Climate Adaptation Planning for British Columbia Provincial Parks:

A guide to conducting a rapid assessment of climate impacts on park management objectives

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October 2013

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Climate Adaptation and BC Parks

Climate impacts potentially affect all levels of park planning and management. Climate adaptation planning seeks to identify and proactively prepare for potential climate change impacts on management sectors. Taking a proactive approach can help reduce future risks, capitalize on new opportunities, and minimize losses due to climate change. Most importantly, integrating climate impacts into park planning and management will help park managers continue to meet their mission of protecting natural and cultural resources, providing recreation opportunities, and protecting the health and safety of park visitors.

British Columbia's (BC) climate has changed significantly over the past 100 years. Average annual temperatures have increased by 0.6 degrees Celsius on the BC coast and 1.7 degrees Celsius in northern BC (Smith and Fraser, 2002). This means that northern BC warmed at a rate more than twice the global average, while coastal areas warmed at about the global rate of 0.7 degrees over the last 100 years (IPCC 2007). Annual precipitation increased in southern BC by 2-4% per decade and sea levels rose by 4 to 12 centimeters along the BC coast. This rapid change has had a host of cascading effects on other important aspects of climate and natural resources. For example, snowpack has been reduced by about 50% and glaciers in southern BC retreated up to one kilometer. Snow and ice are thawing earlier in the spring leading to earlier peak river flows (Smith and Fraser, 2002). Warmer winters have resulted in a mountain pine beetle epidemic leading to a dramatic loss of pine forest (Carroll et al., 2003).

The BC provincial parks' mission is to "protect representative and special natural places within the Province's Protected Areas System for world class conservation, outdoor recreation, education and scientific study." Climate change potentially impacts all aspects of this mission. Recent climatic changes have altered ecological systems, with potentially significant implications for ecological conservation. Scientists have observed shifts in both the timing of ecological events and the distribution of species (Parmesan, 2006; Parmesan and Yohe, 2003; Root et al., 2003; Walther et al., 2002). Many species have shifted their ranges in accordance with changing temperatures, often resulting in poleward or upward in elevation shifts in species distributions (e.g., Moritz et al. 2008). Future ecological impacts of climatic changes are expected to be greater than those recorded in the past century in extent and magnitude (e.g., Thomas et al. 2004). For example, in BC, models project that spruce and fir forests will rapidly shift to higher elevations (Flower et al., 2012). These changes need to be taken into account when making management decisions such as how and where restoration takes place, which lands to protect to maintain connectivity or climate refugia, and whether to manage species shifts through assisted migration.

Climate change also has significant implications for recreation experiences and the health and safety of park visitors. For example, reduced snowpack and earlier spring melt will affect the timing, duration and quality of winter recreation activities. Retreating glaciers change both the character and hydrology of parks such as Garibaldi Park, which has lost half its glacial ice cover since 1900 (Koch et al., 2009). The hydrology of the Fraser River has already changed with earlier snowmelt in the spring leading to early peak flows, lower summer river levels, and higher water temperature (Morrison et al., 2002). These changes have negative implications for Fraser River salmon populations and the cultural and recreational benefits they provide visitors. Human health and safety may be affected if the risk of fire, avalanche, landslides, floods, or high winds increases. For example, increased probability of high precipitation events, could potentially lead to more vehicle accidents (Hambly et al., 2013).

Finally, climate change has important implications for facility placement and maintenance. Sea levels in BC have risen between 3 and 10 cm over the last 50 years (Arlington Group Planning + Architecture Inc. et al., 2013). Impacts of sea level rise include complete inundation of low lying coastal areas including campgrounds or cultural sites, increased storm surge events, and increased cost to infrastructure development and maintenance (Delcan, 2012). More precipitation and winter rain on snow precipitation events may lead to greater flooding and landslides, increasing the cost of road and other infrastructure maintenance (Smith and Fraser, 2002).

Conducting a Rapid Climate Assessment

Here, we provide guidelines for doing a simple and rapid climate impact assessment for any number of management objectives. Such a rapid assessment focuses on identifying major climate trends and potential impacts using existing expertise and a few key web resources. We have based these guidelines on the Adaptation for Conservation Targets (ACT) framework (Cross et al., 2012). The assessment could be conducted over the course of a one- or two-day workshop. Although this kind of rapid assessment is not sufficient to develop a formally adopted action plan, it can help managers start thinking about how climate change will impact park management and identify areas where a full-scale planning effort is warranted. The following checklist provides a step-by-step approach to incorporating climate change

Planning at What Scale?

Climate change impacts can affect management decisions at all scales. For example, changing climatic conditions may lead to dramatic shifts in species and vegetation. If individual ecological reserves were established to protect a specific species or ecosystem type, the goals for these reserves may need to be re-evaluated. At the regional level, managers will need to develop a landscape-scale plan for managing movements of species to new locations and making decisions about where and how conservation priorities may shift. Within individual parks, managers may need to alter their management of individual species and vegetation associations. For example, managers may need to apply active management strategies to reduce new or increasing pressure from competitive (and/or invasive) species, identify microclimatic habitat locations where a priority species may persist (i.e. climate refuges), or change management priorities if a given species is no longer viable within the park.

While climate impacts can occur at any scale, initial climate adaptation planning for BC Parks is probably most efficiently conducted at the sub-regional or management area scale. This is because although climate impacts will vary across the province, they are likely to be similar within a geographic region. So, a single assessment of climate changes and impacts will likely be applicable to all parks within a management area. Furthermore, broad changes to ecosystem structure and function may be similar across a region and benefit from the same adaptive strategies. Ultimately, however, much of the actual implementation will need to occur at local scales. Involving park managers in the climate adaptation planning process if possible, or at a minimum ensuring that managers are aware of climate impacts relevant to their parks, can help facilitate the transition from planning to implementation.

impacts into park management decisions.

1. Identify the management objective

Specifying a specific, targeted management objective helps narrow the scope of initial planning and facilitates the identification of concrete actions or knowledge gaps (Cross et al., 2012). Management objectives should be as focused as possible. Management objectives can either be a top priority decision or an objective that is likely to be seriously affected by climate change. Additional management objectives can be added as resources allow. Planning for these subsequent objectives will likely progress much faster as most of the background climate information gathered for one will apply to others. Keep in mind that new priorities might arise if climate changes threaten currently stable resources or open up new opportunities.

Examples of management objectives include:

- Maintain viable grizzly populations and bear viewing opportunities in mid-coast BC parks
- Manage iconic alpine meadows in Garibaldi Park
- Identify an appropriate location for a new amphitheater in Porpoise Bay Park

2. Develop a conceptual model

Draw a conceptual model using boxes and arrows to illustrate the different factors that affect your management objective and how these elements are connected (Figure 1). These models are extremely useful for a variety of reasons. Conceptual models identify the most important factors affecting an objective. Involving relevant experts in the creation of a conceptual model is critical to ensuring that all the most important variables are identified. These model diagrams are also extremely useful as a communication tool, allowing viewers to quickly see which factors are considered important (i.e. are included) and whether critical components are missing.

There are no real rules to creating a conceptual model. However, the following guidelines can help get you started:

- Start with the management goal on the right side of the page and work backwards including all the factors that affect the behavior of the management goal, ultimately ending up with climate change on the left.
- Limit the amount of time spent on the initial development of the conceptual model. It is easy to get caught up in getting the model exactly right and then have no time to consider the climate impacts

Web Resource:
http://climatechangesensitivity.org/

This digital database provides resource managers with basic and important information about how species and systems will likely respond to climate change based on a series of life history characteristics: generalist/specialist, physiology, life history, habitat, dispersal ability, disturbance regimes, ecology, non-climate related threats, and other factors. Species experts assign each species/system a numeric ranking (1 being the least sensitive and 7 being the most sensitive to climate change) for each of these life history categories based on best available science (see Table 2 for more details). Additional specific questions are included for each category to highlight particular life history characteristics that drive climate change sensitivity, as experts add species and locations, the on-line database grows.

and potential actions. The planning process is iterative, so the conceptual model will need periodic revision as the planning process progresses

- Initially, be comprehensive and try to include all elements that are likely to affect the management objective. In the revision process, aim to trim down the model to only include the most important variables that truly impact the objective.

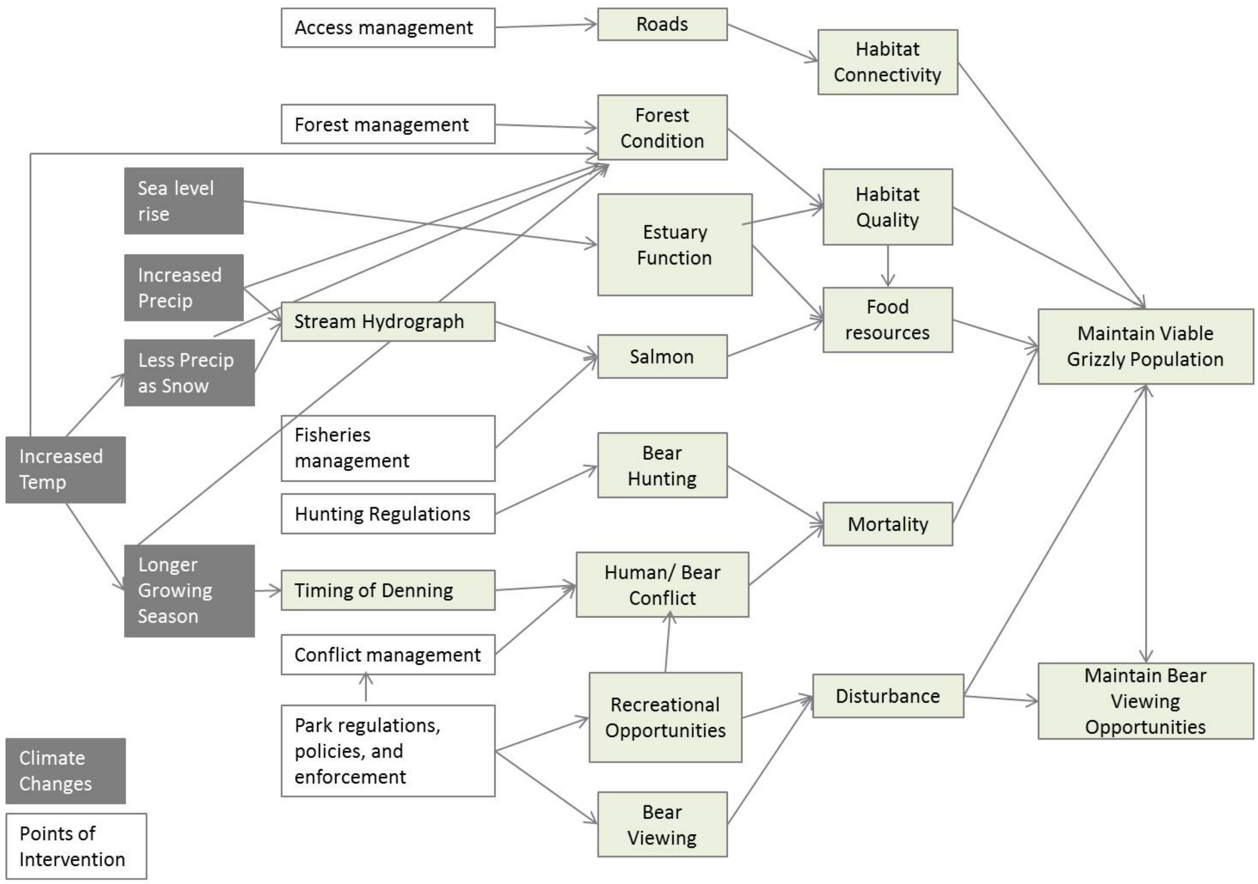

Figure 1: An example conceptual model developed after a one day workshop with BC parks managers in the mid-coast region.

3. Assess potential climate change impacts

The conceptual model can help identify specific climate elements that most directly affect your system. To the extent possible, be specific about what aspects of the climate are important. For example, rather than saying that increased precipitation will affect salmon spawning, say that increased winter flooding due to rain on snow events will affect salmon by increasing streambed scouring of spawning habitat. Consider the following questions:

- How much change is expected?
- How fast is change expected to be?
- What is the range of projected change?

Web Resources:

The following websites can quickly provide summaries and maps of projected climate changes:

www.plan2adapt.ca

www.climatevulnerability.org

www.climatewizard.org

- How certain are projected changes?

Note that in initial exploratory planning, quantitative projections are not necessary. Simply noting that winter precipitation will increase is likely to be sufficient to highlight potential issues. If time and resources allow, identifying quantitative thresholds (if they exist) and comparing these to climate change projections can be a next step. For example, the BC Ministry of Environment identifies 15°C as the maximum daily temperature tolerated by Bull Trout and Dolly Varden and 10°C as the maximum spawning temperature (Oliver and Fidler, 2001). Understanding the likelihood that stream temperatures will exceed these thresholds is valuable information for fisheries managers.

Evaluating Uncertainty for Projected Climate Changes for BC

Average annual temperatures have increased by 0.6-1.7°C in BC (Smith and Fraser, 2002). There is very high certainty that temperatures will continue to increase (Solomon et al. 2007). However, it is uncertain how high temperatures will go and therefore how mild or drastic these changes will be. Estimates range from an increase of 1.7 to 4.5°C by the end of the century. Climate models generally agree that B.C. will experience warmer, wetter winters and hotter, drier summers. However, there is significant variability in how much change is expected (e.g. increase of 2% to 12% in annual precipitation) and a few models project that precipitation in summer will increase rather than decrease.

Sea level rise is another important consequence of climate change for BC. Scientists agree that sea level rise is already occurring and will continue in the future. However, there is significant uncertainty about how high sea levels will go. As of 2008, the most probable estimate of sea level rise was 11 cm for Nanaimo and 50 cm for parts of the Fraser River delta with maximum plausible estimates at 80 cm and 120 cm respectively (Bornhold et al., 2008). However, recently global estimates of sea level rise have been revised upwards (Sriver et al., 2012). Therefore, the 80 and 120 cm projections are likely to be underestimates. Higher mean sea levels mean more frequent and higher high water levels, which in turn will increase flooding and erosion, cause a loss of coastal habitats, submerge cultural, historical and recreation sites, and lead to salt water intrusion into coastal aquifers (Bornhold et al., 2008). These changes are likely to lead to loss of property and increased maintenance and repair costs for coastal infrastructure.

Climate models strongly agree that BC is expected to receive more precipitation overall, but winters are likely to be wetter and summers drier. In other words, current precipitation patterns will intensify. However, precipitation projections are less certain than temperature projections. A few models project that summers will get wetter and winters drier. If many models agree on a certain projection, as they do in the case of wetter winters and drier summers for BC, scientists feel more confident that those changes are the most likely. However, ultimately, these models do not predict the future and so we cannot completely discount the possibility that the few models projecting opposite trends will ultimately be “right.”

Table 1: Projected climate changes for British Columbia. Accessed from http://www.plan2adapt.ca/ on June 12 2013.

Climate Variable	Season	Projected Change from 1961-1990 Baseline		Projected Change from 1961-1990 Baseline	
		2050s Ensemble Median	2050s Range (10th to 90th percentile)	2080s Ensemble Median	2080s Range (10th to 90th percentile)
Mean Temperature (°C)	Annual	+1.8 °C	+1.3 °C to +2.7 °C	+2.7 °C	+1.7 °C to +4.5 °C
Precipitation (%)	Annual	6%	+2% to +12%	9%	+4% to +17%
	Summer	-1%	-8% to +6%	0%	-13% to +7%
	Winter	8%	-2% to +15%	13%	+5% to +23%
Snowfall* (%)	Winter	-10%	-17% to +2%	-12%	-26% to -1%
	Spring	-58%	-71% to -14%	-70%	-88% to -18%
Growing Degree Days* (degree days)	Annual	+283 degree days	+179 to +429 degree days	+468 degree days	+262 to +769 degree days
Heating Degree Days* (degree days)	Annual	-648 degree days	-952 to -459 degree days	-973 degree days	-1554 to -608 degree days
Frost-Free Days* (days)	Annual	+20 days	+12 to +29 days	+30 days	+16 to +48 days

* These values are derived from temperature and precipitation. Visit www.plan2adapt.ca for details on how these variables are calculated.

4. Select climate scenarios

Climate change means that we can no longer use past climate as a guide for the future. However, projecting future climate conditions is no simple task. The complexity of climate change and subsequent ecological responses means that all future projections have a degree of uncertainty associated with them. That uncertainty stems from many different sources. For example, how much climate change we experience in the future is dependent upon the amount of greenhouse gasses humans emit. The IPCC has developed a complex set of emissions scenarios, plausible projections of future greenhouse gas emissions, based on population growth, socio-economic development and technological innovation (Nakicenovic and Swart, 2000). These scenarios provide a range of future emissions that are used as inputs into climate models. By choosing two or more emissions scenarios, planners can see projections of different degrees of climate change. For example, two commonly selected emissions scenarios are the A2 and A1B scenarios. The former is considered a medium-high emissions scenario resulting from a heterogeneous world with high population growth, slow economic development and slow technological change. The latter is a medium emission scenario resulting from rapid economic growth and rapid technological change in the direction of both fossil-intensive and non-fossil energy resources (Nakicenovic and Swart, 2000). Future projections using the same climate model but different emissions scenarios tend to show the same changes, but at different rates. In other words, projections using higher emissions scenarios such as the A2 tend to show faster and more intense climate changes compared to those using the A1B.

In addition to the uncertainty surrounding how much greenhouse gases humans will emit, there is also uncertainty about how the climate will respond to those changes. While climate models are always improving, no model can perfectly replicate the Earth's climate. To some extent this uncertainty can be reduced by using the most up-to-date models and looking for agreement among multiple models. Because each climate model uses slightly different assumptions about how climate variables interact, if the models all project a similar future change, we can feel more confident that a particular result is likely. Climate scientists often use an ensemble mean of multiple models to help reduce the uncertainty associated with individual model projections. An ensemble mean is simply the average projected value, for example temperature change, from a set of different model projections. This approach is particularly good if model projections are qualitatively similar and variation among models is relatively low. For example, all models project increased temperatures, so understanding the mean, high and low of temperature projections gives a useful picture of the range of projected temperature change. Sometimes researchers will weight individual models if they believe that some models better represent climate in a particular region. This is referred to as a weighted ensemble mean.

However, in many cases, model agreement does not exist and as models incorporate more complex aspects of climate they are likely to show more variability in future projections (Maslin and Austin, 2012). For example, precipitation projections in many regions conflict so that some models project increased precipitation and others decreased. An ensemble mean would project no or very slight change in precipitation. In that case, the mean value is less informative and should certainly not be viewed alone. While a lack of agreement among climate models may be frustrating, it is critical to incorporate conflicting model projections into climate adaptation plans. Selecting two or three climate scenarios allows managers to explore how their adaptation actions will perform under different potential future conditions.

Recommendations:

- Select two or three projected future climates or climate scenarios to consider in your planning. See Figure 2 for guidance on selecting climate scenarios.
- Work through one climate scenario at a time rather than trying to identify the risks and actions associated with all climate scenarios at once. This is particularly important if the selected climate scenarios project opposite trends.

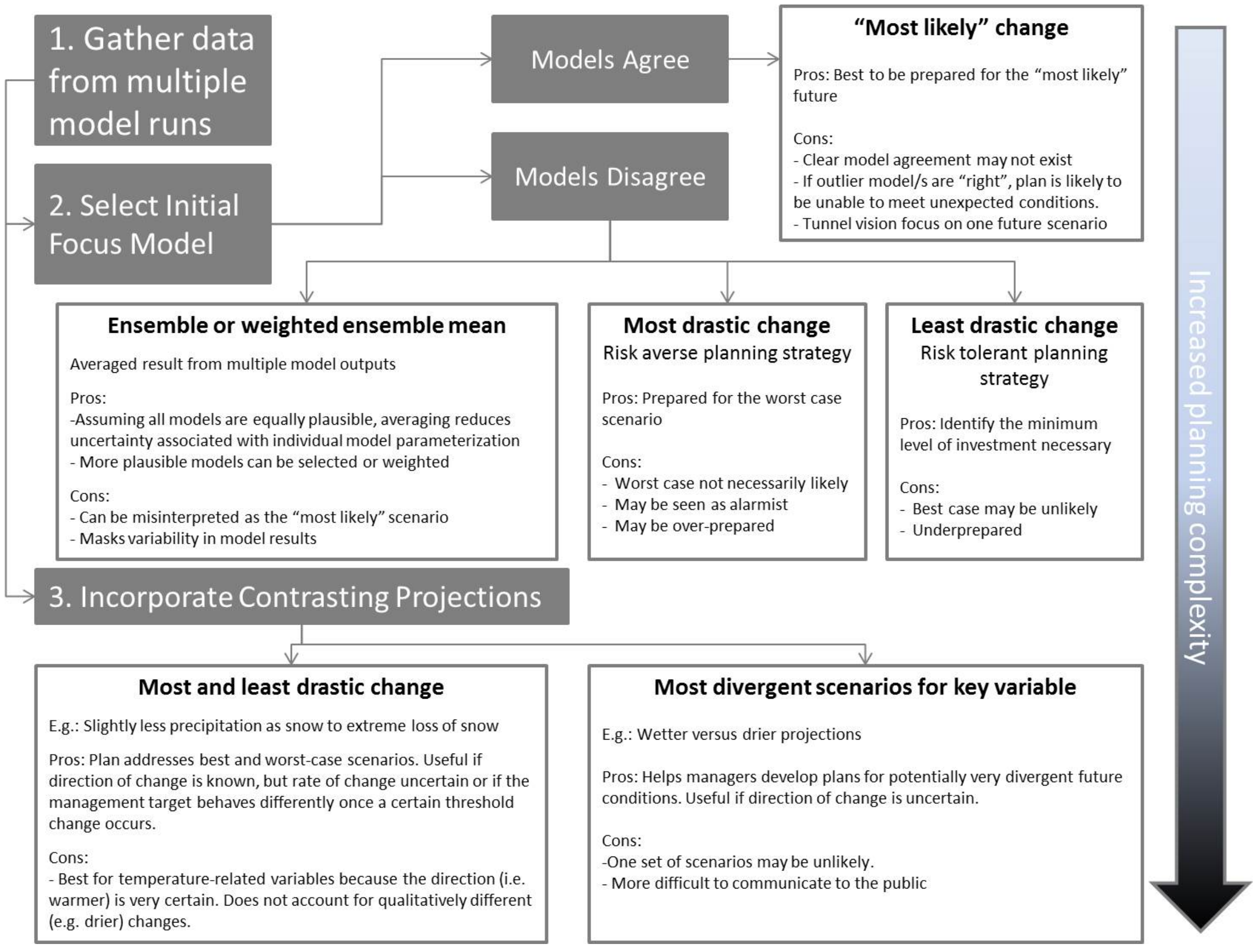

Figure 2: Diagram illustrating the pros and cons of different climate model selection approaches

5. Create a summary table of expected climatic changes and impacts

If potential impacts are complex, it can be helpful to briefly summarize expected climatic changes and impacts in a table. Use the conceptual model as a guide to identify important climate variables and potential impacts. Make a note of the level of confidence or uncertainty associated with each projected change and impact (see Table 2 as an example).

Table 2: Example table summarizing climate impacts

Scenario	Climate Variable	Expected Change	Confidence in Change	Impact	Confidence in Impact	Impact on management objective	Confidence in Management Impact
Mild Climate Change	Sea level rise	80 cm rise	Low (high confidence that sea levels will rise, low confidence that rise will be 80 cm)	Loss of estuary habitat	High (rising sea levels will inundate estuary habitat)	Potentially negative impact on bear populations due to loss of estuary grasses for foraging. Loss of grizzly viewing areas for visitors.	Moderate
	Winter precipitation	Moderate increase	High	Altered stream hydrograph - increased snow accumulation if winter temperatures remain below freezing. Increased winter flows if precipitation falls as rain.	Low (result depends on extent of temperature increase)	Changes to the hydrograph may negatively impact salmon, an important food resource for bears.	Moderate (impacts on salmon may be minimal. Alternatively, bears may be able to switch to alternate food resources if salmon become less abundant)
	Summer precipitation	Decrease	Moderate-High	Lower summer stream flows leading to increased summer stream temperatures	High	Negative impacts on salmon, a food resource for bears	Moderate (impacts on salmon may be minimal. Alternatively, bears may be able to switch to alternate food resources if salmon become less abundant)
	Growing season	Extend	High	Shorter denning time	Moderate	Increased opportunity for bear-human conflict	High

6. Decide on the level of commitment

With some basic information on potential climate impacts in hand, you can assess whether further action is warranted. This decision is likely to be based on some sort of risk assessment. Risk is the product of consequence and probability. Events with large consequences and a high probability of occurring produce high risk and should become high priorities for further planning. Even a qualitative assessment of risk, using rankings as simple as high, medium, and low, can help with priority setting. Other factors to consider include:

- Are impacts likely to occur on a timeframe that warrants action?
- Are resources available to take action?
- How do these climate impacts interact with other management objectives?

- Does climate change exacerbate current management stresses? How are these being handled?
- How well could the management target adapt on its own to potential climatic changes?

7. Identify and evaluate actions

The conceptual model can help identify where management interventions can assist with meeting the management objective. Often, though not always, these points of intervention will be directed towards non-climate stressors, which may be more easily manipulated than climatic changes. In addition, managers often find that actions they are already using are the same ones needed to address climate change, perhaps with some modifications in prioritization or implementation. Of course, at other times radical changes to management actions and even objectives may be necessary.

The following criteria can help evaluate and prioritize actions (from Snover et al., 2007):

- Will the action be effective? How certain are you?
- Do the benefits outweigh the costs?
- Is the action robust? Actions that would benefit the resource regardless of whether or how the climate changes, are considered to be robust. These "no regrets" actions can be implemented despite uncertainty about how the climate will change in the future.
- Is the action flexible? Can it be changed or altered if climate changes happen faster or differently than expected?
- Is the action feasible? Politically, technically and financially? Can it be implemented in the timeframe needed?
- Is there a window of opportunity for implementing an action? For example, changes to infrastructure may be less costly if done during a routine upgrade. Certain legislation or planning processes may only be reviewed every few years.
- Is the action equitable? Who benefits and who pays? Some actions may place an undue burden on one group of people.
- Does the action protect unique environmental or cultural resources?
- How certain are we that the potential climate change impact will occur and that the action will be effective?

Snover and others (2007) recommend that managers keep all action on the table and then organize them by priority, rather than excluding even infeasible actions early on. The following tier system is a helpful starting place:

Tier 1: Actions that can and will be implemented

Tier 2: Actions that are plausible but require more research, information, resources, or legal authority to implement

Tier 3: Actions which are unsuitable at present

Identifying and keeping track of Tier 3 actions can be important because although they may be unsuitable under current conditions, unpredictable changes may make these actions more feasible or necessary in the future.

Summary

Conducting a rapid climate assessment will likely raise more questions than it answers. However, even the most basic exploration of climate change and impacts can highlight important issues for managers to consider. Additional details on climate adaptation planning are provided in the appendices including online and published resources, a quick overview of climate vulnerability assessment data, and additional guidance for selecting climate scenarios. All future resource decisions must be made in the context of a changing climate and engaging in a rapid assessment can be a first step towards systematically integrating climate considerations into parks planning.

Acknowledgements

Funding was provided by the North Pacific Landscape Conservation Cooperative; U.S. Geological Survey National Climate Change and Wildlife Science Center. Climate data was developed by S. Shafer (USGS), P. J. Bartlein (Univ. of Oregon) using Historical CRU CL 2.0 (New et al., 2002), CRU TS 2.1, (Mitchell and Jones, 2005): Coupled Model Intercomparison Project, phase 3 (CMIP3) data: CCSM3 (Collins et al., 2006), (Meehl et al., 2007) the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, we acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy; CGCM3.1(T47) (Zhang and McFarlane, 1995); GISS-ER (Schmidt et al., 2006), MIROC3.2(medres) (K-1 Model Developers, 2004), UKMO-HadCM3 (Gordon et al., 2000); (c) Crown copyright 2005, Data provided by the Met Office Hadley Centre). Special thanks to Tory Stevens for help organizing and conducting the workshops as well as reading and commenting on drafts of this document. Thanks to Steven Hodgson for help organizing the workshop and developing conceptual models. Thanks to the Hakai Beach Institute for their generous hospitality while hosting the workshop.

Citations

Arlington Group Planning + Architecture Inc., EBA Engineering Consultants ltd., DE Jardine Consulting, and Sustainability Solutions Group (2013). sea level rise adaptation primer A toolkit to build adaptive capacity on Canada's south coasts (British Columbia, Canada: Prepared for British Columbia Ministry of Environment).

Bornhold, B.D., British Columbia, Climate Change Branch, British Columbia, and Ministry of Environment (2008). Projected sea level changes for British Columbia in the 21st century.

Carroll, A.L., Taylor, S.W., Régnière, J., and Safranyik, L. (2003). Effect of climate change on range expansion by the mountain pine beetle in British Columbia. In Pages 223-232 in TL Shore et Al.(eds) Mountain Pine Beetle Symposium: Challenges and Solutions, Oct. 30-31, 2003. Kelowna BC. Natural Resources Canada, Infromation Report BC-X-399, Victoria,.

Cross, M.S., Zavaleta, E.S., Bachelet, D., Brooks, M.L., Enquist, C.A., Fleishman, E., Graumlich, L.J., Groves, C.R., Hannah, L., and Hansen, L. (2012). The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. Environmental Management *50*, 341–351.

Dai, A. (2013). Increasing drought under global warming in observations and models. Nature Clim. Change *3*, 52–58.

Delcan (2012). Cost of Adaptation - Sea Dikes & Alternative Strategies (British Columbia, Canada: Prepared for Ministry of Forest, Lands, and Natural Resources Operations).

Flower, A., Murdock, T.Q., Taylor, S.W., and Zwiers, F.W. (2012). Using an ensemble of downscaled climate model projections to assess impacts of climate change on the potential distribution of spruce and Douglas-fir forests in British Columbia. Environmental Science & Policy.

Hambly, D., Andrey, J., Mills, B., and Fletcher, C. (2013). Projected implications of climate change for road safety in Greater Vancouver, Canada. Climatic Change *116*, 613–629.

IPCC (2007). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).

Koch, J., Menounos, B., and Clague, J.J. (2009). Glacier change in Garibaldi Provincial Park, southern Coast Mountains, British Columbia, since the Little Ice Age. Global and Planetary Change *66*, 161–178.

Maslin, M., and Austin, P. (2012). Uncertainty: Climate models at their limit? Nature *486*, 183–184.

Mikkelson, K.M., Dickenson, E.R.V., Maxwell, R.M., McCray, J.E., and Sharp, J.O. (2013). Water-quality impacts from climate-induced forest die-off. Nature Clim. Change *3*, 218–222.

Morrison, J., Quick, M.C., and Foreman, M.G. (2002). Climate change in the Fraser River watershed: flow and temperature projections. Journal of Hydrology *263*, 230–244.

Nakicenovic, N., and Swart, R. (2000). IPCC special report on emissions scenarios (SRES). Intergovernmental Panel on Climate Change, Geneva.

Oliver, G.G., and Fidler, L.E. (2001). Ambient water quality guidelines for temperature : overview.

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 637–669.

Parmesan, C., and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature *421*, 37–42.

Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C., and Pounds, J.A. (2003). Fingerprints of global warming on wild animals and plants. Nature *421*, 57–60.

Smith, R., and Fraser, J. (2002). Indicators of climate change for British Columbia 2002 (Victorica, BC: British Columbia Ministry of Water, Land, and Air Protection).

Snover, A., Binder, L., Kay, J., Sims, R., Lopez, J., Willmott, E., Wyman, M., Hen, M., and Strickler, A. (2007). Preparing for climate change: a guidebook for local, regional, and state governments. Environmental Health Perspectives *117*, 617–623.

Sriver, R.L., Urban, N.M., Olson, R., and Keller, K. (2012). Toward a physically plausible upper bound of sea-level rise projections. Climatic Change *115*, 893–902.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J., Fromentin, J.-M., Hoegh-Guldberg, O., and Bairlein, F. (2002). Ecological responses to recent climate change. Nature *416*, 389–395.

Appendix A: Online resources for climate change adaptation planning

Site	Content	URL
Plan2Adapt	Climate change projects, data, and publications relevant to British Columbia	http://www.pacificclimate.org/tools-and-data/plan2adapt
Pacific Northwest Climate Change Vulnerability Assessment	Climate change projects, data, and publications relevant to the Pacific Northwest (includes U.S. and Canada)	www.climatevulnerability.org
Climate Change Sensitivity Database	Summarizes sensitivities of species and habitats of concern from the Pacific Northwest	www.climatechangesensitivity.org
Climate Wizard	Historic and projected future climate variable data for the US or the world	www.climatewizard.org
NatureServe Climate Change Vulnerability Index	Downloadable Excel workbook; categorizes animal and plant species by vulnerability	www.natureserve.org/prodServices/climatechange/ccvi.jsp
System for Assessing Vulnerability of Species (SAVS)	Questionnaire to evaluate characteristics of terrestrial vertebrate species and assign a SAVS score	www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/
Climate-FVS (forest vegetation simulator)	Downloadable software to project the effects of climate change on forests and trees (currently for the western USA)	www.fs.fed.us/fmsc/fvs/whatis/climate-fvs.shtml
Map of glacially influenced watersheds	ArcGIS shapefile watersheds at any relevant level (3rd, 4th, 5th) that are at least 5% covered by glaciers. These are the watersheds that are most at risk from glaciers melting due to climate change.	http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=33702
Shoreline Sensitivity to Sea Level Rise in British Columbia	An assessment of areas of the British Columbia coastline to identify those that are particularly vulnerable to sea level rise.	http://www.cakex.org/case-studies/46
Conservation Risk Assessment	A database of BC Park known conservation values and threats	BC Parks, BC Ministry of Environment, Victoria, BC Canada (dynamic unpublished database)

Appendix B: Pacific Northwest Climate Change Vulnerability Assessment Data Products Table

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Data Product	Lead Researcher	# of species/ systems	Climate data inputs			Current Status	Data Availability	Link
			Year	Emissions Scenario	Dataset			
Sensitivity Database	Michael Case	As of May 2013 > 150 species and sub-species.	n/a	n/a	n/a	On going	Publicly Available	http://climatechangesensitivity.org/
Vertebrate Climate Envelope Models	Jesse Langdon	350	mean of 2070-2099	A2	USGS	Complete	Publicly available on website	https://www.climatevulnerability.org/
Tree Species Climate Envelope Models	Michael Case	11	mean of 2070-2099	A2	WNA	Preliminary results available	By request	https://www.climatevulnerability.org/
Vegetation system climate envelope models	Michael Case	100	mean of 2070-2099	A2	WNA	Preliminary results available	By request	https://www.climatevulnerability.org/
Species population models	Chad Wilsey	To be determined, maximum of 12	mean of 2070-2099	A1B and A2	USGS	In progress	Preliminary results by 8/13, final results by 8/14	https://www.climatevulnerability.org/
Process-based Vegetation Range Shift Models	Sarah Shafer, USGS	n/a	mean of 2070-2099	A1B	USGS	Preliminary results available	Contact Sarah Shafer, USGS	
Downscaled Climate Variables	Sarah Shafer, USGS	n/a	mean of 2070-2099	A1B and A2	USGS	Complete	Contact Sarah Shafer, USGS	
Land Facets	Carrie Schloss	n/a	n/a	n/a	n/a	Complete	By request	
Climate Adaptation Case Studies	Julia Michalak	n/a	Dependent on Dataset			Complete	Available on website	https://www.climatevulnerability.org/

Appendix C: Pacific Northwest Climate Change Vulnerability Data Products Description with Summary of Strengths and Weaknesses

Downscaled Climate Datasets and Variables

The Vulnerability Assessment project uses the output of five general circulation models, or GCMs: CCSM3, CGM3, GISS-ER, UKMO-HadCM3, and MIROC3.2. These models have been evaluated extensively for their ability to reproduce recent climate changes and project future climate variables. For detailed information about GCMs in general or the specific models we used, see IPCC (2007). We also used two of the emissions scenarios developed by the Fourth IPCC Assessment, namely the A2 (a relatively high emissions scenario resulting from a heterogeneous world with high population growth, slow economic development and slow technological change) and A1B (a medium emission scenario resulting from rapid economic growth and rapid technological change in the direction of both fossil-intensive and non-fossil energy resources) scenarios (Nakicenovic and Swart, 2000).

Table 3 shows directly calculated and derived climate variables developed for the Vulnerability Assessment and used as inputs into the various ecological models. Not all variables were used in all models

Time scale	Variable Type	Variable	WNA Data	USGS Data	Units	Description
Annual	Directly Calculated	mean annual temperature	yes	yes	°C	
		mean warmest month temperature	yes	no	°C	
		mean coldest month temperature	yes	no	°C	
		Continentality	yes	yes	°C	temperature difference between warmest and coldest months
		mean annual precipitation	yes	no	mm	mean of total annual precipitation
		Annual precipitation range	No	yes	mm	wettest month minus driest month
		annual heat:moisture index	yes	no	index	annual heat:moisture index (MAT+10)/(MAP/1000))
		summer heat:moisture index	yes	no	index	summer heat:moisture index ((MWMT)/(MSP/1000))
	Derived	Chilling degree-days	yes	yes	# of days	degree-days below 0°C
		Growing degree-days	yes	yes	# of days	degree-days above 5°C
		Heating degree-days	yes	no	# of days	degree-days above 18°C
		Cooling degree-days	yes	no	# of days	degree-days below 18°C
		Chilling period	No	yes	# of days	number of days with temperature <= 5 °C
		the number of frost-free days	yes	no	# of days	degree-days above 0°C
		frost-free period	yes	no	# of days	length of the frost free period
		Start of Frost Free Period	yes	no	Julian date	the Julian date on which FFP begins

Time scale	Variable Type	Variable	WNA Data	USGS Data	Units	Description
		End of Frost Free Period	yes	no	Julian date	the Julian date on which FFP ends
		precipitation as snow	yes	no	mm	Total amount between August in previous year and July in current year
		extreme minimum temperature over 30 years	yes	no	°C	extreme minimum temperature over 30 years
		Hargreaves reference evaporation	yes	no	index	Hargreaves reference evaporation
		Hargreaves climatic moisture deficit	yes	no	index	Hargreaves climatic moisture deficit
		Annual actual evapotranspiration	No	yes	mm	Actual evapotranspiration is the amount of water actually removed from the earth's surface due to evaporation and transpiration
		Annual potential evapotranspiration	No	yes	mm	Potential evapotranspiration is a measure of the ability of the atmosphere to remove water from the earth's surface. It is dependent on sun energy and wind and assumes that sufficient water is available to meet the evaporation need.
		Annual actual evapotranspiration for days > -4 °C	No	yes	mm	Actual evapotranspiration is the amount of water actually removed from the earth's surface due to evaporation and transpiration
		Annual potential evapotranspiration for days > -4 °C	No	yes	mm	Potential evapotranspiration is a measure of the ability of the atmosphere to remove water from the earth's surface. It is dependent on sun energy and wind and assumes that sufficient water is available to meet the evaporation need.
		Annual actual evapotranspiration for days > 5 °C	No	yes	mm	Actual evapotranspiration is the amount of water actually removed from the earth's surface due to evaporation and transpiration

Time scale	Variable Type	Variable	WNA Data	USGS Data	Units	Description
		Annual potential evapotranspiration for days > 5 °C	No	yes	mm	Potential evapotranspiration is a measure of the ability of the atmosphere to remove water from the earth's surface. It is dependent on sun energy and wind and assumes that sufficient water is available to meet the evaporation need.
		Moisture index	No	yes	index	(annual actual evapotranspiration/annual potential evapotranspiration)
		Moisture index for days > -4 °C	No	yes	index	(annual actual evapotranspiration/annual potential evapotranspiration)
		Moisture index for days > 5 °C	No	yes	index	(annual actual evapotranspiration/annual potential evapotranspiration)
		Total annual snow	No	yes	mm	Total amount of snow fall over the course of one year
Seasonal	Directly Calculated	winter mean temperature	yes	yes	°C	Dec.(prev. yr) - Feb.
		spring mean temperature	yes	yes	°C	Mar. - May
		summer mean temperature	yes	yes	°C	Jun. - Aug.
		autumn mean temperature	yes	yes	°C	Sep. - Nov.
		winter mean maximum temperature	yes	no	°C	Dec.(prev. yr) - Feb.
		spring mean maximum temperature	yes	no	°C	Mar. - May
		summer mean maximum temperature	yes	no	°C	Jun. - Aug.
		autumn mean maximum temperature	yes	no	°C	Sep. - Nov.
		winter mean minimum temperature	yes	no	°C	Dec.(prev. yr) - Feb.
		spring mean minimum temperature	yes	no	°C	Mar. - May
		summer mean minimum temperature	yes	no	°C	Jun. - Aug.
		autumn mean minimum temperature	yes	no	°C	Sep. - Nov.
		winter precipitation	yes	yes	mm	Mean total precipitation for Dec.(prev. yr) - Feb.
		spring precipitation	yes	yes	mm	Mean total precipitation for Mar. - May
		summer precipitation	yes	yes	mm	Mean total precipitation for Jun. - Aug.

Time scale	Variable Type	Variable	WNA Data	USGS Data	Units	Description
		autumn precipitation	yes	yes	mm	Mean total precipitation for Sep. - Nov.
		winter actual evapotranspiration	no	yes	mm	Mean total precipitation for Dec.(prev. yr) - Feb.
		spring actual evapotranspiration	no	yes	mm	Mar. - May
		summer actual evapotranspiration	no	yes	mm	Jun. - Aug.
		autumn actual evapotranspiration	no	yes	mm	Sep. - Nov.
		winter potential evapotranspiration	no	yes	mm	Dec.(prev. yr) - Feb.
		spring potential evapotranspiration	no	yes	mm	Mar. - May
		summer potential evapotranspiration	no	yes	mm	Jun. - Aug.
		autumn potential evapotranspiration	no	yes	mm	Sep. - Nov.
		winter moisture index	no	yes	mm	Dec.(prev. yr) - Feb.
		spring moisture index	no	yes	mm	Mar. - May
		summer moisture index	no	yes	mm	Jun. - Aug.
		autumn moisture index	no	yes	mm	Sep. - Nov.
Monthly	Directly Calculated	maximum mean temperatures for the warmest month	yes	yes	°C	
		minimum mean temperatures for the coldest month	yes	yes	°C	
		precipitation for the wettest month	yes	yes	mm	
		precipitation for the driest month	yes	yes	mm	

Climate Envelope Models

This dataset includes modeled results for recent historical (1961-1990) and future (2070-2099) climate suitability for over 350 terrestrial animal species, 11 tree species, and 100 ecosystems. This part of the project uses climate-envelope models, a correlative statistical approach. As their name implies, these models identify climate variables that are correlated with current species range boundaries allowing us to define the climate space (or envelope) occupied by a given species or ecosystem. We then apply these statistical relationships to projected future climate data to project where, on the landscape, a species' "climate envelope" is likely to be in the future (Pearson and Dawson, 2003). Although climate envelope models have their shortcomings (e.g., they do not take evolution, dispersal, or biotic interactions into account), they often predict range changes similar to those observed for many species over the last century effectively (Green et al., 2008). For the vertebrate models, once projected range shifts were completed, projections were further refined by limiting projected distributions to areas with suitable land-uses and projected suitable biome types. For example, for species unable to live in urban landscapes, areas currently defined as urban were mapped as unsuitable.

- Strengths
  - Transparent: comparatively simple modeling approach based on the straightforward relationship between species geographic distribution and climate conditions
  - Reasonably accurate: climate envelope models have successfully re-created historical range shifts for many species
  - Fast: able to implement models for many species in a relatively short time
  - Spatially explicit: provide spatial projections of future species locations, information that is critical for conservation planning
- Limitations
  - Only provides information about areas that will be climatically suitable in the future, does not account for non-climate factors such as dispersal ability, competition, and other inter-specific interactions
  - Current distribution may be limited by non-climate factors, these are not captured in the models and add uncertainty to the projections
  - Models are built from maps of present day distributions. If these maps have errors at fine scales, then areas of projected expansion or contraction will be inaccurate.
  - Most accurate at continental scales

Species Sensitivity Database

This digital database uses a combination of expert review panels, literature searches and digital databases to summarize the inherent climate sensitivities for species and habitats of concern throughout the Pacific Northwest. Species of concern have been included from a range of taxa including vascular and non-vascular plants, invertebrates, intertidal species, birds, mammals, reptiles, amphibians, etc. The database provides resource managers and decision makers with basic and important information about how species and systems will likely respond to climate change based on a series of life history characteristics: generalist/specialist, physiology, life history, habitat, dispersal ability, disturbance regimes, ecology, non-climate related threats, and other factors. Species experts assign each species/system a numeric ranking (1 being the least sensitive and 7 being the most sensitive to climate change) for each of these life history categories based on best available science (see Table 4 for more details). Additional specific questions are included for each category to highlight particular life history characteristics that drive climate change sensitivity. For example, the average length of time to reproductive maturity could influence a species ability to adapt to changing conditions. In addition, experts also assign a confidence ranking to each sensitivity score that indicates how certain the best available science is for that particular category.

Table 4 summarizes the criteria used to rank species sensitivity in the sensitivity database. Examples provide an illustration of the criteria.

Category	**Description**	**Example**			
		Species	**Sensitivity (7 = most sensitive, 1 = least sensitive)**	**Confidence (5 = very good, 1 = very poor)**	**Explanation**
Generalist/ Specialist	Broadly, where does this species fall on the spectrum of generalist to specialist? Specialists are considered more sensitive to climate change than generalists	Taylor's checkerspot butterfly (Euphydryas editha taylori)	6	5	Foraging dependency and climate sensitive phenology
Physiology	Physiological sensitivity is directly related to a species' physiological ability to tolerate changes in temperature, precipitation, salinity, pH, and CO2 that are higher or lower than the range that they currently experience. If a species can tolerate a wide range of these variables, it would be deemed less sensitive.	Van Dyke's Salamander (Plethodon vandykei)	7	4	Extreme sensitivity to temperature and precipitation changes.
Life History	Reproductive life history characteristics that may affect adaptive capacity including r-selection (many offspring, short generation time) versus k-selection (few offspring, high parental investment) reproduction strategies, frequency and timing of reproduction and length of time to reproductive maturity.	American Marten (Martes americana)	6	5	Optimally, two offspring per reproductive event and one reproductive event a year.
Habitat	Is the species dependent on climate sensitive habitats? How dependent?	Chinook Salmon (Oncorhynchus tshawytscha)	7	5	Dependent upon coastal Lowlands/Marshes/Estuaries/Beaches, seasonal streams, wetlands/vernal pools
Dispersal Ability	The maximum average distance a species will likely move within one year to establish a new population in a more suitable habitat. Are there landscape elements that would prevent this species from moving in response to climate change?	Coeur d' Alene salamander (Plethodon idahoensis)	6	2	No known data exist on dispersal, but as this species is lungless and dependent of seep and waterfall zones to remain moist, dispersal is probably very limited

Category	Description	Example			
		Species	**Sensitivity (7 = most sensitive, 1 = least sensitive)**	**Confidence (5 = very good, 1 = very poor)**	**Explanation**
Disturbance Regimes	Is the species sensitive to different types of disturbance (e.g. fire, flooding, disease) that may be affected by climate change. This relationship may be either positive or negative.	Slickspot peppergrass (Lepidium papilliferum) Idaho	7	3	Highly sensitive to fire, flooding and drought
Ecology	How sensitive are ecological relationships such as foraging, predator prey relationships, and competition to climate change?	Western Toad (Anaxyrus (=Bufo) boreas) - North Cascades, Olympics	7	5	Highly sensitive forage, predator/prey, habitat, hydrology, competition, and disease ecology.
Interacting Non-climatic Stressors	What other stressors may make this species more sensitive to climate change (e.g. habitat loss, invasive species competition, etc.)?	Northern Spotted Owl (Strix occidentalis caurina)	6	4	Habitat loss and degradation, competitive interaction with Barred Owls
Other (weight)	Any other factor not previously mentioned that would affect this species sensitivity to climate change.				

- Strengths
  - Provides detailed natural history information for specific species and habitats tailored to assessing climate change sensitivity
  - Information does not rely on climate projections or assumptions about future climate conditions
  - Highlights known and logical climate sensitivities
  - Transparent information – all information leading to the final ranking of sensitivity is available and ranking process is transparent (as opposed to complex model results which require expert knowledge to understand and interpret)
  - The database is easily updated as new information becomes available
- Limitations
  - Information for many species is limited and so much of the information included is based on expert judgment
  - Species are entered and updated by experts so keeping information current is challenging
  - Assessment of species sensitivity is often based on assumed (not tested) relationships

Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ-DGVM)

Future climate changes will alter vegetation both directly via changes in climate and indirectly via changes in climate-driven disturbance regimes. We simulated future vegetation responses to climate change in the Pacific Northwest using the LPJ (Lund-Potsdam-Jena; Sitch et al., 2003), a dynamic global vegetation model. This model simulates the distributions and productivity of plant functional types (PFTs), such as grass or evergreen needle-leaved trees, using a variety of mechanistic processes (e.g., photosynthesis, resource competition, population dynamics, etc.). The PFTs were combined to define major habitat types, such as grassland or subalpine forest. These vegetation models simulate the physiological responses of plants to changes in atmospheric CO_2 concentrations—an important feature for accurately simulating vegetation responses to future climate change.

The vegetation models are driven by the downscaled modern and future climate data, soil data (CONUS-Soil, Miller and White (1998); Global Soil Data Task 2000), and annual atmospheric CO_2 concentrations (Nakicenovic and Swart, 2000). Modern vegetation simulations were evaluated using Advanced Very High Resolution Radiometer (AVHRR) derived vegetation cover and other land-cover datasets (e.g., Hansen et al., 2003).

- Strengths
    - Is a mechanistic, process-based model and so relies on our understanding of causative relationships between ecological processes rather than statistical correlations.
    - Incorporates more complex ecological interactions that are important known drivers of vegetation composition including: CO_2 concentrations, photosynthesis, plant growth, fire disturbance, and soil moisture.
    - Spatially explicit.
- Limitations
    - Only models plant functional types, not individual species or vegetation systems.
    - As a more complex model, it is more difficult to understand what relationships and factors drive a particular result.
    - Relationships are based on empirically established functions, but are generalized and so may be problematic for particular locations.
    - Parameterization and definition of plant functional types involve decisions made by the modeler and changes in those decisions may lead to very different results.
    - The model projects increases in woody vegetation in many places. This is likely to increased water-use efficiency. The relationship between increases in CO_2 concentrations and water-use efficiency is based on a relatively small number of studies on specific species and thus may over or underestimate this effect.

Land Facet Analysis

One potentially promising strategy for protecting biodiversity in a changing climate is based on the idea of protecting the diversity of abiotic conditions, categorized into unique combinations called “land facets,” that influence patterns of biodiversity (Anderson and Ferree, 2010; Beier and Brost, 2010). This approach has been described as “conserving the ecological stage” or protecting “enduring features”, referring to terms used by Beier and Brost (2010) and Anderson and Ferree (2010), respectively. Species distributions, communities, ecosystems, and broader patterns of biodiversity are clearly influenced by abiotic drivers such as soils, geology, topography, and climate. Whereas climates will change relatively rapidly over the coming century, soils, geology, and topography will remain the same. Thus, local, and some regional, climate patterns and gradients influenced by topography will persist (e.g., higher elevations will still be cooler than lower elevations, although both will likely be warmer) as climates change. The goal of this approach is to protect a diversity of land facets within each conservation reserve system. The assumption behind this approach is that the diversity of land facets will support a diversity of ecosystem types —even as the individual species and habitat types, the "actors" on the "stage," change over time. This is therefore not a strategy aimed at protecting specific species or habitats, but rather an approach to maintaining high levels of biodiversity in general.

Strengths:

- Does not rely on climate projections or climate envelope models and therefore avoids having to address the variability and uncertainty inherent in those model projections
- Land facets can be mapped at a scale fine enough to inform even very local conservation planning decisions
- Can be applied in data poor areas

Limitations:

- The methods used to categorize land facets have a very significant impact on the number and type of facets identified. Depending on the variables included, the statistical approach used, and the scale of analysis, very different land facets are identified. For example, variables used to categorize land facets are often continuous, but must be lumped into discrete categories (e.g. elevation, slope). Even discrete categories like soil type can be lumped or split into many different classifications.
- They are based on the assumption that biodiversity correlates with land facet diversity.
- The approach is dependent on soil data availability.
- Although the theory linking land facets and biodiversity is sound, it is difficult to test given currently poor data on species distribution and abundance. In particular areas, there may not be a clear understanding of how land facet types relate to current biodiversity.
- A land facet approach does not target specific species or ecosystem types, but rather assumes that individual conservation targets will turnover over time.

Appendix D: Guidance for Selecting Climate Scenarios

While climate science and models are always improving, the complexity of climate change and subsequent ecological responses means that all future projections have a degree of uncertainty associated with them. To some extent, this uncertainty can be reduced by improving model performance and looking for agreement among multiple models and emissions scenarios (Littell et al., 2011). Because each climate model uses slightly different assumptions about how climate variables interact, if the models all project a similar future change, we can feel more confident that a particular result is likely. However, in many cases, model agreement does not exist and additional modeling efforts are likely to increase variability in future projections (Maslin and Austin 2012). Designing effective management under this uncertainty is challenging, but there are several established approaches that can help managers. Figure 3 outlines the pros and cons of selecting different climate model combinations for adaptation planning.

Selecting climate scenarios: where to start?

Initially focusing on one future scenario is a good place to start during the early exploratory phase of planning. Focusing on one initial scenario can help planners identify how climate is likely to impact their management system and begin to identify potential management actions. Planners should select which projection to focus on depending on their management goal and planning objective. If there is significant agreement among models, it is logical to focus on the “most likely” future. Other possibilities include selecting the ensemble mean of all models or selecting the worst (most drastic change) or best (least drastic change) case scenarios. Figure 3 explains the benefits and risks of different model selections.

The danger of focusing on one projected future condition is that planners can be lulled into a false sense of certainty, leaving them unprepared if/when future changes do not match their selected scenario. In addition, even if all models agree about the direction of change, there will still variability in the rate of change. Therefore, once planners have a basic understanding of how climate changes can impact their system and the types of actions that may be needed, they should bring in additional climate scenarios. Including multiple projected futures will help test whether proposed management actions are “robust” to multiple possible futures and if not robust, then flexible (see Box 1).

Selecting Climate Scenarios: Agreement about direction, uncertainty about rate of change

For many variables, such as temperature change and related variables (e.g. number of frost free days, amount of precipitation falling as snow, etc.), there is strong agreement about the direction of change; i.e. we know average temperatures will increase; amount of precipitation falling as snow will decrease. The uncertainty associated with these variables surrounds the rate and subsequently the extent of change (for any given year). For example, as temperatures increase we expect to see an increase in the number of frost-free days, a lengthening of the growing period, an increase in the number of heating degree days. The rate of change correlates fairly predictably with the rate of warming, which itself depends on levels of anthropogenic greenhouse gas emissions. Other variables such as amount of precipitation as snow depend on both precipitation and temperature. In this case, all models still project a reduction in the amount of precipitation as snow for the PNW, but the extent of change is slightly more complex because it depends on both amount of precipitation, which is highly variable, and temperature change.

If models agree about the direction of change for key drivers of your management system, it makes sense to select the mean, least and/or most drastic change scenarios to guide the planning process. If ecological conditions respond linearly with temperature change, then the types of management actions that will be effective are likely to be similar among all future scenarios, while the extent or rate at which they are implemented could need to vary depending on the rate of change experienced. However, if there is a threshold of change beyond which ecological response changes dramatically, then developing alternative plans for before and after the threshold is crossed will be important. For example, a species can shift upslope (or be assisted to shift upslope) until there is no longer any higher elevation ground available. At that point, alternative management action might be necessary, such as assisted migration to a new location.

Box 1: Robust versus Flexible Strategies

"Robust" – a robust action is one that will be effective under multiple future climate conditions. At a minimum, these are "no regrets" or "win-win" actions. If you can answer yes to either of the following questions, your planning action can be considered robust:

- Does implementing this action help us meet our management goal even if no climate change takes place? Example: improving habitat connectivity will benefit ecological resilience regardless of climate change.
- Does the action improve resource condition under divergent future conditions? Example: because there is great certainty that temperatures will rise, protecting or restoring vegetated stream buffers will help keep streams cool and improve habitat condition under all projected future changes.

"Flexible" - It may not always be possible to find a robust management action. For example, a particular action may be critical if precipitation decreases in the future but unnecessary or harmful if precipitation increases. In this case, it is important to design the management action to be flexible. An action is flexible if:

- The action is relatively easily reversed once implemented. Example: using prescribed burns to reduce fuel loads. The decision to burn is made annually and therefore prescribed burning can be discontinued if it becomes unnecessary or harmful. In contrast, introducing a species to a new area is very difficult to reverse if the introduction is successful.
- The action can be altered if change occurs more rapidly or dramatically than expected. Example: having a basic assisted migration plan in place, but waiting to actually introduce species until enough evidence suggests that it is necessary.

Selecting Climate Scenarios: Uncertainty about direction and magnitude/rate of change

Although there is significant agreement about temperature related variables, there is considerably less agreement about precipitation changes and more complex climate variables such as potential evapotranspiration. Model projections of precipitation changes often vary widely for both the amount and even direction (increase or decrease) of change. When looking at an average across all models (the ensemble mean), the PNW is projected to see a very slight increase in total annual precipitation of 1-2%. However, individual model projections show either an increase or decrease in total precipitation as well as different degrees of seasonal change (Mote and Salathe Jr, 2010). If there is disagreement among models in both the direction and magnitude of change, it may be important for planners to consider two or three highly divergent climate scenarios, e.g. a drier and a wetter future climate. Selecting divergent climate futures will allow planners to test their management plans for robustness and flexibility.

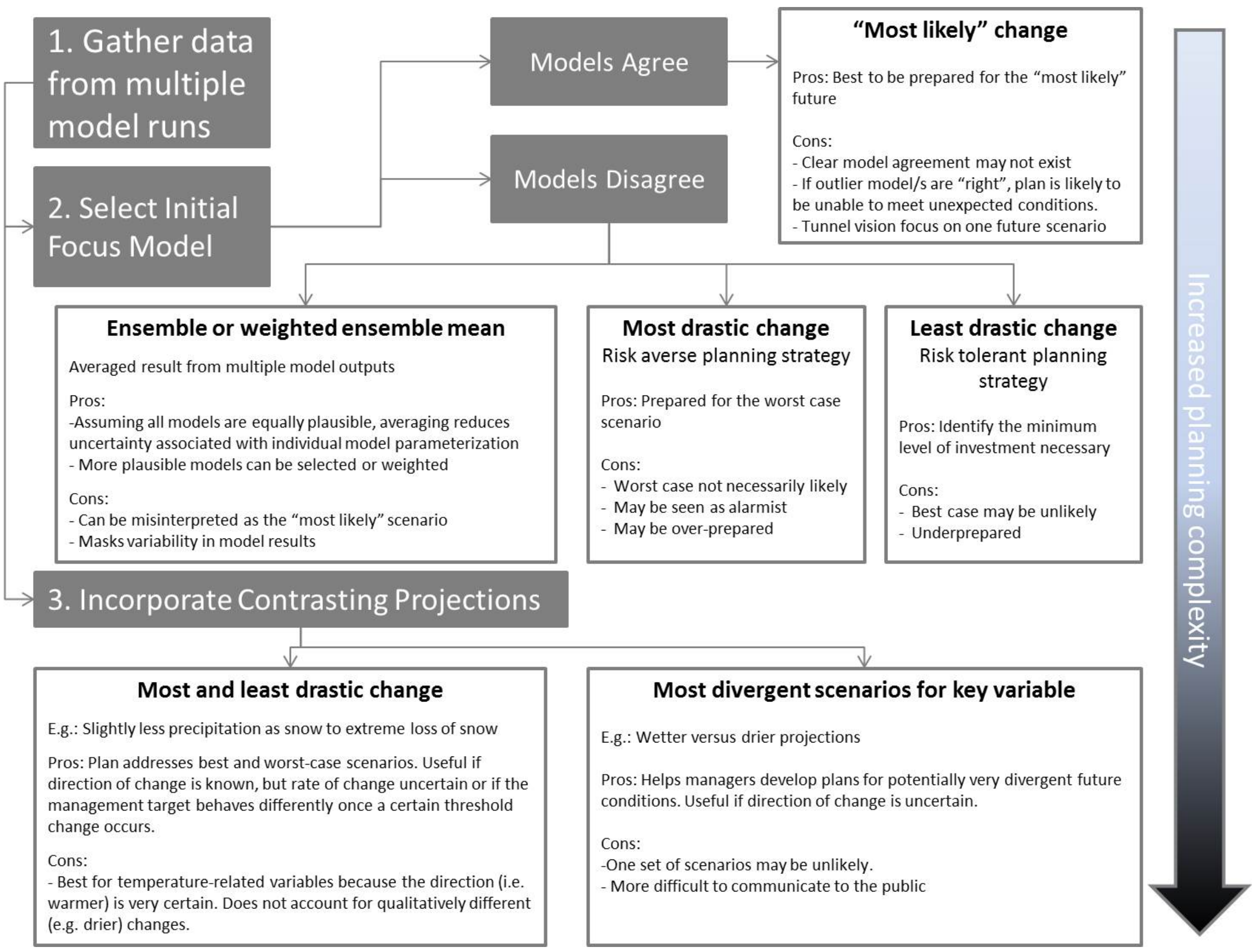

Figure 3 illustrates the pros and cons of different model selection approaches

Appendix E: Climate Adaptation Literature

Papers and reports from the climate adaptation literature, sorted from more general to more specific. Full citation information is provided in the Literature Cited section. Abbreviations: ACT = adaptation for conservation targets, CC = climate change, NWR = National Wildlife Refuge, ONF = Olympic National Forest, ONP = Olympic National Park, TNC = The Nature Conservancy.

Title	**Focus**	**Citation**
Biodiversity management in the face of climate change: a review of 22 years of recommendations	Review of adaptation actions across systems and scales	(Heller and Zavaleta, 2009)
A review of climate-change adaptation strategies for wildlife management and biodiversity conservation	Review focused on biodiversity conservation	(Mawdsley et al., 2009)
Climate change adaptation strategies for resource management and conservation planning	General principles and tools for managing natural resources under climate change	(Lawler, 2009)
The Adaptation for Conservation Targets (ACT) Framework: a tool for incorporating climate change into natural resource management	General approach for climate adaptation planning (ACT framework, with case study for Yellowstone River, USA)	(Cross et al., 2012)
Redesigning biodiversity conservation projects for climate change: examples from the field	Incorporating CC in conservation strategies from TNC plans (across systems and countries)	(Poiani et al., 2011)
Adapting to climate change: a planning guide for state coastal managers	Adaptation actions for coastal systems of the USA	NOAA (2010)
Climate change adaptation for the US National Wildlife Refuge system	Adaptation actions for NWRs in the USA	(Griffith et al., 2009)
Managing for multiple resources under climate change: national forests	Adaptation actions for National Forests in the USA	(Joyce et al., 2009)
Climate change and river ecosystems: protection and adaptation options	Predicted impacts and adaptation actions for rivers and their watersheds	(Palmer et al., 2009)
Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment	Predicted impacts and adaptation for systems of the interior western USA	(Finch, 2012)
Adapting to climate change at Olympic National Forest and Olympic National Park	Adaptation actions (across systems) in ONF and ONP	(Halofsky et al., 2011)

Title	Focus	Citation
Application of structured decision making to an assessment of climate change vulnerabilities and adaptation options for sustainable forest management	Forest management application in southwest Yukon, Canada	(Ogden and Innes, 2009)

Citations

Anderson, M.G., and Ferree, C.E. (2010). Conserving the stage: climate change and the geophysical underpinnings of species diversity. PLoS One *5*, e11554.

Beier, P., and Brost, B. (2010). Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology *24*, 701–710.

Collins, W.D., Bitz, C.M., Blackmon, M.L., Bonan, G.B., Bretherton, C.S., Carton, J.A., Chang, P., Doney, S.C., Hack, J.J., and Henderson, T.B. (2006). The community climate system model version 3 (CCSM3). Journal of Climate *19*, 2122–2143.

Cross, M.S., Zavaleta, E.S., Bachelet, D., Brooks, M.L., Enquist, C.A., Fleishman, E., Graumlich, L.J., Groves, C.R., Hannah, L., and Hansen, L. (2012). The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. Environmental Management *50*, 341–351.

Finch, D.M. (2012). Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment (US Department of Agriculture, Forest Service, Rocky Mountain Research Station).

Gordon, C., Cooper, C., Senior, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F., and Wood, R.A. (2000). The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics *16*, 147–168.

Green, R.E., Collingham, Y.C., Willis, S.G., Gregory, R.D., Smith, K.W., and Huntley, B. (2008). Performance of climate envelope models in retrodicting recent changes in bird population size from observed climatic change. Biology Letters *4*, 599–602.

Griffith, B., Scott, J.M., Adamcik, R., Ashe, D., Czech, B., Fischman, R., Gonzalez, P., Lawler, J., McGuire, A.D., and Pidgorna, A. (2009). Climate change adaptation for the US national wildlife refuge system. Environmental Management *44*, 1043–1052.

Halofsky, J.E., Peterson, D.L., O'Halloran, K.A., and Hawkins-Hoffman, C. (2011). Adapting to climate change at Olympic National Forest and Olympic National Park (US Department of Agriculture, Forest Service, Pacific Northwest Research Station).

Hansen, M., Defries, R.S., Townshend, R.G., and Sohlberg, R. (2003). LBA Regional Land Cover from AVHRR, 1-km, 1992-1993 (Hansen et al.). Available on-line [http://www.daac.ornl.gov] from the Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. doi:10.3334/ORNLDAAC/678.

Heller, N.E., and Zavaleta, E.S. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation *142*, 14–32.

IPCC (2007). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).

Joyce, L.A., Blate, G.M., McNulty, S.G., Millar, C.I., Moser, S., Neilson, R.P., and Peterson, D.L. (2009). Managing for multiple resources under climate change: national forests. Environmental Management *44*, 1022–1032.

K-1 Model Developers (2004). K-1 Coupled Model (MIROC) Description. Technical Report 1, (Tokyo, Japan: Center for Climate System Research, University of Tokyo).

Lawler, J.J. (2009). Climate change adaptation strategies for resource management and conservation planning. Annals of the New York Academy of Sciences *1162*, 79–98.

Littell, J.S., McKenzie, D., Kerns, B.K., Cushman, S., and Shaw, C.G. (2011). Managing uncertainty in climate-driven ecological models to inform adaptation to climate change. Ecosphere *2*, art102.

Mawdsley, J.R., O'MALLEY, R., and Ojima, D.S. (2009). A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology *23*, 1080–1089.

Meehl, G.A., Covey, C., Taylor, K.E., Delworth, T., Stouffer, R.J., Latif, M., McAvaney, B., and Mitchell, J.F. (2007). The WCRP CMIP3 multimodel dataset: A new era in climate change research. Bulletin of the American Meteorological Society *88*, 1383–1394.

Miller, D.A., and White, R.A. (1998). A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling.

Mitchell, T.D., and Jones, P.D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology *25*, 693–712.

Mote, P.W., and Salathe Jr, E.P. (2010). Future climate in the Pacific Northwest. Climatic Change *102*, 29–50.

Nakicenovic, N., and Swart, R. (2000). IPCC special report on emissions scenarios (SRES). Intergovernmental Panel on Climate Change, Geneva.

New, M., Lister, D., Hulme, M., and Makin, I. (2002). A high-resolution data set of surface climate over global land areas. Climate Research *21*, 1–25.

Ogden, A.E., and Innes, J.L. (2009). Application of structured decision making to an assessment of climate change vulnerabilities and adaptation options for sustainable forest management. Ecology and Society *14*, 11.

Palmer, M.A., Lettenmaier, D.P., Poff, N.L., Postel, S.L., Richter, B., and Warner, R. (2009). Climate change and river ecosystems: protection and adaptation options. Environmental Management *44*, 1053–1068.

Pearson, R.G., and Dawson, T.P. (2003). Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography *12*, 361–371.

Poiani, K.A., Goldman, R.L., Hobson, J., Hoekstra, J.M., and Nelson, K.S. (2011). Redesigning biodiversity conservation projects for climate change: examples from the field. Biodiversity and Conservation *20*, 185–201.

Schmidt, G.A., Ruedy, R., Hansen, J.E., Aleinov, I., Bell, N., Bauer, M., Bauer, S., Cairns, B., Canuto, V., and Cheng, Y. (2006). Present-day atmospheric simulations using GISS ModelE: Comparison to in situ, satellite, and reanalysis data. Journal of Climate *19*, 153–192.

Sitch, S., Smith, B., Prentice, I.C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J.O., Levis, S., Lucht, W., Sykes, M.T., et al. (2003). Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biology *9*, 161–185.

Zhang, G.J., and McFarlane, N.A. (1995). Sensitivity of climate simulations to the parameterization of cumulus convection in the Canadian Climate Centre general circulation model. Atmosphere-Ocean *33*, 407–446.