# Towards a framework to support working with uncertainty in natural resource management.

A discussion paper

## Version 1

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## Preface

This discussion paper has been largely an individual effort, and does not necessarily represent the views and policies of the Ministry of Forests, Lands, and Natural Resource Operations. As such it is only a first step in bringing the topic of uncertainty more explicitly into discussions about natural resource management and climate change adaptation. It is hoped that the paper will elicit responses and discussion that can be incorporated into further, potentially more collaborative versions.

Readers are encouraged to send comments to the author (Christine.Fletcher@gov.bc.ca) on how the paper could be revised so that it provides better support to resource managers involved in planning, policy and operations in working with uncertainty.

## Executive summary

Natural resource management is facilitated by classifications of the phenomena being managed. For example, the biogeoclimatic ecosystem classification in British Columbia is used widely in forest management as a basis for designing reforestation regimes, developing management strategies for protecting biodiversity, modeling the potential ecological shifts resulting from climate change, and other purposes. Similarly, managing natural resources under uncertainties presented by climate change and other biophysical, social, political, and economic dynamics will be facilitated by a conceptual framework or classification to help understand the dimensions of uncertainty and the range of potential responses.

The intention in this paper is to make a first step towards an explicit framework for thinking about, and managing under uncertainty for natural resource management in British Columbia. The paper introduces some ideas about the types of uncertainty faced by natural resource managers, and the types of responses that are available to deal with uncertainty. The ultimate hope is that this can be a step towards developing a common language among resource managers for talking about and addressing uncertainties.

Uncertainty does not exist "out there" in biophysical or socioeconomic systems. It arises because people think that there are shortcomings in the understanding of the characteristics and dynamics of parts of the biophysical or socioeconomic world, or of the values and goals that should inform decision making and action.

Uncertainty has different interacting aspects or dimensions that preclude a simple classification or taxonomy of mutually exclusive classes. Therefore, for the purposes of this paper, a framework of the dimensions of uncertainty was developed. The framework includes:

- ***Sources*** of uncertainty in biophysical, socioeconomic, political or technological systems.
- ***Causes***, including inherent variability, lack of knowledge, unclear language, decisions on how to scope or bound a problem, unpredictable human behaviour, and unclear or competing human values.
- ***Levels or degrees***, which include the degree to which the full range of potential dynamics and related outcomes is known, and the degree to which probabilities of the various outcomes can be quantified. Therefore, the degree of uncertainty ranges from the ability assign quantitative probabilities, through being limited to qualitative descriptions of direction and magnitude, to almost complete ignorance.
- ***Practical considerations*** that affect whether and how to respond, including *reducibility, controllability, and importance*.

Reference to such a framework could help resource managers to avoid missing important uncertainties, and to choose appropriate responses to the uncertainties.

Common responses to uncertainty include proceeding as though there is none, awaiting more certainty before acting, treating the problem as a lack of information, and focusing on better-understood parts of the problem that can be addressed with familiar tools or knowledge. However, not all uncertainties involve a lack of knowledge, and some may require types of knowledge, skills, and processes that are outside one's current toolkit. Therefore, recognition of the full range of potential responses to uncertainty can be useful to ensure that managers are meeting uncertainties with appropriate responses.

Potential responses to uncertainty include:

- ***Enhancing knowledge and understanding*** through research, inventory, monitoring, analysis and scenario development, as well as clarification of definitions for important concepts and terms.
- ***Implementing practices*** that help adapt to or buffer against uncertainty and change.
- ***Developing responsive decision making processes, institutions, and regulatory frameworks***; and
- ***Building and maintaining relationships*** to assist in the deliberations needed for the difficult work of clarifying and balancing multiple values and objectives, and to enable decisive and timely action in response to uncertainty and change.

Sometimes, uncertainties can be addressed by increasing what we know confidently. Sometimes, they must be addressed by increasing the chance that our objectives will be achieved, perhaps not optimally but at least satisfactorily. Sometimes uncertainties are deep enough that we must develop decision processes, institutions, and relationships that allow us to function and respond in ways that maintain the fundamental goals of resource management, which may include sustainability, fairness, and inclusivity within the context of providing socially desired values.

It was not the objective in this paper to create firm links between the various dimensions of uncertainty and particular response types. The idea was to provide a framework for managers to assess which dimensions of uncertainty are most important in a particular situation and then determine what responses fit the circumstance. It was also an objective to highlight that some uncertainties may warrant responses other than gathering more information and knowledge, or implementing some kind of insurance (i.e., diversification, safety factors, and buffers). Some types of uncertainty require efforts to clarify language and develop commonly understood definitions; to design responsive decision making processes, regulatory mechanisms, and institutions; and to develop skills and forums for deliberation to clarify and balance objectives.

Mental models, or metaphors, underlie the management of resources. Prevalent metaphors for forest and ecosystem management include farming and engineering. Metaphors or mental models imply different views about the relationship between humans and the non-human world, the value of the natural environment, and the relative weights of different values. Working under or with different mental models will tend to produce different outcomes since each model reflects different objectives and value systems. Uncertainty is generally a relevant issue in resource management, and particularly critical with respect to climate change. Therefore, it will be worthwhile to ask if the mental models that underlie natural resource policy and practice facilitate or potentially set up barriers to addressing and adapting to uncertainty. The idea of viewing resource management as a collective journey is discussed briefly, and the implications of farming or engineering metaphors, which tend to stress knowing and controlling, are compared to those of a journey metaphor, which emphasizes relationship, cooperation, learning, and flexibility. None of these metaphors is wrong or better in all situations, and more than one metaphor can be at play in a particular situation. In the context of climate change adaptation, it will be worthwhile for resource managers to be explicit about which metaphors inform their practice to ensure that acknowledgement of uncertainty is encouraged rather than hindered.

The hope is that the paper will foster discussion among resource managers in British Columbia and will serve as a useful first step in developing a framework of common terms and concepts for talking about and working under uncertainty.

*Scientists agree that the globe will warm, but the range of estimates is an order of magnitude greater than the variability in the historic record* (IISD 2006)

## Introduction

There may have been a time in British Columbia (BC) when the future of the forest sector seemed fairly certain. From the 1950s through most of the 1980s, the North American and global economies were expanding. Uses for species such as lodgepole pine and aspen were found, greatly expanding the timber supply. Conflicts among people with different values and aspirations for forests were significantly less complex than today. The Constitution had yet to be repatriated and revised with a recognition of aboriginal rights and title, which led to a resurgence of First Nations political and legal activity. The number and strength of wood supply competitors were limited. The immense mountain pine beetle infestation of the 2000s had yet to hit. And climate change was not yet a widespread concern. The world has changed. Natural resource managers face quickly changing and highly uncertain economic, social, cultural and environmental circumstances. While only one source of uncertainty, climate change presents some compelling challenges.

Natural resource managers will be challenged to design management systems and practices that will achieve desired values in natural resource systems that may be very different from those that exist today. For example, we don't know for certain what the future forest landscape will look like in terms of tree species distributions, ecosystem functioning, disturbance regimes and other factors (Millar, Stephenson and Stephens 2007). Uncertainties about the composition and function of future forest, range, wildlife, and hydrologic systems are a consequence of uncertainties about how and at what rate climate will change; how the various aspects of climate (temperature, rain, snow, wind, growing season) will change and interact; how those changes will affect forest ecosystems; how management responses will perform under new and uncertain climatic conditions; and even how people in different parts of the world will respond to the risk of climate change and to any actual changes that do occur (e.g. how much mitigation effort will actually be undertaken?).

Uncertainties about climate change are vast and irreducible, that is, not amenable to resolution in the short term through the normal means of research and analysis. But what are natural resource managers and decision makers supposed to do about these uncertainties? Do we keep doing what we've been doing while waiting for better information? Do we embark on fundamental changes to management policies and practices based on projections of the most likely future climate in different parts of the province? What sort of balance should we attempt to achieve between caution and action in an uncertain world? How do we structure our organization so that we can learn and adapt? How can we increase the chance that we implement what we learn about change, complexity and uncertainty?

## Purpose

Developing responses to all of those questions is beyond the scope of this paper. However, to begin moving towards answers will require an understanding of the characteristics or dimensions of uncertainty, and the range of potential responses. It is difficult to manage something if you don't have a conceptual framework or classification that provides a structure for understanding and acting. The objective in this paper is to outline an initial framework for thinking about uncertainty. In BC, the biogeoclimatic ecosystem classification (BEC) is the primary classification system for understanding forest ecosystems and making choices about how to manage them. For example, the BEC system is used widely in forest management as a basis for designing reforestation regimes (e.g., Mah and Astridge 2014), developing management strategies for protecting biodiversity (Haida Gwaii Management Council 2014; Wong et al. 2003), and modeling the potential ecological shifts resulting from climate change (Wang et al. 2012). If there weren't a generally accepted ecosystem classification, the entire process of forest management, including discussions among everyone involved, would be much more confusing and unclear. Therefore, the intention in this paper is to make a first step towards a developing framework that could help to support managing under uncertainty.

An assumption underlying this paper is that although people often talk about uncertainty, there is a lack of common language and shared terminology. Developing reasoned responses to uncertainty will be difficult if there is no framework for helping to think through it. The focus in the paper is to develop a framework for thinking through uncertainty that supports adaptation and maximizes the chance that all important uncertainties are identified. An important purpose of a framework or classification for uncertainty is to decrease the risk that any types or sources of uncertainties are missed (Krayer von Krauss et al. 2006). The hope is that the discussion of uncertainty presented here can assist movement towards a common vocabulary that will enhance the ability of resource managers to work together in developing responses to climate change and the associated uncertainties.

The paper provides some initial ideas about:

- a framework for describing the various dimensions of uncertainty;
- potential research, inventory, management, policy and relational responses to uncertainty; and
- the limits that underlying beliefs or ideas about resource management (as being like farming or engineering) might create when developing responses to uncertainty.

*Scope*

The purpose of this paper is mainly to foster development of a more common framework for uncertainty in BC. Consequently, the discussion is general and conceptual. The paper deals only very briefly with quantitative analytical techniques available for assessing uncertainty (for more information, see for example Morgan and Henrion 1990), and it does not address issues such as the cognitive limitations of scientists in making quantitative estimates under uncertainty (Anderson 1998). The assumption is that prior to attempting to use sophisticated analyses to understand uncertainty, it would make sense for natural resource managers to become more familiar with the topic in general.

The uncertainties associated with understanding and managing under climate change – uncertainties about the nature and rate of changes, about ecosystem responses to climatic change, and about human responses to these changes – were important motivators for writing this paper. However, climate change is not the only source of uncertainty in resource management; so the paper addresses the topic of uncertainty generally, and not only climate change-related uncertainty.

## Definitions of uncertainty

Uncertainty can be defined in many ways, including: a lack of confidence about one's knowledge related to a specific question (Sigel et al. 2010); "deviation from the unachievable ideal of completely deterministic knowledge" (Walker et al. 2003, p. 5); or lack of confidence in the understanding about the possible outcomes of an event, the probabilities of specific outcomes, or both (Refsgaard et al. 2007). Most definitions imply that uncertainty emerges from the relationship between a decision maker or stakeholder and the system of interest (Brugnach et al. 2008). As an expression of confidence, therefore, uncertainty "... is always a product of judgement (it is never independent of people, even if some of the sources are)" (Brown 2004, p. 374).

The common elements of uncertainty that emerge from the variety of definitions are: knowledge or information, confidence, values, and a relationship between people and a decision making situation. Uncertainty does not exist simply "out there" in a biophysical or socioeconomic system (Brown 2004).

Uncertainty arises because people think that there are shortcomings in their understanding of the characteristics and dynamics of parts of the biophysical or socioeconomic world, or of the values and goals that should inform decision making and action (Brugnach et al. 2008).

## Dimensions of uncertainty

There is often a tendency to view uncertainty as primarily a technical issue, with a focus on describing gaps in knowledge about ecological structure, composition, and function. However, natural resource management is not really just about ecosystem dynamics; it has important economic, social, and cultural components, and even environmental terms such as ecosystem or sustainability are diversely understood and defined. Therefore, as well as uncertainties stemming from limited knowledge of ecosystems, this discussion will include sources of uncertainty associated with human values and understandings.

There is no single agreed upon framework for classifying uncertainty. Brugnach *et al.* (2008), Dame and Christian (2006), Elith et al. (2002), Hulme (2009, pp. 83-84), Morgan and Henrion (1990, pp. 47-72), Rotmans and van Asselt (2001), Sigel et al. (2010), van Asselt and Rotmans (2002), and Walters (1986, p. 162) provide some examples.

Some authors have developed taxonomies – that is, frameworks of more or less mutually exclusive categories – of imperfect knowledge or confidence. For example, Brown (2004) classifies uncertainty based on the degree of knowledge about the set of potential outcomes and probabilities associated with those outcomes. Alternatively, Brugnach et al. (2008) categorize uncertainty based on its source; that is, whether it results from the fundamental unpredictability or variability in some – usually biophysical – process; from lack of knowledge; or from the existence of multiple, often conflicting values, which creates uncertainty about decision making goals.

The difficulty with taxonomies is that uncertainty has several interacting and overlapping dimensions, all of which may be useful in deciding how to respond to it (Sigel et al. 2010). Simplification into a few mutually exclusive categories may obscure some of the dimensions. One intention of this paper is to help navigate through the barriers to action frequently presented by uncertainty, and simply listing the multiple dimensions may not best support that objective. Therefore, the approach used in this paper is to begin by outlining the dimensions of uncertainty most frequently highlighted in the literature, and then describing a framework that integrates those dimensions with a view to facilitating understanding the characteristics of uncertainty, which can then guide development of appropriate responses.

The term “system” is use frequently in this paper. A system consists of a group of interacting or interdependent components, which could be biological, physical, social, economic, or political in nature. A system therefore comprises components and relationships. A system of interest is a particular set of interacting and interdependent components that together form a problem for a manager or decision maker.
(http://www.merriam-webster.com/dictionary/system)

Frequently discussed dimensions of uncertainty are:

(1) The source or “location” in the system of interest, that is, the specific components, relationships or outcomes about which there is uncertainty. Sources of uncertainty include elements and relationships in biophysical, socioeconomic, cultural and political systems; and in technology and infrastructure.
(2) The nature or cause, including inherent variability, lack of knowledge, unclear language, decisions on how to scope or bound a problem, unpredictable human behaviour, and unclear or competing human values.
(3) The degree of uncertainty, which includes the degree to which the full range of potential behaviours and related outcomes is known, and the degree to which the probabilities of the various outcomes can be quantified. The degree of uncertainty ranges from the ability assign quantitative probabilities, through being limited to qualitative descriptions of direction and magnitude, to almost complete ignorance.
(4) Practical considerations that affect whether and how to respond:
    - Reducibility – The ability to reduce the uncertainty through research, information gathering, or technological intervention;
    - Controllability – The ability to control factors that determine the condition of the system; and
    - Importance or significance of the uncertainty to decision makers and managers.

These dimensions are overlapping and related, not mutually exclusive.

Figure 1 outlines a framework that includes the various dimensions of uncertainty.

The sections following the figure describe the various dimensions and their components in more detail. **If you are not interested in the details of the various dimensions at this time, you can skip to the section on policy and management responses, which begins on page 11.**

**<u>Location/source:</u>**

*"Where" in the world or in the system does the uncertainty arise?*

- biophysical system
- social, political, economic system
- technology / infrastructure

**<u>Cause (type):</u>**

*What leads to the uncertainty?*

facts/values/language

- incomplete knowledge
- inherent variability
- decisions on scope and resolution
- language (linguistic)
- inability to predict future human behaviour
- conflicting objectives and values

**<u>Degree (level):</u>**

*To what extent are the nature, direction, and magnitude of outcomes or impacts known?*

- statistical
- qualitative
- scenario
- recognized ignorance
- complete ignorance (unknown unknowns)

**<u>Practical considerations:</u>**

*What kind of response does the uncertainty warrant, if any?*

- ability to reduce uncertainty
- ability to control determining factors
- importance or significance

*Figure 1: Dimensions of uncertainty*

### *Source or location*

The source or location concerns "where" in the system of interest the uncertainty exists; that is, in what components, relationships, or outcomes. Walker et al. (2003) and Refsgaard et al. (2007) refer to this as the location of uncertainty, while Sigel et al. (2010) label it as the source. The source or location can be related to the components, parties, or dynamics in biological, physical, social, economic, cultural or political systems, as well as in technology and infrastructure. As an example, some potential sources of uncertainty associated with making a decision on the tree species to use for regenerating a recently harvested stand are described below.

- Biophysical system:
    - What will the future climate be like? What climate projections should be used in developing policy and making operational decisions?
    - What tree species will be able to survive or thrive in the range of climatic conditions that may occur over time?
    - How should species composition be managed at stand and landscape levels to ensure adequate diversity to provide a buffer against hazards?
    - What forces (natural disturbances, pathogens, and insects) will regenerated stands face that may result in loss of the reforestation investment?
- Technology and infrastructure:
    - Are there enough sources of seed including seed orchards to meet regeneration demands?
    - Will there be sufficient organizational and technical capacity to protect new and growing stands?
- Social. economic, and political
    - What are the economic costs and benefits of implementing various regeneration strategies?
    - Who should bear the costs?
    - Are relationships among the various parties sufficiently strong to allow for collective navigation through the complexities of the issue?
    - Can flexibility and regulation be implemented in ways that achieve a satisfactory social and political balance? How?
    - Can competing public and private sector goals and objectives be reconciled in a way that allows for implementation of regeneration strategies directed at adaptation to climate change?
    - What are the specific objectives of climate change adaptation with respect to reforestation? If building and maintaining "resilience" is an objective, what is the definition of that term and is there agreement on it?

### *Nature or Cause*

Uncertainty can be caused by (1) inherent variability in the behaviour of a system, (2) limited knowledge, (3) decisions on scope and level of detail; (4) unclear use and fundamental limitations of language, (5) unpredictability of human behaviour, particularly far into the future, and (6) ambiguity about objectives, especially unresolved conflicts among competing objectives. An additional component of nature or cause is whether the uncertainty relates to facts or to values.

*Inherent variability*

The first cause relates to the variable or chaotic nature of a system. It has been termed inherent unpredictability (Walker et al. 2003; Brugnach et al. 2008), phenomenological uncertainty (Sigel et al. 2010), variability (Morgan and Henrion 1990), and stochasticity (Walker et al. 2003). Examples of fundamental or inherent variability include:

- fluctuation in daily temperature and precipitation;
- average weather conditions for a month or season in relation to longer-term trends; and
- conditions such as soil moisture and nutrients, or tree and shrub species cover for a particular site within a broader forest or vegetation type or polygon.

In some cases, like the last example, it might theoretically be possible to define more vegetation types each of which would be more homogeneous. Similarly, Regan et al. (2002) assert that it is unlikely that any biological system is inherently random, but may appear so because the deterministic processes that define the system are hard to fully specify. However, homogeneity is a relative term, and there are practical limits on the ability to define and collect information on ecological or social strata. Hence, almost any class or stratum set up to support analysis, planning, and decision making will contain internal variability. For the purposes of this discussion, variability applies to a circumstance in which the uncertainty cannot be reduced, so the decision maker must deal with the variability in some way.

*Incomplete knowledge*

The second cause, incomplete knowledge about the system (Brugnach et al. 2008), has also been labelled epistemic or epistemological uncertainty (Regan et al 2002; Sigel et al. 2010). Limitations in knowledge about the various components of a system (e.g., wildlife, trees, water), about the dynamics of the components (e.g., population changes, growth and yield, hydrology) and about how the components interact (e.g., influence of forest conditions on wildlife or water quality and quantity) can generally be addressed through research; by collecting information through inventories, surveys, or monitoring. Sensitivity analysis can assist in understanding the implications of the uncertainty on the decision being made.

*Scoping or bounding*

Thirdly, uncertainty can be generated by the way in which a problem is defined – that is, the temporal, spatial, and issue-based boundaries that limit the problem size – and by the manner in which it is assessed – that is the level of detail (Walters 1986, p. 162). These decisions may be made for pragmatic reasons such limitations of time and resources, to lack of understanding of the all of the facets of the situation, or to disciplinary biases. This kind of uncertainty arises when one excludes or fails to consider – either explicitly or inexplicitly – factors that are important in determining the dynamics of the system of interest. For example, undertaking an ecological and technical examination of options for climate change mitigation or adaptation could ignore economic constraints on the forest industry that may affect the feasibility of implementing such actions.

*Language*

A fourth cause of uncertainty is language. Linguistic uncertainty (Regan at al. 2002; Krupnick et al. 2006) stems from imprecise and culturally specific use of language, and from the nature of language as essentially a model of reality – a means of representing and communicating about the world and our experiences of it. Careful use of language is important to avoid unnecessary confusion (Krupnick et al. 2006). However, since language represents phenomena – things, interactions, processes, and values – there will always be some uncertainty associated with it (Regan et al. 2002). For example, consider the term "endangered." Where exactly is the boundary between conditions in which a species is endangered or not? What is the nature of endangerment? While research can move us closer to a common understanding of the issues associated with extinction and persistence, it is unlikely that a single word can ever capture the full complexity of the underlying processes (Regan et al. 2002). A small sample of other terms about which there may not be universal agreement include resilience, critical types and ranges of natural variability (Holling and Meffe 1996), undue risk, appropriate species, and significant impact.

The best that can be done with respect to language-related uncertainty is to clarify terms to the extent possible, including recognizing the challenges of communicating across disciplines and other cultures (Regan et al 2002), and also acknowledging the constant potential for uncertainty and confusion to arise due to language. Linguistic uncertainty requires the addition of approaches to the uncertainty "toolkit" beyond those employed to provide new knowledge or information or to reduce risks through diversification and buffering. For example, uncertainties stemming from cultural or disciplinary difference require skillful questions and intentionality to achieve understanding, and to avoid or resolve conflicts (LeBaron 2003).

### *Unpredictable human behaviour*

A fifth cause of uncertainty is the inability to predict human behaviours, particularly further into the future (Sigel et al. 2010). The extent of global climate change will depend substantially on human choices and behaviour such as use of fossil fuels and development of alternative energy technologies (IPCC 2014). As reflected in work of the IPCC, specifically the development of several emissions scenarios – or representative concentration pathways – future human behaviours are highly uncertain and that uncertainty is irreducible. Decisions must be made in the face of this uncertainty.

### *Differences or lack of clarity in values and objectives*

A sixth cause of uncertainty is conflicting or unclear objectives (Brugnach et al. 2008). If management goals cannot be described definitively, it will be difficult to know how to evaluate alternative courses of action since the evaluative framework will effectively be uncertain. For instance, Lebel et al. (2006) outlines a critical value-related uncertainty related to adaptation: "Who decides what should be made resilient to what? For whom is resilience to be managed, and for what purpose?" Sometimes uncertainties related to values may result from limitations in knowledge about what people want; however, in many cases, the uncertainty stems more from difficulties in resolving conflicts among different and competing objectives. In such cases, an appropriate response may be to undertake deliberative processes such as negotiation, collaborative learning, and dialogue to help achieve increased agreement on objectives, or on how to balance competing objectives (Brugnach et al. 2008).

### *Fact and value uncertainty*

An important distinction related to causes of uncertainty – particularly for those accustomed to managing biophysical systems – is between fact and value uncertainty (Sigel et al. 2010). Uncertainties of fact relate to characteristics of biological, physical, social, and economic systems that in principle could be perceived and measured through the senses. Fact-related uncertainty results when there is a lack of confidence about factual knowledge that is necessary for describing some aspect of the world. Value uncertainty relates to the importance that people place on the various characteristics and outcomes of a system (Sigel et al. 2010; Brugnach et al. 2008). Human values can be expressed by the way people frame problems (Brugnach et al. 2008). Framing in this context refers to the process of making sense of a situation, such as defining the system of interest, what the overriding objectives are, which aspects or outcomes of a problem or system are most important, how success should be defined, and what levels of hazard and risk are acceptable (Brugnach et al. 2008; Gray 2004). Value or norm-related uncertainty exists when there is a lack of confidence about knowledge regarding norms and values (Sigel et al. 2010), when it is not clear how to achieve an appropriate balance among competing or conflicting objectives (Brugnach et al. 2008; Krupnick et al. 2006),and when there are different interpretations of a policy objective. For example, consider the development of management responses for endangered species. In this case, decision makers will need to interpret information about the degree of endangerment, and then weigh the risks to various biological, social, and economic values in deriving a management regime.

Sigel et al. (2010) see the distinction between fact and value uncertainty as a separate dimension. While this distinction is undoubtedly of high importance, it was viewed as a component of the source and cause dimensions with a view to developing a parsimonious framework.

### *Degree of uncertainty: level of knowledge about potential outcomes and probabilities*

Specialists in risk analysis often promote the assignment of probabilities to potential outcomes to enable quantitative exploration of options and definitive description of preferable actions (Krupnick et al. 2006). This approach to quantitative risk assessment implies knowledge of the magnitude and direction of all potential outcomes associated with a strategy, and the ability to reliably assign probabilities to each outcome (Sigel et al. 2010; Hoffman et al. 2014). While perhaps ideal from an analytical perspective, the prerequisites of such an approach are often not met (Brown 2004; Sigel et al 2010).

Walker et al. (2003) outline four levels or degrees of uncertainty:

- *Statistical uncertainty* corresponds to the ability to assign quantitative probabilities to a known set of potential outcomes.
- *Scenario uncertainty* exists when the range of potential outcomes is known, but probabilities cannot be defined because of a lack of understanding of how a system functions. Refsgaard et al. (2007) describe a closely related category of qualitative uncertainty, which denotes the ability to describe the probabilities of outcomes in categorical or qualitative terms.
- *Recognized ignorance* occurs when knowledge is sufficient to realize that there is a lack of knowledge about relationships among system components, and that this lack of knowledge creates uncertainty about potential outcomes and also about statistical properties like probabilities.
- Finally, *total ignorance* exists when knowledge is so limited that one does know that they do not know. These are the “unknown unknowns” made famous by Donald Rumsfeld (Pawson et al. 2011). While the popular press may have had difficulty acknowledging the reality of such a paradoxical juxtaposition, such uncertainty plays a substantial role in decision making in large, complex socioeconomic-ecological-political systems. The

simple act of scoping a problem down to a size and complex with which a particular set of policy analysts or other experts can cope, can excludes potentially important components and processes (Walters 1986). This scoping can therefore introduce unknown (or unacknowledged) unknowns. Examples of issues subject to a high degree of, if not almost total, ignorance include: policies of future governments and those of current governments in different parts of the world that can affect GHG emissions; and potential emergence of new technology that could alter currently perceived relationships between fossil fuel use and economic development.

Of course, the degree of uncertainty can change when new information is collected or knowledge generated. The act of acknowledging ignorance, particularly the potential for unknown unknowns, allows for inquiry and exploration, which can lead to searches for data about things and dynamics that had not previously been contemplated. As Pawson et al. (2011) note "The whole point is the steady conversion of 'unknowns' to 'knowns'" while recognizing that some eventualities will always remain unforeseen and unknowable.

An additional distinction related to the degree of uncertainty is between magnitude and direction (Hoffman et al. 2014). Uncertainty about the direction of change generally presents more decision making challenges than uncertainty about the magnitude of an impact or change, since sensitivity analysis can support decision making if magnitudes are unknown. However, sometimes uncertainty about magnitudes can be problematic. For example, uncertainty about the magnitude of change that would result in crossing a critical threshold – say, if the persistence of species will be threatened if habitat falls below a given level – can create difficult challenges, since it may require decision makers to balance risks across different values, and lead to debates about how risks should be assessed and treated (Klinke and Renn 2002; Lempert and Collins 2007).

***Practical considerations – reducibility, controllability, and importance***

The extent to which uncertainties can be reduced, the extent of control managers have over factors that determine the condition of the system being managed, and the importance or significance of the uncertainty to decision makers all affect whether and how to respond to uncertainties.

<u>Reducibility</u>

Sigel et al. (2010) highlight the ability to resolve or reduce uncertainty as one of its key dimensions. The ability to reduce uncertainty must be placed within the context of a particular decision. That is, can knowledge be generated or information collected within the time frame of a decision process, or do limitations on time and resources mean that a decision will need to be made under residual uncertainty? The ability to reduce uncertainties in the context of a decision will depend on the financial and human resources available, and the nature or cause of the uncertainty. Some uncertainties may not be reducible, due to inevitable occurrence of novel events, to chaotic behaviour of complex systems, and to the freedom of human action. Furthermore, generating new information also creates new questions and new uncertainties (Sigel et al. 2010). The degree of reducibility will affect whether an appropriate response is to gather more information, to institute a monitoring program to detect emerging trends, to make decisions frequently to incorporate new information, or to diversify to increase chances that objectives will be at least partially achieved.

*Controllability*

Controllability refers to the degree of control over factors that are important in determining the behaviour of a system, including the system's response to an uncertain event (Hoffman et al. 2014). For example, variables like precipitation, vegetation cover, river water levels, and wildfire can be important in determining the levels of valued ecosystem components such as water quantity and quality, wildlife and fish populations, or timber supply. Lower levels of controllability usually result in higher uncertainty about the future condition of a system, and consequently about degree to which values of interest will be present. The degree of control also affects the type of response to uncertainty that is suitable. For instance, if the level of a determining variable can be controlled quite closely, the level of uncertainty could be reduced by regulating activities (e.g., control removal of forest cover or install infrastructure to withstand or absorb potential disturbance); developing incentives to encourage particular kinds of activity; and monitoring actual activities. If the level of the determining factor cannot be closely controlled, such as with climate, the appropriate responses to the resulting uncertainty could include diversification, application of a buffer or safety factor, implementation of a cautious approach to resource use levels, or relatively frequent and regular decision making to incorporate of changing conditions and new information into decisions.

*Importance or significance*

Not all uncertainties are equally important to a decision. Resource managers and decision makers should attempt to focus efforts on uncertainties that are most critical in achieving objectives. With respect to information gaps, it is worthwhile to assess both if and how much it is worth investing in gathering more information (Hoffman et al. 2014). Also, it will be worthwhile to evaluate which of the various sources and causes of uncertainty are most important. Gaps in technical knowledge are often the focus of discussions of uncertainty; but uncertainties related to things like organizational readiness, responsibilities for costs and risks, and clarity and agreement about objectives can often be greater barriers to achieving objectives than technical information (Brugnach et al. 2008).

## Policy and management responses to uncertainty

The section provides an overview of (1) common responses to uncertainty, most of which avoid full acknowledgement of it; (2) day-to-day responses frequently employed by many individuals, with the purpose of highlighting the diverse ways in which we are accustomed to addressing uncertainties; and (3) the diverse set of responses needed to acknowledge the various dimensions of uncertainty described in the previous section.

### *Common responses to uncertainty*

Since the various dimensions of uncertainty are present in almost all aspects of resource management, it follows that managers must respond to uncertainty in some way. Hoffman et al. (2014) outline five types of common responses to uncertainty.

- *Proceed as though there is no uncertainty.* While effectively ignoring that there is uncertainty can allow for faster decisions and action, the potential drawbacks include: incomplete understanding of the problem being faced and poor decisions when the anticipated future circumstances and management outcomes turn out to be incorrect. In a comparative study of foresters and those working in the agricultural sector, Hoogstra and Schanz (2008) found that "… foresters experience the future as the most certain time period. Decisionmakers in forestry, as in other business sectors, seem to ignore the uncertainty and pretend that the future is certain."

- *Await more certainty before acting.* While potentially avoiding errors due to insufficient knowledge, the potential implications of such an approach include continuing to act in accordance to past conditions and plans when circumstances have changed, and missing opportunities to reduce risks or capitalize on potential benefits.
- *Frame the problem as being a lack of information:* This approach places focus on something that can be done – collecting information – but it can lead to analysis paralysis, and failure to think about how to make a good decision given the uncertainty.
- *Focus on better-understood problems or parts of the problem:* Similar to the previous point, this response facilitates action, but it can also lead to a false sense of accomplishment and encourage actions that are not appropriate for the actual circumstances, and can divert focus from the most important aspects of the problem.
- *Understand and work with uncertainty:* Pausing and reflecting on uncertainty can appear to waste valuable time, and perhaps be underpinned by fear that one will appear incompetent. Further, implementing strategies such as diversification and leaving buffers can appear to lead to sub-optimal solutions. However, consciously incorporating uncertainty into decisions and strategies increases the chance of achieving desired outcomes. It also enhances the capacity for flexible thinking, which can be helpful when facing future uncertainty and complexity.

This list of common responses highlights that while uncertainties often present substantial challenges, common responses frequently address only a portion of the challenges, and sometimes ignore them. Other than the last response, these responses deal quite directly with knowledge: trying to increase what is known through information gathering or analysis, or focusing on what is known. Both of these responses ignore that unacknowledged uncertainties could threaten achievement of management objectives.

Better information and understanding of how biophysical and socio-economic systems work and may respond to management actions are undoubtedly important in dealing with uncertainty. However, there are limitations to information gathering, research, and analysis, which include (Holling 1978; Walker et al. 2003; Brown 2004; Sigel et al. 2010):

- Finite resources for research, inventory and analysis;
- The immense complexity of interactions within and among environmental, economic and social systems, which preclude full understanding;
- The development and application of new technologies means that new relationships and impacts are always occurring;
- Understanding of the past does not guarantee understanding of the future;
- Understanding of potential implications of uncertainty does not preclude the need to makes difficult balancing decisions among competing values and risk. For example, do we minimize potential losses or damages, or minimize loss of opportunities?

Therefore, as well as information gathering, research and analysis, other approaches to uncertainty are needed. But what does understanding and working with uncertainty actually mean?

### *Day-to-day responses to uncertainty*

To begin to explore this question, it is useful to examine how people respond to uncertainty in day-to-day personal and work lives. Following are some examples of day-to-day responses, many of which relate to improving the information available to support decision making, but some which are different.

- Do research or monitor to fill in gaps in our knowledge (What is the best technology for ensuring your basement doesn't flood? What are the options for a new vehicle/new camping equipment/new exercise gear?).
- Be prepared for a range of conditions (Take clothing layers and/or raingear to deal with potential changes in weather).
- Check weather reports as you travel to see if you can avoid bad conditions.
- Diversify (Hold an investment portfolio).
- Safety factor (Leave a time buffer in case traffic is bad. Take a first aid kit in case there's an accident. Take an extra set of eyeglasses in case one breaks).
- Have insurance (A kind of safety factor in which risk is pooled among many people).
- Leave options open (Defer making a final decision until absolutely necessary. Take extra gear on your trip, even though it weighs a lot, in case you have the chance to do something special.).
- Be adaptable (Be ready to choose an alternative if your first choice isn't available).
- Avoid highly consequential irreversible or difficult-to-reverse decisions (Test paint on a small portion of your wall before buying gallons).
- Build and maintain relationships (Get to know travel or camping companions before you embark on a trip. Be cordial with your neighbour, because you may need to borrow their snow blower if a blizzard strikes).

As this partial list makes apparent, it is common to behave in ways that are adaptive towards uncertainties in our lives.

### *Resource management responses*

This section outlines responses to uncertainty that are relevant for natural resource management. They are based on the examples of individual actions provided in the previous section, and on responses discussed in the literature on uncertainty, specifically: Brugnach et al. 2008; Folke et al. 2005; Fulmer 2000; IISD 2006; Krupnick et al. 2006; McGrath 2011; Millar et al. 2007; and Peterson et al. 2003. The responses to uncertainty can be divided into four general categories: (1) enhancing information and knowledge; (2) implementing practices that help adapt to or buffer against uncertainty and change; (3) developing responsive decision making processes, institutions, and regulatory frameworks; and (4) building and maintaining relationships.

- Enhance information and knowledge
    - Collect information (inventory).
    - Research.
    - Adaptive management (experimentation, learning and adjustment)
    - Monitor – look for early warning signs and feedback about the impacts of decisions and actions.
    - Analysis, scenario development and scanning.

        - Sensitivity analysis to understand implications of uncertainty (realizing that using the results requires an attitude toward risk – do we minimize risks, minimize regrets, etc.?)
        - Anticipate and project an array of plausible futures; test strategies to see how they perform under each scenario.
        - Strategic scanning (what is coming?) – is the organizations doing or producing what is in demand and needed for current and emerging conditions, as opposed to what it has traditionally done?
    - Clarify language and definitions of important concepts and terms.[1]
- Implement practices that help adapt to or buffer against uncertainty and change:
    - Prepare for a range of conditions.
    - Diversify.
    - Have a safety factor (buffer, insurance, design for extreme events, redundancy).
    - Be adaptable and flexible.
    - Resist or defend against influence of change agents; e.g., increased protection measures, removal of invasive organisms, resistance breeding, block invasions/migrations) – short-term protection of high-value components or systems
    - Enhance recovery and resilience. Support conditions that allow accommodation of gradual changes and return to previous condition after disturbance or change (e.g., support for regeneration in changing, harsher conditions; biotic legacies; functional redundancy, response diversity)
    - Facilitate response to change. Support of adaptation to new conditions (e.g., seed transfer; migration, connectivity, diversity).
- Develop responsive decision making processes, institutions, and regulatory frameworks
    - Revisit decisions regularly (allows for feedback to emerging knowledge).
    - Avoid making irreversible decisions. Focus on iterative, small, reversible change
    - Leave options open.
    - Be adaptable.
    - Share risks.
    - Develop incentives (economic, regulatory)
    - Promote organizational capacity – enable flexibility, decisiveness (rapid response).
    - Avoid paralysis by decisively making clear and transparent assumptions to guide action, while acknowledging that direction changes will likely be needed in the future.
    - Decision rules such as:
        - no regrets, robustness (strategies that perform well compared to alternatives across a wide range of plausible futures);
        - maximin (minimize the maximum loss, or choose the alternative with the best of the worst possible outcomes);

[1] Language-related uncertainty may not always be resolvable by seeking more information to help refine terms and concepts. It may involve deliberation among experts and negotiation among stakeholders to resolve differences in perspectives and values (e.g., what is a reasonable risk threshold for a development that affects water quality?). Addressing language-related uncertainty may warrant a separate category, but such a category seemed substantially narrower than the others discussed here, so here it was conceptualized as an issue of clarity and information.

        - minimax regret (minimize the worst-case regret or minimize potential opportunities lost)
- Build and maintain relationships
    - Facilitate decisive, rapid action based on trust (i.e. lack of trust leads to requirement for comprehensive and lengthy consultation)
    - Build capacity for constructive deliberation among stakeholders and regulators – relationship building, trust, networks – to clarify objectives and work towards understanding of how to balance competing values.

While several of these responses to uncertainty involve reducing uncertainty about the inputs to decisions or about circumstances in which decisions need to be made, several focus instead on *reducing uncertainty about whether or not objectives can be achieved*.

The assumption in this section has been that there is a desire either to reduce uncertainty, or reduce its negative effects on desired outcomes. In some cases, however, reducing uncertainties may actually be counterproductive. Smithson et al. (2008) outline several potential reasons for maintaining uncertainty, including: building social capital by retaining privacy, keeping costs within reason, and avoiding violation of rights. On an individual level, most people would not wish to know their time of death, nor would they want prior knowledge of gifts they've received. In the context of natural resource management, however, the assumption retained for this paper is that reduction in uncertainties and/or in the negative outcomes associated with uncertainties would in most cases be desirable.

<u>*Linking responses with dimensions*</u>

The initial intention was to develop a tool such as a decision tree to connect the various dimensions of uncertainty (i.e., sources, causes, and levels) with the appropriate response or responses. It became apparent however, that all types of responses may be appropriate for all dimensions depending on the circumstance. For example, while in general uncertainties related to lack of knowledge about biophysical dynamics would appear to be addressed best by research or information gathering, the timeframe for a decision or the available resources may limit the ability to respond by improving the knowledge base. Instead, discussions among stakeholder about how to allocate scarce resources and how to treat the risks to affected values may be needed, and a management strategy designed to mitigate or spread risks.

So, given the numerous dimensions of uncertainty and the potential diversity of applicable responses it was concluded that it would be best simply to outline the dimensions and response types. Resource managers can then make reference to the dimension and response type framework to define responses that are appropriate for the specific circumstances.

<u>*Section summary*</u>

To summarize this section, common responses to uncertainty tend to assume that current knowledge and information are accurate and adequate for making decisions, or that the problem is lack of information and therefore that gathering information is necessary. However, uncertainties do not always stem from lack of information. Uncertainties can result from difficulties in balancing the diversity of human values. Further, it is not always possible to reduce uncertainties in time for a decision, or at all due to the inherently uncertain nature of some processes. Therefore, in addition to improving knowledge and information, other responses to uncertainty may be warranted. These include implementing practices that help adapt to or buffer against uncertainty and change; developing responsive decision making processes, institutions, and regulatory frameworks; and building relationships that will support flexibility and decisive action.

## Mental models for resource management systems – help or hindrance to adaptation?

> *Climate change ... has no clear or obvious precedents. It makes anachronistic the language and metaphors we have long used to describe the interdependence of humanity and nature.* Miller (2008)

Mental models, or metaphors, underlie most of what people do, including managing resources (Lakoff and Johnson 1980; Raymond et al. 2013). It is not common to talk about metaphors in the context of natural resource management. But, as the quote from Miller highlights, the uncertainties associated with climate change present resource managers with some profound challenges. We are often not even aware of the basic assumptions, worldviews, or metaphors we employ (Raymond et al. 2013). Therefore, it is worthwhile to look at those assumptions when developing management approaches so that we can understand how they might limit or enhance our ability to understand the components and processes of the system being managed, and to formulate goals and objectives that are reasonable, realistic, sustainable and inclusive given the biophysical, social, cultural, economic and political dynamics and values at play (Raymond et al. 2013). Different mental models or metaphors may also be more or less suitable for supporting acknowledgement of and adaptation to uncertainties.

Metaphors or mental models imply different views about how the world works, how it can best be understood, the relationships between humans and the non-human world, the value of the natural environment, the relative weights of different ways of knowing and being, and how to measure the outcomes of human actions (Raymond et al. 2013).

Dominant metaphors underlying natural resource management are:

- Forests and range lands as mechanical systems or machines; resource management as engineering (Holling and Meffe 1996; Keulartz 2007)[2]. Discussions about resource management frequently reference the *mechanisms* that underlie observed dynamics, the *levers* that can be pulled, and the manners in which systems can be *optimized*.
- Resource management as farming. Trees, forage, animals are referred to as *crops* that can *tended* and *harvested* (Docherty 2004).
- War. Popular media and the resource management sector make references such as *war* on the mountain pine beetle, *war* in the woods, insect *attack*, an *arsenal* of management approaches, and Old Growth Management Area *deployment*.

Most metaphors have utility; they would not be employed otherwise. However, at question here is whether the mental model or metaphor helps or hinders in dealing with a changing, complex, and uncertain world. In fact, one could even ask if the metaphor is consistent with seeing the

[2] If there is doubt about the applicability of this metaphor, one may wish to do an internet search for “natural resource management” together with “ecological engineering,” “biological systems engineering” or “environmental engineering.”

world as changing, complex, and uncertain, or whether substantial efforts are taken to ensure that it is as stable and predictable as possible (Holling and Meffe 1996). The authors in Holling (1978), a seminal text in bringing more awareness to uncertainty in resource management, encouraged resource managers to “embrace uncertainty.” They were not explicit and precise in their use of that phrase; however, they most likely did not mean necessarily liking uncertainty, but rather acknowledging that it is and always will be part of reality. A key question is whether the metaphors implicit in contemporary resource management are consistent with acknowledging uncertainty, or if they rely on ignoring or eliminating it.

While it is not a straightforward matter explicitly to devise alternative metaphors for resource management – they tend to be implied through practice and experience rather inform actions explicitly – it can still be informative to imagine how management might differ under alternative metaphors. Raymond et al. (2013) encourage those involved in researching and managing ecosystems “to make implicit metaphors explicit … and to find ways to systematically consider the merits of different metaphors during environmental decisionmaking.” How do engineering and farming metaphors in resource management affect research, analysis, decision making, institutions, and practices? How do those effects compare to those that might result when operating from a journey metaphor[3]? How do these metaphors affect the ability to respond to climate change and the related uncertainties? Table 1 provides some ideas about how looking at forest and range management as a journey as opposed to as farming or engineering might affect resource management.

In generating Table 1, the assumptions related to farming and engineering metaphors – trees and other living things as crops to be tended and harvested, and ecosystems as machines to be understood and manipulated – tend to focus on maximizing the ability to predict and control behaviour and performance to produce desired goods and services. A journey metaphor was assumed to emphasize relationship, cooperation, inquiry, flexibility, and learning.

It is acknowledged that some of the characterizations in Table 1 may appear as caricatures; however, the intention is not to imply that one approach is right and the other wrong. Nevertheless, it is reasonably clear that a central goal of much of contemporary natural resource management is to maximize the extent to which resource systems are known and understood so that they can be controlled and predicted. The intention here is briefly to explore the implications of that outlook, and an alternative.

[3] The notion of resource management as a journey was inspired by the work of Michelle LeBaron of the UBC Faculty of Law. See LeBaron (2003).

*Table 1. Management under assumption of certainty* versus *acknowledgement of uncertainty*

| | **Assume certainty is achievable** (e.g., resource management as engineering or farming) | **Acknowledge uncertainty** (e.g., resource management as a journey) |
|---|---|---|
| Decision processes | Deterministic – predict, control.<br>Comprehensive, detailed, precise, optimal.<br>Focus on most likely future.<br>Seek stable, durable decisions.<br>Work towards certain outcomes. | Adaptive – frequent decisions, hedging, safety factors, incremental change, reversibility, testing ideas.<br>Satisfaction over range of possible futures (robustness).<br>Acknowledge need to revisit and revise decisions.<br>Work towards certainty that cooperative relationship can be built and maintained. |
| Research | Seek best (point) estimate – reduce or eliminate uncertainty. | Understand uncertainty – range of estimates, nature of transition in times of change. |
| Analysis | Based on best estimates to support defensible decisions. | Explore implications of uncertainties to decision.<br>Scenario analysis – Examine outcomes of potential strategies under range of plausible futures. Help anticipate the unexpected. |
| Implementation and intention of practices | Best practices to achieve desired substantive outcomes.<br>Maximize stability and predictability to optimize provision of desired products and services.<br>Seek optimal outcomes. | Range of practices.<br>Design management practices as learning opportunities.<br>Acknowledge and plan for the diversity and unpredictability of natural systems.<br>Seek satisfactory as opposed to optimal outcomes. |
| Assessment & monitoring | Performance measures relative to expectations | Management as learning.<br>Reliance on monitoring as early warning |
| Engagement | Focus on getting the best information or explaining why the proposed approach is justified. | Focus on collaboration, recognizing that “inefficiencies” may be warranted by higher degrees of buy-in, trust, and willingness for future cooperative work. |
| View of the unexpected | Unfortunate and unpleasant. | An ongoing reality. |

The items in this table are not new; however, using a different guiding metaphor will result in different emphasis on the various components of policies, practices, and institutions.

## Summary and conclusions

Uncertainty does not exist "out there" in a biophysical or socioeconomic system (Brown 2004). It arises because people think that there are shortcomings in the understanding of the characteristics and dynamics of parts of the biophysical or socioeconomic world, or of the values and goals that should inform decision making and action (Brugnach et al. 2008).

The purpose of this paper was to introduce some ideas about the types of uncertainty faced by natural resource managers, and the types of responses that are available to deal with uncertainty. The ultimate hope is that this can be a step towards developing a common language among resource managers for talking about and addressing uncertainties, because managing any problem or system is difficult without such a common understanding.

Uncertainty has different interacting aspects or dimensions that preclude a simple classification or taxonomy of mutually exclusive classes (Sigel et al. 2010). Therefore, for the purposes of this paper, a framework of the dimensions of uncertainty was developed. The framework includes:

- ***Sources*** of uncertainty in biophysical, socioeconomic, political or technological systems;
- ***Causes***, including inherent variability, lack of knowledge, unclear language, decisions on how to scope or bound a problem, unpredictable human behaviour, and unclear or competing human values;
- ***Levels or degrees***, which include the degree to which the full range of potential dynamics and related outcomes is known, and the degree to which the probabilities of the various outcomes can be quantified. Therefore, the degree of uncertainty ranges from the ability assign quantitative probabilities, through being limited to qualitative descriptions of direction and magnitude, to almost complete ignorance; and
- ***Practical considerations*** that affect whether and how to respond, including *reducibility, controllability, and importance*.

Use of such a framework could help resource managers to avoid missing important uncertainties, and to choose appropriate responses to the uncertainties.

Common responses to uncertainty include proceeding as though there is none, awaiting more certainty before acting, treating the problem as a lack of information, and focusing on better-understood parts of the problem that can be addressed with familiar tools or knowledge. However, not all uncertainties involve a lack of knowledge, and some may require types of knowledge, skills, and processes that are outside one's current toolkits. Therefore, recognition of the full range of potential responses to uncertainty can be useful to ensure that managers are addressing uncertainties with appropriate responses.

Potential responses to uncertainty include:

- ***Enhancing knowledge and understanding*** through research, inventory, monitoring, analysis and scenario development, as well as clarification of definitions for important concepts and terms.
- ***Implementing practices*** that help adapt to or buffer against uncertainty and change.
- ***Developing responsive decision making processes, institutions, and regulatory frameworks***; and
- ***Building and maintaining relationships*** to assist in the deliberations needed for the difficult work of clarifying and balancing multiple values and objectives, and to enable decisive and timely action in response to uncertainty and change.

Sometimes, uncertainties can be addressed by increasing what we know confidently. Sometimes, they must be addressed by increasing the chance that our objectives will be achieved, perhaps not optimally but at least satisfactorily. Sometimes uncertainties are deep enough that we must develop decision processes, institutions, and relationships that allow us to function and respond in ways that maintain the fundamental goals of resource management, which may include sustainability, fairness, and inclusivity within the context of providing socially desired values.

Depending on the circumstances, most types of response to uncertainty could be appropriate for the various sources, causes, and levels of uncertainty; therefore, it was not possible to create a framework that makes unique connections between dimensions and types of response. The idea was to provide a framework for managers to assess the dimensions of uncertainty that are most important in a particular situation, and then determine what responses fit the circumstance. It was also an objective to highlight that some uncertainties may warrant responses other than gathering more information and knowledge, or implementing some kind of insurance (i.e., diversification, safety factors, or buffers). Some types of uncertainty require efforts to clarify language and develop commonly understood definitions; to design responsive decision making processes, regulatory mechanisms, and institutions; and to develop skills and forums for deliberation to clarify and balance objectives.

Mental models, or metaphors, underlie most of what people do, including managing resources (Lakoff and Johnson 1980; Raymond et al. 2013). Prevalent metaphors for forest and ecosystem management include farming and engineering (Docherty 2004; Holling and Meffe 1996). Metaphors or mental models imply different views about the relationship between humans and the non-human world, the value of the natural environment, and the relative weights of different values (Raymond et al. 2013). Working under or with different mental models will tend to produce different outcomes since each model reflects different objectives and value systems. Since uncertainty is generally relevant in resource management, and particularly critical with respect to climate change, it will be worthwhile to ask if the mental models that underlie natural resource policy and practice facilitate or potentially set up barriers to addressing and adapting to uncertainty. The idea of viewing resource management as a collective journey (LeBaron 2003) was discussed briefly, and the implications of farming or engineering metaphors, which tend to stress knowing and controlling, are compared to those of a journey metaphor, which emphasizes relationship, cooperation, learning, and flexibility. None of these metaphors is wrong or better in all situations, and more than one metaphor can be at play in a particular situation. In the context of climate change adaptation, it will be worthwhile for resource managers to be explicit about which metaphors inform their practice to ensure that acknowledgement of uncertainty is encouraged rather than hindered.

The hope is that the paper will foster discussion among resource managers in BC and will serve as a useful first step in developing a framework of common terms and concepts for talking about and working under uncertainty.

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