Draft Report #2:

Assessment and Decision-making for Climate Change: An Overview of Four Approaches

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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 et al. 2007). Visible evidence of changes in climate are 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 report summarizes some of the findings of one project[2] that was among 16 funded by the FFESC under their 2009 call for proposals.

This is Report #2 in the series of reports from the West Kootenay Climate Project and focuses on methodologies. We discuss three approaches to 'assessments' - vulnerability, resilience, and risk - which are often considered alternative frameworks within which to assess climate change and its potential impacts. In addition, we discuss a process called Structured Decision-Making which is a methodology for using available information to effectively make decisions. We also discuss some more general issues relating to undertaking assessments and making decisions. Literature and terminology has rapidly grown up around such assessments in the last decade, and we encountered much confusion and overlap in ideas as we approached this task.

For each subject area we discuss:

[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

- An overview of the approach and why we were interested in the approach
- Key elements of that approach – highlighting similarities and differences between approaches
- How the approach was used in this project
- Our assessment of the utility of the approach

We make efforts here to clearly define the key components of each approach, and look for linkages or places of integration between the different approaches.

We note upfront that many authors have taken the approach to simply accept that many of these concepts, such as vulnerability, resilience, impacts and adaptive capacity are simply imprecise by their nature (e.g., Walker et al. 2004; Trask 2007), or that they are "differential concepts" – i.e. those that are affected by different factors in different situations (O'Brien 2004), and therefore tend to not lend themselves to strict and precise definitions. Efforts to conjoin many of these concepts are underway, but are at a fledgling stage of development (Gallopin 2006; Jansen and Ostrom 2006). We also note that many authors tend to fall into either a vulnerability or resilience camp in terms of their terminologies, while a few use the terms interchangeably. All of this leads to confusion, and reflects the early stage of maturity of assessment and analysis in this rapidly growing field of interest.

2.0 VULNERABILITY ASSESSMENTS

Vulnerability has been linked to terms such as resilience, marginality, susceptibility, adaptability, fragility, risk, exposure, sensitivity, coping capacity and criticality.

Vulnerability Assessments (VA) have been applied in a wide variety of situations, but the common thread has generally been an evaluation of the potential for a negative outcome as a result of some external threat (Fussel and Klein 2006, Miller et al. 2010). The Vulnerability Assessment framework has been adopted in the last few decades by many practitioners investigating the potential impacts of climate change, and for identifying opportunities for adapting to those impacts (e.g., Cruz et al. 2007, Williamson et al. 2007, Glick et al. 2011), and the framework also provides the core approach undertaken in IPCC assessments. However, even though it is relatively well developed and often applied, "vulnerability" and its components has been defined differently in different fields, and this has lead to confusion (see review in Fussel and Klein 2006 and Chapin et al. 2009). Here, we use the IPCC definition:

Vulnerability: *the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC - Parry et al. 2007).*

Vulnerability assessments have a variety of purposes: including providing evidence to encourage mitigation actions, to prioritize vulnerable regions or groups for action, and for recommending adaptation policies for a particular region or sector. Vulnerability assessments have become more wholistic as they have developed (Parry et al. 2004), changing their focus from simple impact assessments through to integrated assessments that attempt to identify the residual impacts that remain once adaptation has moderated some of the impacts (Adger 2006; Fussel and Klein 2006). Integrated vulnerability assessments involve a series of stages which usually are not all completed the first time through any piece of work due to the diverse expertise required and large complexity of such a project.

Although "integrated" assessments that encompass all aspects of the Social-Ecological Systems (SES) are widely touted as the most useful (Fussel and Klein 2006; Figure 1), in reality, the concepts have typically been applied by professionals specializing in one field or another and even when inter-disciplinary teams are created, there remains a tendency for funds and foci to be primarily funneled into either ecological or social systems.

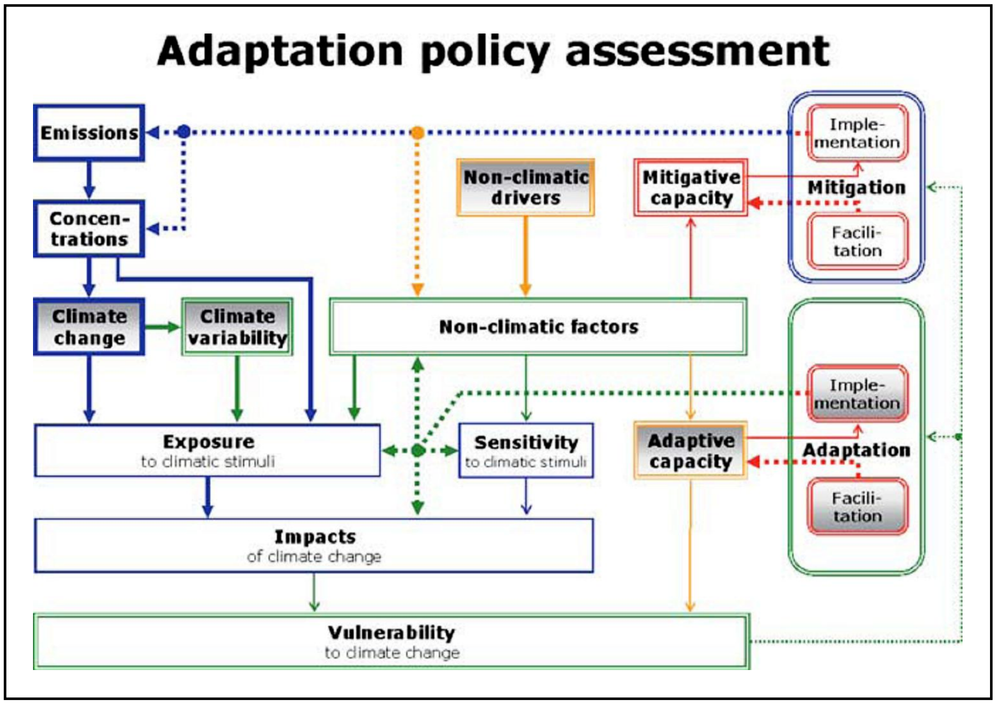

Figure 1.1. The fourth level of vulnerability assessment as described by Fussel and Klein (2006).

Originally developed within the social realm, the vulnerability approach has primarily been applied with a focus on the communities or human institutions in the social realm. Vulnerability has generally been measured against the ability of a community or institution to continue to receive ecological goods and services to maintain economic and social well-being . When applied to a more integrated view of SESs, adaptive capacity and to a lesser extent sensitivity, have generally focussed on social or economic institutions, with the role of ecosystems in the assessment being limited to the extent that the human institutions are directly dependent on the ecosystems. In these assessments the ecological aspects of the assessments (i.e. the ecosystems and their constituent non-human species) have generally been considered as intermediaries between the physical effects of climate change, and the capability of those ecosystems to supply resources and ecosystem services to the human communities and institutions (e.g., Williamson et al. 2007).

Alternatively, a number of vulnerability assessments have focussed on ecosystems and/or their constituent species themselves as the focal entity for assessment (Czucz et al. 2009; Steffen et al. 2009; Glick et al. 2011, Klausmeyer et al. 2011). These assessments tended to focus on identifying which species may be most vulnerable to predicted climate change, and why, in order to prioritize and develop adaptation measures intended to minimize losses to biodiversity. In response to significant changes in regional climate, species have three general adaptation responses: a) they can tolerate the changes with increasing stress (resistance), b) they can shift their ranges to areas with suitable climate (range shifts or “climate change migration”), or c) they can reorganize their community structures – i.e. go through a regime shift. In the ecosystem-focused analyses, ”loss” of an ecosystem due to climate change migration or a regime shift is generally presumed to be the outcome against which vulnerability is assessed. The key question is how vulnerable are ecosystems to extirpation, range shifts or loss of functions, and by association, what would be the concomitant loss or change in associated goods and services from those landscape?

In this context, vulnerability assessments – both ecological and social – encompass many of the concepts enmeshed within “resilience”. Where resilience management is intended to promote stability or change that results in the system (ecosystem) retaining a similar state, being governed by similar processes, and maintaining a similar flow of goods and services[3], vulnerability assessments identify which particular sections of the SES require most attention in order to result in the desired outcome of stability.

2.1 Components of Vulnerability

The definitions associated with different aspects of a vulnerability assessment differ depending on whether the VA is focused on ecosystems, social systems or is attempting to provide an integrated assessment. We have noted that many studies are not explicit about how they define these different elements, and often use terms interchangeably between the social and ecological aspects of their study realm without clearly defining which is being assessed. We have focused on the ecological system in our use of the VA approach, hence the following discussion primarily relates to the application of VA concepts to the ecological system.

Vulnerability *is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC - Parry et al. 2007).*

2.1.1 Exposure

Exposure: *the nature and degree to which a system is exposed to significant climatic variations* (IPCC – McCarthy et al. 2001).

Exposure generally applies to the specific changes in climate variables that are projected to occur in an area, including the frequency and intensity of extreme events, as well as the rate of change. In the case of ecosystem assessments this component sometimes includes changes in hydrologic processes and disturbance regimes that are predicted to accompany the changes in climate (Glick et al. 2011). In addition, non-climatic factors may impact exposure (see Figure 1.1). For example some authors have considered the availability of microhabitats as a mitigating factor in determining level of exposure (Williams et al. 2008).

2.1.2 Sensitivity

Sensitivity: *the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC – Parry et al. 2007).*

Typically sensitivity can be considered an innate characteristic of a species, including characteristics such as physiology and genetic diversity (Klausmeyer 2010). In some assessments external factors are also included within the sensitivity analysis, especially when assessing ecosystems. The following is a list of factors used to predict general sensitivity in a range of studies or reviews (from Swanton et al. 2011; Glick et al. 2011; Dawson et al. 2011).

Species and ecosystem characteristics:

- Reproductive strategy: K-selected species are likely to be more sensitive (slow population response time), with r-selected species conversely more likely to adapt
- ecological amplitude – species/ ecosystems with wide ecological tolerances or are generalists are less sensitive; species/ ecosystems in specialized niches will be more sensitive (e.g., those associated with high water tables dependent on surface runoff and/or seepage)

[3] Note though that resilience itself does not automatically confer a 'positive' value – a knapweed field may be highly resilient but does not provide the goods and services expected from mature forest stand. A lack of vulnerability conversely typically confers a positive outcome.

- Species with specific tolerances for variables that are likely to be affected by climate change (e.g. temperature sensitive spawning)
- species adapted to disturbances will tend to have lower sensitivity
- diversity – lower species and/or genetic diversity leads to higher sensitivity; increased redundancy reduces sensitivity
- dependence on specific environmental cues (e.g. phonological impacts) that are likely to be altered by climate change
- poor dispersal ability (as individuals, or as populations)

External factors:

- dependence on other species that are likely to be affected by climate change
- landscape pattern – ecosystems that occur in isolated locations are more sensitive
- rarity - rare ecosystems/ species will tend to be more sensitive
- range location – species in the middle or near the northern edge of their range were less sensitive; species near mountain tops more sensitive
- systems that are dependent on particular factors that themselves are vulnerable to climate change – e.g. timing and volume of snowmelt to maintain water levels for a particular species are likely more sensitive.
- over-harvested populations that have reduced genetic diversity due to non-natural selection pressures,

In a landscape level assessment in California, Klausmeyer et al. (2011) used climatic tolerance or "coping range" as an indirect measure of sensitivity. Climatic tolerance was determined from historical climate variability associated with each landscape unit. In an Hungarian assessment Czucz et al. (2009) used bio climate envelope mapping and projected range changes as an indirect indicator of ecosystem sensitivity. Other authors have emphasized the need for detailed assessments of individual species traits, such as metabolic requirements, phonological links, life history and population dynamics (Williams et al. 2009, Glick et al. 2011).

Previous studies have treated the capacity for species or ecosystems to shift their range as an adaptation option under both sensitivity and adaptive capacity. Inherent species characteristics that affect the capacity for range shifts such as reproductive rates, dispersal distances and home range sizes have generally been considered as aspects of sensitivity. However, habitat and landscape features that affect the capacity for range shifts have been treated under adaptive capacity.

In some contexts, resilience has been considered synonymous with sensitivity. More resilient systems – those with high diversity at multiple scales - are considered likely to have lower sensitivity to climate change . However, the analogy does not hold in all cases, for example, a system that has crossed a temperature threshold may or may not return to similar state after disturbance, regardless of its diversity.

2.1.3 Adaptive capacity

Adaptive Capacity: *the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC Parry et al. 2007).*

In the social context, adaptive capacity generally refers to planned adaptation which results from deliberate policy decisions and actions. Capacity in this context can be limited or enabled by many factors. Report # 8 for this project investigates one aspect of adaptive capacity for forest management and identifies barriers and opportunities with respect to adaptation (Pearce 2012).

From an ecological perspective, adaptive capacity has been interpreted in a number of different ways. An ecosystem's inherent adaptive capacity is partially based on characteristics of its constituent species (e.g., reproductive strategies, dispersal rates, etc.), but also is dependent on the ecosystem's various environmental components (moisture regime, parent material, topography, etc.). Some of these factors are considered within sensitivity in some analyses, and others within adaptive capacity.

Czucz (et al. 2009) defines species adaptive capacity as an "autonomous adaptation caused by organism, species and ecosystem level responses to the changing external conditions" These responses can include modification of behaviors, evolution over multiple generations, retractions in range to local refugia, and major shifts in ranges (i.e. "migration[4]") to areas with more suitable climates.

Ecosystem adaptive capacity has also been thought of in terms of existing "adaptive constraints" (Klausmeyer et al. 2011; Czucz et al. 2009), which reflects the level of limitation to adaption caused by non-climate stress to the ecosystem. Constraints to adaptation can be caused through prevention of migration (e.g., landscape fragmentation), or transformation due to loss of ecosystem resilience (e.g., loss of species, habitats or functionality). Mechanisms could include reduced population size, loss of genetic diversity, ecosystem simplification, loss of redundancy, fragmentation, pollution or other factors.

Landscape characteristics such as relief, landscape diversity and the presence of regional hydrologic features have be been used as sensitivity criteria (Klausmeyer et al. 2011), while others assessments have considered landscape characteristics in determining adaptive capacity (Czucz et al. 2009). The presence of local topographic and microclimate diversity that increases the potential for local refugia (e.g. shaded canyons, waterfall spray zones) has been treated as ecosystem sensitivity by some authors, while others have treated them as a contribution to adaptive capacity. For example landscapes with significant topographic variation (i.e. mountains) were considered to increase adaptive capacity, because there are potentially shorter distances required for a range shift to move from one climatic regime to another. Alternatively Williams et al. (2008) have considered adaptive capacity and resilience as components of species sensitivity, and topographic buffering as a component of exposure.

The scale and level of generalization of the studies has in part determined what elements are appropriate indicators of sensitivity and adaptive capacity. For example Klausmeyer et al. (2011) in their assessment for California have utilized a landscape scale, while in Hungary Czucz et al. (2009) have worked at a more detailed "habitat type" scale. The assessment for northern Wisconsin (Swanston et al. 2011) is somewhere between the first two, using broad ecosystem units.

We suggest that the variety of approaches to allocating ecosystem characteristics to sensitivity or adaptive capacity reflects the current fledgling development of vulnerability assessments for ecosystems, and the dominant application of this framework thus far, to assessing the vulnerability of human systems.

2.1.4 Impacts

Impacts: *The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:*

- *Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation.*
- *Residual impacts: the impacts of climate change that would occur after adaptation (IPCC – Parry et al. 2007).*

[4] Although the term migration is often used in relation to climate change adaptation (e.g., "assisted migration"), this is a change from the way the term has previously been used, where it generally referred to annual cyclic movements between seasonal habitats. Climate change migration is not seasonal, and it is not cyclic.

The ecosystem vulnerability assessments completed for Wisconsin and Hungary, both evaluated impacts through the use of projected bio-climate envelope shifts (Swanston et al. 2011, Czucz et al. 2009). Using this methodology does not take into account limitations on range shifts by the individual species (an important aspect of adaptive capacity), so it is only a measure of potential impacts. We found few assessments that included evaluations of post-adaptation residual impacts and residual vulnerabilities for ecosystems. This is not surprising given that a recent review of 22 years of recommendations for ecological adaptation measures, most were general principles and only a fraction contained sufficient detail to be directly implementable (Heller and Zavaleta 2009).

3.0 RESILIENCE

Within the climate change literature resilience is used both in general parlance, and as a catch phrase to describe a series of hypotheses based on a theoretical ecological framework. In addition, a group of theorists have created the "Resilience Alliance" that advocates for a specific approach to dealing with the complex problems of climate change and systems. The Resilience Alliance (and others) then promote resilience management, an approach that stresses the need to understand and promote the resilience of systems.

The term resilience then encompasses theories, an assessment approach, and management strategies. These different element can make it complex to separate general use of terms versus specifics, and can cause confusion in the literature.

In common usage, resilience refers to the ability of a system or individuals to cope with a stress, and is often used in this general way to describe a desirable goal for systems in relation to climate change. Resilience is also often used as the flip-side of vulnerable, though strictly speaking they refer to different traits – resilience is the ability to absorb and self-organize, whereas vulnerable is the susceptibility to be harmed (Adger 2006). The IPCC reports use resilience in this general way: (IPCC – Perry et al. 2007):

- *the resilience of ecosystems – (i.e. their capacity to adapt) is likely to be exceeded ….*
- *many arctic human communities are already adapting to climate change. Indigenous people have exhibited resilience to changes in their local environments for many thousands of years;*
- *non-climate stresses increase vulnerability to climate change by reducing resilience ….*

In ecological resilience literature, resilience has been defined more specifically as:

- the ability to absorb disturbances, to be changed and then to re-organise and still have the same identity (to retain the same structure and ways of functioning). (Holling and Meffe 1996); or
- *the capacity of a social-ecological system to absorb a spectrum of shocks or perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks through either recovery or reorganization in a new context (from Chapin et al. 2009).*

3.1 Components of Resilience

Resilience theory includes a variety of inter-connected ideas, including multiple stable states, thresholds, reversibility, and the adaptive cycle and panarchy. These concepts are discussed in the following sections.

3.1.1 Multiple Ecosystem States

The concepts of resilience of ecosystems are built upon early work that suggested that ecosystems can exist as multiple stable states, or "basins", and could shift between these states often with relatively little external pressure (May 1977; Dublin 1990; Knowlton 1992). These states or basins have been defined with the depth of the basin relating to the stability or resistance of that ecosystem state, and the 'threshold' being the point at which a system can rapidly shift into a separate basin (Holling 1973). If systems have two or more attractors – multiple states that they can exist in – then they can shift from one to the other unpredictably. Systems that tend to have only a single attractor tend to rebound into that single system state when pressured. The drivers of the shifts tend to be feedback loops that either dampen or propel a directional change (Carpenter 2003; Scheffer et al. 2009). These ideas are generally accepted within the science community (Groffman et al. 2006), and many examples of shifting between alternate states are available in the literature (see below).

Multiple states, or basins have been described using a ball and cup analogy (Figure 3.1) – a resilience assessment is about understanding "what basin the system is in", where it is in the basin (close to an edge / threshold), what direction is it moving in within the basin, and how one might alter the stability landscape. This type of model encourages the user to consider the ease of movement within the basin (how stable is the current location of a system), and how it may transform if transformation is either inevitable, or the only useful option left from a management perspective. Chapin et al. (2009) have used the analogy of a series of depressions on a slope to illustrate a situation where there is a directional change in a state variable, such as temperature under climate change. This increases the likelihood that a system will not return to its past state following disturbance, but move in a particular direction after disturbance.

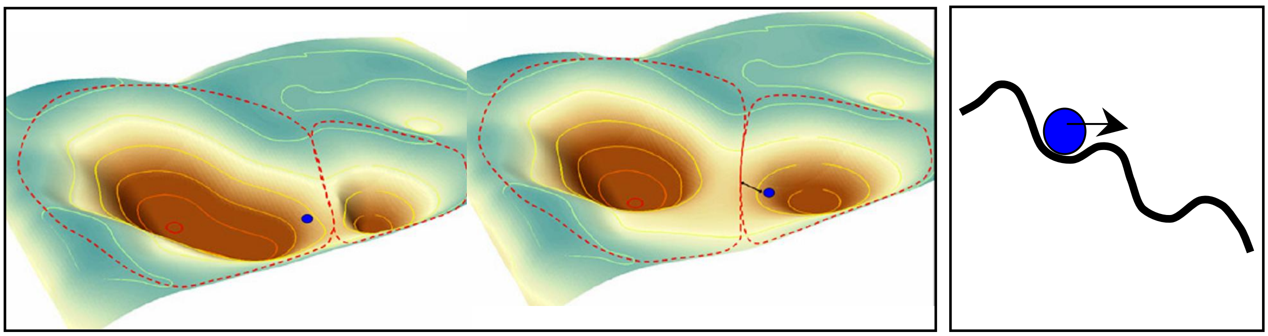

Figure 3.1. Examples of a stability landscapes, with a ball 'crossing a threshold' into a second state, or stability basin (from www.resalliance.org), and an example of stability landscape where a significant external controlling factor is persistantly changing in a particular direction (adapted from Chapin et al. (2009).

3.1.2 Thresholds

Ecological Threshold: *The point at which there is an abrupt change in the ecosystem quality, property or phenomenon, or where small changes in one or more external conditions results produce large and persistent responses in an ecosystem* (Fagre 2009; Resilience Alliance undated).

Threshold responses can occur as systems cross particular points of linear change, or when positive feedbacks cause the system to show a cascade of responses. As such, they are often unexpected, and tend to have large implications for the ecosystem and the goods and services they provide. Planning for resource management becomes particularly difficult when systems are close to or crossing thresholds, because the outcomes of management actions become much less certain. Looking for thresholds is therefore a key thrust of the resilience approach to understanding systems and management responses.

There are a growing number of studies reporting where systems have crossed thresholds[5]: early ecology research showed how changes in density of individual species could have significant responses in the broader ecosystem – for example sea otter predation on sea urchins causing massive shifts in kelp density as numbers of individual species shifted back and forth (Estes et al. 1978). A similar terrestrial example would be the re-introduction of wolves into Yellowstone National Park affecting elk populations, and thereby triggering a shift in willow ecosystems (Ripple and Bascta 2004). As climate change proceeds, undoubtedly species and ecosystems will be pushed across a number of thresholds. The challenge is to identify them, and try to understand how to manage for them.

3.1.3 Reversibility and hysteresis

Crossing a threshold is in itself important because thresholds – by definition - promote a rapid or large change – with little warning. However, thresholds that lead to state changes are particularly of interest / concern if the change is irreversible, or apparently so, within a reasonable timeframe. 'Hysteresis' is the term used when a system changes state, but the pathway between the states is different in each direction. Using the terminology of the Adaptive Cycle (Section 3.2) systems are most likely to change pathways after long periods of conservation or acquisition of resources , in the period of revolt, when a system shifts into the renewal phase.

Systems may be prone to irreversible change when particular elements alter the successional trajectory of a particular site – for example, invasive species colonization after a fire event, which blocks the natural successional pathway by preventing the typical seral species from colonizing the site. With additional pressures such as climate change, the chances of moving into an irreversible alternate trajectory becomes greater. Overlay these changes with human stressors on the system, and it becomes ever more complex to understand the dynamics and predict how systems may respond. Understanding whether a change is reversible or not is critical in the management context because it determines whether restoration is a feasible option, or whether management should move in a new direction. Becoming stalled in a state of successional arrest or chaos a particularly critical state to recognise and avoid, since significant management effort can be wasted in these circumstances, with significant long-term effects on the goods and services potentially available from the system.

In one such example cheatgrass invaded the native perennial grassland system after heaving grazing. Cheatgrass is a highly flammable annual, which then allowed a frequent fire regime to become established. Together, the two factors – new species and fire – did not facilitate a shift back to perennials even when the original trigger of over-grazing was removed because the shift in species had caused a process shift (rate of fire spread) within the ecosystem that wasn't undone by a simple reversing of the actions (from Laycock 1991). The lack of recovery in Newfoundland cod stocks is another stark example (Biggs et al. 2009, Hamilton et al. 2004).

When factors interact together, even more complex interactions can occur. The combination of fire and invasive species have long been identified as factors that interact together at multiple scales, driving community shifts (particularly in grassland or dry forest systems) and that appear to be very difficult to reverse (Laycock 1991; D'Antonio and Vitousek 1992). Invasive species can alter ecological processes at multiple scales - altering soil structure, moisture and nutrient availability, all the way up to interacting with fire hazard and spread rates. Overlay external pressures – grazing, or climate change - onto these processes – which directly affect natural disturbance rates, particularly fire, but also through insects which may change their life histories in relation to changes in climate, then the system potentially becomes more dynamic, and even harder to make predictions about.

[5] The resilience alliance is maintaining an online database of ecological thresholds in different systems, which has grown and currently includes more than 270 references. www.resalliance.org/index.php/thresholds_database

3.2 The Adaptive Cycle and Panarchy

The ideas of resilience have been promoted as a explanatory theory for the natural cycles of growth, development and disruption that characterize both traditional ecology and the rise and fall of culture regimes (Walker et al. 2004) – a phenomenon that has been termed “panarchy theory” (www.resalliance.org/index.php/panarchy). Panarchy theory is characterized by multi-scalar inter-locking loops of growth (r), conservation (K), collapse (omega) and transformation (alpha) (Figure 3.2), which link to potential changes in resilience at different phases of a system cycle.

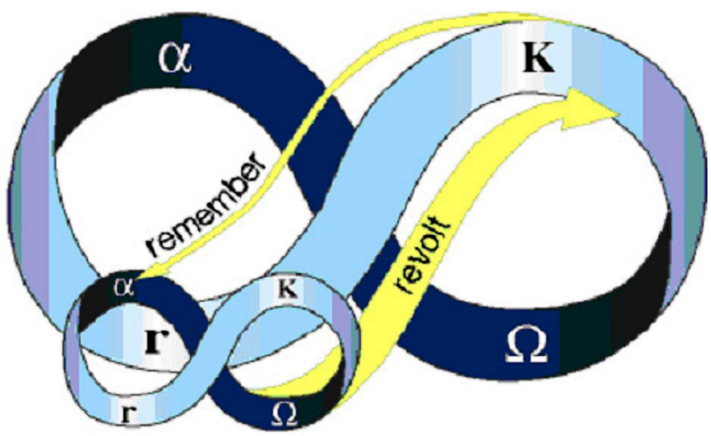

Figure 3.2. The adaptive cycle: r = growth, K = conservation, omega = collapse and alpha = reorganization or renewal. Cycles at multiple scales are looped within one another, resulting in the potential for small changes at one scale to result in large changes at another scale. Figure from www.resalliance.org

Moving through the adaptive cycle, the growth and conservation phases mirror the ecological models of population growth and maintenance, and are consistent with traditional theories of forest management (e.g., a stand of trees moves through a period of rapid growth to a mature and stable state for a long period). Theoretically, concepts of disturbance have been integrated and are assumed to reset the stand to an early seral phase during renewal, and the process repeats itself through time. A key difference with the adaptive cycle model is that the collapse and regrowth phases are recognised as the time most likely to see changing players in the system (for example the invasion by new species, or changes in governing political parties and ideologies), ultimately leading to different inter-relationships between players, and different ultimate trajectories (i.e. a regime shift).

The original state may repeat itself through time, but alternatively, there may be thresholds crossed or changing conditions that result in a ‘transformation’ to a new state. Trajectories may follow similar pathways (e.g., forest succession but with a different species composition), or may follow very different trajectories (become a system dominated by different natural disturbance regimes), or the system may move into a chaotic or arrested state of successional development, which may be persistent, and near impossible to recover from (e.g., knapweed field or brush field).

Transformation cannot be categorized as generically good or bad, but the transformation itself will likely result in at least a temporary disruption of the goods and services that human systems typically rely upon. Following transformation, the new state will likely supply different goods and services than we had adapted to and planned for in the past, and society at that point will decide whether the outcome was a net benefit or loss.

3.3 Thresholds, feedback loops and regime shifts: some forest examples

The potential for phenomenal effects arising from the action of multiple feedback loops and thresholds should no longer be a surprise forest managers in North America – since there are multiple significant examples from local ecosystems.

At the global scale, climate change seems to be causing various positive feedback loops resulting in an increasing rate of warming (e.g. Fussel 2009). This includes earlier snowmelt in spring, loss of permanent snowcover, resulting in even faster warming due to the albedo effect due to reduced reflectance. This warming has had various implications for insect populations and north american forest ecosystems. In southern Alaska, the spruce bark beetle has rapidly adapted to undertake its life-cycle in one, rather than two years, resulting in what was at the time the largest documented mortality of forests caused by insects in North America (Werner and Holsten 1983). The effect of feedback loops at this scale have surprised scientists working in detail on both the snow and ice melt rate , and those working on beetle population dynamics.

The mountain pine beetle outbreak in BC shows a similar story, though the scale of mortality has surpassed even that in Alaska. In this case, multiple thresholds and feedback loops have been identified. At the population scale, outbreak dynamics are initiated as aggregating hormones draw in even more beetles, and cause even a healthy tree's resistance to be overwhelmed (Berryman 1976; Berryman et al. 1989). In addition, physiological changes within the beetle, combined with multiple years when temperatures did not drop sufficiently to result in significant population mortality, have triggered a population feedback loop that has resulted in BC's staggeringly large mountain pine beetle epidemic (Raffa et al. 2008). In addition, landscape level mortality of trees appears to be contributing large-scale feedback to global climate change itself, by creating a large source of greenhouse gases released by decomposing dead trees (Kurz et al. 2008, BC MoE 2010).

In the southern prairies significant areas of the landscape have been altered from a mixed conifer-deciduous forest to a primarily deciduous forest. The primary drivers appear to have been an increase in fire frequency as a result of human settlement patterns in the 1900s. This change in dominant tree species also had cascading impacts on many other plant and animal species (Paine et al. 1998). At the same time, high-grading of white spruce further reduced the dominance of boreal species. Climate change effects may continue this shift by continuing to alter the natural disturbance regime in these systems.

3.4 Applying resilience theory

A key idea embedded in the concept of resilience is that as resilience declines, the magnitude of the shock or pressure from which a system cannot recover without significantly changing gets smaller. Identifying and avoiding factors that lead to decreasing resilience is promoted, so as to avoid enforced large-scale turbulent changes. An example of the application of the concepts of resilience theory to forest management is provided through analysis of the British Columbia Mountain Pine Beetle epidemic (Burton 2010). In this paper the unprecedented massive MPB outbreak is presented as an example of the collapse phase of the adaptive cycle in action. It is hypothesised that policies of fire suppression, in combination with natural growth to a conservation phase, resulted in a system which lacked resilience to change. The driver of forest management policy, combined with climate change, caused the system to cross various temperature and life-history thresholds for the beetles (see above), and resulted in a significant collapse of the mature forest system. This resulted in the loss of 15 million hectares or so of forest and a significant impact on British Columbia's mid-term timber supply.

At the same time, Burton (2010) highlights that the alternative future growth trajectories for this landscape could be considered "silver linings" of the collapse, if management decisions are made that increase the resilience of landscape into the future. This will require making forest management choices that promote mixed species trees that are more adapted to the future climate conditions than the mature pine stands previously present on these sites. Burton also makes recommendations relating to increasing both ecological and social – planning for diversification, spreading risks (in terms of tree species planted, and forest products produced), and embracing inevitable change rather than fighting it in a command-and-control approach.

Similar approaches to resilience management have been promoted in many other venues and some key principles are summarised in Report #9 (adaptation actions).

3.5 Exploring and Promoting Resilience

The Resilience Alliance is "a multi-disciplinary group that explores the dynamics of complex systems" and have compiled a series of workbooks that outline an approach to assessing resilience. The Resilience Alliance approach has a number of defining characteristics, including:

- the need to assess the social-ecological system as a unit (rather than separating out the different elements and recombining them later),
- thinking about systems as loops of change through time, in order to try to identify when systems become more or less open to changing their fundamental structure,
- the importance of cross-scale interactions (interlocking loops occurring at multiple scales),
- the importance of different drivers acting at different scales.
- encouraging true multi-disciplinary thinking and interaction with the idea that little can be achieved unless everyone is slightly out of their comfort zone.
- within the goal of resilience-based management, emphasizing the need to manage for general system properties / processes rather than for narrowly defined production goals (e.g. timber supply, number of moose etc); emphasizing impacts to processes.

In this project, we intended to apply the concepts of resilience theory directly, by working through the Resilience Alliance Workbooks for scientists and practitioners (available at: www.resalliance.org/index.php/resilience_assessment). However, after an extended effort, we realized that the workbooks themselves did not lend themselves to this type of application because:

- we found the structure to be non-linear, and difficult to follow in a practical setting. Could possibly have been applied with considerably longer time devoted to workshops by the practitioners;
- the concept of resilience was conceptually pleasing, but it was not actually well understood by most participants in the project (at all levels).
- *a priori* prediction of thresholds may be useful for the most simple of potential relationships (e.g. drought tolerance of tree species), but typically there is insufficient information to predict where thresholds within ecosystems will be crossed. That said, considering potential thresholds was a useful exercise for all involved in the process.
- built from mathematical models and theories, this approach tends to be research oriented in its most strict application, and outside the realm of interest of many practitioners, and not focused on working towards problem-solving real world issues.
- the forceful push of the RA workbooks to fully integrate social and ecological systems appears to be good advice, but was beyond the scope of this project, and would take significant time and open-ness on the part of all concerned. Recognising this need throughout forest management frameworks however could be beneficial in the long-run. Concurrent time commitments by participants across a large cross-section of disciplines and interests will often be difficult to organize.

In summary – we presented concepts of resilience to the practitioners, and used the Resilience Alliance Workbooks to guide our workshop direction in terms of addressing key ideas with both scientists and clients– drivers, historical context of change, examining linkages between factors and discussing potential thresholds in the ecological system (See Report #10; Pinnell 2012). We did not attempt to strictly follow the workbooks but continued to use the general idea of resilience with practitioners through the series of workshops.

In addition, in developing the vulnerability assessment, we found applying the hypotheses outlined above provided a useful framework for considering which of the various ecosystems may be most vulnerable to future climate changes.

4.0 RISK MANAGEMENT

Risk management is defined as the culture, processes and structures directed towards realizing potential opportunities while managing adverse impacts. It is therefore both an assessment tool, and a fairly structured framework for prioritizing actions and decisions.

Risk: *the combination of the probability of an event occurring and its potential consequences (reference??).*

Risk: *the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect on health, property, the environment, or other things of value (CSA 1997)*

Risk assessment or management provides a structured framework for decision-making, and has the advantages of including formalized methods for assessing and including uncertainty. Because it focuses on the specific consequences associated with potential events, it can have multiple outcomes for a single event – based on the level of uncertainties and potential consequences.

The IPCC report on climate change (Parry et al. 2007) notes that risk management activities can focus on both mitigation and on adaptation. Mitigation activities directly reduce risk by reducing the upper bound of climate change itself, while adaptation risk management focuses on risk management within the lower bounds of change (see Figure 4.1).

4.1 Components of risk management

In its most straightforward application, risk analysis can focus on whether a particular issue is sufficiently important to require attention and is focused on identifying three different levels of outcomes a) that there is a problem and action should be taken immediately, b) that there is a need to undertake more analysis about a potential problem and c) that there is no issue to be dealt with.

Alternatively, with more complex problems such as climate change, risk analysis can be used to identify and prioritize potential hazards, and so focus attention on the action items required to reduce the most significant hazards, or to identify monitoring that may be appropriate to test the risk hypothesis. Risk analysis includes a) assessing the risks (risk identification and risk estimation), and b) identification of management actions (risk aversion and risk acceptance – with a focus on looking at risk acceptability).

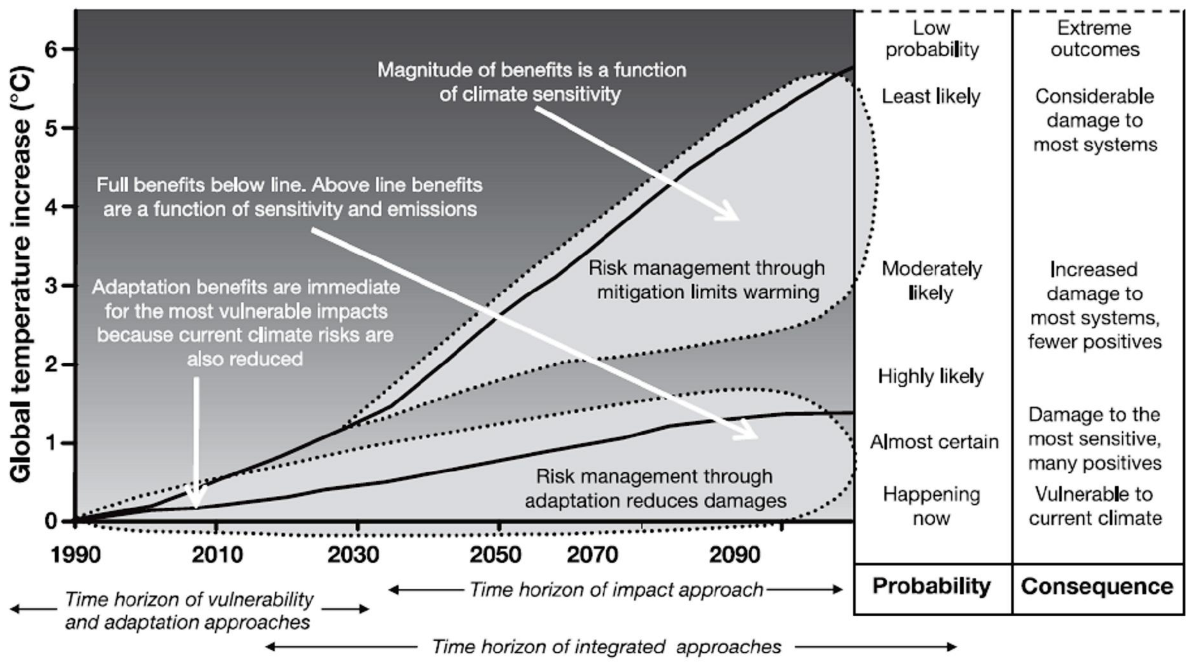

Figure 4.1. Synthesis of risk management approaches to climate change. (IPCC – Carter et al. 2007, p. 140).

The CSA standards[6] for risk management outline a series of clear steps to undertake risk management assessments, which broadly includes:

- Initiation – defining the problem, identifying key players and stakeholders, and identifying potential decisions that need to be made;
- Preliminary analysis – identifying potential hazards using risk scenarios, including engaging with stakeholders to understand their perspective on hazards
- Risk estimation – estimating the frequency and consequences associated with different scenarios, with the goal to determine the acceptability of the potential risks. This analysis should include both the hard or tangible costs and benefits (e.g. financial) and the soft benefits and risks (e.g. trust, quality of life, non-monetary based resource values);
- Risk evaluation – analyse the risks (from above) in terms of the needs, and concerns of stakeholders in relation to its benefits and costs. This includes assessing the differences in perceptions about risk, and communicating effectively to all relevant parties (managers, technical experts and lay people often perceive acceptability of risk in different ways);
- Risk Control – identifying the potential effectiveness and costs of risk control options, and assessing the acceptance level associated with residual risk;
- Action – implement the chosen strategies, and establish a monitoring program.

In this project, we did not apply a risk management approach, however we suggest that the vulnerability assessment we have undertaken provides a foundation from which to undertake a more comprehensive risk assessment procedure focussed on risks posed to specific values of interest. As outlined in Report # 9 (Pinnell et al.

[6] This list follows the general outline of the CSA standards – but many more detailed steps are provided in that approach.

2012), the assessment of ecosystem vulnerability provides a starting point for making priorities for decision-making, but does not provide all the relevant information to decision-makers.

5.0 STRUCTURED DECISION-MAKING

In climate change adaptation, vulnerability assessments, resilience, and even risk management, are most often used to evaluate the relative importance of addressing (the impacts of climate change. However, the challenge for decision-makers is to decide “what to do” to reduce impacts, or in some cases, to capture opportunities from climate changes. As described by Ohlsen et. al. (2005) in relation to Canadian forest sector adaptation:

> *“The development of climate change adaptation plans requires an evaluation of all the costs and all the benefits of alternative strategies, undertaken in the face of multiple uncertainties, in the context of existing institutional arrangements and stakeholder engagement processes.”*

Based in decision theory and risk analysis, structured decision making (SDM) encompasses a simple set of concepts and helpful steps, rather than a rigidly-prescribed approach for problem solving. A website designed to illustrate the application of structured decision making (SDM) in environmental resource management decisions[7] describes this approach as:

> *…an organized approach to identifying and evaluating creative options and making choices in complex decision situations such as climate change adaptation. It is designed to deliver insight to decision makers about how well their objectives may be satisfied by potential alternative courses of action. It helps find 'win-win' solutions across groups, clarifies the irreducible trade-offs that may exist between alternate potential courses of action and helps to communicate how people view these various options.*

Key SDM concepts include making decisions based on clearly articulated fundamental objectives, dealing explicitly with uncertainty, and responding transparently to legal mandates and public preferences or values in decision making. The process marries value-focused thinking and technical information in flexible planning frameworks that often use graphic presentation tools to highlight tradeoffs between alternatives.

5.1 Components of Structured Decision-making

SDM includes six distinct steps within a flexible framework: 1) define the problem and clarify the decision context; 2) define the management objectives and set evaluation criteria; 3) create alternatives; 4) estimate consequences related to evaluation criteria; 5) evaluate trade-offs and decide; 6) implement and monitor (Hammond et. al., 1999; Gregory et. al., 2012). Ohlsen et. al. (2005) incorporated climate change adaptation and risk management in their recommended structured decision framework as shown in Figure 5.1 and described below the figure.

Define the problem and set management objectives

Managers make a direct statement of the adaptation problem and the required decision or evaluation context. Management objectives – what matters – are clearly articulated, and corresponding evaluation criterion are defined for describing the absolute or relative performance of alternative risk management strategies in measurable terms.

[7] http://structureddecisionmaking.org/index.htm by Compass Resource Management

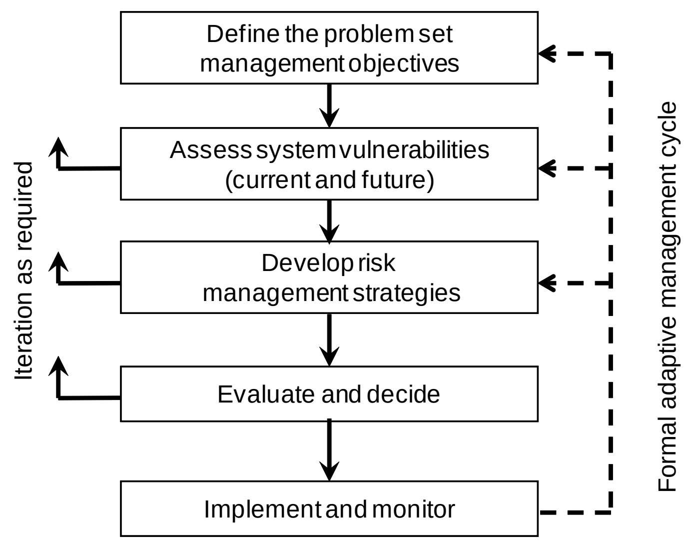

Figure 5.1. A framework for developing and evaluating climate change adaptation strategies (Ohlsen et. al. 2005).

Assess system vulnerabilities

Trace the pathways (Figure 5.2) that lead from climate to the previously stated management objectives, first examining current climate conditions, then incorporating projections of future climate to identify which management objectives are sensitive under both current and future climate scenarios.

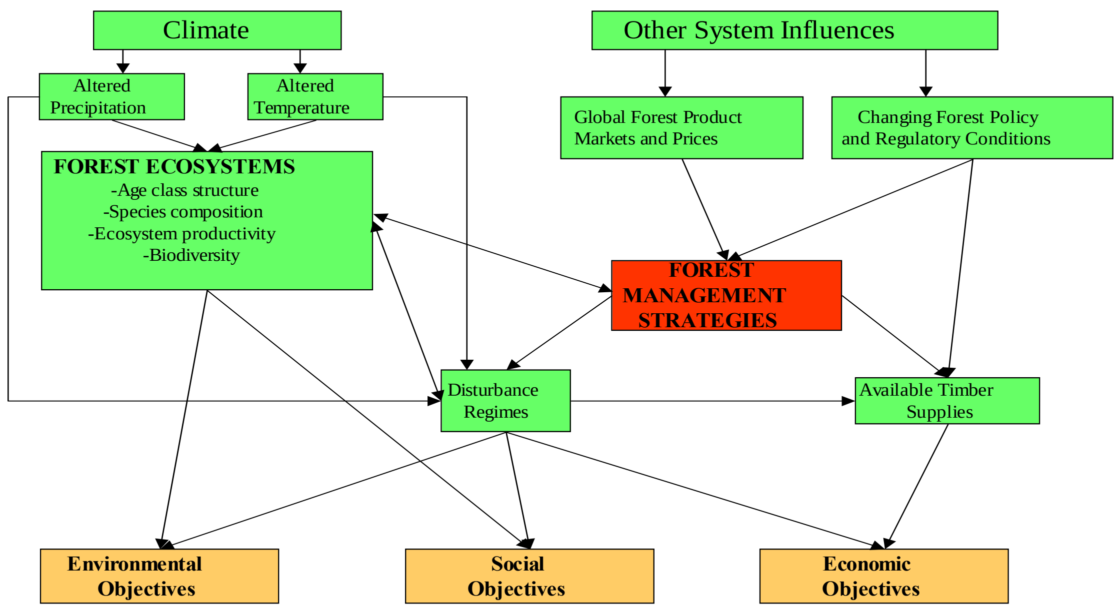

Figure 5.2. Conceptual model of a forest management problem relating key climate factors and management objectives. (Ohlsen et. al. 2005)

Develop risk management strategies

Systematically develop alternative, internally consistent adaptation strategies that will address long-term vulnerabilities to climate change or take advantage of opportunities (e.g. policies, field practices, monitoring).

Estimate consequences and decide

Clearly project the expected outcomes in terms of the evaluation criteria, i.e., the costs and benefits, giving particular care to reporting the nature, extent, and significance of uncertainty and variability in all projected results. Summarize the trade-offs that may exist either across strategies or across objectives for decision-makers to consider in the values-based task of evaluating consequences and trade-offs.

These authors emphasize that the development and evaluation of adaptation strategies should involve decision-makers, stakeholders, experts, and analysts. This should also be an iterative process, during which multiple strategy refinements are made until an acceptable balance of all consequences is found, if possible.

5.2 Applying Structured Decision-making

SDM has been used in planning and policy analysis by business and government (see Gregory et. al., 2012). As yet, it has not been widely applied to climate change adaptation – in fact it is not listed as a an adaptation assessment tool (section 2.2.3) in the IPCC Fourth Assessment Report (2007). In 2005, Ohlsen et. al. recommended a flexible framework that incorporates key principles of structured decision-making and risk management as a practical way to integrate climate change adaptation into forest management planning in Canada. SDM has been tested and recommended for climate change adaptation in forestry by Ogden and Innes (2007) in the South Yukon and Mills (2008) in the mountain pine beetle outbreak in BC.

The project team tested this approach in the final workshop with practitioners. The team created a set of worksheets modeled after Ohlsen et. al. (2005), Ogden et al. (2007) and Mills (2008). Three problem contexts were chosen: road management decisions, reforestation decisions and decisions related to management of forests between free-growing age and maturity, with different team members facilitating groups of practitioners for each decision context.

Learnings from this test include:

- A substantial amount of preparation was required to create the decision context information and worksheets.
- All participants need to have a basic familiarity with background information about climate change and potential impacts, or this information must be included explicitly up front in the process.
- The geographic area examined needs to be relevant to the decision context, i.e. a landscape scale is required to examine biodiversity impacts of alternatives.
- The knowledge and skill of the facilitator in both the topic area and the approach is important to the success of the approach.
- The group addressing road management successfully completed the worksheets and found the approach was valuable. Participants in the groups exploring decisions for reforestation and free-growing to mature forest management did not complete the worksheets, but were supportive of continuing to explore this approach, including hosting workshops with their colleagues for their specific operations.
- Participants identified the following strengths of the approach: structuring decisions, integrating values, prompting brainstorming of options, driving conversations amongst practitioners with diverse views, and *eye opening* regarding the complexity of adaptation decisions and by prompting *thinking outside the box*.
- Practitioners made several recommendations about simplifying the worksheets, calibrating some of the consequence measures and improving the process including having the worksheets projected so everyone could follow the facilitator’s use of the worksheets.

6.0 ADDITIONAL CONSIDERATIONS

6.1 Thresholds of significance

Irrespective of the approach taken for an assessment, all the approaches have to attempt to quantify the significance of the types of changes that are projected to occur. In general, terms like vulnerability, resilience, and to a lesser degree risk – are relative, rather than an absolute; however, understanding the significance of any change is obviously key to understanding the potential hazards, and prioritizing adaptation actions.

Within IPCC vulnerability assessments (Schneider et al. 2007), the significance of a particular degree of climate change for a particular variable is defined in relation to two potential types of threshold:

- *a non-linear threshold or change in state where a system shifts from one set of conditions to another (e.g., forest to grassland, alpine to treed, crossing temperature sensitivity for a fish species, economic viability to inviabilitity); and,*
- *a linear change in condition that results in crossing some threshold of acceptability.*

Although critically important, it is recognised that identifying either type of threshold is plagued with difficulties. In complex systems, understanding relationships and triggers between factors is extremely difficult and predicting thresholds in parameters can be challenging except in the most obvious of cases. The concept of non-linear thresholds has mostly been attributed in a *post hoc* explanatory fashion. Similarly, defining 'acceptable' thresholds of risk or change is value-laden and normative. Identifying key hazards from an engineering perspective (e.g., risks associated with loss of infrastructure) can be relatively straightforward, but assigning the risks associated with the changing economics of a particular mill or on losing critical habitat for an endangered species is much more difficult.

The IPCC aims to identify 'key'[8] vulnerabilities, and the use the concept of risk (probability of occurrence * magnitude of consequence) to capture uncertainty. Key vulnerabilities are recognized on they basis of the following:

- *magnitude of impacts,*
- *timing of impacts,*
- *persistence and reversibility of impacts,*
- *likelihood and confidence in the estimates,*
- *potential for adaptation,*
- *distribution of the impacts, and*
- *importance of the systems at risk.*

The consideration of potential change levels, thresholds and adaptation possibilities can then be used to identify the 'coping ranges' of the system – defining the limits within which climate change must not surpass in order to maintain a certain set of values. Defining specific coping ranges can be difficult, but can be a useful mental model to engage with stakeholders, since they may have an intuitive sense of what parameters can or cannot be coped with.

Within resilience approaches, significance of a change is assessed in terms of the potential for a 'change of state', or more specifically, using the dynamic terminology, a 'regime shift'. Regime shifts and process changes are

[8] Although they have a list of factors, they also recognize the process of defining significance has two aspects – scienitific and a normative / value-based.

periods of instability, where the trajectory of a system can change rapidly and unexpectedly, and as a result, can significantly affect the values present in a system. This definition of significance can be used within the vulnerability framework to assess which of a series of ecosystem changes may result in the highest vulnerabilities. We used this approach in our vulnerability assessment (Report #7; Utzig and Holt 2012).

Within risk management, thresholds around level of risk and the acceptability of that risk have to be identified. There are a number of different technical approaches to this, but typically they are based on a range of scenarios (see discussion below), or they are based on expert opinion. Typically, the outcome from the scenarios are a range of frequency estimates, accompanied by estimates of uncertainty. Potential consequences can then be assessed, and measured against financial factors and a range of soft factors (e.g., level of trust). The third piece is to then determine the acceptability of the risks and potential consequences – this can be the most challenging as it is dependent on the value set of those making the determination, as different groups (e.g., technical experts versus lay people) often have quite markedly different opinions on the subject.

6.2 The need for more collaboration

Assessment processes such as vulnerability, resilience and risk assessments are considered a possible framework within which to 'mainstream' climate change language and adaptation needs because its concepts are accessible at the community level (e.g. May and Plummer 2011). Risk assessment in particular has typically been utilized specifically in the decision-making context, and standards for risk management (e.g. the CSA or ISO Risk Management Standards) typically involve upfront ensuring that the right players are engaged in the assessment process (e.g. appropriate information managers and decision-makers). As a result, risk management approaches tend to be less focused on academic or technical type assessments that are disengaged from decision-making and governance issues. However, even though this is generally considered a positive element of risk focused approaches, the continued lack of comprehensive climate change adaptation policies begs the need for yet further collaborative engagement in the process leading to more specific decision-making.

> *It could thus be stated that adaptation is not only, or particularly, a technical issue, but that it can be characterized as a complex social interaction process and that it should be studied as such. Only then can adaptation to climate change also be regarded as a window of opportunities. Dealing with climate adaptation not only demands a rethink of how we arrange our social-ecological or socio-technical systems but also how we govern them*. Van Nieuwaal et al. 2009 quoted from Plummer and May 2011.

Three needs have been identified that would improve further development of risk management approaches and are equally valuable to all assessment procedures, if they are to be increasingly successful (e.g. May and Plummer 2011):

- to further develop participatory approaches that genuinely engage all the relevant actors in order to increase their effectiveness (e.g. solving the problems of community-based processes that are volunteer-run),
- to create a process that focuses on social learning – identifying ways to ensure that individual learning translates into broader learning, and
- develop adaptive governance or adaptive co-management. Adaptive co-management is the concept of bringing forward adaptive management (from the field of ecology) with co-management (from common property resources)(Plummer 2009; Folke et al. 2005). Key elements include shifting away from "consultation" to linking key players, and also to avoid the 'failure to learn' often embedded in these processes.

7.0 APPLICATION TO THIS PROJECT

In this project, we considered each of the four methodologies outlined above, but applied or implemented them to differing degrees.

For example, we investigated using a resilience approach as an assessment tool, but opted in the end to use the more linear vulnerability assessment framework as the primary structure. We incorporate the theories of resilience as part of the interpretation toolbox, to attempt to understand which of the large number of predicted changes may be most significant. We found confusion in the early stages of the project, particularly between the vulnerability and the resilience literature.

We did not use a risk assessment approach – though in retrospect it may have provided sufficient structure upfront to direct the assessment towards decision-making in a more direct fashion. However, we also believe that the preliminary work looking at ecosystems provides a solid basis for moving forward – one aspect of which may be to integrate these results into a risk assessment framework.

We used the structured-decision making process as the basis for one of our practitioner workshops, and foresee that this could be useful moving forward, but also was limited by the amount of time we had for hands-on practical engagement with practitioners.

Table 7.1 summarises the information on the three assessment approaches and the one decision-making framework we contemplated. We note that there are likely many other ways to approach this complex topic and that significant effort is currently needed to determine which approach may be most appropriate in what context.

We also note that integration of multiple concepts, from a wide range of fields, is most likely to be required as we move ahead with tackling the issue of climate change and forest management. This poses a significant challenge to the way in which problems have typically been approached within forest management in BC historically.

Table 7.1. Comparison of three assessment and one decision-making tools

Qn	Vulnerability	Resilience	Risk	SDM
What is it?	A process of assessment leading to a relative ranking of 'vulnerability' to stressor(s).	A series of theories based in ecological science. A branch of 'management' intended to promote resilience A process of assessment – as laid out by the Resilience Alliance in workbooks.	A process for assessing the implications of probability of occurrence * consequences, to identify highest priority areas of concern.	A process to support transparent decision-making that incorporates values and technical measures
Theoretical basis?	Provides a framework for organizing an assessment. Not based in any particular theoretical framework. Potentially incorporates theory from a wide range of disciplines, within the assessment itself.	Primarily based in theories of ecological science – multiple stable states, thresholds, regime shift, adaptive cycle etc. More recently been applied to a wider field – e.g. to elements of social systems.	Detailed framework for approaching risk assessment (e.g. CSA).	Decision theory and risk analysis
Primarily used by?	Scientists evaluating regions and sectors. Some initial use	Scientists understanding how systems work.	Engineers assessing hazards	Large business and government agencies

	now by communities and sectors.	Secondarily, practitioners in promoting how to create resilience.	Decision-makers – to prioritize effort	
Primarily applied to:	Social systems Secondarily to ecological systems. Integrated assessment promoted – but structure not fully developed.	Originally – ecological systems. Resilience alliance promotes fully integrated application of ideas to social-ecological systems.	Socio-ecological systems involving hazards to ecosystems and humans	Complex business decisions Complex publicly managed socio-ecological systems
Utility in this project	Framework for organizing assessment approach	Theories useful in assessing the 'significance' of the ecological changes predicted.	Did not apply risk approaches – but consider this a potential 'next step' for practitioners in moving from assessment to decision-making.	Helpful in structuring decision information – was explored later in the project and deserves more exploration

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