Additional Analysis of the Potential Economic Costs to the State of Washington of a Business-As-Usual Approach to Climate Change: Lost Snowpack Water Storage and Bark Beetle Impacts

A Report from
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Authorship and Contact Information

The Program on Climate Economics of the Climate Leadership Initiative (CLI), conducts research on the potential economic consequences and benefits of climate mitigation, preparation and economic development policies. In 2009, ECONorthwest produced a report for the CLI Climate Economics Program under the supervision and guidance of the CLI Climate Economics Advisory Committee. The report, entitled "An Overview of Potential Economic Costs to Washington of a Business-As-Usual Approach to Climate Change," calculated some of the potential costs that Washington might expect in the next several decades from unabated global climate change.

At the request of the Washington Department of Ecology, the Climate Leadership Initiative (CLI) developed additional economic cost analysis of projected future impacts to Washington. Specifically, CLI analyzed the projected costs of lost water storage capacity in Washington's snowpack as well as the cost of bark beetle infestations to Washington's forestry sector. This document provides the results of the cost analysis for these two additional parameters.

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Table of Contents

Executive Summary

This analysis adds two economic cost parameters to 18 previously analyzed by the Climate Leadership Initiative and ECONorthwest in a 2009 report titled "An Overview of Potential Economic Costs to Washington from a Business as Usual Approach to Climate Change." Examined here are the potential economic costs of lost natural water storage from declining snowpack expected in the coming decades as well as the economic costs of bark beetle infestations to Washington's forestry sector.

Economic Costs of Lost Natural Water Storage

Extensive research has concluded that snowpack has declined over the 20th Century across the Pacific Northwest with the largest reductions occurring in lower elevations. Recent research projects April 1 snow water equivalent (an important measure of snowpack) to decrease by an average of approximately 28–30% across the state by the 2020s, 38–46% by the 2040s and 56–70% by the 2080s.

Mountain snowpack is an "ecosystem service" in that it stores significant quantities of winter precipitation for use in spring and summer. To arrive at a net economic cost to Washington from the future loss of this ecosystem service, the analysis uses a replacement cost approach in that we estimate the capital cost of constructing a comparable volume of reservoir capacity using cost projections from 39 feasibility studies conducted across the American west in the last decade.

The current volume of water stored within Washington's snowpack is estimated to be worth $30.9 billion. By 2020, reductions in snowpack will yield a net cost of $7.1 billion to Washingtonians, $11.1B by 2040, and escalating to $18 billion by 2080.

Economic Costs to Forestry Associated with Beetle Infestations

Global climate change - both observed to date as well as projected for the future - is expected to impact Washington's forested landscapes and the economic benefits currently obtained from those landscapes in multiple ways. One area of concern is the possibility of increased infestation of bark beetles in forests. Several species of beetle have infested Washington forests in the past decades, killing trees and supplying dry fuel for intense fire, particularly in lodgepole pine species.

Beetle impacts to forestry represent a potential direct economic cost to Washington's economy due to lost timber sector revenues as well as tax revenue to the public sector. Estimating these direct costs in 2020, 2040 and 2080 is complicated by the complexity of changes in the ranges of beetle species of concern, range changes in host tree species, and other dynamics within forests such as the incidence and severity of fire. Each of these changes is expected to occur as climate change related impacts, including changes in historical temperature and precipitation patterns, accrue in Washington over the coming decade.

In order to fully address this complexity, this analysis uses four scenarios of the future state of forests in the state and estimates the economic costs associated with each: no change from historical beetle impacts; reduced beetle kill impacts due to shifts in range; increased beetle kill impacts due to increased incidence of drought; and finally a combination of drought impacts and shifts in range.

Due to the high variability of modeled precipitation projections, and the complexity of the interactions between climate factors and beetle infestations, it is difficult to predict which scenario is the most likely. Given the likelihood projected in the literature that range contraction may be significant, up to 60% by the late 21st century, and that persistent drought may more than double water-stress in eastern pine forests and contribute significantly to range contraction, we conclude that the final scenario – a combination of drought impacts and range shifts - as the most likely to occur.

Given this scenario, the historical average costs of $120 million for 300,000 acres lost to beetle infestations may increase by $31 million in 2020, $28.7 million by 2040, and actually decline by $19.7 million by 2080. The 2080 reduction is primarily due to contraction of pine habitat throughout the eastern portion of the state. While beyond the scope of this analysis, the greater impact to Washington's forestry sector may be the loss of suitable growing conditions for tree species most favored by the forest products industry.

Revised Potential Costs to Washington from Unabated Climate Change

The inclusion of these two new cost analyses increases the total economic costs to Washington by 187% over the 2009 CLI estimated total cost in 2020, 169% in 2040, and 138% in 2080.

Potential Economic Costs in Washington Under a Business-as-Usual Approach to Climate Change, 2020, 2040, and 2080 (2008 dollars per year)

	2020	2040	2080
Total of 20 Parameters	**$10.9B**	**$17.5B**	**$30.8B**
Average Cost per Household per Year	$3,633	$4,916	$6,553

Introduction

In a 2009 report produced by ECONorthwest for the University of Oregon's Climate Leadership Initiative (CLI) Climate Economics Program, 18 specific economic costs to the State of Washington associated with unabated global climate change at atmospheric concentrations of CO_2E accruing at current and projected rates of growth were analyzed. The report found that:

> By 2020, these costs total $3.8 billion per year. The major components of climate-change costs are potential health-related costs of about $1.3 billion per year, potential reductions in salmon populations, with a value of $530 million per year, and energy costs of about $220 million. In addition, continuing with the activities that contribute to climate change potentially would cost Washingtonians almost $1.4 billion per year in missed opportunities to implement energy-efficiency programs and about $19 million per year in health costs from burning coal. The combined total annual costs would increase with time, more than three-fold by 2080.[1] (p. iv)

On a per household basis, the calculated costs of unabated climate change to Washingtonians were projected to reach $1,250 by 2020, or 2% of current median household income. These costs grow to 3% by 2040 and as much as 5% by 2080. The following table summarizes the costs analyzed for the State of Washington in the 2009 report.

Potential Economic Costs in Washington Under a Business-as-Usual Approach to Climate Change, 2020, 2040, and 2080 (dollars per year)

Potential Cost	2020	2040	2080
Costs of Climate Change			
Increased Energy-Related Costs	$222M	$623M	$1.5M
Reduced Salmon Populations	$531M	$1.4B	$3B
Increased Coastal & Storm Damage	$72M	$150M	$352M
Reduced Food Production	$35M	$64M	$364M
Increased Wildland Fire Costs	$102M	$208M	$462M
Increased Health-Related Costs	$1.3B	$2.2B	$4.4B
Lost Recreation Opportunities	$75M	$210M	$612M
Subtotal for Costs of Climate Change	*$2.3B*	*$4.9B*	*$10.7B*
Additional Costs from BAU Activities that Contribute to Climate Change			
Inefficient Consumption of Energy	$1.4B	$1.6B	$2.2B
Increased Health Costs from Coal Energy	$19M	$23M	$31M
Subtotal for Costs of BAU Activities	*$1.4B*	*$1.6B*	*$2.2B*
Total	**$3.8B**	**$6.5B**	**$12.9B**
Average Cost per Household per Year	$1,250	$1,800	$2,750

[1] Climate Leadership Initiative and ECONorthwest. 2009. "An Overview of Potential Economic Costs to Washington of a Business-As-Usual Approach to Climate Change." From: www.theresourceinnovationgroup.org.

As noted in the 2009 CLI analysis, global climate change will likely extract additional economic costs beyond the 18 items analyzed for that publication. Two additional cost issues have been raised by the Washington Department of Ecology for further analysis:

- Costs related to lost water storage as the snowpack declines
- Net cost of climate-related insect infestations of state and private forestland

This document provides additional analysis to assess the potential economic costs to Washington associated with these two issues.

Background on Economic Analysis & Methodology

In order to assure analytical continuity with the previous analysis conducted for the State of Washington, CLI has prepared cost estimates for 2020, 2040 and 2080 based upon peer-reviewed climate change impact projections. Impacts within the 2009 CLI analysis were assessed against the Intergovernmental Panel on Climate Change's A1F1 scenario, which models the Business as Usual global emissions case in which the international community achieves no significant emission reductions. Because the source climate projections used by the current analysis were modeled against the IPCC A1B scenario[2], the economic costs presented here likely understate the costs that would be observed using the A1F1 scenario.

In order to update average annual household costs presented in the previous analysis, this work uses previous assumptions on population from the U.S. Census Bureau. Census projections for the State of Washington are available through 2030 after which projected population growth rates for the United States as a whole were used.

From a methodological perspective, assessing the economic costs to forestry associated with bark beetle infestations is a direct cost to the State of Washington associated with foregone timber and associated tax revenues. Accordingly, the estimation of economic costs in this case follows from the 2009 CLI report. But unlike costs presented in the prior analysis, the complexity of the parameters associated with a changing climate regime and the associated responses of tree and beetle species has led us to use a scenario basis to outline possible futures and the associated economic costs

Assessing the economic cost of lost natural water storage associated with declining snowpack, however, represents a different sort of economic cost than was previously developed. Mountain snowpack provides an "ecosystem service" by

[2] "The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies)." Source: *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press, Cambridge, UK and New York, NY, USA.

storing water as snow that is released in snowmelt during the spring and summer months when human water demands in Washington peak. Replicating this water storage provided by mountain snowpack would require the construction of comparable reservoir capacity, involving the expenditure of significant capital for construction. The economics literature includes several analytical approaches to valuing ecosystem services that do not have readily available market prices. Given the scope of the current project, the analytical strategy for calculating the economic costs of lost snowpack storage used here is the replacement cost approach in which the cost of constructing and operating equivalent water storage infrastructure is estimated and used as a proxy value of snowpack water storage to Washington's economy.

Consistent with the previous CLI analysis, all costs are presented in 2008 dollars unless otherwise noted.

1. Economic Costs of Lost Natural Water Storage

1.1 Background: Climate Change and Mountain Snowpack

Extensive research conducted over the last decade by the University of Washington's Climate Impacts Group has concluded that spring snow water equivalent has declined over the 20th Century across the Pacific Northwest with the largest reductions occurring in lower elevations.[3] Other research has concluded that global climate change will cause more of Washington's winter precipitation to fall as rain rather than snow in the future, augmenting winter flows while reducing summer flows.[4] Miles and Lettenmaier (2007) estimated reductions in April 1 snow water equivalent (SWE) of 28% by 2020 and 41% by 2040 based on A1B modeled emission scenarios.[5] More recent analysis by Elsner et al. (2010) suggests April 1 SWE is projected to decrease by an average of approximately 28–30% across the state by the 2020s, 38–46% by the 2040s and 56–70% by the 2080s.[6]

1.2 Estimating Lost Water Storage from Snowpack Declines

Recent research from the Climate Impacts Group has quantified expected snow pack loss for each watershed in Washington from which estimated lost storage potential can be derived.[7] The Columbia Basin Climate Change Scenarios Project (Hamlet et al. 2010) provides extensive historic and modeled future data for several parameters for nearly 300 locations across Washington.

For the purposes of this analysis, 17 major Washington watersheds representing 21,047 square miles were selected from which data were obtained from the most downstream monitoring station available in order to incorporate the greatest extent of the watershed possible. These data correspond with April 1 SWE, representing peak levels in nearly every basin examined. Current basin level SWE data represent the average depth across the full extent of the basin. In order to provide the most conservative estimate of costs to Washington, several watersheds in Northeast and Eastern Washington were excluded given the relatively large proportion of these basins that extend into British Columbia and Idaho.

The primary purpose of this analysis is to estimate the change in volume of water stored at mid to high altitude in the form of snow due to changes in regional climate

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[3] Mote, P.W. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. *Geophysical Research Letters* 30(12) 1601

[4] Hamlet, A.F., and D.P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. *Journal of the American Water Resources Association* 35(6):1597-1623.

[5] Miles, E. L. and D. P. Lettenmaier (2007). *HB 1303 Interim Report: A Comprehensive Assessment of the Impacts of Climate Change on the State of Washington*. University of Washington JISAO Climate Impacts Group. Seattle, Washington

[6] Elsner, M. E., L. Cuo, N. Voisin, J. Deems, A. Hamlet, J. Vano, K. Mickelson, S. Lee, and D. Lettenmaier (2010) "Implications of 21st century climate change for the hydrology of Washington State" *Climactic Change* (102) 225-260

[7] Data and summary information were obtained from the Columbia Basin Climate Change Scenarios Project website at http://www.hydro.washington.edu/2860/. These materials were produced by the Climate Impacts Group at the University of Washington (Hamlet et al. 2010) in collaboration with the WA State Department of Ecology, Bonneville Power Administration, Northwest Power and Conservation Council, Oregon Water Resources Department, and the B.C. Ministry of the Environment.

regimes. Because the dynamics of spring snowmelt, soil water storage and other factors that govern the translation of winter snow into spring and summer streamflow are remarkably complex, the current analysis focuses solely on historic and future projected changes in SWE. It should be noted that the volume of water contained as SWE (or any observed losses thereof in the future) will not be directly correlated to changes in streamflow. While snow water equivalent is defined as the amount of water that a given volume of snow would yield if hypothetically melted, other dynamics such as water stored in soils and local topography will also greatly affect observed changes in streamflow. Water stored in soils will increase as snowpack declines, thus offsetting the lost storage capacity of snowpack.

Peak SWE corresponding to April 1st is presented in Table 1.1. The change reported in 2020, 2040, and 2080 respectively from the historic SWE baseline represent the mean estimate from runs of 10 different global circulation models downscaled to the Pacific Northwest. To account for inter-annual variance in precipitation, Hamlet et al. (2010) averaged SWE values for each year based on 10 years prior to the year and 10 years following.

Table 1.1. Historic and Modeled Future Snow Water Equivalent (in inches – rounded to nearest ½ inch) for Selected Watersheds – A1B Scenario – Columbia Basin Climate Change Scenarios Project (Hamlet et al. 2010)

	Basin Size sq. miles	Peak SWE Historic	Peak SWE 2020	Peak SWE 2040	Peak SWE 2080
Quinault River	264	18	13	10	8
Nooksack River	786	10	7	5	2.5
Skagit River	3,093	28.5	23	20	15
Stillaguamish River	262	6.5	4	3	1.5
Skykomish River	535	22.5	16	12	7
Snoqualmie River	1,537	14.5	10	7.5	4
Green River	399	8	5	3.5	1.5
White River	427	16	12	9	5
Nisqually River	286	7	4	3	2
Cowlitz	1,400	12.5	8.5	7	3.5
Lewis	730	15.5	10	7	3
Klickitat River	1,297	6.5	4.5	3.5	2
Yakima River	5,615	7	5	4	2
Wenatchee River	1,301	21	17	15	10
Entiat River	419	17	15	13	9
Lake Chelan	924	21	19	17	13
Methow River	1,772	10	9	8	5.5

1.3 Estimating Artificial Water Storage Costs

To determine an average unit cost for artificial water storage capital costs, several water storage assessments performed by the Bureau of Reclamation for projects in the western United States over the past decade were reviewed. In each case, the most fully developed cost estimates for each project prepared by the Bureau were used in this analysis. The estimated construction costs for reservoirs were isolated from other capital costs presented, including pumping stations, pipelines, and energy infrastructure. It should be noted that reservoir construction costs are highly influenced by the underlying geology, local topography and other factors that are highly site specific. By averaging unit costs over a wide range of projects (n = 39), the estimated cost used here accounts for a wide range of site specific variability.

The projects reviewed include one in Washington State (the proposed Black Rock Reservoir) associated with the Yakima River Basin Water Storage Study[8], six in Idaho associated with the Boise-Payette Water Storage Assessment Project[9], and 32 in Colorado associated with the Southern Delivery System Assessment.[10] The final average unit cost of $1,956.15 per acre foot (in 2008 dollars) in capital construction costs is used here to estimate the replacement cost of lost snowpack water storage. It should be noted that the use of reservoir capacity as a proxy for the value of lost ecosystem services associated with declining snow water equivalent does not represent a recommendation to construct these reservoirs. Indeed, it is highly unlikely that such facilities could be feasibly constructed. Further, the attendant costs of dam construction on habitat, protected species, and other preferred land uses are not included in this proxy cost parameter, nor are annual operations and maintenance costs.

1.4 Economic Valuation of Lost Natural Water Storage

Assessing the current value of natural water storage in the 17 selected major watersheds to Washington's economy and future losses associated with climate-induced reductions in SWE entails conversion of basin level SWE to a volume in acre feet. Estimated volumes can then be multiplied by the unit cost of equivalent reservoir capacity ($1,956.15) to provide estimated costs. Table 1.2 provides a summary of results for the analysis.

Table 1.2. The Volume and Economic Value of Baseline and Projected Snow Water Equivalent for 17 Watersheds in Washington State

	Volume in Acre Feet	Total Economic Value	Value Lost from Baseline
Baseline SWE	15,837,646.41	$30,980,813,808	--
Projected SWE - 2020	12,178,576.93	$23,823,124,627	$7,157,689,181
Projected SWE - 2040	10,134,959.75	$19,825,502,660	$11,155,311,148
Projected SWE - 2080	6,588,031.86	$12,887,179,268	$18,093,634,540

The current volume of water stored within Washington's snowpack is estimated to be worth $30.9 billion on the basis of replacement cost. By 2020, reductions in SWE will yield a net cost of $7.1 billion to Washingtonians, escalating to $18 billion by 2080 as snowpack further declines.

[8] United States Department of the Interior, Bureau of Reclamation. 2008. "Economics Technical Report for the Yakima River Basin."
[9] United States Department of the Interior, Bureau of Reclamation. 2008. "Final Boise-Payette Water Storage Assessment Study."
[10] United States Department of the Interior, Bureau of Reclamation. 2004. "Southern Delivery System Environmental Impact Statement – Review of Cost Estimates for Current Water Development Projects in the Front Range."

2. Economic Costs to Forestry Associated with Beetle Infestations

2.1 Background: Forest Industry and Climate Change.

Global climate change - both observed to date as well as projected for the future - is expected to impact Washington's forested landscapes and the economic benefits currently obtained from those landscapes in multiple ways. Warming summer and winter temperatures, increased rates of evapo-transpiration, altered hydrological patterns and amplified weather variability will result in changes to the distribution, composition and extent of forests within the state.

The extent of forested lands within Washington State is twenty-two million acres, accounting for more than half of the current land cover. State and federal public ownership accounts for about 57% of forested lands with the remaining 43% in tribal or private ownership.[11] The importance of forests to Washington's economy is significant; in 2005, the sector generated $16 billion in gross business income, employed 45,000 people with a total payroll of approximately $2 billion.[12]

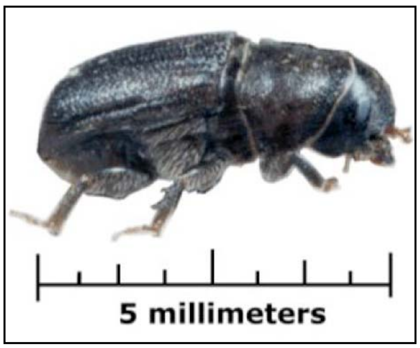

Figure 1. Mountain pine bark beetle. Courtesy USFS.

Several species of beetle (mountain pine beetle, Douglas-fir beetle, and western pine beetle) have infested Washington forests in the past decades, killing trees and supplying dry fuel for intense fire, particularly in lodgepole pine species. Some forest scientists observe that single species and uniform age harvest management increases susceptibility to beetle infestation, fire, and water stress. However scientists also anticipate reduced beetle infestations as climate related disturbances create rapid increases in fire, species turnover, and age diversity. They caution that even if conditions for mountain pine bark beetle infestation and current host forest stands are limited by climate change, existing insect species may be replaced with new ones that find new conditions more suitable.[13]

These climate-related stresses, when coupled with existing stressors associated with past land management practices, are likely to prove beneficial for the spread of bark beetle species in western North America. Three bark beetle species of special concern for Washington include: the mountain pine beetle, *Dendroctonus ponderosae*; the Douglas fir beetle, *D. pseudotsugae*; and the Western pine beetle, *D. brevicomus*. For pine species, the impact area will be primarily east of the Cascades

[11] Washington State Department of Natural Resources. 2010. "Statewide Forest Resources Assessment and Strategy."
[12] Partridge, C. and B. McGregor. 2007. *The Future of Washington Forests*. Washington Department of Natural Resources, Olympia.
[13] Littell, J., E.E. O'Neil, D. McKenzie, J. Hicks, J.A. Lutz, R.A. Norheim, and M.M. Elzner. 2009. "Forest Ecosystems, Disturbances, and Climatic Change in Washington State, USA." *Climatic Change.* DOI 10.1007/s10584-010-9858-x

where the most vulnerable species (ponderosa pine, lodgepole pine, and western white pine) currently thrive at relatively low elevations. The extent to which beetle infestations will affect forest productivity and revenues is uncertain: therefore, projections are based on clearly defined assumptions and scenarios.

Figure 2. Mountain pine beetle impact in Yellowstone N.P. Courtesy USFS.

Interactions among climate, beetle infestations, fire and harvest revenues are complex and difficult to predict and assess. The Climate Leadership Initiative and ECONorthwest 2009 analysis included interactions between fire and climate factors.[14] This report adds the additional factor of beetle infestation to refine the previous analysis. One complexity with the potential to render more uncertainty to an analysis is that beetle-killed timber may or may not be harvested, and timber killed in fires may or may not be salvaged. Also, fire in one forested area deemed to be aided and abetted by beetle-kill conditions may move out of the infested area into timber not infested.

2.2 Projected Range Shifts of Pine Forest

This analysis focuses on climate driven beetle-kill impacts on pine forests, which are most vulnerable to insect damage. Forest statistics show that ponderosa pine and lodgepole pine are intermingled and present over a roughly equal number of acres in Washington. Whitebark pines occupy relatively low acreage at high elevations where disturbance is minimal and so are not included separately in this analysis. It should be noted that some forest scientists have identified the potential for beetles currently specific to pine species to jump to fir species in the future, which are present to some extent in higher elevation pine forests.

The Washington Department of Natural Resources 2010 assessment describes the pine zone as follows:

> The ponderosa pine zone occupies the driest forested environments at the lower fringes of the forested landscape where even Douglas-fir cannot survive. The true ponderosa pine zone is not very extensive, even though ponderosa pine is one of the most widespread tree species in Eastern Washington. In Eastern Washington, [lodgepole pine] is most abundant in the western portion of the Okanogan Highlands, but is present in all forested regions. Nearly always

[14] Climate Leadership Initiative and ECONorthwest. 2009. "An Overview of Potential Economic Costs to Washington of a Business-As-Usual Approach to Climate Change." From: www.theresourceinnovationgroup.org.

> successional to other species in the forests of Eastern Washington, lodgepole pine develops extremely dense stands of small trees that are highly susceptible to stand-replacing fire events.[15]

Williams and Liebhold (2002) add further to the dynamic complexity of this assessment by pointing out that beetle outbreak areas may diminish if the range of susceptible tree species contracts due to warming temperatures. For instance, pine species ranges are projected to increase 15 meters in elevation for each 1 degree Celsius increase in temperature, while beetle infestations are projected to increase 30 meters in elevation for the same 1 degree C. increase.[16] Conversely, they note that ranges may expand with increased precipitation, contradicting the conventional notion that drought is the primary driver in beetle infestations. The authors also found that climate factors are less important in predicting beetle outbreaks than susceptible species distribution.[17] While the conventional wisdom regarding drought and beetle-kill may be true on an annual basis, longer term precipitation increases may inevitably lead to host tree range expansion and ensuing elevated levels of beetle infestation. Increased precipitation east of the Cascades by as much as 30% over a historical baseline in the late 20th century support this scenario, along with a number of climate models that project increased annual precipitation. A further complexity that confounds beetle infestation predictions is that trees will become more stressed and have higher susceptibility under alternating conditions of both drought and increased precipitation.[18]

Littell et al. provide an instructive distinction between energy limited west side Washington forests and east side water limited forests when considering climate change.[19] Warmer temperatures in energy limited forests will enhance productivity by reducing both cloud cover and competition. On the east side, conversely, productivity will be reduced as soil moisture is reduced with more evaporation and transpiration. (Note that higher levels of CO_2 projected in climate models may partially offset this by improving drought resistance.) The effects of increased water demand and forest stress will be particularly strong in mountainous areas with snowpack projected to decline up to 70% from late 20th century levels by 2080.[20]

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[15] WA DNR 2010. Pages 9-10

[16] Williams, D.W., and A. M. Liebhold. 2002. "Climate change and the outbreak ranges of two North American bark beetles." USDA Forest Service. Northeastern Research Station.

[17] Williams and Liebhold, 2002.

[18] Williams and Liebhold, 2002.

[19] At broad scales, forests of western North America can be partitioned into two climatically mediated classes of limitation: energy-limited versus water-limited domains (Stephenson 1990, 1998; Milne et al. 2002; Running et al. 2004; Littell and Peterson 2005; Littell et al. 2008). Energy-limiting factors are chiefly light (e.g., in productive forests where competition reduces light to most individuals or climates where cloud cover limits light) and temperature (e.g., high-latitude or high-elevation forests). Tree growth in energy-limited ecosystems appears to be responding positively to increasing temperatures over the past 100 years (McKenzie et al. 2001). Littell et al. 2009.

[20] Elsner et al (2010) "Implications of 21st century climate change for the hydrology of Washington State" Climactic Change (102) 225-260

Under reduced precipitation and snow pack scenarios, Littell et al. identify Douglas fir as the most climate sensitive timber species due to its high water requirements leading to higher mortality and reduced regeneration under drier conditions. They also find low-elevation ponderosa pine stands highly vulnerable as summer season evapo-transpiration exceeds annual precipitation in future projections. The authors project that the overall area of Washington forests that are severely water limited will increase by 32% in the 2020s and an additional 12% in 2040s and 2080s. This culminates to 56% more water-stressed forests compared to the 20th century under modeled projections. For example, 32% of current Douglas-fir habitat will be outside its suitable climate range by 2060, and 27% of lodgepole pine by 2040.

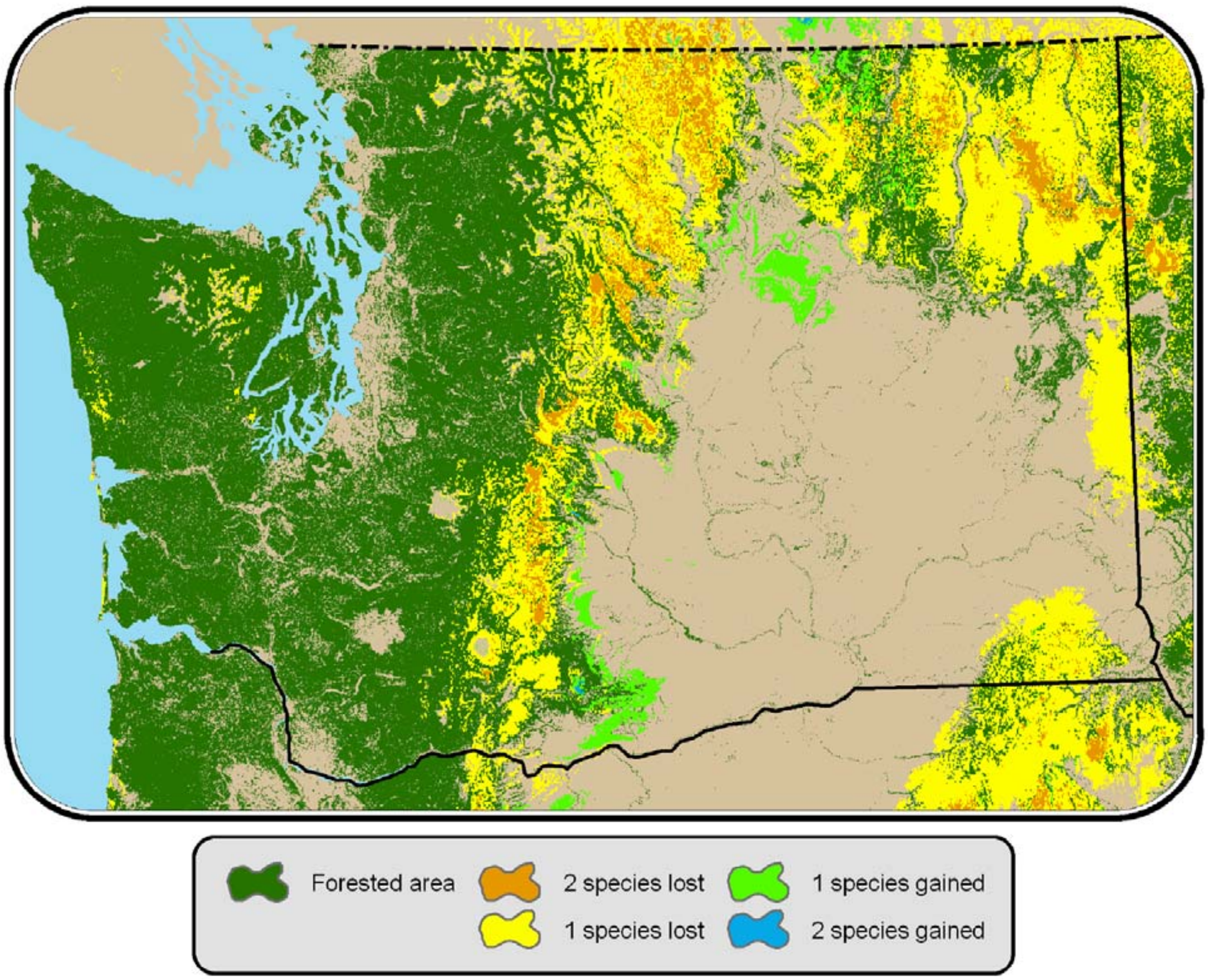

Figure 3. Change in number of pine species for which climate is suitable in the 2060s. From Littell et al. 2009.

2.3 Beetle Infestation and Range Shift Dynamics

Scientists debate management of the impact of beetle infestations from two perspectives: natural cycles may help thin lodgepole or ponderosa pine crowns and therefore decrease potential fire intensity on the one hand; and on the other, human intervention may be required because dead and dying timber stands lead to more intense fire and soil sterilization.

CLI's analytical approach to estimating the economic costs of bark beetle damage requires accounting for changes in the extent and composition of forested lands in Washington resulting from global climate change. Carroll et al. (2003) noted that climate-induced changes in tree ranges may in fact reduce the prevalence of beetle outbreaks in localized areas due to the diminished range of host trees and climatic conditions unfavorable to beetle life history.[21] Littell et al. examined likely changes in the extent and range of tree species in Washington in 2020, 2040 and 2080 using two emission scenarios for global circulation models. The analysis also examined changes in the probability of beetle attacks for the same time periods and emission scenarios. These analyses predict an increased probability of conditions favorable for bark beetle attacks throughout much of Washington's forested lands, but the level of these impacts depend on host availability.

Carrol et al. predict that with projected warming trends, mountain pine beetles will generally move north to higher latitudes, west toward the coast, or uphill to cooler elevations. The most rapid movement will be uphill rather than to the north; however, uphill movement will be constrained by the fact that cold-blooded beetles migrate uphill at twice the rate of the movement of host trees to maintain a relatively constant temperature rate, and thus would likely run out of suitable host species.[22] In association with the migration driven by warmer temperatures, host trees will also be weakened by reduced precipitation, making them even more susceptible to intensified infestations. Warmer winter temperatures will also result in reduced winter-kill of beetle populations, allowing for additional breeding during the year.[23] Williams and Liebhold noted that beetles inject fungi to aid in tree mortality, but the effects of climate change on fungi survival are unknown. Littell et al. observed that beetle-kill loss may be suppressed at lower elevations by early emergence of adults being out of synch with vulnerability of host trees.

As trees are lost at their southern range, there is increased likelihood of susceptibility to the north and across the Canadian border. Eventually, the area affected in the State of Washington will probably diminish with this northerly trend. Carrol et al. estimate a potential total latitudinal shift of 7 degrees or almost 500 miles during the course of the next century, effectively shifting the problem from Washington to British Columbia as the state's conifer forests are converted to shrub land, grass land, or deciduous tree species that are naturally more drought and beetle resistant. In other words, climate driven shifts in species distribution may reduce the overall impact of beetle infestations in Washington by reducing beetle habitat.

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[21] Carroll, A.L., S.W. Taylor, J. Regniere, and L. Safranyik. 2003. "Effects of Climate Change on Range Expansion by the Mountain Pine Bark Beetle in British Columbia." Canadian Forest Service, Pacific Forestry Centre.
[22] Williams and Liebhold 2002.
[23] Note that host trees must be killed in order for beetle reproduction to take place. Carroll et al. 2003

Figure 4 shows the variable trend in pine beetle activity over the last decade, with an increase in the last five years.

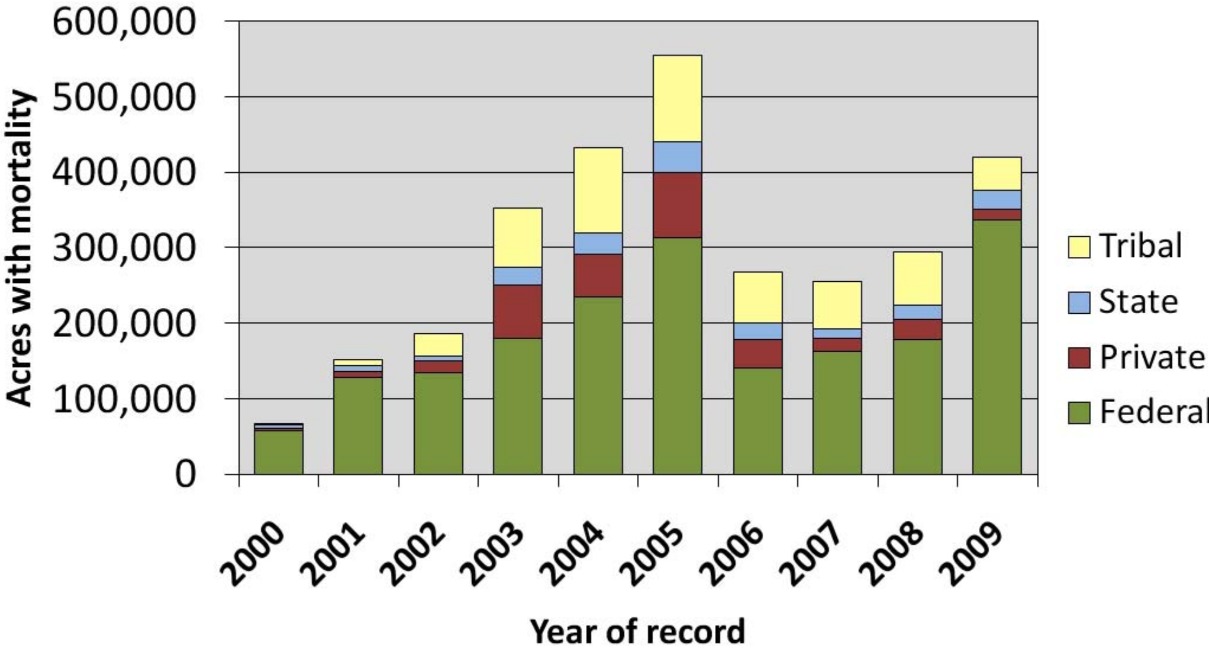

Figure 4. Trend in pine bark better activity in Washington State 2000-2009. Demonstrates a 300,000 acre mortality average over the last ten years for all ownerships and all pine species. Note high variability and that state and private lands only account for 10% or 30,000 acres 2006-2009 (WA DNR E-6).

As presented in Table 2.1, there are other infestations affecting Washington's forests in addition to pine bark beetles. Bear root disease, fir engraver beetles, and western spruce budworm infestations are each of substantial magnitude compared to pine bark beetle infestations.

Table 2.1. Total area of forest land in Washington containing new tree mortality, tree defoliation, or foliage disease (WA DNR Resource Assessment E-4).

Year	Total area in millions of acres	Pine Bark Beetles (acres)	Fir Engraver Beetle (acres)	Bear Damage or Root Disease (acres)	Western Spruce Budworm (acres)
2005	1.50	**554,000**	368,000	233,000	352,000
2006	1.29	**267,000**	140,000	236,000	556,000
2007	1.42	**255,000**	236,000	184,000	355,000
2008	1.36	**295,000**	181,000	310,000	451,000
2009	1.73	**420,000**	157,000	592,000	412,000

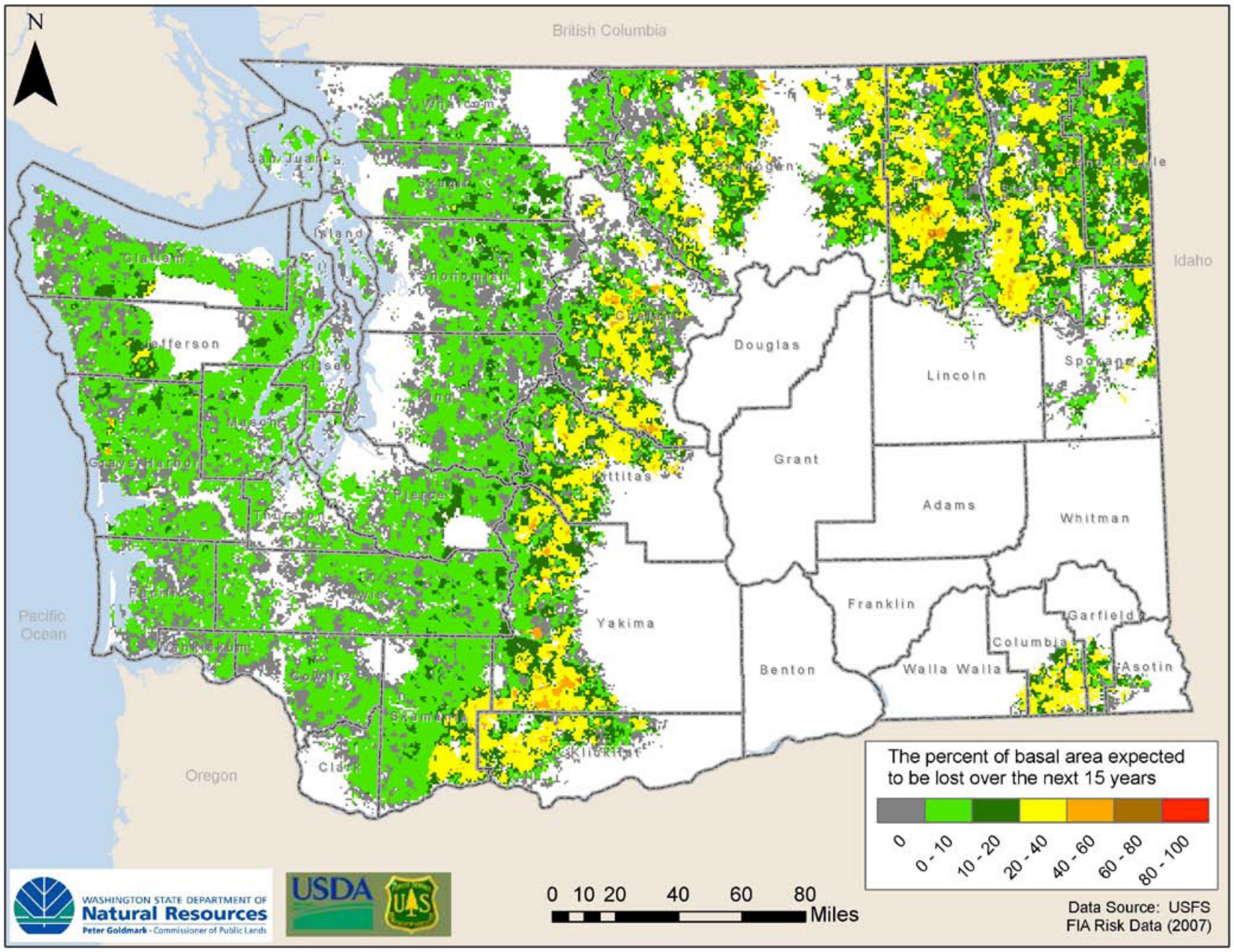

Figure 5. Insect and Disease Risk and Mortality Predictions for Trees in Washington State Through 2022 (WA DNR Resource Assessment E-10).

2.4 Assumptions Used in Economic Analysis of Beetle Infestations

Table 2.2 provides a summary of the potential economic impacts of climate change factors other than beetle infestations. It should be understood that the sources referenced above provide little certainty and a variety of sometimes conflicting hypotheses related to the relationship between drought, fire, and beetle infestations. Based on information that low value lodgepole pine and high value ponderosa pine are fairly evenly distributed in the pine zones in Washington, we have assumed that dollar values for ponderosa pine should only be applied to 50% of the total acres lost to beetles in the data set and only 10% value placed on lodgepole pine. Further, we have not included a value for salvage logging of beetle-infested areas, as we have no reliable data. To assure continuity with the 2009 CLI analysis, we assume the value of one ponderosa pine acre to be $1000 due to its high commercial value, but only $100 for one lodgepole pine acre as lodgepole is used primarily for firewood and fence poles. We also assume a 2:1 ratio of lodgepole to ponderosa mortality, due to high density and drought propensity of lodgepole compared to ponderosa pine.

Table 2.2. Summary of non-beetle climate impacts including range shift, fire, and suppression costs. Note that Douglas-fir and ponderosa pine are valued at roughly $1000/acre based on CLI 2009 economic analysis.						
Year	**Doug-fir range shift (million acres)**	**Ponderosa pine range shift (million acres)**	**Total acres lost to fire>hist.[24]**	**Fire Suppression cost[25] (millions)**	**Total Incremental Costs (billions)**	**Tax Revenues Lost[26] (millions)**
Historic	9	5	166,000	$12		$8.3
2020	0.9	0.75	84,000	$18	$1.752	$87.6
2040	1.8	1.5	171,000	$37	$3.508	$175.4
2080	3.6	3	380,000	$82	$7.062	$353.1

These projections are primarily driven by contraction of pine habitat east of the Cascades and Douglas-fir contraction west of the Cascades. We have not assumed any increase in fire suppression costs resulting from beetle infestations, as the literature provides little information on this subject. Nor have we assumed any losses for the tourism industry, as there is only anecdotal information on how beetle infestations may affect tourist activity.

Due to the uncertainties of climate projections, particularly precipitation forecasts which are crucial to projecting the virulence of beetle infestations, we offer four possible scenarios. Tax losses are based on Washington Department of Revenue harvest statistics for 2005-2009 as shown in Table 2.3.[27] We have selected only eastern Washington counties to incorporate into our analysis losses to pine beetle sensitive species (ponderosa and lodgepole pine) most likely to have an economic impact resulting from insect mortality (see Figure 5).

Table 2.3. Summary of private and public land harvest values and tax revenues for twenty eastern Washington counties in millions of dollars (WA Dept. of Revenue, Harvest Statistics, 2010).						
Year	**Private Harvest Value**	**Public Harvest Value**	**Total Harvest Value**	**Private Land Tax**	**Public Land Tax**	**Total Tax Revenue**
2005	$131.2	$38.4	$169.6	$6.6	$1.9	$8.5
2006	$132.9	$39.8	$172.7	$6.6	$2.0	$8.6
2007	$107.6	$38.2	$145.8	$5.4	$1.9	$7.3
2008	$41.4	$18.8	$60.2	$2.1	$0.9	$3
2009	$25.4	$14.8	$40.2	$1.3	$0.7	$2
5 Year Average	**$87.7**	**$30**	**$117.7**	**$4.4**	**$1.5**	**$5.9**

[24] CLI & ECONorthwest. 2009. Note that each acre is valued at $1000.
[25] CLI and ECONorthwest. 2009.
[26] Washington Department of Revenue. 2010. "Harvest Statistics." Retrieved November 2010, from www.dor.wa.gov/content/findtaxesandrates/othertaxes/.../forst_stat.aspx.
[27] Washington Department of Revenue. 2010. "

Because of the dynamic relationships among the various climate factors (temperature, precipitation, range shift, and beetle infestations) in selecting four possible scenarios, we partially isolate some of these factors to provide a better understanding of possible futures.

2.4.1 Scenario One: No change from recent historical pattern.

This scenario assumes that inevitable temperature increases over the course of the next century will drive more virulent beetle attacks by increasing beetle populations under conditions of reduced beetle winter kill and some doubling of annual lifecycles. However, the scenario also assumes the increased populations will be largely offset by more vigorous forest growth with increased precipitation and carbon dioxide (CO_2) fertilization effects. CO_2 fertilization will limit the effect of diminishing stand area with uphill migration by expanding downhill movement in drier low elevation eastern pine habitat. Pine forest habitat will not diminish significantly under this scenario, and pine species will be more drought resistant with higher CO_2 levels than in recent history. Historical losses for both ponderosa and lodgepole due to beetle infestations will be relatively constant at 300,000 acres/year, or $120 million if there is no salvage logging.

Table 2.4. Beetle Damage Costs Base on Scenario One Assumption of No Change in Net Acres Lost Annually to Beetle Infestations (2000-2009).

Year	Ponderosa Pine Acres Lost to Beetle	Lost Value (millions)	Lodgepole Pine Acres Lost to Beetle	Lost Value (millions)	Total (millions)	Tax Loss (millions)
Historical 2000-2009	100,000	$100	200,000	$20	$120	$6
2020	100,000	$100	200,000	$20	$120	$6
2040	100,000	$100	200,000	$20	$120	$6
2080	100,000	$100	200,000	$20	$120	$6

2.4.2 Scenario Two: Reduced beetle kill impacts due to range shift.

Scenario Two assumes that pine forest habitat in Washington will contract significantly as it migrates north and to higher elevations over the course of the next century, thus contracting and diminishing proportionally the economic impact of beetle kill infestations. Even with increased drought resistance due to the CO_2 fertilization effect and increased precipitation, these factors will not preclude diminishing pine forest area: scrub woodland and grass land replaces historical pine stands under conditions of increased disturbances such as wildfire and periodic beetle infestations. We estimate that contraction at 15% by 2020, 30% by 2040 and 60% by 2080. We roughly estimate this annual beetle cost reduction due to range contraction at $18 million by 2020, $36 million by 2040, and $72 million by 2080.

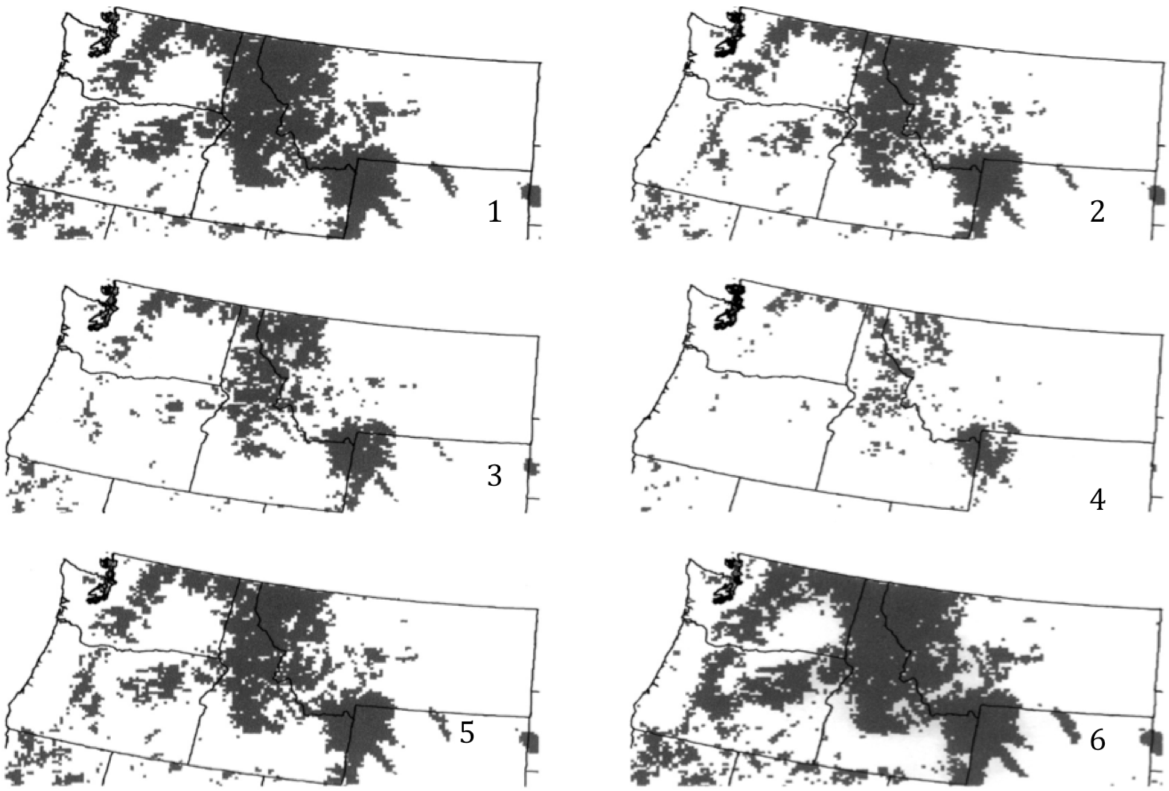

Figure 6**. Climate warming may diminish pine beetle outbreaks, while an increase in precipitation may increase outbreaks (Williams & Liebhold 2002). Map 1 represents historical temperature conditions, and maps 2, 3 and 4 represent a 2, 4, and 8 degree Celsius warming respectively. Map 5 represents historical temperature and a 0.5mm/day decrease in precipitation, and Map 6 represents historical temperature and 0.5 mm/day precipitation increase, demonstrating greater outbreak area driven primarily by increased precipitation.**

Table 2.5. Beetle Damage Costs Based on Scenario Two Assumption (areas covered by pine forests will contract by 15% by 2020, 30% by 2040, and 60% by 2080).

Year	Ponderosa Pine Acres Lost per year	Lost Value (millions)	Lodgepole Pine Acres Lost per year	Lost Value (millions)	Total (millions)	Tax Loss (millions)
Historical (2000-2009)	100,000	$100	200,000	$20	$120	$6
2020	85,000	$85	170,000	$17	$102	$5.1
2040	70,000	$70	140,000	$14	$84	$4.2
2080	40,000	$40	80,000	$8	$48	$2.4

2.4.3 Scenario Three: Increased beetle kill impacts due to drought.

Scenario Three assumes CO_2 fertilization and precipitation increases will provide some vigor to vulnerable pine stands, and limit their contraction. A combination of increased temperature and persistent periods of drought, both climatic factors favorable to beetle populations, will stress pine stands and increase the virulence and frequency of beetle attacks. Periods of increased precipitation, interrupted by periods of drought, will maintain pine stand habitat area but subject them to periods of high vulnerability. Under this scenario we can assume some likelihood that pine beetles will jump to other species, including Douglas-fir. There is some anecdotal evidence that this is already happening, but this is not assumed in Scenarios One and Two. Resulting economic losses will escalate over the next century, and water deficit in the eastern pine forest region will be the primary driver. However, the studies cited above by Carrol et al., Williams and Liebhold, and Littell et al. suggest this scenario is highly uncertain.

Table 2.6. Water Deficit Shifts with the Business as Usual Model Projections (as used by Littell et al. 2009).

Year	Mean Water Deficit (mm)	% Change from 2000-2003
Historical (2000-2003)	96	--
2020	142	148%
2040	177	184%
2080	209	217%

Table 2.7. Beetle Damage Costs Based on Scenario Three Assumption of Water Deficit as Driver of Increasing Levels of Infestation.

Year	Ponderosa acres lost to beetle kill	Ponderosa $ lost to beetle kill (millions)	Lodgepole acres lost to beetle kill	Lodgepole $ lost to beetle kill (millions)	Incremental Increase (millions)	Tax Loss (millions)
Historical (2000-2009)	100,000	$100	200,000	$20		$6
2020	148,000	$148	296,000	$29.6	$57.6	$8.9
2040	177,000	$177	354,000	$35.4	$92.4	$10.6
2080	209,000	$209	418,000	$41.8	$130.8	$12.5

2.4.4 Scenario Four: Combination of Range Shift and Drought Stress.

The most likely scenario may be a combination of range contraction and water deficit as projected in Scenarios Two and Three. One reason for this is the likelihood that persistent drought may accelerate range shifts by causing beetle and fire related disturbances. Table 2.8 summarizes the beetle infestation costs of the combination of factors underlying these two scenarios. In this case, costs increase by 2020 by $31 million, see a slightly less increase in 2040 of $28.7 million, but due to dramatic range contraction, beetle kill costs actually decrease over the historical losses by $19.7 million.

Table 2.8. Scenarios Two and Three Combined: Forest Habitat Contraction combined with Increasing Water Deficit						
Year	**Ponderosa acres lost to beetle kill**	**Ponderosa $ lost to beetle kill (millions)**	**Lodgepole acres lost to beetle kill**	**Lodgepole $ lost to beetle kill (millions)**	**Total Incremental Increase> Historical (millions)**	**Tax Loss (millions)**
2000-2009	100,000	$100	200,000	$20	$120	$6
2020	125,800	$125.8	251,600	$25.2	$31	$7.6
2040	123,900	$123.9	247,800	$24.8	$28.7	$7.4
2080	83,600	$83.6	167,200	$16.7	-$19.7	$5

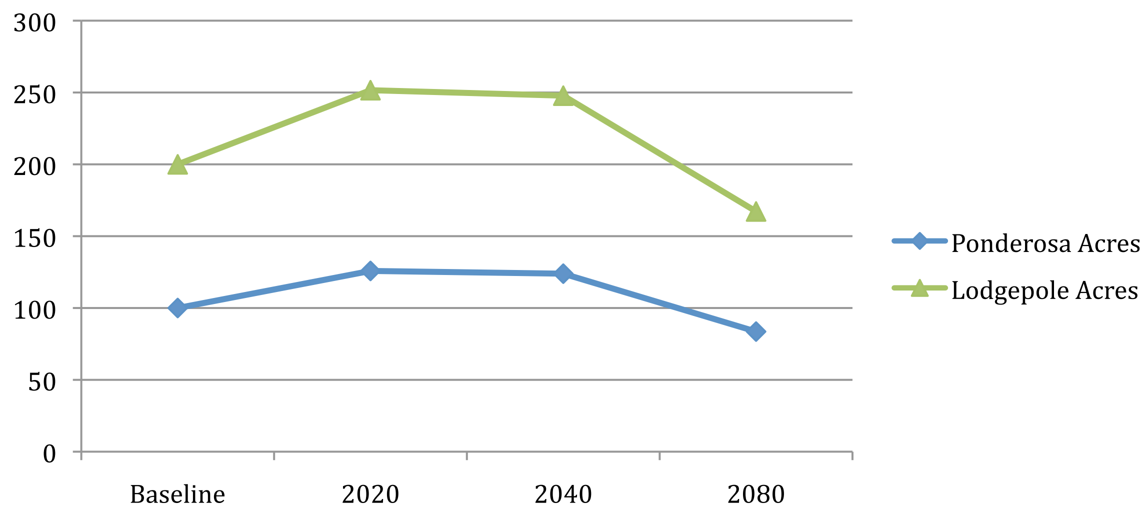

Figure 7 Acres Lost in Thousands for Scenario Four Over Four Time Periods

Based on these projections, and assuming that ponderosa pine losses due to beetle-kill infestations are the primary economic consequence of these projections, we estimate that in the most likely scenario (Scenario Four) historical average costs of $120 million for 300,000 acres lost to beetle infestations may increase by $31 million in 2020, $28.7 million by 2040, and actually decline by $19.7 million by 2080. The 2080 reduction is primarily due to contraction of pine habitat throughout the eastern portion of the state. We have not assumed any increase in fire suppression costs resulting from beetle infestations, as the literature provides little information on this complicated relationship. We have not addressed the potential loss in property values in the wildland-urban interface associated with beetle infestations.[28] Nor have we assumed any losses for the tourism industry, as there is only anecdotal information on how beetle infestations may affect tourist activity.

[28] See Price, McCollum, and Berrens (2010) "Insect Infestation and Residential Property Values: A Hedonic Analysis of the Mountain Pine Beetle Epidemic" Forest Policy and Economics. 12: 415-422 for emerging research in this area.

Note that even in the worst case beetle kill scenario, Scenario Number Three driven by persistent drought, the incremental $131 million damage attributable to beetle-infestation by 2080 is only about 3% of total climate driven costs by our estimates.

2.5 Summary and Conclusions

Due to the high variability of modeled precipitation projections, and the complexity of the interactions between climate factors and beetle infestations, it is difficult to predict which scenario is the most likely. Under Scenario One there would be no incremental increase in costs from beetle infestations above the historical period. Under Scenario Two there would be a reduction in beetle infestation losses due to range contraction of pine species. Even under Scenario Three, the scale of the incremental costs in this unquantifiable worst case is likely to be relatively minor compared to other impacts such as fire and climate driven stand shifts as demonstrated in Table 2.7. Given the likelihood projected in the literature that range contraction may be significant, up to 60% by the late 21st century, and that persistent drought may more than double water-stress in eastern pine forests and contribute significantly to range contraction, we favor the Scenario Four as the most likely.

Revised Costs to Washington from a Business as Usual Approach to Climate Change

To update the previous CLI analysis of the economic costs to Washington of a business as usual approach to climate, the following table incorporates the costs estimated for lost winter snowpack (as the cost of replacement) as well as the potential damage caused by bark beetle infestations (in terms of lost timber) into the larger analysis.

Potential Economic Costs in Washington Under a Business-as-Usual Approach to Climate Change, 2020, 2040, and 2080 (dollars per year)

Potential Cost	2020	2040	2080
Costs of Climate Change			
Increased Energy-Related Costs	$222M	$623M	$1.5B
Reduced Salmon Populations	$531M	$1.4B	$3B
Increased Coastal & Storm Damage	$72M	$150M	$352M
Reduced Food Production	$35M	$64M	$364M
Increased Wildland Fire Costs	$102M	$208M	$462M
Increased Health-Related Costs	$1.3B	$2.2B	$4.4B
Lost Recreation Opportunities	$75M	$210M	$612M
Lost Natural Water Storage	$7.15B	$11.1B	$18.1B
Impacts to Forestry of Beetle Kill	$31M	$28.7M	- $19.7M
Subtotal for Costs of Climate Change	*$9.5B*	*$15.9B*	*$28.6B*
Additional Costs from BAU Activities that Contribute to Climate Change			
Inefficient Consumption of Energy	$1.4B	$1.6B	$2.2B
Increased Health Costs from Coal Energy	$19M	$23M	$31M
Subtotal for Costs of BAU Activities	*$1.4B*	*$1.6B*	*$2.2B*
Total	**$10.9B**	**$17.5B**	**$30.8B**
Average Cost per Household per Year	$3,633	$4,916	$6,553

The inclusion of these two new cost analyses increases the total economic costs to Washington by 187% over the 2009 CLI estimated total cost in 2020, 169% in 2040, and 138% in 2080. The relatively high cost of lost natural water storage in snowpack accounts for the vast majority of this increase.

The cumulative analysis significantly increases average costs on a household basis as well. As noted in the analysis on lost natural water storage in snowpack, these costs represent the lost value of ecosystem services that are freely provided at present. Unlike direct costs to households such as increased rates for electricity, the loss of value provided by lost natural water storage would not be fully realized in household budgets. But Washingtonians would be poorer by virtue of losing the services of mountain snowpack as currently enjoyed. Indirectly, the loss of mountain snowpack would require public and private expenditures to secure future water supply for use by citizens, industry and agriculture. Further, scenic and recreational losses would be realized.

This second analysis of the economic costs to Washington from a business-as-usual approach to climate change adds two additional cost parameters to the 18 examined by CLI in 2009. In so doing, the projected net costs of unabated climate change have grown significantly. It is clear that climate change will likely exact costs beyond the 20 economic parameters examined in these two analyses and that further research is warranted.