West Kootenay Climate Vulnerability and Resilience Project

Report #7:

An Ecosystem Vulnerability and Resilience Assessment for West Kootenay Ecosystems

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1.0 INTRODUCTION

Recent reports by the International Panel on Climate Change (IPCC) confirm that global climate change is underway, and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas (GHG) emissions (IPCC 2007). In British Columbia, analysis of the last hundred years of climate data confirms that parallel climatic changes are also occurring in this province (Spittlehouse 2008), and in the Columbia Basin (Murdock and Werner 2011, Utzig 2012a). Visible evidence of changes in climate is also becoming increasingly apparent to local people – witnessed through a wide range of changes in broad variety of different indicators.

Results from downscaled global climate models (GCMs) illustrate the range of potential climate changes for BC over the next century, depending on what assumptions are made about future greenhouse gas emissions. Potential changes for southern British Columbia include increases in annual temperatures and precipitation, decreases in summer precipitation, decreases in snowpack at low elevations, increases in annual and interannual climate variability and increases in the frequency and magnitude of extreme weather events.

The British Columbia government has recognized that the uncertainties associated with climate change demand a forest management approach that differs from the traditional (MoFR 2008). With the establishment of the Future Forest Ecosystems Initiative (FFEI) in 2006, the province began a move toward looking for ways to adapt the forest and range management framework with respect to potential future climates. The province established the Future Forest Ecosystem Scientific Council[1] (FFESC) in 2008 to deliver research grants to support the objectives of the FFEI. This series of reports summarizes some of the findings of one project[2] that was among those funded by the FFESC under their 2009 call for proposals.

This Report is #7 in the series of reports from this project and presents the methods and results for the Ecosystem Vulnerability and Resilience Assessment for the West Kootenay study area, with particular reference to climate change projections to 2080.

In this project, we have employed a modified Vulnerability Assessment approach based on the framework outlined by Fussel and Klein (2006). We have also incorporated key concepts from resilience theory into the assessment to assist in understanding how potential ecosystem changes resulting from climate change may unfold throughout the study area. In Report #2 (Holt et al. 2012), we provide an overview of Vulnerability Assessments and resilience theory as these approaches apply to assessing the potential ecosystem modifications or transformations that may result from climate change. This Report (#7) presents the results of the assessment for ecosystems in the West Kootenays. In the discussion we review the implications of the results, and examine the extent to which resilience theory is useful in explaining the projected ecosystem changes, including the potential for regime shifts. In Report #9 (Pinnell et al. 2012), we further develop ideas around how the results of the vulnerability assessment can be applied and linked to forest management adaptation options for the West Kootenay Region.

2.0 VULNERABILITY ASSESSMENT APPROACH

In contrast to many climate change Vulnerability Assessments, we chose to focus on the “ecological system,” specifically forest ecosystems, rather than the “social ecological system” or the “social system”. In forest-dependent social ecological systems, forest ecosystems are the basis for the goods and services that support the social systems, and therefore are one of the key components to understanding the potential impacts and vulnerabilities of the full social ecological system. Our discussion of the social system is limited to examining

[1] Further information on FFESC: http://www.for.gov.bc.ca/hts/future_forests/council/index.htm
[2] Resilience and Climate Change: Adaptation Potential for Ecological Systems and Forest Management in the West Kootenays. For further information on the project: http://kootenayresilience.org

potential adaptation measures that may be taken by forest managers and practitioners to moderate potential adverse effects (Report #9, Pinnell et al. 2012), and the identification of opportunities and barriers for implementing adaptation measures (Report #8, Pearce 2012).

The framework employed in our assessment is similar to what has been outlined by Fussel and Klein (2006), but has adjusted the components to be more applicable to assessing ecosystems rather than social systems (Figure 1). Our assessment is initiated by identifying and examining the key drivers for the ecosystems present in the study area. We have grouped these in three broad classes: non-climatic environmental drivers, human-related drivers (i.e. development pressures/threats) and climate change-related drivers. The climate change and other environmental drivers in turn influence the two key components that determine the potential impacts: exposure and sensitivity. Vulnerability to those potential impacts is then moderated by the ecosystem's adaptive capacity. In this case we estimate an ecosystem's "inherent' adaptive capacity, and consider whether that has been enhanced or degraded by past and ongoing human-related activities, and then assign the ecosystem a resulting "effective" adaptive capacity.

The approach for rating each of the components of the Vulnerability Assessment are described below, and summarized in Table 1. ***The ratings for each of the components are relative between assessment units within the West Kootenay study area, they are not absolute ratings that can be compared to ratings of areas outside the study area.***

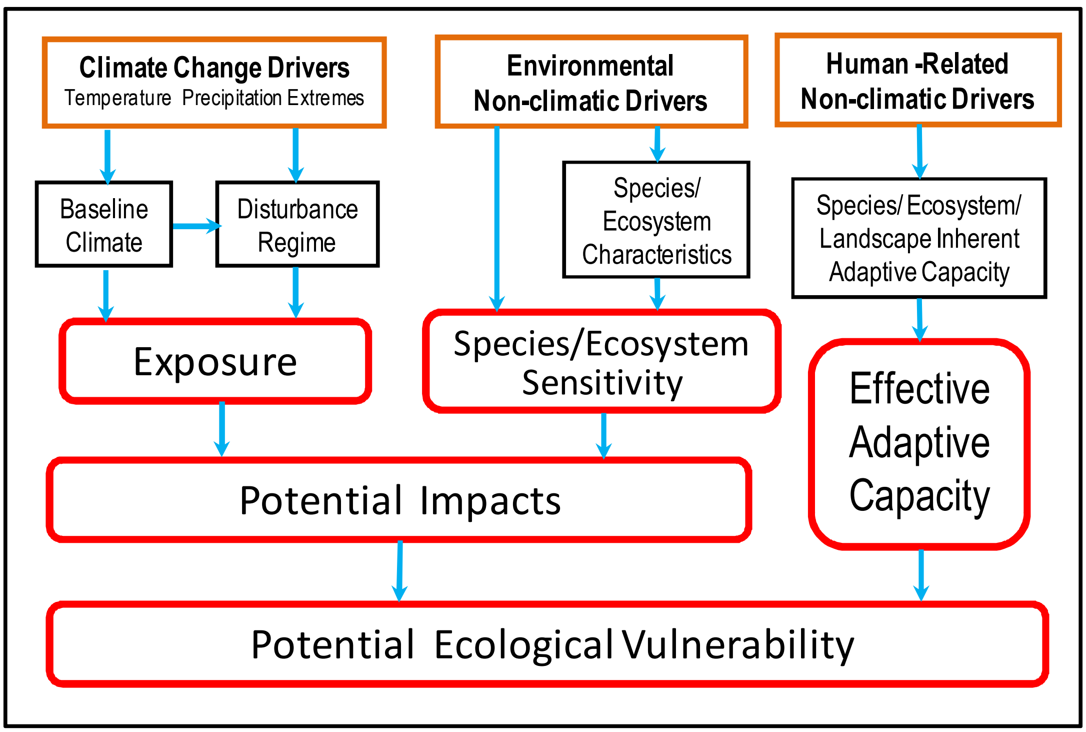

Figure 1. Framework for assessing the vulnerability of West Kootenay ecosystems. Orange boxes are groups of drivers, black boxes are existing conditions, red boxes are outcomes of the analysis (adapted from Fussel and Klein 2006 and Klausmayer et al. 2011).

2.1 Unit for Ecological Assessment

Defining an ecosystem unit to be assessed is a first step (i.e. vulnerability or resilience of what?). Given the scale and uncertainty of the projected climate changes, the size and complexity of the study area, and the limited time and resources available for the assessment, we restricted our assessment to broad-scale generalized ecosystems. Traditionally in BC the logical unit for assessment would have been a Biogeoclimatic unit or an Ecosection. However, because both of those classification systems are based on an assumption of a relatively stable climate and species distribution, neither system will adequately portray the range of niches and biological diversity of the province as the impacts of climate change proceed over the coming decades. As climate change proceeds, species distributions will respond species-by-species, depending on their individual tolerances to changing conditions (Parmesan 2006). As this occurs, many species assemblages and ecosystems within BEC units will begin to disaggregate. As well, as climate envelopes evolve into new combinations of climate variables, today's BEC units will also disintegrate and/or evolve into new species assemblages with newly defined climate envelopes. To fill this classification void, we developed an alternative system for identifying broad ecosystems[3]. As climate change proceeds over the coming decades and/or centuries, it may be more appropriate to use a more mechanistic approach to defining assessment units – one based on environmental factors that will remain relatively constant as climate change proceeds (i.e. enduring features). Macro topography plays a key role in determining the distribution of climate envelopes in BC, and will remain a relatively constant factor for the time scales under consideration (decades and centuries).

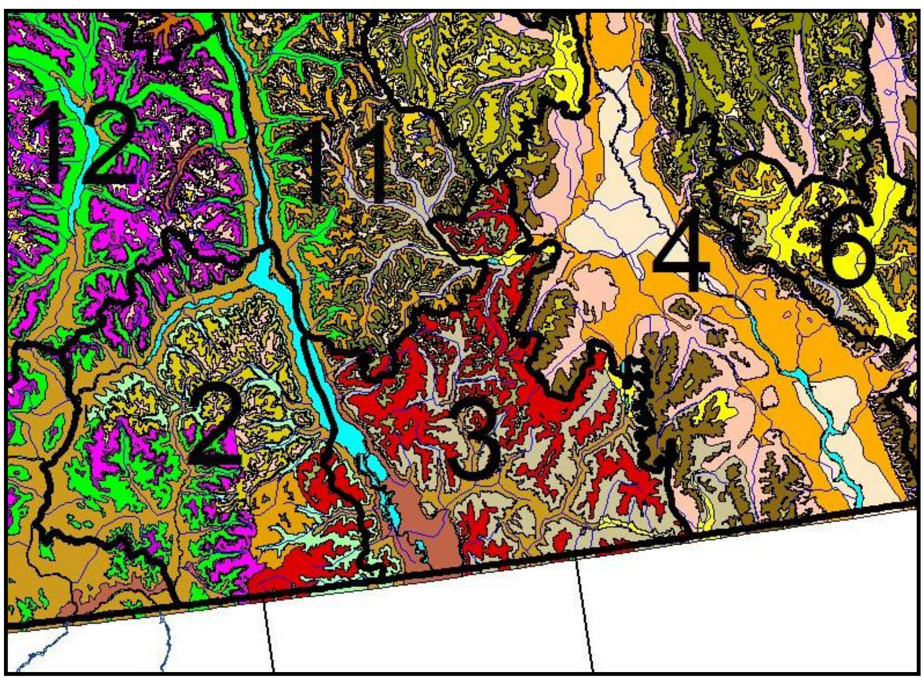

Figure 2. An example of draft Regional Landscapes, outlined in heavy black, and current BEC units, shown in contrasting colours.

Using topographic breaks and uniform elevational sequences of currently mapped biogeoclimatic units we defined geographic areas with relatively similar regional climates (see Figure 2). Each of these areas are defined as a unique "Regional Landscape" (RL). Climatic variability within the RLs is primarily determined by aspect and elevation, with

[3] These were developed in cooperation with Deb MacKillop of the BC MoFLNRO.

some contributions of meso/micro topographic elements. The climatic variation between RLs is assumed to result principally from macro topography interacting with weather systems. Because macro topography is stable in the face of climate change, we assume that the climate within individual RLs will likely remain relatively homogeneous even as climate change proceeds[4]. Preliminary bioclimate envelope modeling results in the West Kootenays appear to be generally consistent with that assumption (Utzig 2012).

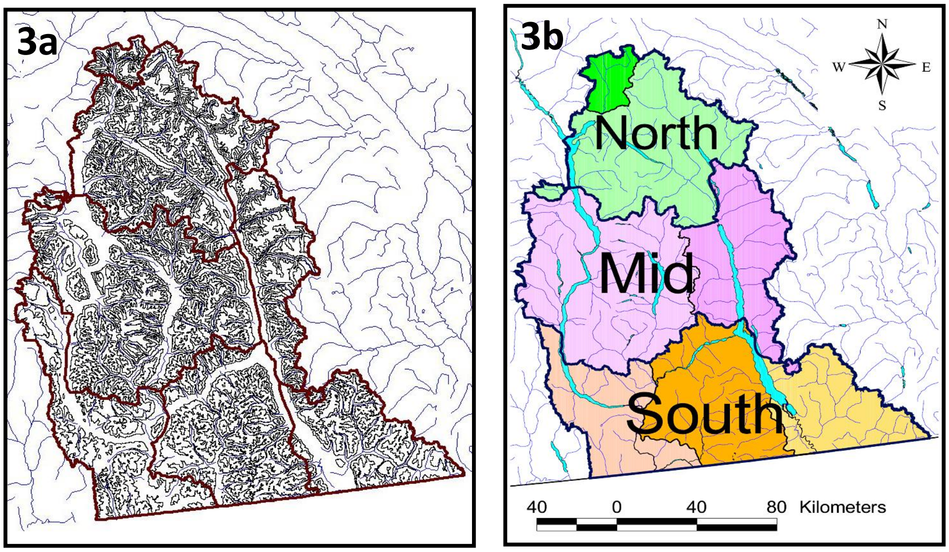

Figure 3. Map 3a illustrates West Kootenay Regional Landscapes with 500m contour slices, and 3b illustrates Regional Landscapes grouped into Subregional Climatic units.

For the purposes of this work, the basic assessment unit has been defined as a 500m elevational band within a RL (<1000m, 1000-1500, 1500-2000, >2000). However, for more detailed work, the basic units could be further subdivided based on aspect or finer topographic subdivisions. In this case we have grouped the RLs of the study area into three subregions, North, Mid and South, with our basic assessment unit being an elevation band within a subregion (Figure 3).

2.2 Drivers

Ecological 'drivers' are defined as any natural or human-induced factor that directly or indirectly causes a change in an ecosystem (Nelson 2003). In our early engagement with participants in the project workshops we identified a wide range of potential drivers for ecosystems in the West Kootenays (see Report # 10), and here we have focused on those considered to be most significant at the scale of broad ecosystems.

In this case we consider three main groupings of drivers for the assessment: climate change, non-climate environmental drivers (i.e. environmental elements of ecosystems), and other human-related drivers. Climatic drivers include annual and season temperature and precipitation, including variability, extremes and the associated magnitude and frequency of storms and wind events. The projected changes from reference conditions add a further dimension to this driver.

Environmental drivers include factors such as topography, landform, slope position, and parent material.

[4] This assumption would be less likely to be valid under a severe climate change scenario where there may be significant shifts in the patterns of weather systems. For example if there is a significant shift in continental vs. maritime influences or the long-term seasonal pattern of the jet stream.

Human-related drivers include the collection of post-industrial activities that are undertaken by humans on the landscape. These include activities such as access construction, forest harvesting, mining, dam construction, urbanization, habitat management and ecological restoration. These activities are considered in how they potentially alter the adaptive capacity of ecosystems (both positively and negatively).

2.3 Exposure

Exposure has been defined differently in various Vulnerability Assessments. In many Vulnerability Assessments, the analysis of exposure is limited to presentation of a table of projected changes in annual mean temperature and precipitation; other studies have used the degree to which key climatic variables depart from the recent range of variability; and others include indirect impacts of climate change which occur through modifications of disturbance regimes. We include both changes in seasonal climatic variables, and changes in disturbance regime. Our examination of drivers undertaken through a dialogue with forest practitioners highlighted those two drivers as likely significant determinants for the character of local ecosystems, and they are both closely linked with potential climate change. The primary disturbance agents for our study area are fire, insects, forest pathogens, wind, and geomorphic processes such as snow avalanching, flooding, channel instability, surface erosion and mass wasting. Their contribution to exposure is considered in the context of changes from the recent range of natural variability (RONV).

Due to the uncertainty associated with climate change projections, we assessed exposure for three different scenarios: “warm/ moist” (HadCM3_B1), “ hot/ wet” (CGCM3_A2) and “very hot/dry” (HadGEM_A1B). These illustrative scenarios provide a reasonable representation of the range of the various scenarios produced by the IPCC (see Report #3, Utzig 2012a for additional details).

2.4 Sensitivity

Our evaluation of sensitivity of the ecosystems to changes in climate and associated changes to disturbance regimes focused on attributes of the ecosystems currently occupying the assessment unit, including dominant tree species and basic ecological processes and functions. We considered factors such as the contrast between the current disturbance regime and projected disturbance regimes, suitability of current tree species for projected climates, and fuel loading where relevant. One key factor was what has been termed “functional-response diversity” by Folke et al. (2004) – an example being the presence or absence of fire tolerant species that can potentially cope with increases in fire frequency.

We recognize that many other factors affect the potential sensitivity of ecosystem or components of ecosystems. For example keystone or foundation species affected by projected changes would likely increase sensitivity of the ecosystem due to the potential for cascading impacts. Due to the scale of our assessment we did not attempt to include more detailed assessment of species level sensitivity, though suggest this would be a relevant next step, especially in relation to individual species of concern (e.g. rare and endangered), keystone species, foundation species and those associated with particular values.

2.5 Potential Impacts

The Vulnerability Assessment combines elements of exposure and sensitivity to estimate “potential impacts.” In addition to exposure and sensitivity, our assessment of potential impacts also considered the results from our analyses of projected bioclimate envelope shifts. We have summarized the potential impacts by summarizing the projected bioclimate envelope shifts for the three climate scenarios described above, for each assessment unit. We have designated these “potential” impacts because of the level of the uncertainty in the projections of climate change and the associated impacts, but also because they potentially can be modified by future adaptation and/or mitigation actions[5].

More detail on the projected bioclimate envelope shifts can be found in Report #5 (Utzig 2012b). The broad ecosystem units considered are[6]:

Alpine (Alp): alpine tundra (e.g., IMA, CMA)

Alpine transition (Atran): parkland/ woodland alpine transition (e.g., ESSFdmp, ESSFvcw)

Wet ESSF (W ESSF): wet Engelmann spruce-subalpine fir forest (e.g., ESSFvc)

Dry ESSF (D ESSF): dry Engelmann spruce-subalpine fir forest (e.g., ESSFdm)

CWH: coastal western hemlock forest (e.g., CWHmm)

Coast transition (Ctran): coastal transition cedar-hemlock forest (e.g., CWHds, ICHmc)

MSW: wet montane/ sub-boreal spruce forest (e.g., SBSmc)

MSD: dry montane/ sub-boreal spruce forest (e.g., SBPS, SBSdw, MSdk)

Wet ICH (W ICH): wet interior cedar-hemlock forest (e.g., ICHvk)

Moist ICH (M ICH): moist interior cedar-hemlock forest (e.g., ICHmw)

Dry ICH (D ICH): dry interior cedar-hemlock forest (e.g, ICHdw)

Grand Fir (GF): grand fir – Douglas-fir forest (e.g., ICHxw)

Wet IDF (W IDF): wet interior Douglas-fir forest (e.g., IDFww)

Dry IDF (D IDF): dry interior Douglas-fir forest (e.g., IDFdm)

Ponderosa Pine (PP): ponderosa pine forest and grassland savanna (e.g., PP)

Grassland-Steppe (GS): grassland and steppe (e.g., BG)

CAUTION: To assist BC readers envisioning the type of climatic environments that may occur in the future, the bioclimate envelopes have been designated with names of the most similar ecosystems that currently exist in BC. **Although these bioclimate envelopes are described with ecosystem names that are familiar, it should not be assumed that the future ecosystems that will develop in these climate envelopes will be identical to ecosystems that readers are familiar with.**

2.6 Adaptive Capacity of Ecosystems

The evaluation of adaptive capacity, this assessment considered two major groups of factors: the "inherent" adaptive capacity of the assessment unit based on its specific characteristics, and secondly human-related activities and their associated effects on adaptive capacity. We designated the combination of these two groups of factors as "effective" adaptive capacity. Because our assessment unit is the functional space, rather than the ecosystem currently occupying that space, many of the factors considered under inherent adaptive capacity relate to the ability of the ecosystem in that space to transition to ecosystems under projected climate regimes. These included the presence or absence of species adapted to projected environments, either in-situ or nearby, topographic or aquatic features that facilitate or constrain range shifts for terrestrial species (i.e. natural

[5] The emission scenario (B1) utilized in the Hot/ Moist climate scenario assumes short- to medium-term reductions of greenhouse gas emissions, which may include some mitigation measures.
[6] The example ecosystem units in parentheses are from the BC Biogeoclimatic Classification system – further information can be found at: http://www.for.gov.bc.ca/hre/becweb/system/how/index.html

fragmentation), and the magnitude and direction of projected shifts (e.g., alpine to forest vs. interior rainforest to fire-maintain savanna).

Human-related factors that contributed to the final determination of effective adaptive capacity included factors such as fragmentation due to forest harvesting, urbanization, agriculture or reservoir construction, reduced species and/or genetic diversity, pollution and modified disturbance regimes. For ecosystems and species whose ranges may shift as a result of climate change, the condition of ecosystems within the corridors between their present range and future ranges may also be relevant.

2.7 Potential Vulnerability

Vulnerability has been determined by considering the potential impacts, resulting from exposure and sensitivity, and effective adaptive capacity – i.e. the magnitude and direction of change and the capacity for reducing and/or accommodating the impacts of those changes. We have provided three ratings for each assessment unit, related to the three climate scenarios described above.

In determining the vulnerability ratings, we employed resilience theory concepts to assist in understanding the key question of "vulnerability to what?" We have defined the "what" to be a regime shift. The relative ratings of vulnerability are based on the likelihood of a regime shift, the magnitude of the shift and the manner in which the shift is hypothesized to proceed. Report #2 (Holt et al. 2012) provides an overview of regime shift theories and relevant factors, but the key points are summarized below:

> Ecological regime shifts are large, sudden changes in ecosystems that last for substantial periods of time …. Ecological regime shifts are widely regarded as undesirable as they often have considerable impacts on human well-being …… (e.g., the collapse of Newfoundland's cod fishery) … Most regime shifts come as surprises, and the conditions and mechanisms leading to them only become clear once the shift has occurred. Regime shifts typically result from a combination of gradual changes in an underlying driving variable (or set of variables), combined with an external shock, such as a storm or fire. Gradual changes in underlying drivers usually have little or no apparent impact up to a certain point, and then unexpectedly lead to a regime shift when that threshold is crossed. Once an ecosystem is close to a threshold, a shift is often precipitated by a shock that under previous conditions had no dramatic consequences …… To avoid large-scale disruptions to human societies, there is accordingly an urgent need to improve our ability to anticipate and avert ecological regime shifts[7].

Our assessment of "potential vulnerability", as with "potential impacts," is based on assuming that no social based adaptation measures have been taken. The potential vulnerability will reflect our combined evaluations of potential impacts and effective adaptive capacity (see Table 1 for summary of major factors considered).

The Vulnerability Assessment ratings generally reflect the average or mesic/modal ecosystems within each of the assessment units. Drier sites (i.e. very xeric to submesic) will be more prone to drought impacts, and more likely to be sources of species more capable of coping with increasing drought. In contrast, moist and wet sites (i.e. subhygric to subhydric) will be less affected by increasing drought, especially those where the moisture source is a regional water table. Moist and wet sites dependent on local seepage and runoff water sources may be more severely impacted, as shifts to decreased snow accumulation, less frequent and more high intensity precipitation events, and more prolonged droughts lead to reduced periods of soil saturation, seepage and localized water ponding. However, assessment of potential impacts and vulnerabilities at this level of detail were beyond the scope of this first phase analysis.

[7] From Biggs et al. (pp. 826, 2009), citing (Scheffer et al. 2001 and Carpenter 2003).

Table 1. Summary of key assessment criteria for each component of the assessment.

Exposure	Sensitivity	Effective Adaptive Capacity	Potential Vulnerability
Projected temperature and precipitation changes Increase in extreme weather events Severity of projected climate-related changes in disturbance regimes[8]	Current disturbance regime Diversity of tree species Presence of fire tolerant spp. where relevant Fuel loading where increased fire was a consideration	Local and downslope tree species seed sources Potential for species shifts from down-slope Natural connectivity Soil capability Degree of human-caused fragmentation/ disturbance	Collective ratings of exposure, sensitivity and effective adaptive capacity Likelihood and severity of regime shift Degree of uncertainty (range of possible outcomes)

In general terms we consider three potential outcomes:

- **No regime shift** – This includes the system remaining as it is today, or changing in relatively minor ways. This would include maintaining a similar natural disturbance regime and successional pathway, but may include potential changes in dominant tree species (e.g., shift from W ICH or W ESSF to coastal transition ICH or CWH).
- **Non-catastrophic regime shift** – This likely includes changes in natural disturbance regime, and potentially changes in successional pathways and dominant tree species. However the shift can proceed in an orderly non-disruptive manner (e.g., Alpine to ESSF or ICH with gradual forest in-fill), or it can follow a disturbance event (e.g., IDF forest conversion to grassland/ savanna following fire due to regeneration failure).
- **Catastrophic regime shift** – This type of change generally includes a significant change in natural disturbance regime and major shifts in dominant species. This type of shift almost always is associated with an intensive disturbance event (e.g., stand-replacing fire or epidemic insect outbreak). The distinguishing factor is that the shift is disruptive and disorderly. Rather than shifting to a successional phase leading into renewal, the system moves into a 'stalled' or 'chaotic' phase, from which it could take a long period of time to recover (or may be irreversible). This is potentially more likely in areas where the magnitude of change is greater, the current ecosystems have limited diversity, and in areas where ecosystems have infrequent stand-replacing disturbances, allowing persistent ecosystems to essentially become relics of previous climatic conditions. Other contributing factors may include a lack of seed source for suitable species, or competition by early successional and/or invasive species that arrest succession. The occurrence of a high severity stand-replacing fire in an old growth stand of Wet ICH, followed by a few years of hot dry summers could be an example of such an event. These types of stands currently are driven by gap-replacement disturbance regimes with extremely low occurrence of drought tolerant seral species, hence the likelihood of a prolonged chaotic recovery – or a possible regime shift to non-forested brush. These types of regime shifts are the most likely to result in significant and long-term interruptions in ecosystem goods and services (Chapin et al. 2009, Folke et al. 2004).

[8] NDT = Natural Disturbance Types, 1 = rare stand initiating events; 2 = infrequent stand initiating events; 3 = frequent stand initiating events 4 = frequent stand-maintaining fires; 5 = alpine and subalpine environments; changes from NDT 1 to 2 were considered moderate, 1 to 3 or 4 and 2 to 4 severe; from 3 to 4 moderate; and 5 to 2,3 or 4 low; estimated severity often varied between scenarios; for more information see: http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm

In describing the estimated likelihood of catastrophic regime shifts, we have used IPCC (2012) likelihood ratings:

- Virtually certain 99–100% probability
- Very likely 90–100% probability
- Likely 66–100% probability
- About as likely as not 33–66% probability
- Unlikely 0–33% probability
- Very unlikely 0–10% probability
- Exceptionally unlikely 0–1% probability

3.0 RESULTS

The following two tables provide the results from the vulnerability assessment. For each assessment unit, Table 2 summarizes background that is used to inform the final vulnerability assessment ratings, including information on: reference period climate characteristics, climate change projections for the 2080s (averages and ranges for the three scenarios), reference period disturbance regimes, key characteristics of currently mapped ecosystems, non-climate environmental drivers, human-related drivers, and inherent adaptive capacity. This information is a summary of the orange and black boxes at the top of the framework diagram (Figure 1).

Table 3 provides a summary of potential impacts and relative ratings of exposure, sensitivity, effective adaptive capacity and potential vulnerability for each assessment unit (the red boxes in Figure 1).

The potential impacts include information on the currently mapped general ecosystems and the general ecosystem bioclimate envelopes projected by the three climate scenarios (see Report #5 for more detail, Utzig 2012b; and Appendix 1 of this report for abbreviations). The final two columns provide information on the key contributing factors to the ratings, as well information related to the potential for a regime shift, and which type of regime shift.

The assessment ratings include: Very High, High, Moderate, Low and Very Low (VH, H, M, L and VL). Assessment units rated VH or VL are considered the highest and lowest rated assessment units in the study area, compared to all the other assessment units in the study area. ***The ratings are relative between assessment units within the West Kootenay – they are NOT absolute ratings that can be compared to ratings of areas outside the study area.*** The key assessment criteria for each of the vulnerability assessment ratings are summarized in Table 1.

Note that the ratings in the assessments refer to the vulnerability of individual assessment units - a particular location or functional space, not whether the current ecosystem occupying that space is itself vulnerable. For example, if a particular zone (e.g., moist interior cedar-hemlock – ICH) is projected to 'move', or expand in overall extent it (the vegetation zone) could be considered to be 'not vulnerable,'. However, if a particular location currently occupied by that type is likely to shift into a non-forested brush field we would rate that 'ecosystem space' as vulnerable, since we are rating the space where the moist ICH was located.

Table 2. Summary of climatic, environmental and human-related drivers, and other factors affecting exposure, sensitivity and adaptive capacity.

Assm't Unit	Reference Period Climate	Reference Period Disturbance Regimes[9]	CC Drivers Direct/ Indirect Key Changes	Species/ Ecosystem Characteristics[10]	Non-climate Environmental Drivers	Human-related Drivers	Inherent Adaptive Capacity
North <1000m	Moderate to deep snowpack; generally favourable climate for tree growth; few moisture deficits, and generally limited to southern portion.	Mostly gap replacement disturbance regimes and moderate to long return interval stand-replacing events; major river valleys with stream channel erosion and flooding disturbances.	Summer temp. increases (+5ºC: 4 to 7); possible decreases in summer precip. (-13%: +4 to –34); increased temp. in spring (+3ºC: 2 to 5); and fall (+4ºC: 3 to 5); winter temp. increases (+3 ºC: 1 to 5); winter precip. increases (+10%: 5 to 16). Shorter snow season; longer more intense fire season – more area burned; change in flow regimes – potential channel instability.	Predominantly old growth Cw/Hw forests; rare seral stands of Fd, Lw and Pw, with Hw and Cw; limited presence of fire tolerant spp.	Mixed glacio-fluvial, fluvial and morainal parent materials.	Duncan and Arrow reservoirs limit terrestrial range shifts by destroying riparian and other valley bottom connectivity; forest harvesting has fragmented historically continuous old growth forest cover; agriculture clearing and rural settlement in the Lardeau and Columbia valleys.	Being the lowest elevations, no options for upward elevational shifts from below; Trout Lake locally limits valley bottom terrestrial range shifts; high relief limits regional connectivity to low passes (E-W connectivity most limited); abundant landform/ site diversity.
North 1000-1500m	Deep snowpack; generally favourable climate for tree growth; moisture deficits rare.	Dominated by gap replacement disturbance regimes and very long return interval stand-replacing events; some snow avalanching.		Predominantly old growth Cw/Hw forests; rare seral stands of Fd and Pw, with Hw and Cw; some old growth Se/Bl forests at upper elevations; little presence of fire tolerant spp.	Mainly morainal parent materials.	Forest harvesting has fragmented historically continuous old growth forest cover in valley bottoms of many tributary valleys.	Steep mountainous terrain provides significant opportunities for elevational range shifts, high relief limits regional connectivity to low passes (especially E-W connectivity); snow avalanching is significant in some valleys; moderate landform/ site diversity.
North 1500-2000m	Very deep snowpacks; shorter growing seasons; moisture deficits rare.	Dominated by gap replacement disturbance regimes and very long return interval stand-replacing events; exten-sive snow avalanching.		Predominantly old growth Se/Bl (Hm) forests; some woodland/ parkland forests at upper elevations; no fire tolerant spp.	Mixed morainal and colluvial parent materials.	Locally mining has had impacts (e.g. Silvercup Ridge); limited forest harvesting fragmentation.	Steep mountainous terrain provides some opportunities for elevational range shifts; shallow/ coarse soils may limit upward movement; fragmentation due to extensive snow avalanching and topography.
North >2000m	Dominated by short growing seasons; extremely deep snowpack.	Extensive snow avalanching; localized mass wasting.		Dominated by parkland/ woodland types with Bl (Se,Hm. Pa); with some alpine and significant non-vegetated rock.	Dominated by bedrock, colluvium and shallow soils.	Locally mining and commercial recreation have had limited impacts.	Steep mountainous terrain provides some opportunities for elevational range shifts; lack of soil may limit upward movement; very fragmented by lower elevation habitats.

[9] When referring to disturbance return intervals (years): high frequency: ~<75; short ~75-150; moderate ~150-300, long ~300-500, very long ~>500; insects and forest pathogens are also important disturbance agents, but outbreaks are generally episodic and their impacts are often tree species and age class specific, and therefore too complex to summarize in this table (see Report #6 Pinnell 2012).

[10] Tree species abbreviations according to standard BC forest inventory system – see: http://www.for.gov.bc.ca/hre/becweb/resources/codes-standards/index.html

Assm't Unit	Reference Period Climate	Reference Period Disturbance Regimes[9]	CC Drivers Direct/ Indirect Key Changes	Species/ Ecosystem Characteristics[10]	Non-climate Environmental Drivers	Human-related Drivers	Inherent Adaptive Capacity
Mid <1000m	Moderate snowpack; generally favourable climate for tree growth; some moisture deficits.	Mainly short to moderate return interval mixed fire regimes; major river valleys with stream channel erosion and flooding disturbances.	Summer temp. increases (+5°C: 4 to 7); possible decreases in summer precip. (-18%: +4 to –40); increased temp. in spring (+4°C: 2 to 5); and fall (+4°C: 3 to 5); winter temp increases (+3 °C: 1 to 5); winter precip. increases (+8%: 5 to 13). Shorter snow season – especially at lower elevations; longer more intense fire season – more area burned; change in flow regimes – potential channel instability.	Dominated by mixed species seral stands of Lw, Fd, Pl, Pw , with Hw and Cw; some stands with Bg and Py in the southern and eastern main valleys; some old growth Cw/Hw forests; moderate to high diversity including fire tolerant spp.	Mixed glacio-fluvial, fluvial and morainal parent materials.	Arrow and Duncan Reservoirs limit terrestrial range shifts by destroying riparian and other valley bottom connectivity; forest harvesting has fragmented forest cover and reduced the amount of old forests; agricultural clearing and rural development has reduced forest cover in the Slocan, Columbia and Kootenay valleys; localized settlement impacts; access and related human activities have reduced natural populations and provided vectors for invasive spp.	Being the lowest elevations, no options for upward elevational shifts from below; Kootenay and Slocan Lakes limit valley bottom terrestrial range shifts; high relief limits regional connectivity to low passes (especially E-W connectivity); abundant landform/ site diversity.
Mid 1000-1500m	Moderate to deep snowpack; generally favourable climate for tree growth; limited moisture deficits.	Mainly moderate to long return interval fire regimes, with some gap replacement disturbance regimes along the northern edge; minor snow avalanching.		A mix of old growth Cw/Hw forests and seral stands of Lw, Fd, Pl, Pw, with Hw and Cw.	Mainly morainal parent materials with minor glaciofluvial.	Forest harvesting has fragmented once continuous forest cover and reduced the amount of old forests; access and related human activities have reduced natural populations and provided vectors for invasive spp.; localized mining impacts.	Mountainous terrain provides significant opportunities for elevational range shifts, however the high relief limits regional connectivity to low passes (especially E-W connectivity); some snow avalanching: moderate landform/ site diversity.
Mid 1500-2000m	Deep snowpacks; generally favourable climate for tree growth; moisture deficits rare.	Dominated by gap replacement and long return interval stand-replacing events; some snow avalanching.		Predominantly old growth Se/Bl forests with some seral stands of Pl	Mixed morainal and colluvial parent materials.	Forest harvesting has fragmented once continuous forest cover and reduced the amount of old forests in some areas; local mining impacts.	Steep mountainous terrain provides some opportunities for elevational range shifts; shallow/ coarse soils may limit upward movement; some fragmentation due to snow avalanching and topography.
Mid >2000m	Dominated by short growing seasons; extremely deep snowpack.	Extensive snow avalanching and localized mass wasting.		Dominated by parkland and woodland types with Bl (Se,Pa,La); with some alpine and significant non-vegetated rock.	Dominated by bedrock , colluvium and shallow soils.	Localized mining and commercial recreation impacts.	Mountainous terrain provides some opportunities for elevational range shifts; lack of soil may limit upward movement; very fragmented by lower elevation habitats.

Assm't Unit	Reference Period Climate	Reference Period Disturbance Regimes[9]	CC Drivers Direct/ Indirect Key Changes	Species/ Ecosystem Characteristics[10]	Non-climate Environmental Drivers	Human-related Drivers	Inherent Adaptive Capacity
South <1000m	Cool wet winters with variable low to moderate snowpacks; long growing season with significant moisture deficits.	High frequency, low intensity fire regimes on some S. aspects; mixed fire regimes with short return intervals in remaining areas.	Summer temp. increases (+5°C: 4 to 7); possible decreases in summer precip. (-18%: +4 to –44); increased temp. in spring (+4°C: 2 to 5); and fall (+4°C: 3 to 5); winter temp. increases (+4 °C: 1 to 5); winter precip. increases (+7%: 4 to 12). Shorter snow season – possibly none at lowest elevations; longer more intense fire season – more area burned; change in flow regimes – potential channel instability.	Dominated by mixed seral stands of Fd, Lw, Pl, Py, Pw, often with Bg, Hw and Cw; rare old growth stands of Cw//Hw; some south aspects dominated by Fd, Lw and Py; high diversity, including fire tolerant spp.	Mixed, glaciofluvial, morainal and fluvial parent materials, with some lacustrine.	Arrow Reservoir limits terrestrial range shifts by destroying riparian and other valley bottom connectivity; forest harvesting has fragmented forest cover and reduced the amount of old forests; agricultural clearing and rural development has reduced forest cover in the Columbia and Kootenay valleys; fire suppression has contributed to high fuel loads; localized settlement impacts; invasive spp. and smelter impacts.	Being the lowest elevations, no options for upward elevational shifts from below; Kootenay Lake limits valley bottom terrestrial range shifts; some E-W connectivity abundant landform/ site diversity.
South 1000-1500m	Moderate snowpacks depths; long growing season occasional moisture deficits.	Mainly short to moderate return interval mixed fire regimes in the Monashees and Purcells, and moderate return intervals in the Selkirks.		Dominated by mixed species seral stands of Lw, Fd, Pl, Pw , often with Hw and Cw; including Bg and Py in the lower elevations; some old growth Cw/Hw forests.	Mainly morainal parent materials with minor glaciofluvial.	Forest harvesting has fragmented once continuous forest cover and reduced the amount of old forests; access and related human activities have reduced natural populations and provided vectors for invasive spp.; localized mining impacts.	Rolling mountainous terrain provides some opportunities for upward elevational and lateral range shifts; moderate landform/ site diversity.
South 1500-2000m	Moderate to deep snowpack; generally favourable climate for tree growth; occasional moisture deficits.	Presently dominated by gap replacement disturbance regimes and long return interval stand-replacing events in the Selkirks and moderate to long intervals in other areas.		Some old growth Se/Bl forests, mainly in the Selkirk Mountains; significant area of seral Pl stands, some with Se/Bl, dominantly in the Monashee and Purcell Mtns.	Mixed morainal and colluvial parent materials; shallow materials and bedrock on ridge crests.	Forest harvesting has fragmented once continuous forest cover and reduced the amount of old forests in some areas.	Rolling mountainous terrain provides opportunities for elevational range shifts into the area, but limits lateral shifts due to fragmentation, especially in the Monashees and Purcells.
South >2000m	Dominated by short growing seasons; deep snowpack.	Some snow avalanching and localized mass wasting.		Occurrence mainly in the Selkirk Mountains; dominated by parkland and woodland types with Bl (Se,Pa,La); with some alpine and non-vegetated rock.	Dominated by bedrock , colluvium and shallow soils.	Localized mining and commercial recreation impacts.	High relief terrain provides some opportunities for elevational range shifts; lack of soil may limit upward movement; very fragmented by lower elevation habitats.

Table 3. Potential impacts and relative ratings of exposure, sensitivity, effective adaptive capacity and potential vulnerability for study area assessment units, including comments on contributing factors and potential regime shifts (see text for more detail on each element).

Assm't Unit	Exposure	Sensitivity	Potential Impacts[11]	Effective Adaptive Capacity	Potential Vulnerability	Comments	
						Key Contributing Factors[12]	Regime Shift (RS)
North <1000m	H-M-H	M	From M/W ICH to PP and/or GF/ MSD and/or GS	L	VH-H-VH	Magnitude and direction of NDT shift (2/1 to 4/3), lack of local seed source for fire-resistant tree spp., fragmentation by reservoirs and harvesting, no downslope seed source availability	RS very likely; likely catastrophic
North 1000-1500m	M-H-VH	VH	From M/W ICH/ W ESSF to D/M/W ICH and/or Ctran/ MSD and/or PP/ GS	M	M-M-VH	Uncertainty of exposure/ impacts and possible magnitude of NDT shift (1/2 to 2/3 or 4), lack of local seed source for fire-resistant tree spp., moderate fragmentation	RS likely to very likely; likely to be catastrophic
North 1500-2000m	VL-VL-VH	VH	From W ESSF/ Atran to W ICH/ and/or CWH/Alp and/or PP/ D ICH	M	L-L-VH	Possible magnitude of NDT shift (1/5 to 1/5 or 4/3), no local seed source for fire-resistant tree spp., minimal fragmentation	RS unlikely, but if so, likely catastrophic
North >2000m	L-VL-M	M	From Atran/ Alp to W ICH/ W ESSF and/or Alp/ Atran and/or D/W ICH/ D ESSF	L	L-VL-L	Limited magnitude and direction of NDT shift (5 to 1 or 5 or 3/2), tree spp. seed source downslope, natural fragmentation	RS about as likely as not; very unlikely to be catastrophic
Mid <1000m	M-L-M	L	From D/M ICH to PP/ GS and/or GF/ MSD	L	M-M-M	Moderate NDT shift (3/2 to 4/3 or 4), some local fire resistant tree spp. seed sources, extensive fragmentation, no downslope seed source availability	RS likely; unlikely to be catastrophic, significant invasive spp. risk
Mid 1000-1500m	H-H-VH	M	From M ICH/ W ESSF to PP/ D ICH and/or MSD/ GF/ Ctran and/or GS/ PP	H	H-H-VH	Magnitude and direction of NDT shift (2/1 to 3/4 or 4), some local and downslope seed sources, limited fragmentation	RS likely to very likely; about as likely as not to be catastrophic
Mid 1500-2000m	H-M-VH	VH	From W ESSF to D/M/W ICH and/or Ctran/ MSD and/or PP	M	H-H-VH	Uncertainty of exposure/ impacts and possible magnitude of NDT shift (1 to 2-3-4), lack of local tree spp. seed source, some available downslope, limited fragmentation	RS likely to very likely, likely to be catastrophic
Mid >2000m	L-L-M	M	From Atran/ Alp to W ICH and/or Ctran/ Alp and/or PP/ D ICH/ D ESSF	L	L-VL-M	Limited magnitude and direction of NDT shift (5 to 5 or 3/4), downslope seed sources, natural fragmentation	RS about as likely as not; very unlikely to be catastrophic

[11] For more detail on the projected impacts see Section 3.2 and Appendix 3 of Report #5 (Utzig 2012a); for explanations of the ecosystem shift abbreviations see Appendix 1 of this report.
[12] NDT = Natural Disturbance Types, 1 = rare stand initiating events; 2 = infrequent stand initiating events; 3 = frequent stand initiating events 4 = frequent stand-maintaining fires; 5 = alpine and subalpine environments; for more information see: http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm

Assm't Unit	Exposure	Sensitivity	Potential Impacts[11]	Effective Adaptive Capacity	Potential Vulnerability	Comments	
						Key Contributing Factors[12]	Regime Shift (RS)
South <1000m	M-L-M	VL	From D ICH/ GF to GS/ PP/ GF	VL	L-L-M	Limited magnitude of NDT shift (3/4 to 4/3), local seed source for tree spp., extensive fragmentation, no downslope seed source availability, past fire suppression	RS likely to very likely (localized); unlikely to be catastrophic, high invasive spp. risk
South 1000-1500m	L-VL-H	VL	From D/M ICH to PP/D ICH and/or GF/ MSD/ D IDF and/or GS	VH	VL-VL-H	Limited magnitude of NDT shift (3/2 to 3/4), local and downslope seed source for tree spp., moderate fragmentation,	RS about as likely as not; about as likely as not to be catastrophic
South 1500-2000m	M-M-H	M-H	From D/W ESSF to D/W ICH and/or Ctran/ MSD and/or D/W IDF/ PP/ GS	M	L-L-M	Limited magnitude of NDT shift (3/1 to 3/2 or 3), downslope seed source for tree spp., low fragmentation	RS unlikely, but if so, about as likely as not to be catastrophic (localized risk)
South >2000m	L-L-M	L	From D/W ESSF/ Atran to W ICH and/or Ctran and/or D ICH/ W IDF/ PP	L	VL-VL-L	Limited magnitude of NDT shift (3/1/5 to 2/3), downslope seed sources, natural fragmentation	RS likely; very unlikely to be catastrophic

4.0 DISCUSSION

In this paper we used bioclimate and tree species projections for the West Kootenay region under three climate change scenarios as the primary underpinnings for a Vulnerability Assessment for broad scale ecosystems in the region. We also used supporting evidence on projected changes in fire regime and insect populations to contemplate whether predictions for these potentially important drivers of ecosystem shift generally supported the directional shifts projected by modeling, and could be used to provide potential (or at least partial) mechanisms for the changes projected.

Using a Vulnerability Framework - with terms clarified for use in the ecological context - the direct and indirect effects of exposure and ecosystem sensitivity are summarized, and combined with effective adaptive capacity to result in potential ecological vulnerability. A key element determining overall vulnerability was the extent to which natural disturbance regimes for the ecosystems were projected to change in the future, and how this would be translated into potential regime shifts in different ecosystems. Packaged in this way, our assessment applies concepts of resilience within a Vulnerability Assessment framework.

4.1 Ecosystem Shifts in the West Kootenays

The low elevation assessment unit in the North Subregion, currently dominated by Moist and Wet ICH is highlighted as one of the most vulnerable systems (High to Very High) in the West Kootenays. These systems are predominantly NDT1 – gap dynamic dominated – forested ecosystems that are projected (by both bioclimate shifts and fire dynamics) to potentially become NDT 3 / 4 - frequent fire dominated systems. This shift, combined with the general lack, or minor occurrence, of fire adapted species through much of the unit (e.g., Ponderosa pine, lodgepole pine, Douglas-fir, western larch) has the potential to result in a change in pathway during the renewal phase of the adaptive cycle (e.g., after a stand-replacing disturbance event). In addition, the original pathway (successional development of a forested ecosystem) may become 'arrested' or 'chaotic' or 'stalled', thereby slowing the new pathway of sequestration of resources and regrowth. This leaves the ecosystems not only potentially failing to provide the wide array of goods and services humans are currently adapted to, but may also result in the system moving into a state that is irreversible (or only slowly reversible), for example being shrub-dominated or invasive species dominated.

Although the assessment unit at low elevation in the South Subregion – currently a mix of NDT 3 and 4, with moderate and high frequency and short fire return intervals – is projected to shift to hotter drier climates, with all three scenarios projecting shifts to NDT 4 grassland/ savanna bioclimate envelopes for a significant portion of the area, the vulnerability ratings assigned are all Low and Medium – despite significant human-related impairment of adaptive capacity. Although the shift from forest and open forest to grassland and savanna is a major structural change, many of the dominant species currently occupying the projected envelopes are already present on drier sites in the assessment unit. Therefore in spite of the significant changes projected, we have rated these systems less vulnerable overall, because the natural disturbance type and ecosystem development pathway remains similar. Though in general we expect these systems to be less likely to move into a 'stall' or 'chaotic state', there is significant risk that invasive species could colonize sites after a disturbance event, preventing a typical return to a more productive successional pathway, possibly warranting a higher vulnerability rating.

Mid elevation systems in the South Subregion are given a 'high vulnerability' rating for one scenario, since the magnitude of predicted natural disturbance shifts is much greater (from NDT2 to NDT 4).

In the Mid Subregion, the mid elevation bands are given similar ratings to the wetter ecosystems in the North (High or Very High vulnerability), because of the similar predicted regime shift. The lower and highest elevation bands of the Mid are given lower vulnerabilities since the change in natural disturbance regime is less likely to result in a catastrophic regime shift.

The use of three climate scenarios has resulted in three sets of impact and vulnerability ratings. This range can be used to get some understanding of the potential range of futures that could be expected. Where it is more clear (though by no means certain) in what direction the system is headed then it becomes easier to translate into management adaptation direction. Where the three scenarios result in quite different potential outcomes it makes translation into management direction more difficult, with the need to concentrate on robust options, rather than optimal options (see Report #9 for additional discussion, Pinnell et al. 2012).

In terms of consistency of the projections from the three scenarios, the low elevation in the North Subregion and mid elevation in the Mid Subregion are most consistent – and predicted to have the highest vulnerabilities. Alternatively, the highest elevation bands in the South, North and to a slightly lesser extent the Mid, have consistently Low and Very Low vulnerability ratings. In theory then, this information provides managers with consistent predictions on what the future may have in store, so making it easier to use this information to help set priorities for action. Alternatively, the mid elevation band in the North has Low, Low and Very High vulnerability ratings – depending on scenario, and the South mid elevation band has ratings of Very Low, Very Low and High ratings, resulting in significant uncertainty out potential outcomes. For these systems, choosing ecologically appropriate adaptation strategies will be particularly challenging.

We have only touched on the major mechanisms of change in these ecosystems, however ultimately this magnitude of change will drive a number of interconnected positive feedback loops, including the interactions across scales (tree to stand to landscape), and between natural processes and management decisions. Together these factors create a potential cascade of responses resulting in a high likelihood of stand replacing fires, followed by a shift to a potentially new pathway and state as new climate conditions make the site unsuitable for current species. Where we have indicated the potential for a catastrophic regime shift, this may mean moving into a 'stalled' successional pathway where the system is open to invasion non-native or undesirable species, which may be difficult to 'manage our way back from', resulting in the worst potential scenario for managers to contemplate.

4.2 Vulnerability, Resilience and Thresholds

That thresholds at multiple scales exist throughout ecological systems is not in doubt, but the current theories are weak in allowing predictive power to identify where and when thresholds may surface. There is clear evidence that climate change can induce threshold responses in ecosystems – but the basic science around these thresholds, in particular prediction of potential threshold responses in advance of them occurring, is not well developed and hard to test (Groffman et al. 2006; Suding and Hobbs 2009). It is however useful to contemplate potential implications arising from crossing thresholds, even if we have difficulty in predicting where they are, and in what systems they exist. The examples of thresholds in the literature are typically the result of years of focused research into the basic ecology of a species or system (e.g., Mountain Pine Beetle – Raffa et al. 2008). Further basic science on understanding the dynamics of forested ecosystems could improve basic understanding of how systems may respond into the future.

That said, recent work suggests some patterns are starting to emerge about the types of systems where thresholds may occur. A recent paper reviews examples of thresholds across disparate fields and systems, and highlights number of warning signs that appear to be present across a range of highly diverse systems (Scheffer et al. 2009). These include observing chaotic patterns prior to a threshold being reached, and seeing slower recovery times with increasing pressures as thresholds are approached (e.g. a lag in population response times).

In addition, patterns are emerging about the types of systems where thresholds may be particularly relevant and include those where there is a strong 'self-organized' structure (Suding and Hobbs 2009) in the ecosystem (e.g., strong species effects, priority effects, strong interactive groups of species) – because of strong feedbacks between species, and where loss of one species causes knock-on effects to others. Secondly, ecological thresholds have been observed in systems where many species can rapidly colonize a site (e.g., priority species effects - where the species that arrives first can drive the system). We hypothesize that this could be relevant in ecosystems particularly vulnerable to colonization by invasive species. Thirdly, evidence of thresholds has often come from arid systems. Our analysis supports this, as the driest forest systems potentially change to non-treed systems presumably as moisture thresholds are crossed. However, our results were also intuitively unexpected because systems not considered close to such a threshold (e.g., drier areas of the wet ICH at low elevation) were also projected to change state towards grassland. The learning from this is that the scope of climate change being predicted by these three scenarios is of sufficient magnitude that anticipation of potential thresholds appears to require us to think considerably outside the scope of what may at first glance appear reasonable. In addition, the scenarios provide a snapshot of the future, but there's no suggestion that the rate and direction of climate change will slow after 2080, leaving the longer term future unknown at this time. This is an issue for forest management since forest practitioners routinely make assumptions over much longer timeframes into the future (e.g., allowable annual cuts modeled for 250 years).

Looking for and understanding potential feedback loops appears critical – since critical thresholds are those that, once crossed, propel the system through a state where feedback moves the system quickly into new dynamics and potentially then regime shift. Systems with positive feedback loops – events that build upon one another – causing a cascade of responses will tend to react suddenly and dramatically. Systems with negative feedback loops will tend to react more slowly – with the internal dynamics 'dampening' any changes (Scheffer et al. 2009). Some feedback systems appear relatively intuitive (e.g., drying, moisture stress, increased stand level mortality, increased insect and pathogen susceptibility, increased probability of fire, increased fire size due to increased fuel). Future work should identify what other types of feedback loops may be relevant in these systems since understanding potential pathways is key to linking to appropriate management strategies moving forward.

The concepts of resilience, multiple stable states and thresholds appear to be useful in understanding, or at least developing a theoretical framework for understanding the potential dynamics of West Kootenay ecosystems. It has been noted by others (e.g. Suding and Hobbs 2009), that practitioners seem to be using theoretical resilience constructs that "appear to work", rather than striving to prove or follow particular elements. This project is at fault for this; however, those same authors also note that there really isn't time to wait for rigorous testing of all these ideas in individual ecosystems before making management decisions. The results from this assessment support this notion, though also suggest that the variety of potential futures provides a strong incentive for caution.

4.3 Implications for Managers

Note that Report #9 (Pinnell et al. 2012) takes the Vulnerability Assessment results and considers practical applications for practitioners.

The concept of multiple states for an individual ecosystem in a particular place or location is highly relevant in a management context – as humans obtain goods and services from particular ecosystems in particular places in particular states. The current management paradigm (e.g., sustained yield, BEC classification) has assumed that ecosystems will maintain a particular state, and we have subsequently planned accordingly, tying social infrastructure to goods and services assumed to be available in perpetuity. The whole concept of sustainability of resource management is tied into the idea that the system can continue 'in its current state and functioning' into the future. However, for many years it has been known that "without an understanding of the dynamics of shifting between multiple states, the manager may be disappointed by the lack of expected response" to management actions when system dynamics are not well understood (Laycock 1991; Holling 1996).

It has been suggested that a way to make the problem more tractable is to focus specifically on thresholds that relate to individual values / services (Groffman et al. 2006). Although we agree this would narrow the focus of the perceived work, we suggest that our results – potential significant shifts and high vulnerability in ecosystems that were least obvious at the beginning of the study – should encourage us, at this time, to maintain a broader investigation into the potential effects of climate change on whole ecosystems until we have gained a better understanding of which of the ecosystems in British Columbia are really most vulnerable.

Focusing on specific values also requires models and managers to define the 'desired level' of a particular service that we wish to maintain – which may change in future. In reviewing the literature on vulnerability of ecosystems it becomes very clear that British Columbia has a significant advantage over many areas of the world, having relatively highly functioning systems as a starting point. Striving to maintain the opportunities and flexibility that this confers should be prioritized as a general strategy. . We can't today predict how people will value and prioritize goods and services into the future.

In his 1996 overview paper, Holling summarizes more than 20 years of research and thought, and concludes that systems in general are inherently complex, characterized by long periods of apparent stability and punctuated by periods of rapid shift where the trajectory of a whole system can be altered very rapidly and in potentially irreversible ways. Overlaying management practices on top of ecosystem dynamics results in further complexity and the potential for further surprises. Holling, and many others, suggest that engaging in real adaptive management of systems is the only way forward under these circumstances – true learning while doing. In British Columbia, managers and scientists have spent a large amount of effort defining what might constitute adaptive management – writing manuals and attending workshops – however, it appears that none of the resource ministries have yet taken on the key principles in their management structure. Monitoring, flexible policies and a move away from rigid output goals are key pieces – all of which we have moved away from in the last decade or so – rather than towards. Holling highlights the need to create flexible institutions. Effective flexible institutions are those where the connections binding people to people and people to nature are strong, and they demonstrate true flexibility when "signals of change are detected and reacted to as a self-correcting process and where knowledge and understanding accumulate" (Holling 1996). The need for moving this direction has never been greater.

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