and emergent vegetation[1949]

**Metalimnion:** the intermediate zone in a stratified lake in which the temperature change with depth is rapid, below the epilimnion and above the hypolimnion; also known as the thermocline or the mesolimnion[1950]

**Metapopulation:** two or more geographically separated populations that interact to some degree[1951]

# N

[1947] Dodds & Whiles. (2010, p. 143)
[1948] Dodds & Whiles. (2010)
[1949] Dodds & Whiles. (2010)
[1950] Dodds & Whiles. (2010)
[1951] Dodds & Whiles. (2010)

# O

**Oligotrophic:** nutrient-poor system with relatively low primary production[1952]

# P

**Pacific Decadal Oscillation** (PDO): long-lived El Niño-like pattern of Pacific climate variability

**Periphyton:** the mixed assemblage of organisms attached to solid substrates in lighted benthic habitats, including algae, bacteria, protozoa, and invertebrates; a biofilm containing algae; also called aufwuchs and microphtyobenthos[1953]

**pH:** activity of hydrogen ions (which is closely related to concentration), expressed as $\log_{10}$ (moles $H^+$ liter$^{-1}$)[1954]; a measure of the acidity or alkalinity (i.e. basicity) of a substance, ranging on a scale of 0 to 14, where 7 is "neutral" (neither acidic nor basic). The scale is logarithmic (i.e. a substance with pH 5 is ten times more acidic than a substance with pH 6).

**Phenology:** the study of natural phenomena that recur periodically (e.g. development stages, migration) and their relation to climate and seasonal changes.[1955]

**Phytoplankton:** the plant forms of plankton

**Pond:** an inland body of freshwater naturally formed by processes such as glacial retreat; generally smaller and shallower than lakes.

**Precipitation:** the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds

**Puget Sound:** a large estuary complex in the Pacific Northwest

# Q

[1952] Dodds & Whiles. (2010)
[1953] Dodds & Whiles. (2010)
[1954] Dodds & Whiles. (2010)
[1955] Parry et al. (Eds.) (2007, p. 879)

# R

**Radiative forcing:** measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system; an index of the importance of the factor as a potential climate change mechanism

**Realignment adaptation:** a type of adaptation typically used in already significantly disturbed systems in which the system (e.g., an organism, population, community, or ecosystem) is changed to be healthy under expected future conditions rather than returned to historical conditions

**Recruitment:** the number of fish entering each size or age class[1956]

**Relocation:** a type of adaptation in which a system (e.g., an organism, population, community, or ecosystem) is moved to a new location, either by natural processes or through human assistance (latter also known as assisted migration)

**Reservoir:** similar to lakes, but constructed by humans. Levels are generally controlled by an outlet at a dam. Natural lakes that have been dammed may also function as partial reservoirs.

**Resilience:** the amount of change or disturbance that can be absorbed by a system (e.g., an organism, population, community, or ecosystem) before the system is redefined by a different set of processes and structures; the ability of a system to recover from change or disturbance without a major phase shift

**Resistance:** the ability of a system (e.g. an organism, population, community, or ecosystem) to withstand a change or disturbance without significant loss of structure or function

**Response adaptation:** a type of adaptation that facilitates the transition of ecosystems from current, natural states to new conditions brought about by a changing climate

[1956] Dodds & Whiles. (2010)

**Riffle:** a rapidly flowing portion of a river or stream where the influence of the bottom can be seen at the surface[1957]

**Riparian** (habitat or ecosystem): related to or located near water; often a transition zone between terrestrial and aquatic habitats[1958]

**Riparian buffer:** an area adjacent to a stream or other water body where vegetation is left intact to reduce pollution inputs[1959]

**River:** the common term for a large stream.

# S

**Saltwater intrusion / encroachment:** displacement of fresh surface water or groundwater by the advance of salt water due to its greater density; usually occurs in coastal and estuarine areas due to reducing land-based influence (e.g. from reduced runoff & associated groundwater recharge; from excessive water withdrawals from aquifers) or increasing marine influence (e.g., relative SLR).[1960]

**Scenario-based planning:** a systematic method that considers a variety of possible futures that include the key uncertainties in a system (as opposed to a focus on the accurate prediction of a single outcome). Scenarios are specific to the planning process, are accompanied by narratives, and are used to evaluate policy and management options. Participants are able to explore the effectiveness of various strategies, identifying actions that work well across multiple scenarios and are robust under situations of high uncertainty.[1961]

**Secondary production:** tissue production by heterotrophic organisms[1962]

**Sensitivity (to climate change):** the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.

[1957] Dodds & Whiles. (2010)
[1958] Dodds & Whiles. (2010)
[1959] Dodds & Whiles. (2010)
[1960] Parry et al. (Eds.) (2007, p. 880)
[1961] Gregg et al. (2011); Peterson, Cumming and Carpenter. (2003)
[1962] Dodds & Whiles. (2010)

**Shredder:** an organism that makes its living shredding organic material for food[1963]

**Species diversity:** generally measured as the number of species in an area and their evenness (relative abundance) [1964]

**Species richness:** the number of species in an area[1965]

**Spring pulse onset:** date of the beginning of the spring or early summer snowmelt-derived streamflow for snowmelt-dominated rivers[1966]

**Stratification**: density differences in water that can maintain stable layers[1967]

**Stream:** the water flowing in a natural channel (as distinct from a canal).[1968]

**Sublittoral:** bottom region between littoral and profundal zones[1969]

# T

**Threshold:** The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.[1970] *See also climate threshold.*

**Trophic cascade:** influence of consumer organisms on those lower in the food web with alternating effects at each trophic level (top-down control)[1971]

**Trophic state:** total ecosystem productivity, including heterotrophic and autotrophic pathways[1972]

# U

# V

**Vulnerability (to climate change):** the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts. It is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

**Vulnerability Assessment:** process of identifying, quantifying, and prioritizing the vulnerabilities in a system; a key tool for carrying out climate change adaptation planning for natural systems and informing the development and implementation of resource management practices

# WXYZ

**Water column:** a conceptual column of water from surface to bottom sediments

**Water cycle:** *See hydrologic cycle*

**Water year:** *See hydrologic year*

**Wet meadow:** a meadow without open water but saturated soils[1973]

**Wetland:** lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water;[1974] areas inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation adapted for life in saturated soil conditions[1975]

[1963] Dodds & Whiles. (2010)
[1964] Dodds & Whiles. (2010)
[1965] Dodds & Whiles. (2010)
[1966] Stewart, Cayan and Dettinger. (2005, p. 1138)
[1967] Dodds & Whiles. (2010)
[1968] U.S. Geological Survey. (2008)
[1969] Dodds & Whiles. (2010)
[1970] Parry et al. (Eds.) (2007, p. 882)
[1971] Dodds & Whiles. (2010)
[1972] Dodds & Whiles. (2010)
[1973] Dodds & Whiles. (2010)
[1974] U.S. Fish and Wildlife Service. (1993)
[1975] Dodds & Whiles. (2010)

## 2: SRES SCENARIOS AND CLIMATE MODELING

The explanation of SRES scenarios is excerpted from the IPCC's AR4 Synthesis Report (p. 44). Figure 31 was accessed online at http://sedac.ciesin.columbia.edu/ddc/sres/, December 2, 2010.

**SRES scenarios**

SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. {WGI 10.1; WGII 2.4; WGIII TS.1, SPM}

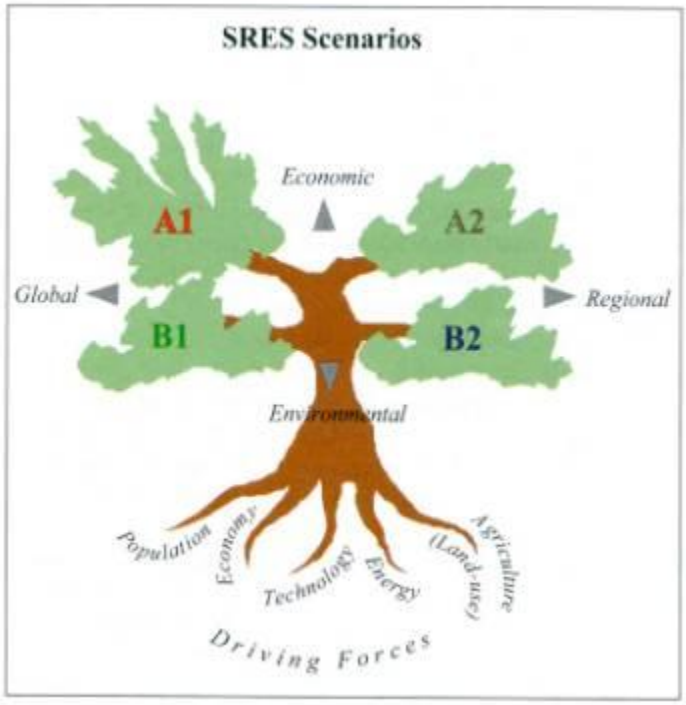


**Figure 31.** SRES Scenarios.

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. {WGIII TS.1, SPM}

**Climate modeling**

Global Models

Envisioning global climate in a future with much higher greenhouse gases requires the use of physically based numerical models of the ocean, atmosphere, land, and ice, often called global climate models

(GCMs) or climate system models.[1976] A common set of simulations using 21 GCMs was coordinated through the Intergovernmental Panel on Climate Change (IPCC).[1977] These models typically resolve the atmosphere with between 6,000 and 15,000 grid squares horizontally, and with between 12 and 56 atmospheric layers.[1978]

Simulations of 21st century climate require projections of future greenhouse gases and sulfate aerosols (which reflect sunlight and also promote cloud formation, thereby offsetting greenhouse gases locally), of which more than 40 were produced and six "marker" scenarios selected (B1, B2, A1, A1B, A1F1, A2) under the auspices of the IPCC.[1979] Three of these scenarios were commonly chosen for forcing the GCMs: B1, A1B, and A2.[1980] A2 produces the highest climate forcing by the end of the century, but before mid-century, none of the scenarios is consistently the highest.[1981] Though B1 is the lowest of the IPCC illustrative scenarios, it still produces changes in climate that many scientists call "dangerous" — a threshold that a growing number of political leaders have stated their intention to avoid.[1982] At the high end, scenario A1FI results in even higher climate forcing by 2100 than A2 or A1B.[1983] Mid-2000s global emissions of $CO_2$ exceeded even the A1FI scenario.[1984]

Downscaled Climate Models

*Note: While the information described here pertains to Washington State, it is often applicable for sub-global (e.g., regional, local) modeling elsewhere.*

Global climate models do not account for the atmospheric processes that determine the unique spatially heterogeneous climatic features of Washington.[1985] Statistical downscaling is based on fine-scale data derived using assumptions about how temperature and precipitation vary over complex terrain in order to interpolate the sparse station network (about 50-km spacing) to a 0.0625° grid.[1986] Information simulated by the coarse-resolution global models (with output on a 100-to-300 km grid) is then used to project the future climate.[1987] This approach represents the mean climate and local regimes quite well but does not take into account how the terrain influences individual weather systems.[1988]

Salathé, Jr. et al.'s (2010) results show that, with increased spatial resolution relative to global models, regional climate models can represent the local forcing from the complex terrain to produce more realistic spatial and temporal variability of temperature, precipitation, and snowpack in the State of

[1976] *Mote and Salathé, Jr. (2010, p. 29)
[1977] *Mote and Salathé, Jr. (2010, p. 29-30)
[1978] *Mote and Salathé, Jr. (2010, p. 30)
[1979] *Mote and Salathé, Jr. (2010, p. 30)
[1980] *Mote and Salathé, Jr. (2010, p. 30)
[1981] *Mote and Salathé, Jr. (2010, p. 30)
[1982] *Mote and Salathé, Jr. (2010, p. 31). The authors cite Schellnhuber et al. (2006) for information on changes in climate that many scientists call dangerous.
[1983] *Mote and Salathé, Jr. (2010, p. 31).
[1984] *Mote and Salathé, Jr. (2010, p. 31). The authors cite Raupach et al. (2007) for information on mid-2000s emissions and state "…we must emphasize that the scenarios used here may not span the range of possibilities" (p. 31).
[1985] *Salathé, Jr. et al. *Regional climate model projections for the State of Washington*. (2010, p. 52)
[1986] *Salathé, Jr. et al. (2010, p. 52)
[1987] *Salathé, Jr. et al. (2010, p. 52)
[1988] *Salathé, Jr. et al. (2010, p. 52)

Washington.[1989] With the ability to resolve topographic effects, more robust changes in mountain snowpack and extreme precipitation emerge.[1990] These changes are consistent between the two regional simulations despite differences in seasonal precipitation and temperature changes in the global and regional model results.[1991] It is clear that changes in the seasonal climate and the frequency of extreme events may be locally much more intense than can be inferred from statistical methods.[1992] The implication is that, while a valuable tool for regional climate impacts assessment, multi-model ensembles of global climate projections and statistical methods may under represent the local severity of climate change.[1993]

[1989] *Salathé, Jr. et al. "Regional climate model projections for the State of Washington." In: *Washington Climate Change Impact Assessment.* (2009, p. 65)
[1990] *Salathé, Jr. et al. (2009, p. 65)
[1991] *Salathé, Jr. et al. (2009, p. 65)
[1992] *Salathé, Jr. et al. (2009, p. 65)
[1993] *Salathé, Jr. et al. (2009, p. 65)

# 3. MAJOR CLIMATE PATTERNS IN THE NPLCC: ENSO AND PDO

*This explanation is excerpted from a webpage written by Nathan J. Mantua (Ph.D.) of the University of Washington's Joint Institute for the Study of the Atmosphere and Oceans and Climate Impacts Group. The webpage is not copied in its entirety; sections that explain climate variability and its impacts on climate in the NPLCC are emphasized. The full-text can be accessed at http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm (last accessed December 9, 2010).*

**Introduction**

In addition to El Niño, there are other heavily researched climate patterns that exert important influences on regional climates around the world. For instance, many studies highlight the relative importance of the Pacific Decadal Oscillation and Arctic Oscillation/North Atlantic Oscillation in North American climate. Each of these major patterns--El Niño/Southern Oscillation, Pacific Decadal Oscillation, and Arctic Oscillation/North Atlantic Oscillation--has characteristic signatures in seasonally changing patterns of wind, air temperature, and precipitation; each pattern also has a typical life time for any given "event".

**A PDO definition**

The Pacific Decadal Oscillation, or PDO, is often described as a long-lived El Niño-like pattern of Pacific climate variability (Zhang et al. 1997). As seen with the better-known El Niño/Southern Oscillation (ENSO), extremes in the PDO pattern are marked by widespread variations in Pacific Basin and North American climate. In parallel with the ENSO phenomenon, the extreme phases of the PDO have been classified as being either *warm* or *cool*, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean.

Two main characteristics distinguish the PDO from ENSO. First, typical PDO "events" have shown remarkable persistence relative to that attributed to ENSO events - in this century, major PDO eras have persisted for 20 to 30 years (Mantua et al. 1997, Minobe 1997). Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO. Several independent studies find evidence for just two full PDO cycles in the past century (e.g. Mantua et al. 1997, Minobe 1997): cool PDO regimes prevailed from 1890-1924 and again from 1947-1976, while warm PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990's. Recent changes in Pacific climate suggest a possible reversal to cool PDO conditions in 1998, an issue that is discussed in more detail at the end of this article.

The North American climate anomalies associated with PDO warm and cool extremes are broadly similar to those connected with El Niño and La Niña (Latif and Barnett 1995, Latif and Barnett 1996, Zhang et al. 1997, Mantua et al. 1997). Warm phases of the PDO are correlated with North American temperature and precipitation anomalies similar to those correlated with El Niño (Figure 4): above average winter and spring time temperatures in northwestern North America, below average temperatures in the southeastern US, above average winter and spring rainfall in the southern US and northern Mexico, and below average precipitation in the interior Pacific Northwest and Great Lakes regions. Cool phases of the PDO are simply correlated with the reverse climate anomaly patterns over North America (not shown), broadly

similar to typical La Niña climate patterns. The PDO-related temperature and precipitation patterns are also strongly expressed in regional snow pack and stream flow anomalies, especially in western North America (see Cayan 1995, Mantua et al. 1997, Bitz and Battisti 1999, Nigam et al. 1999). A summary of major PDO climate anomalies are listed in Table 1.

**Table 1:** Summary of North American climate anomalies associated with extreme phases of the PDO.

| Climate Anomalies | Warm Phase PDO | Cool Phase PDO |
|---|---|---|
| **Ocean surface temperatures in the northeastern and tropical Pacific** | Above average | Below average |
| **October-March northwestern North American air temperatures** | Above average | Below average |
| **October-March Southeastern US air temperatures** | Below average | Above average |
| **October-March southern US/Northern Mexico precipitation** | Above average | Below average |
| **October-March Northwestern North America and Great Lakes precipitation** | Below average | Above average |
| **Northwestern North American spring time snow pack** | Below average | Above average |
| **Winter and spring time flood risk in the Pacific Northwest** | Below average | Above average |

**An ENSO definition**

*This definition is excerpted from the Climate Impacts Group website El Niño/Southern Oscillation, available at http://cses.washington.edu/cig/pnwc/aboutenso.shtml (last accessed 1.18.2011)*

The El Niño/Southern Oscillation (ENSO) is the major source of inter-annual climate variability in the Pacific Northwest (PNW). ENSO variations are more commonly known as **El Niño** (the warm phase of ENSO) or **La Niña** (the cool phase of ENSO).

An El Niño is characterized by stronger than average sea surface temperatures in the central and eastern equatorial Pacific Ocean, reduced strength of the easterly trade winds in the Tropical Pacific, and an eastward shift in the region of intense tropical rainfall. A La Niña is characterized by the opposite – cooler than average sea surface temperatures, stronger than normal easterly trade winds, and a westward shift in the region of intense tropical rainfall. Average years, i.e., years where there is no statistically significant deviation from average conditions at the equator, are called ENSO-neutral. Each ENSO phase typically lasts 6 to 18 months.

Although ENSO is centered in the tropics, the changes associated with El Niño and La Niña events affect climate around the world. ENSO events tend to form between April and June and typically reach full strength in December (hence the name El Niño, which is Spanish for "Little Boy" or "Christ Child"; La Niña means "Little Girl"). The ENSO influence on PNW climate is strongest from October to March; by summer, Northern Hemisphere wind patterns are such that they effectively trap ENSO-related disturbances in the tropics.

The CIG has demonstrated numerous linkages between changes in ENSO and variations in PNW climate and natural resources. El Niño winters, for example, tend to be warmer and drier than average with below normal snowpack and streamflow. La Niña winters tend to be cooler and wetter than average with above normal snowpack and streamflow. These linkages and the availability of ENSO forecasts a few months to one year in advance of the event's maturation provide resource managers opportunity to consider how a particular ENSO forecast may affect resource management choices.

**Interactions between ENSO and PDO**

*This explanation is excerpted from the Climate Impacts Group website Impacts of Natural Climate Variability on Pacific Northwest Climate, available at http://cses.washington.edu/cig/pnwc/clvariability.shtml (last accessed 1.18.2011).*

The potential for temperature and precipitation extremes increases when ENSO and PDO are in the same phases and thereby reinforce each other. This additive effect is also seen in the region's streamflow and snowpack. There is no evidence at this time to suggest that either PDO or ENSO dominates with respect to temperature and precipitation when the two climate patterns are in opposite phases (i.e., an El Niño during a cool phase PDO or a La Niña during a warm phase PDO). The opposite effects on temperature and precipitation can cancel each other out, but not in all cases and not always in the same direction. Similar effects are seen on regional streamflow.

# 4. RESOURCES FOR ADAPTATION PRINCIPLES AND RESPONSES TO CLIMATE CHANGE

1. **Recommendations for a National Wetlands and Climate Change Initiative.** Association of Wetland Managers, Inc. January 20, 2009. Available online at http://www.aswm.org/calendar/wetlands2008/recommendations_2008_112008.pdf (accessed January 14, 2011).

   ***Summary:*** The report discusses the role U.S. agencies, Congress, states and local governments could play in implementing a national wetlands and climate change initiative (pp. 4-6). It also includes chapters on specific measures needed to better protect and adapt coastal and estuarine lands (pp. 7-10) and freshwater wetlands (pp.10-12). It concludes with a chapter on priority management-oriented and basic research needs (pp. 13-15)

2. **A New Era for Conservation: Review of Climate Change Adaptation Literature.** Glick, Patty; Staudt, Amanda; Stein, Bruce. March 12, 2009. Report produced by the National Wildlife Federation. Available online at http://www.nwf.org/News-and-Magazines/Media-Center/Faces-of-NWF/~/media/PDFs/Global%20Warming/Reports/NWFClimateChangeAdaptationLiteratureReview.ashx (accessed January 25, 2011).

   ***Summary:*** The report reviews the common barriers to climate change adaptation (including solutions; pp. 9-13), describes five overarching principles of climate change adaptation (pp. 12-17) and provides a six-stage framework to use as a guideline for developing adaptation strategies (pp. 18-23). It also includes sector-specific adaptation strategies for forests (pp. 23-29), grasslands and shrublands (pp. 30-35), rivers, streams, and floodplains (pp. 36-43), and coasts and estuaries (pp. 44-52).

3. **Biodiversity management in the face of climate change: A review of 22 years of recommendations.** Heller, Nicole E. and Zavaleta, Erika S. 2009. *Biological Conservation.* 142: 14-32. Available online at http://people.umass.edu/gce/Heller%20and%20Zavaleta,%202009.pdf (accessed January 13, 2011).

   ***Summary:*** See Table 1 (pp. 18-22) for a list of recommendations for climate change adaptation strategies for biodiversity management.

4. **Climate change adaptation strategies for resource management and conservation planning.** Lawler, Joshua J. 2009. *Annals of the New York Academy of Sciences (The Year in Ecology and Conservation Biology).* 1162: 79-98. Available online at http://training.fws.gov/branchsites/lkm/climate_change/june_09/cc-adaptreview.pdf (accessed January 13, 2011).

   ***Summary:*** Lawler provides an overview of general strategies for addressing climate change including removing other threats and reducing additional stressors, expanding reserve networks, increasing connectivity, restoring habitat and system dynamics, adaptive management, and translocation. Specific recommendations for addressing climate change in freshwater, marine, and terrestrial systems are also provided.

5. **A review of climate-change adaptation strategies for wildlife management and biodiversity conservation.** Mawdsley, Jonathan R.; O'Malley, Robin; and Ojima, Dennis S. 2009. Available online at http://www.uwpcc.washington.edu/documents/PCC/mawdsley-etal-2009.pdf (accessed January 13, 2011). *Conservation Biology.* 23(5): 1080-1089.

   ***Summary:*** Mawdsley and colleagues describe sixteen adaptation strategies, organized by strategies related to land and water protection and management (seven strategies), direct species management (four strategies), monitoring and planning (four strategies), and reviewing and modifying existing laws, regulations, and policies regarding wildlife and natural resource management (one strategy).

6. **Preparing for climate change: a guidebook for local, regional, and state governments.** Snover, Amy K.; Whitely Binder, Lara; Lopez, Jim; and Colleagues. 2007. In association with and published by ICLEI – Local Governments for Sustainability, Oakland, CA. Available online at http://cses.washington.edu/cig/fpt/guidebook.shtml (accessed January 13, 2011).

   ***Summary:*** The guidebook provides a suggested checklist for governments on how to prepare for climate change. It includes five milestones: initiate your climate resiliency effort, conduct a climate resiliency study, set preparedness goals and develop your preparedness plan, implement your preparedness plan, and measure your progress and update your plan.

7. **Climate Savvy: Adapting conservation and resource management to a changing world.** Hansen, Lara J. and Hoffman, Jennifer R. 2011. Island Press: Washington, DC. Available online for preview and purchase at http://islandpress.org/bookstore/detailsee40.html (accessed July 13, 2011).

   ***Summary:*** Hansen and Hoffman assess the vulnerabilities of existing conservation and resource management tools to climate change, then describe how these tools can be adapted to address climate change impacts. The book begins with a general overview of climate change and its effects, and key facets of building a plan to address climate change impacts. The tools include protected areas, species-based protection, connectivity, regulating harvests, reduction of pollutants, control of invasive species, pests, and disease, restoration, and a broader rethinking of governance, policy, and regulation.

8. **U.S. natural resources and climate change: concepts and approaches for management adaptation.** West, Jordan M.; Julius, Susan H.; Kareiva, Peter; and Colleagues. 2009. *Environmental Management.* 44: 1001-1021. Available online at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2791483/pdf/267_2009_Article_9345.pdf (accessed January 13, 2011).

   ***Summary:*** West and colleagues provide several concepts and approaches for assessing impacts to support adaptation, management strategies for resilience to climate change, responding to barriers and opportunities for implementation, and advancing the nation's capability to adapt. Twelve tables provide examples of specific approaches that are in use or have been proposed (e.g. Table 5, pp. 1009, provides examples of adaptation actions that focus on restoration as a means of supporting resilience).

# 5. LIST OF REVIEWERS AND INTERVIEWEES

**Reviewers**

Alaska

**Bill Hanson**, US Fish and Wildlife Service
**Erin Uloth**, USDA Forest Service
**Gordie Reeves**, USDA Forest Service
**Greg Hayward**, USDA Forest Service
**Katrina Bennett**, University of Alaska – Fairbanks
**Laura Baker**, The Nature Conservancy
**Rob DeVelice**, USDA Forest Service
**Wayne Owen**, USDA Forest Service

British Columbia

**Doug Biffard**, BC Ministry of Environment
**James Casey**, World Wildlife Fund – Canada
**John Richardson**, University of British Columbia
**Tory Stevens**, BC Ministry of Environment

Washington

**Alan Hamlet**, Climate Impacts Group, University of Washington
**Jennie Hoffman**, EcoAdapt
**Lara Whitely Binder**, Climate Impacts Group, University of Washington
**Lisa Crozier**, National Oceanic and Atmospheric Administration
**Marketa Elsner**, Climate Impacts Group, University of Washington
**Rachel M. Gregg**, EcoAdapt
**Timothy J. Beechie**, National Oceanic and Atmospheric Administration

Oregon

**Dede Olson**, USDA Forest Service
**Doug Spencer**, US Fish and Wildlife Service
**Keith Hatch**, Bureau of Indian Affairs
**Sharon Selvaggio**, US Fish and Wildlife Service
**Stan Gregory**, Oregon State University

California

**Amy Merrill**, Stillwater Sciences
**Emily Limm**, Save the Redwoods League
**Hugh Safford**, USDA Forest Service
**Iris Stewart-Frey**, Santa Clara University
**Joseph Furnish**, USDA Forest Service
**Michael J. Furniss**, USDA Forest Service

Native Alaskans, First Nations, Tribal

**David Graves**, Columbia River Inter-Tribal Fish Commission
**Eric Quaempts**, Umatilla Tribe
**Laura Gephart**, Columbia River Inter-Tribal Fish Commission

Other

**Doug Inkley,** National Wildlife Federation
**Garrit Voggesser**, National Wildlife Federation
**Jim Murphy**, National Wildlife Federation
**Michael Murray**, National Wildlife Federation

**Interviewees** ***(continued on next page)***

Alaska

**Bill Hanson**, US Fish and Wildlife Service
**Dave D'Amore**, USDA Forest Service
**Doug Vincent-Lang**, Alaska Department of Fish and Game
**Ed Berg**, US Fish and Wildlife Service
**Eran Hood**, University of Alaska – Southeast
**Erin Uloth**, USDA Forest Service
**Evie Whitten**, The Nature Conservancy
**Gordie Reeves**, USDA Forest Service
**Greg Hayward**, USDA Forest Service
**Katrina Bennett**, University of Alaska – Fairbanks
**Laura Baker**, The Nature Conservancy
**Mike Goldstein**, Alaska Coastal Rainforest Center
**Paul Brewster**, USDA Forest Service
**Paul Hennon**, USDA Forest Service
**Rick Edwards**, USDA Forest Service
**Rick Fritsch,** National Oceanic and Atmospheric Administration
**Rob DeVelice**, USDA Forest Service
**Roman Motyka**, University of Alaska – Southeast
**Sara Boario**, USDA Forest Service
**Shannon Atkinson**, University of Alaska – Fairbanks
**Tom Ainsworth**, National Oceanic and Atmospheric Administration
**Wayne Owen**, USDA Forest Service

British Columbia

**Angeline Tillmanns**, Adelaide Consulting
**Darcy Dobell**, World Wildlife Fund – Canada
**Dave Secord**, Tides Canada
**David Close**, University of British Columbia
**Doug Biffard**, BC Ministry of Environment
**Hans Schreier**, University of British Columbia
**James Casey**, World Wildlife Fund – Canada
**Jenny Fraser**, BC Ministry of Environment
**Linda Nowlan**, World Wildlife Fund – Canada
**Markus Schnorbus**, Pacific Climate Impacts Consortium
**Mike Wei**, BC Ministry of Environment
**Robyn Hooper**, Pacific Institute for Climate Solutions
**Stewart Cohen**, Environment Canada
**Tory Stevens**, BC Ministry of Environment

Oregon

**Ben Clemens**, Oregon State University
**Carl Schreck**, Oregon State University
**Chuck Houghten**, US Fish and Wildlife Service
**Dede Olson**, USDA Forest Service
**Doug Spencer**, US Fish and Wildlife Service
**Jimmy Kagan**, Oregon Institute for Natural Resources
**Karen Bennett**, USDA Forest Service
**Kathie Dello**, Oregon Climate Change Research Institute, Oregon State University
**Keith Hatch**, Bureau of Indian Affairs
**Lenise Lago**, USDA Forest Service
**Michael J. Hampton**, USDA Forest Service
**Phil Mote**, Oregon Climate Change Research Institute, Oregon State University
**Sara O'Brien**, Defenders of Wildlife
**Sharon Selvaggio**, US Fish and Wildlife Service
**Steve Caico**, US Fish and Wildlife Service
**Suzanne Knapp**, Oregon Governor's Office
**Tim Mayer**, US Fish and Wildlife Service

California

**Armand Gonzales**, California Department of Fish and Game
**Emily Limm**, Save the Redwoods League
**Hugh Safford**, USDA Forest Service
**Joseph Furnish**, USDA Forest Service
**Kimberley Johnson**, USDA Forest Service
**Louanne McMartin**, US Fish and Wildlife Service
**Michael J. Furniss**, USDA Forest Service
**Peter Moyle**, University of California – Davis
**Rick Kearney**, US Fish and Wildlife Service

Native Alaskans, First Nations, Tribal

**Abby Hook**, Tulalip Tribes
**Bob Heinith**, Columbia River Inter-Tribal Fish Commission
**Bruce Jones**, Northwest Indian Fisheries Commission
**Charles P. O'Hara**, Swinomish Indian Tribal Community
**Claire Wood**, Confederated Tribes of Siletz Indians

| | |
|---|---|
| Washington<br><br>**Carmen Revenga**, The Nature Conservancy<br>**Chris Konrad**, US Geological Survey<br>**Elizabeth Gray**, The Nature Conservancy<br>**George Pess**, National Oceanic and Atmospheric Administration<br>**James Schroeder**, The Nature Conservancy<br>**Jennie Hoffman**, EcoAdapt<br>**Jon Hoekstra**, The Nature Conservancy<br>**Lara Whitely Binder**, Climate Impacts Group, University of Washington<br>**Marketa Elsner**, Climate Impacts Group, University of Washington<br>**Mary Mahaffy**, US Fish and Wildlife Service<br>**Rachel M. Gregg**, EcoAdapt<br>**Tim Beechie**, National Oceanic and Atmospheric Administration | **David Graves**, Columbia River Inter-Tribal Fish Commission<br>**Ed Knight**, Swinomish Indian Tribal Community<br>**Jim Weber**, Northwest Indian Fisheries Commission<br>**Kyle Dittmer**, Columbia River Inter-Tribal Fish Commission<br>**Laura Gephart**, Columbia River Inter-Tribal Fish Commission<br>**Lilian Petershoare**, USDA Forest Service<br>**Mike Kennedy**, Confederated Tribes of Siletz Indians<br>**Preston Hardison**, Tulalip Tribes<br>**Ray Paddock**, Central Council Tlingit and Haida Indian Tribes of Alaska<br>**Reid Johnson**, Central Council Tlingit and Haida Indian Tribes of Alaska<br>**Rishi Sharma**, Columbia River Inter-Tribal Fish Commission<br>**Stephen Kullmann**, Wiyot Tribe<br>**Tim Nelson**, Wiyot Tribe<br><br>Other<br><br>**Dave Cleaves**, USDA Forest Service<br>**Garrit Voggesser**, National Wildlife Federation<br>**Myra Wilensky**, National Wildlife Federation<br>**Steve Torbit**, National Wildlife Federation |

# X. BIBLIOGRAPHY

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