Metaphors and Mental Models of Risk
Expert Thinking about Ecosystems

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Resource Management and Environmental Studies)

UNIVERSITY OF BRITISH COLUMBIA

APRIL 2006

ABSTRACT

Ecosystems are important to human survival and well-being (MEA, 2005). Human knowledge of ecosystems largely consists of the conceptual distinctions made by experts. Experts use different metaphors and mental models to define ecosystem risks and shape our thinking. Decision makers face a dilemma when experts use conflicting frames of reference to define the same problem.

This research attempts to answer three questions. Do experts have different mental models of risk? Do their mental models of risk stem from different underlying worldviews? Do their worldviews arise from differences in their professional background or work experience?

Repertory grid methodologies were used to elicit expert mental models. The analysis relied on Shaw and Gaines's (1989) methodology for comparing experts' conceptual systems.

The data for this study was collected through a two-stage survey. The interview stage of the survey was used to identify widely shared conceptual distinctions experts use to talk about ecosystems. During the second stage, experts were asked to complete a web-based questionnaire, applying these shared distinctions to describe how several concepts or types of ecosystems differed from one another.

The Interview stage of the survey revealed that ecological integrity was the dominant mental model of risk and the experts shared a common set of beliefs. These beliefs were most heavily influenced by the experts' current position and previous work experience.

The Internet stage of the survey revealed that the eco-concepts shared more similarities than differences. The eco-concepts as a whole belonged to one of two metaphoric categories that distinguished pristine from human-impacted systems. There was also a broad consensus among experts in the way they used the derived assessment criteria to describe the eco-concepts.

The findings suggest that the survey subjects shared a common underlying mental model of ecosystem risk

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ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Tim McDaniels, and the members of my committee, Dr. Les Lavkulitch, Dr. Peter Nemetz and Dr. Terre Sattersfield for their friendship, continuing support and encouragement throughout my journey of discovery.

I would also like to acknowledge my partner in life, Donald Graham's daughter Nancy. Nancy and her Dad understood long before I did the challenges we face in managing our relationship to the natural world. Without Nancy, it is doubtful that I would have survived, much less completed my journey.

I would like to thank Andrea Porter-Chapman for her help with the data processing, and Dominic Lachance for his help in programming my web-site

1.0 INTRODUCTION

Ecosystems are important to our survival and wellbeing. The Millennium Ecosystem Assessment (MEA, 2005) was the first global attempt to achieve a consensus about ecosystems' contribution to human welfare. Yet thinking and acting in terms of ecosystems is a relatively recent occurrence. It may be intuitively appealing to some decision makers but it is still controversial from a scientific perspective. Like any concept, experts often do not agree on what the concept means or use the concept in the same way. Our knowledge of ecosystems nonetheless still consists largely of conceptual distinctions made by experts. Expert thinking about ecosystems will play a critical role in developing human responses to the challenges identified by the MEA.

This research study elicits experts' mental models of ecosystem risk in an effort to create a consensual assessment framework. (See Chapter 2, Problem Statement.) Do experts share or have different mental models of ecosystem risk? If they have different mental models, are they associated with different worldviews? Do these worldviews reflect differences in the work backgrounds of the experts? Can we find common ground among experts by attempting to logically structure and draw some general conclusions about how experts conceive of ecosystem risk? Making experts more aware of their mental models of risk may facilitate better risk communication, interdisciplinary collaboration, and breakthrough thinking.

In Chapters Three and Four, the reader will find an overview of the ecosystem concept and criticisms of its use, and a discussion of the risks to which ecosystems are now exposed. The more informed reader may wish to skip these chapters, and proceed directly to Chapter Five, Key Concepts, and Chapter Six, Research Methods, which provide the background to the study.

Chapter Five provides an explanation of several key concepts such as metaphors, mental models, worldviews, and personal constructs the reader will need to understand the study. Chapter Six describes the research methods used in the study. Experts' metaphors and mental models of risk were elicited through textual analysis, questioning key informants and by having experts perform a task. Nvivo, computer assisted qualitative data analysis software (Richards 2000), was used to structure the textual and interview data: (1) to develop a framework and typology of experts' mental models of risk, and (2) to code and analyse the interviews. Repertory grid methodologies

(Jankowicz, 2004; Fransella, Bell, & Bannister, 2004; Stewart, 1998) provided the means by which the conceptual systems of experts could be elicited without distortion, through manual or computer-based interactive interviewing techniques. The survey analysis relied in part on Shaw and Gaines's (1989) methodology for comparing the conceptual systems of experts. A worldview scale was also developed and tested to assess the extent to which the experts shared a common set of beliefs

A careful review of the scientific literature (Chapter 7) suggests that experts may have different mental models of ecosystem risk. Three different mental models of ecosystem risk seem to dominate the scientific literature. The carrying capacity model seeks to determine the optimal rate of resource consumption or waste discharge that an ecosystem can absorb (e.g., Rees, 1996). The biological integrity model focuses on the survival of natural self-regenerating communities of species (e.g., Angermeir & Karr, 1994). The ecosystem health model tries to safeguard ecosystem services and functions critical to our well-being (e.g., Costanza, 1992). The typology and framework developed from this analysis of the literature was used to develop the interview questionnaire.

The results of the interviews with key informants and the web-based survey are reported in detail in Chapter Eight. Over fifty experts knowledgeable about ecosystem risks were interviewed. These experts were drawn from many different disciplines or lines of work. They were asked to describe what they thought was important about ecosystems. The interviews were used to identify widely shared conceptual distinctions that many people use to talk about ecosystems. Many of these concepts are commonly used in the literature of assessment sciences without any clear or consistent definition. (See Appendix 1-7.) Thirty-two constructs (i.e. eco-assessment criteria) were elicited from experts, and used to develop a web-based repertory-grid survey. During the second stage of the survey the original respondents were resurveyed. Invitations were also sent out to a cross-section of professional discussion lists, inviting other experts to complete a short web-based questionnaire. Forty-two persons completed this stage of the survey. Everyone used a common set of assessment criteria developed from the original interviews to describe how several concepts or types of ecosystems differed from one another. (See Appendix 8-10.)

The Interview stage of the survey revealed that ecological integrity was the dominant mental model of risk, shared by almost half the respondents. Moreover the experts shared a common worldview. Over eighty percent of the respondents agreed with the beliefs comprising discourse #1 and three-quarters of them disagreed strongly with the constituent beliefs of discourse #3. The respondents' worldviews were most heavily influenced by their current position and previous work experience. Supporters of ecological integrity as a mental model of risk were more likely to support discourse #1 (95%) than supporters of other mental models of risk. Human population growth and consumption were also thought to be the main threats to ecosystems.

During the Internet stage of the survey, potential respondents were asked to apply a common set of assessment criteria to describe different types or concepts of ecosystems. The eco-concepts as a whole belonged to one of two contrasting metaphoric categories that distinguished pristine from human-impacted systems. Concepts such as integrity, health, sustainability, and carrying capacity appear to occupy nearly the same conceptual space. For example, ecological integrity was a subset of natural or pristine. Sustainability could not be distinguished from carrying capacity. The results also showed that there was a broad consensus among experts in their use of these assessment criteria. Therefore the findings suggest that experts may share a common underlying mental model of ecosystem risk. Moreover, the derived assessment criteria could provide a common basis for the integration of the work of different disciplines, and could facilitate risk communication and interdisciplinary collaboration

Chapter Nine provides the conclusions and recommendations for future research. Metaphors play an important role in ecosystem thinking and decision makers need to be aware of their uses and abuses. Experts' mental models of ecosystems appear to resemble working memory constructs or sketches. At this stage, their mental models appear to support description and classification of different phenomena but do not support inference and prediction. The experts' mental models in some circumstances may actually be barriers to breakthrough thinking and action. The generic set of driving forces and assessment criteria developed through this research could be used as a basis of integration. They represent commonly held beliefs, and views about the future and potential fate of the Earth's ecosystems.

2.0 PROBLEM STATEMENT

Ecosystem metaphors and mental models of risk help define ecological problems and the kinds of information needed by decision-makers to solve them. Without a shared frame of reference, decision-makers cannot evaluate the weight of evidence, compare options, set priorities or allocate resources to the management of ecosystem risks. When experts have different mental models of ecosystem risk, these mental models can become barriers to communication and a potential source of conflict. If an expert's mental model of ecosystem risk differs from that of other participants, they may find risk communication difficult. By making experts more aware of their mental models of ecosystem risk, we hope to facilitate risk communication, interdisciplinary collaboration, and breakthrough thinking.

The context for this research project is the dilemma that decision makers face when experts use conflicting frames of reference to define the same problem. Experts use different metaphors and mental models of risk to define ecological problems, influencing the kind of information provided to decision-makers. Without a shared frame of reference, decision makers may find it difficult to evaluate options or set priorities for the management of ecosystem risks.

2.1 Research Questions

Through my research I undertook to answer three research questions:

1) Do experts have different mental models of ecosystem risk?
2) Do their mental models of ecosystem risk stem from different underlying worldviews?
3) Do their worldviews arise from differences in their professional background or work experience?

An expert is someone who is widely recognized as a reliable source of specialized knowledge or skill, whose judgement is recognised by the public and his or her peers. Experts may have advanced training and/or prolonged experience. There is no need for an individual to have professional or academic qualifications to be accepted as an expert. In this respect, fishermen having many years of experience tending their nets would be recognized as being knowledgeable about the state of the fishery.

An ecosystem is a bounded set of dynamic relationships between living things and their environment. It is the smallest unit of the biosphere that can sustain life over the long term (Kimmins, 1992; Evans, 1956). Experts understand ecosystems from the parts, processes, and specific places they study (see Figure 2.1).

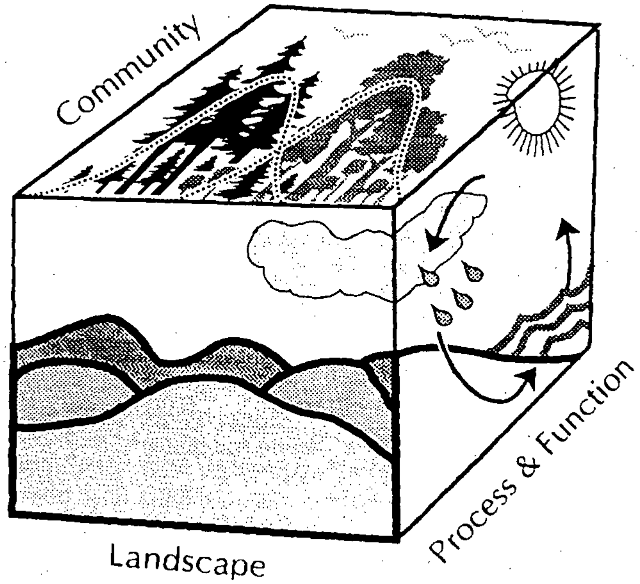

Figure 2.1 Ecosystems (adapted from Allen, Bandurski & King 1993)

Experts view ecosystems in different ways. Some see them as a collection of parts, a patchwork of biological communities. For example, conservation biologists study ecosystems as communities, guilds or assemblages of different species. Other experts have studied ecosystems solely in terms of processes, such as the exchange of materials and energy. Many see them as distinct places, set in a matrix of air, water, soil and biota. For example, landscape ecologists and geographers often look at ecosystems as real places. Experts may even think that ecosystems are a distinctive method or field of study (e.g., ecosystem approach). In order to compare experts' mental models of ecosystem risk, it is necessary first to sort out exactly what is being compared.

In trying to understand the experts' mental models of ecosystem risk, their views about major threats and driving forces of ecosystem change are also as important as their views about what should be managed, conserved, and protected.

Scientists have talked about ecosystems since the 1930s. There is considerable controversy about the nature of ecosystems and their importance to our survival. Some authors have questioned the existence of ecosystems as a distinct level of biological organization (e.g., Fitzsimmons, 1999; Kapustaka & Landis, 1998) or the usefulness of the concept (e.g., Suter, 1993). These scientists criticize attempts to give scientific credibility to what they think are essentially romantic, moral or ethical notions such as integrity, health or sustainability. Moreover, they think that these fictions can mean whatever people want them to mean, and that the vague moral imperatives they imply offer no clear way to measure progress or assess risk. However, they do admit that these ideas exert a powerful hold on the public consciousness.

In spite of the controversy, the concept is increasingly being incorporated into environmental legislation, in both Canada and the United States, as either a policy goal or a management approach. An ecosystem perspective is appealing to policy makers who are looking for a more holistic, multi-issue, place-based approach to decision making to replace existing piecemeal approaches to conservation, resource management, and environmental protection (CBD COP-5, 2004; Pitcher, 2000; CCME, 1996; Christensen et al., 1996; Maltby & Weir, 1996; Thomas, 1996; Environment Canada, 1995; US EPA, 1995; Tomalty, Gibson, and Alexander, 1995; IJC, 1978a). Thinking and acting in terms of ecosystems makes sense in the North American context because of the uneven pattern of settlement and regional industrial development. Regional ecosystem constraints have to be acknowledged in geographic areas that have particularly sensitive resources, have high pollution loadings or are subject to conflicting demands. Many environmental issues are interdependent and require a co-ordinated response strategy.

In recent years there has been widespread recognition that resources must be managed as dynamic integrative systems because the physical, chemical and biological components of the environment are interdependent (Environment Canada, 1994). Moreover, the capacity of ecosystems to sustain life should be protected (Johnson, 1988). If the productivity of farm, forest, lake and marine areas is not maintained, people may not be able to obtain the necessities of life (Kimmins, 1992).

Mental models consist of personal mental constructs that people use to simplify and organize their understanding of the world (Gentner, 2002; Rouse & Morris, 1986; Craik 1943). Mental models are highly simplified, incomplete, and constantly evolving. They typically contain errors and contradictions. The study of mental models is useful because it provides insight into how people understand a particular domain of knowledge (Johnson –Laird, 1983; Gentner & Stevens, 1983). Are expert mental models of ecosystems actual inductive models that shape human cognition or simply working memory sketches describing risky situations?

Mental models often employ metaphors and incorporate worldviews, acquired beliefs and causal assertions.

Metaphors involve direct comparisons between two seemingly unrelated domains that help us to understand one domain in terms of another (Gentner, 1983). Scientific metaphors aim to explain or predict. A source domain is used to make inferences about a target domain (e.g. human health is used to explain ecosystem health). Examples of good scientific metaphors include Kepler's use of balance scales to explain magnetism, and Rutherford's use of the solar system to explain the functioning of atoms. An example of a good contemporary scientific metaphor is greenhouse gases. In contrast, expressive metaphors evoke or describe. As metaphors become more conventional, there is a shift from comparison and inference to categorization. What distinguishes a good scientific metaphor from a conventional metaphor? Do ecosystem metaphors help or hinder expert reasoning about risk?

Some claim that the meaning of ecosystem metaphors such as health, integrity or sustainability cannot be quantified (e.g. Lancaster 2000; Ryder 1990). This research will demonstrate that these ecological concepts can be operationally defined. Once defined, it will obvious that these terms may not be conceptually distinct, and may actually represent a continuum of thought and action.

Mental models of risk are not solely matters of individual cognition (Slovic et. al., 1997) but also correspond to worldviews, deeply held concerns and beliefs about society, its functioning and potential fate (Kempton, Boster, & Hartley, 1995; Dake, 1991). Experts live and work in very different institutional and occupational contexts. Membership in different reference groups helps generate distinct ways of looking at the world, and distinctive representations of what constitutes risk. Years of professional training, work experience, institutional affiliation, and even gender differences, can influence how experts frame and gauge the relative importance of environmental issues (Slovic et al., 1997; Slovic et al., 1995; Stern & Dietz, 1994; Kraus, Malmfors & Slovic, 1992; Dake, 1992).

2.2 Research Objectives

A three-step research strategy was used to elicit experts' metaphors and mental models of risk. First, a key word search and formative evaluation of the use of these terms in the scientific literature provided the basis for interviews with experts. Second, the experts interviewed acted as key informants, and helped to identify widely shared conceptual distinctions that experts use to talk about ecosystems. During the third step of the study, experts were asked to use these shared distinctions, to describe several concepts or types of ecosystems.

My research objectives were:

- To elicit repertory grids (elements, constructs, and values) from experts that described ecosystems.
- To compare the underlying conceptual structures of experts to establish the degree of consensus or conflict.
- To determine whether or not experts drawn from different institutional and professional backgrounds have different worldviews.
- To determine if underlying differences in the conceptual structure of experts are correlated with these worldviews.
- To develop a common set of elements and constructs that experts can use to make distinctions about the domain (i.e., different types and concepts of ecosystems).
- To take the first steps in developing a conceptual model that would be suitable for guiding decision making about ecosystem risks and that would facilitate risk communication.

This study elicited experts' mental models of risk in order to answer the question: do experts have different mental models of ecosystem risk? Second, it determined whether or not differences in the way that experts look at ecosystems might be attributed to differences in their worldviews or professional backgrounds. Lastly, the study examined the feasibility of developing a consensual mental model of ecosystem risk that could help guide decision-making.

2.3 Need for the Study

Risk, by definition, is "adverse" (Bartell, Gardner & O'Neill, 1992). Environmental change, however, is neither inherently beneficial nor inherently adverse. Someone must make this judgement. Social science research has shown that our notions of risk depend on assumptions and judgements that are inherently subjective (Slovic 1997, Kunreuther & Slovic, 1996). Expert and lay perceptions of ecological risk differ (U.S.EPA 1990; 1987). Nevertheless, experts play a leading role in defining the criteria by which risks are evaluated, and in this role, their personal beliefs, values, and priorities often come into play (Lackey, 1997; Menzie-Cura, 1996).

Values refer to enduring preferences about what is moral, desirable or just (Kempton, Boster and Hartley, 1995). Values influence choice and action (Brown, 1984). They often express core life concerns or goals that people find important (Axelrod, 1994). Values can also influence perception by amplifying or filtering information (Stern & Dietz, 1994). People tend to focus on different dimensions of risk and weigh them very differently (Gregory et al., 1996; Knetsch, 1990). For, example, they place a greater value on losses relative to gains, and discount future gains at rates higher than future losses (Kahneman & Tversky, 1979). Nevertheless, at the level of values, even among groups with conflicting viewpoints, there may be a broad cultural consensus about what people want or don't want to happen to the environment (Kempton, Boster, and Hartley, 1995).

A common conceptual framework is needed to facilitate collaboration and risk communication. At present, there is no generally accepted classification of valued ecological components, processes or attributes (U.S. EPA, 1994). "Valued ecosystem components and attributes", "receptors", and "resources at risk" describe characteristics of ecosystems that are considered by society to be important and potentially at risk from human activities or natural hazards (U.S.EPA, 1992, Beanlands and Duinker, 1983). Concerns about valued ecosystem components and attributes drive environmental decision-making. Generally speaking, ecosystem concerns do not tend to be highly valued in relation to other life domains or core values. Ecosystem concerns engage us only when more fundamental life domains or core values are threatened: our health and well-being; our standard of living; our way of life; our fundamental understanding and expectations of the world around us (Eyles, 1996; 1990).

Ecological risk assessment is goal driven. Everyone agrees that ecological risk assessments should provide insights that help decision makers assure, in some respect, the value of ecosystems (Suter & Bartell, 1993). However, there is no consensus about what is to be protected or how to measure and represent these valued ecosystem components and attributes (Commission on Risk Assessment and Risk Management, 1997; Menzie-Cura, 1996; Suter & Barnthouse, 1993; Beanland & Duinker, 1983). Without clear policy goals it is difficult if not impossible to set priorities and to strike an appropriate balance among ecological, human health, and welfare concerns.

Even Glenn Suter (2000), one of the most determined critics of the ecosystem approach and the use of normative concepts, such as ecosystem health, biological integrity and sustainability in risk assessment supports the development of generic assessment endpoints. He recommends a pragmatic approach to doing explicitly and consistently what has been done implicitly and inconsistently in the past. These endpoints should not be abstract notions, such as health or integrity, or indicators, but ecological entities, processes or attributes considered to be worthy of protection in most contexts. They would be real operationally defined properties of a component of the environment. Generic assessment endpoints are needed for screening assessments to identify hazards, for monitoring environmental status and trends, and for the development of inferential methods and models. They would also facilitate risk communication, and help justify risk management action.

"Value-focused thinking" (Keeney, 1992) in contrast to "alternative-focused thinking" starts with identifying what people want (their goals) rather than what they don't want. The values held by different expert groups made explicit by their goals may be quite similar: when other things are equal nobody prefers more environmental damage, fewer jobs, higher priced products or greater health risks (Gregory & Keeney, 1994). An approach based on decision analysis involves representing values as a set of planning objectives, defining measures to judge the achievement of these objectives, and then investigating trade-offs that represent different stakeholder views about priorities among these objectives (Keeney & McDaniels, 1994). Differences in priorities or weights assigned to these values or differences in opinion about how well a measure achieves an objective are easier to resolve than differences in what is wanted (Gregory, 1997).

Our system of governance is set up to reconcile different interests, not differing views of reality (Lovins, 1977). Without a shared frame of reference, experts cannot evaluate the weight of evidence nor compare possible policy options. Moreover, if the public or stakeholders do not share the experts' perspective, the mere force of logic and more facts won't move them. The lack of consensus about what is important and worthwhile about ecosystems holds back progress in applying this approach to environmental decision-making. In setting the public policy agenda, the credibility and the usefulness of the policy advice offered by experts is undermined when their different worldviews, beliefs and values clash. What is needed is a process for building consensus about the goals of ecosystem risk management, and for defining and measuring important values that ecosystems represent.

2.4 Contribution to Knowledge

A generic set of assessment criteria was developed that express commonly held values and describe ecosystem risks in a way that can be generally understood. These assessment criteria may reflect a common underlying mental model of ecosystem risk. This research takes the preliminary steps required to explore the feasibility of creating an ecosystem risk assessment framework.

Most of the research literature focuses on eliciting lay mental models of risk and differences in the ways experts and lay people perceive risk (e.g. Bostrom, 1996; Margolis, 1996). Moreover, often the expert's mental model of risk has been presumed, and imposed like a template on lay perceptions of risk (e.g., Morgan et al., 2002.) This research elicited indirectly expert mental models of ecosystem risk. This has been attempted only once before (Lazo et al., 1999).

This research also contributes to the scientific literature on knowledge elicitation (e.g. Hoffman, 1995). It employed novel methods of knowledge elicitation and analysis (Gaines & Shaw, 1989). Moreover, it contributes to the scientific literature on the role of expert judgement in risk assessment (e.g., Otway & von Winterfeldt, 1996), expert disagreement (e.g., Chociolko, 1995) and evaluating the expertise of experts (e.g., Schrader-Frechette, 1996).

Many claim that quantitative methods are inappropriate when we aim to uncover meanings that are derived from language and are context dependent (e.g., Roberts & Wilson, 2002). This research demonstrates that this is not the case, and that computer-aided quantitative methods can vastly increase our understanding of what scholars are saying.

Observation and experimentation are recognized scientific research tools. Professional training and experience also come into play in framing risk assessment questions and in the interpretation of research findings (Slovic & Peters, 1998; Slovic 1997). There is a considerable body of research on the role of heuristics and bias in judgements (e.g., Slovic, 1992; Kahneman & Tversky, 1982). However, little research has been conducted on mental models of risk as knowledge structures underlying expert judgement.

3.0 ECOSYSTEMS

From an ecosystem perspective, nature can be partitioned into a hierarchy of biological systems from the cell to the biosphere. Each of these naturally occurring hierarchical levels of organisation shares similar temporal and spatial scales, and interacts with higher and lower levels in systematic ways. Smaller, fast-changing component systems are embedded in larger, normally slow-changing systems. Component systems only affect the larger system as contributors to trends among their cohort. Therefore each level in the organisational hierarchy experiences higher levels as constraints and the lower levels as noise (Costanza, Norton, & Haskell, 1993).

Like all natural systems, ecosystems are shaped by competing demands and limited by available resources. Terrestrial life, for example, depends on the rate at which energy of the sun is fixed by plants through the process of photosynthesis. The survival and reproduction of species depend on the transformation of energy in food webs. These food webs are fed by the biogeochemical cycling of nutrients throughout the system. As open systems, ecosystems must dissipate vast quantities of incoming solar energy through complex food webs. If enough high quality energy is available, structure emerges. If too much is applied; chaos ensues; and the system falls apart. Open systems do not maximize or minimise their functioning. Their functioning represents an optimum, a trade-off of all the forces acting on them. (See Kay & Schneider, 1994 and Schneider, & Kay 1994.)

Ecosystems cannot be decomposed into parts whose individual behaviour can be linearly summed to give the behaviour of the whole system. The magnitude and direction of change in open dynamic systems is not predictable because often it is the result of the cumulative interaction of small changes, and the pathways followed are an accident of circumstance (Kay, 1991). Critical mechanisms of ecological change are often unknown to science: either we lack signals or the ability to read them. Ecosystem processes also operate either too quickly or too slowly or at scales that are difficult for humans to observe. Moreover, lagged effects are common, meaning that some problems will continue to get worse even after action is taken to address these problems.

Ecosystems also demonstrate emergent properties. Although there may be catastrophic setbacks from time to time, generally speaking ecosystems have some degree of resilience to change and have the capacity to maintain their existing composition and level of organisation. Ecological systems can respond to environmental change by (1) operating as before, even though operations may be temporarily unsettled; (2) operating at a different level using the same dissipative structures; or (3) new structural components emerging to replace or augment the existing structure (Kay 1991). Resilience refers to the limited capacity of ecosystems to recover from perturbations, and to maintain their structural stability and their functional organisation in the face of changing environmental conditions. Ecosystems also have a considerable amount of redundancy. They can carry out critical functions in more than one way and have a reserve capacity to perform these functions beyond current needs (Bormann, 1985; Pimm, 1984). Biodiversity is a critical factor in the resilience of ecosystems because the ability of the ecosystem to regenerate is a function of the species available for the recovery process (Kay and Schneider, 1994).

Tansley (1935), the British ecologist who coined the term ecosystem, thought of it as one of the many levels of biological organisation that are the building blocks of nature. His contemporaries such as the American Clements (1916) and his rival Gleason (1939) could not agree on the nature of ecosystems. For Clements a plant community was a complex organism whose life cycle could be traced through an orderly path of ecological succession culminating in a climax vegetative community that would remain relatively stable in the face of change. For Gleason it was every plant species for itself.

Clements (1916) and Elton (1927) used their explanations of the process of plant and animal succession to support their view that nature was relatively constant in the face of change, and that nature would repair itself when disrupted, and return to its previously balanced state. Forbes' (1925) classic study of a northern lake as a microcosm, a relatively closed, self-regulating system, and Nicholson and Bailey's (1935) work on the stability of animal populations supported this point of view.

Lindeman (1942) was the first to demonstrate, through his studies of the trophic dynamics of a small lake, that ecosystems could be described and bounded in nature, and that their metabolism could be analysed. By reducing the complexity of ecosystems to energy flows, he provided a common denominator for future studies of plants, animals, and their habitat that erased the distinctions between the ecosystem's living and non-living components. Hutchinson (1948), Lindeman's mentor, developed the notion of the ecosystem's cyclical feedback or self-regulating mechanisms. It was not until the 1950s that Eugene Odum (1953) wrote the first textbook presenting the ecosystem as the unifying concept in ecology.

Aldo Leopold has also had a significant influence on thinking about ecosystems. Leopold's most famous work was the Sand County Almanac (1949) a collection of essays published after his death in which he described his notion of a "land ethic" stressing that "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends to do otherwise." (pp. 224-225). In another posthumously published collection of essays he stated:

> "The last word in ignorance is the man who says of an animal or plant: What good is it? If the biota has built something in the course of aeons, we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering."
>
> (Round River, 1953 pp.145-146)

By the 1960s, ecologists began to view ecosystems as complex systems. Because of public concern about the effects of nuclear fallout throughout the Cold War, the Oak Ridge National Laboratory became one of the largest supporters of ecosystem research in the United States, using computer simulation models to trace the movement of radionuclides within ecosystems (Van Dyne, 1966). Holling led another important node of systems research in Canada at the University of British Columbia (Holling, 1978).

Bormann and Likens (1967) were the first to develop an experimental approach to ecosystem studies. The Hubbard Brook Ecosystem Study (www.hubbardbrook.org) started in 1963. The research program used the mass-balance approach to analyse inputs, outputs, and fluxes of water and elements in small (10-80 ha) forested watersheds. They were able to measure the subsequent export of nutrients after a small watershed was deforested. They argued that the export or retention of nutrients could provide an insight into an ecosystem's functioning (Bormann & Likens, 1979; Likens et al. 1977) and were also successfully able to demonstrate the effects of acid rain on a forested ecosystem (Bormann, 1985; Likens and Bormann, 1974). Schindler and others (Schindler, 1990; Schindler & Turner, 1982; Schindler, 1974) undertook similar studies of the effects of pollutants such as phosphorus and acid rain in the late 1960's at the Experimental Lakes Area in Ontario. (See Johnston & Vallentyne, 1971.) Major advances were also made in developing regional methods of investigation and assessment (Barnthouse & Suter, 1986; Beanlands, 1983; O'Neill et al., 1982).

Ecologists have long pondered how species diversity contributes to ecosystem stability. Any ecosystem's species can be divided into so-called functional groups, based on whether they *produce*, *consume* or *decompose* organic matter, the source of energy for living organisms. Every working ecosystem needs at least one species from each of these functional groups to process energy effectively. But is it sufficient for an ecosystem to have just one species from each group (for example, a plant, a herbivore and a decomposer) or does a functioning ecosystem require the hundreds to thousands of species that we typically find (Naeem, 2004)?

The origin of the diversity–stability hypothesis was a paper written by MacArthur (1955) in which he proposed that the diversity of a food web was a measure of community stability. Charles Elton (1958) also argued that simple communities were more easily upset than richer ones, more subject to destructive fluctuations in populations, and more vulnerable to invasions. Ramon Margalef (1963) also elaborated a theory based on the premise that species diversity was the cornerstone of an emergent stable system. He observed that, as ecosystems matured, there was an increase in structural complexity and a decrease in energy flow per unit biomass. In mature climax systems, he said, the future is more dependent on the present than it is on inputs coming from the outside. In other words, the stability of the ecosystem depends in part on its biological diversity and on the complexity of its food webs. This hypothesis became accepted dogma as a result of the Brookhaven symposium in 1968 (Woodwell & Smith, 1969).

However, by the early 1970s Robert May's (1973) analysis of randomly generated statistical models of ecological communities led him to believe that diversity destabilizes community dynamics. Other ecologists (Yodzis, 1981; Pimm & Lawton, 1978) using similar approaches found results that supported May's hypothesis.

Since the Convention on Biodiversity was signed in 1992, ecologists have been deeply divided over the potential effect of biodiversity on ecosystem processes. Interest in the diversity-stability hypothesis was rekindled following the publication of a collection edited by Schulze and Mooney

(1993). Since the first experiments were carried out at Imperial College London in the 1990's (http://www.diversitas-international.org/), dozens of experimental studies have been conducted around the world. The most significant of these have been the Cedar Creek experiments (http://cedarcreek.umn.edu/) led by Tilman (Tilman et al., 2001), and the BIODEPTH experiments (http://www.cpb.bio.ic.ac.uk/biodepth/contents.html) led by Andy Hector (Hector et al., 1999).

More recent evidence has contradicted May's earlier findings. The basic argument for a positive relationship between diversity and stability at the community level rests on evidence of averaging and negative covariance effects (Tilman, 2000; McCann, 2000). Increasing diversity increases the odds that communities will contain species that may survive adverse changes in environmental conditions. Moreover, species within a given trophic level often compete with each other. Consequently, when one species declines, others are freed from competition, and increase. This reduces the population variability of the community as a whole (Naeem, 2004).

Compensatory growth is a widely observed process by which one species within a functional group often increases in response to the reduction or loss of another in the same functional group. A larger number of species per functional group increases the probability that compensatory growth will occur (Naeem & Li, 1997). Species coexist because of trade-offs (1) between their competitive abilities and their dispersal abilities; (2) between their competitive abilities and their susceptibility to disease, herbivory or predation; (3) between their abilities to live off average conditions and their abilities to exploit resource pulses; or (4) between their abilities to compete (Tilman, 2000).

May's (1973) results reflected the fact that in randomly constructed communities, strong consumer-resource interactions are unlikely to be coupled to weak interactions that dampen their destabilizing effects. Increasing diversity can increase food-web stability under one condition: the distribution of consumer–resource interaction strengths must be skewed towards weak interaction strengths (McCann, 2000). The weight of evidence now suggests that variable population densities sum to produce a relatively constant biomass at the community level. Diversity must now be added to the list of factors — including species composition, disturbance regime, soil type and climate — that influence ecosystem functioning (Tilman, 2000).

Whole ecosystem studies became increasingly unfashionable in the 1970s due to the loss of consensus in American society that urgent action was required to protect the environment, a decline in public trust in the government, and a growing resistance to active government intervention in the economy. For example, when NEPA 1970 introduced Environmental Impact Assessment, ecologists learned to base their recommendations on just a few key issues (Bocking, 1995). The demand generated by impact assessments for scientific evidence reflected the demand of American regulatory proceedings for evidence that could be considered factual and value-free. In the Hudson River Power Station hearings, ecologists found that by focusing on a single fish species rather than the entire ecosystem they were able to provide evidence that was more reliable and better suited to the cost and time constraints imposed by the impact assessment process.

However, following the publication of Silent Spring in 1962, public concern grew about the effects of pesticides on fish and wildlife and the threat of cancer in humans. Because of the multiple sources, pathways, and routes of exposure to toxic substances in the Great Lakes Basin, the Science Advisory Board recommended an "ecosystem approach" to the International Joint Commission for the assessment and control of pollution in the Great Lakes (IJC, 1978a & b). The ecosystem approach has become the framework through which environmental activists, industry, the scientific community, government and the public have created a shared vision of the future of the Great Lakes region (Bell, 1994). It has been widely copied elsewhere (Convention on Biological Diversity COP-5 2004; Maltby & Weir, 1996; U.S. CRS, 1994). Some simply view the ecosystem approach as a process of collaborative decision-making (Keystone Centre, 1996), a matter of getting enough people to the table so that society can make a decision about your value choices.

An ecosystem or adaptive management approach to policy and planning has emerged since the 1970's (Christensen et al., 1996; Lubchenco, 1994; Walters & Holling, 1990; Walters, 1986; Holling ed., 1978). It starts with an acceptance of scientific uncertainty, policies as experiments and the need to learn from experience – that it is better to accept change and prepare for it. Human beings and their institutions are parts of the system under study. As a management approach, it attempts to accommodate multiple values and interests. Ecosystem management also seeks to balance current use with future needs and to avoid foreclosing any vital options. It defines progress in sustainable ways. The goals of ecosystem management (Grumbine, 1994) are to maintain viable populations of all native species, maintain evolutionary and ecological processes, and to incorporate within a system of protected areas a representative selection of ecosystem types across their natural range of variation. Ecosystem management hopes to accommodate human use and occupancy within these constraints.

Some think that a paradigm shift in theory and practice (described in Table 3.1) is already underway.

Table 3.1 The Paradigm Shift in Environmental Science.

FROM	TO
Resources	Ecosystems
Humans	Humans and other species
Laboratory	Field
Reactive	Proactive
Short term effects	Long run sustainability
Discipline-based approaches	Multi-disciplinary approaches
Fragmented studies	Integrated assessments

Paradigms shape how people perceive problems and filter and evaluate evidence. A paradigm is the dominant intellectual perspective defining the conduct of inquiry in a given domain. It is the fundamental conceptual framework for a subject matter, defining what should be studied, what questions should be asked, and what rules should be used to interpret the answers that are obtained. The paradigm is the broadest unit of consensus, defining normal science within a scientific community and serving to differentiate one scientific community from another. (See Funtowitcz & Ravetz, 1992; Kuhn, 1970.) Paradigms also serve ideological functions because, as beliefs about what the world is like, they are used to legitimize or justify courses of action.

3.1 Criticisms of the Ecosystem Approach

One of the major obstacles limiting the standing of ecology, as a science, is the lack of a commonly accepted theoretical framework (Vigerstad & McCarty, 2000, Schneider & Kay, 1994). Whereas Odum (1953) once hoped that the ecosystem would be the unifying concept in ecology, others claim that the concept is fading from ecological theory (O'Neil, 2001; Worster, 1990).

Few ecologists today study whole ecosystems. The most challenging and practically important problems of contemporary ecological science occur over much longer time scales and much larger spatial scales than are currently being investigated. May (1999) found, for example, that only 25 % of ecological field studies exceeded plots $10m^2$ in size and forty percent lasted less than a year.

Some critics even question the existence of ecosystems (Fitzimmons, 1999; Kapustka & Landis, 1998). More than sixty years after Tansey first proposed the concept, ecologists have not yet developed a recognized classification scheme for ecosystems (U.S. NRC, 1993). Ecosystems are mental constructs not real entities.

Those who accept the usefulness of the ecosystem concept cannot agree on the nature of ecosystems. For some, ecosystems are tangible spatial entities, patchworks of living biological communities, governed by the laws of natural selection and evolution (O'Neil et al., 1986). O'Neil (1996) called them localized transient experiments in species interaction. Still others think of ecosystems as a nested set of diffuse temporal functions, explaining thermodynamic processes such as energy flows and nutrient cycling (Allen & Hoekstra, 1992; Kay, 1991). Finally, the concept is often used as a convenient heuristic device to describe the problem space being studied. Natural scales of integration can be used to study issues such as deforestation (Bormann et al., 1974). A medium of interaction such as water can be used to represent the processes affected, and to define the boundary of a system such as a watershed that is being studied. Moreover, ecosystems themselves have become the subject of action plans or response strategies (EC, 2000; EC 1995; CCME, 1996; IJC, 1994).

Strenuous opposition comes from those who claim the ecosystem approach is unscientific or simply not useful (e.g., Suter & Bartell, 1993). Thinking and acting in terms of ecosystems challenges the norms of conventional science. One commentator referred to the ecosystem approach as the end of the world as we know it (Gibson, 1994) because we now face an uncertain world, where there are no longer any linear cause and effect mechanisms to blame.

Ecosystem studies in recent years have come to rely on normative constructs such as health and integrity. Critics insist that values, moral and ethical concerns, have no place in scientific inquiry, and defend science as methodology for acquiring objective information through observation and experimentation (Lancaster, 2000; Gilbertson, 2000; Kapustka & Landis, 1998). However, they confuse means with ends. For example, the IJC (1997) still uses scientific methods to achieve its "fishable, drinkable, and swimmable" goals for the Great Lakes. Water quality objectives are based on aquatic toxicology studies, using experimental organisms under controlled laboratory conditions, and these objectives are incorporated in standards or guidelines that are enforced through periodic sampling (Gilberston, 2000).

Critics of the ecosystem approach have a different orientation to science than supporters. They prefer traditional reductionist scientific methods, which require the investigator to choose a narrow enough study focus to permit hypothesis testing under controlled conditions. Typically this means a focus on the effects on individual organisms while ignoring issues that affect other levels of biological organisation. Underscoring this point of view is the belief that evolution and natural selection operate exclusively at the level of the individual (Kapustka & Landis, 1998; Williams, 1966). Therefore risk assessments and recovery plans should be tailored to the life history needs of individual species (Goldstein, 1999). The critics go further by suggesting, for example, that any effects that cannot be accounted for by conventional single-species toxicity tests are unlikely to be accounted for by ecosystem-level responses (Suter, 1998 personal communication). In other words, if one's goal is to protect individuals, ecosystem-level effects can be disregarded.

On the other hand, ecosystem-level assessments are clearly required when ecological processes such as acidification or eutrophication are involved. Traditional toxicological methods have failed to deal with ecosystem complexity and cannot be relied upon to evaluate or interpret ecological effects (Munkittrick & McCarty 1995, Harris et al., 1990). Ecologically relevant changes generally involve growth and reproduction or survival regardless of the biochemical factors involved. Schindler (1987) found in his studies that indirect effects were nearly always more significant than direct effects. These indirect effects include changes in individual behaviour, species composition and survival, population levels, food and habitat availability. Moreover, lab results are not helpful in dealing with complex mixtures or synergistic effects. Lab findings are also rarely extrapolated to populations and confirmed in the field. As well, pollutant or species-at-a-time response strategies are increasingly impractical in today's world.

More recently, the ecosystem approach has come under fire from critics who say that it is intellectually dishonest, using fictions about nature to lend scientific credibility to what are essentially spiritual, romantic or ethical ideals (LeRoy & Cooper, 2000; Fitzimmons, 1999). Moreover, they feel that these ideals will also mean that we will have to revise ground rules under which society operates, leading to more authoritarian and less democratic decision-making, and a significant erosion of property rights and individual liberty.

3.2 Ecological Risk Assessment

Risk is a combination of two factors: the probability that an adverse event will occur, and the consequences of an adverse event. Risk analysis has only recently been applied to ecological issues. EPA's Framework for Ecological Risk Assessment (1992) extended the four-step paradigm, developed by the NRC in Risk Assessment in the Federal Government: Managing the Process (1983) for health risk assessment, to ecological issues. The starting point for developing the framework and guidelines in North America was the work of Beanlands and Duinker (1983) and Barnthouse and Suter (1986). Both EPA (1992) and Environment Canada (1996) have since developed guidelines for ecological risk assessment. Ecological risk assessment is an assessment of the risks of business as usual, not an evaluation of the potential benefits from alternatives to business as usual.

Historically, practitioners have insisted that risk assessment must be kept separate from risk management (see e.g., Ruckelshaus, 1985, and Suter & Barnthouse, 1993). They claimed the role of the risk assessor, as a subject-matter expert, was to provide objective answers to well-defined technical questions. Complex policy choices involving subjective value trade-offs were thought to be better left to risk managers and politicians. Munkittrick (2004) has identified three fundamentally different approaches to assessment: the stressor, effects, and value based approaches (see Table 3.2)

Table 3.2 Comparison of Different Approaches to Assessment

Criteria	Stressor	Effects	Values
Focus	Stress-response	Ecological indicators	Ecosystem uses or benefits
Boundaries	Impact area	Biological components	Human uses
Advantage	Based upon experience	Field studies	User surveys
Disadvantage	Ignores interactions and cumulative effects	Time and expense of baseline monitoring	Not based upon ecosystem properties or responses
Question	How to mitigate critical impacts?	What factors limit system performance?	How do I protect important uses?

Source: adapted from Munkittrick, 2004

In Munkittrick's terms traditional risk assessment combines the values and stressor-based approaches that focus on potential stressor-response pathways and on valued ecosystem components or uses. Stakeholders play a different role in the stressor and effects based approach to assessment (Munkittrick, 2004). In the stress-based approach, stakeholders help define the valued ecosystem components, while in the effects-based approach their role is to help define whether or not the changes are acceptable.

Ecological risk assessment is a three-stage process used to estimate the probability of adverse effects on plants and animals from exposure to stressors (chemical, physical or biological agents that may induce adverse effects). The process includes problem formulation, analysis of exposure and effects, and risk characterization. (See U.S.EPA, 1992 and EC, 1996.) The results of ecological risk assessments, in most cases, are not scientific estimates of actual risk, but conditional estimates of the risk that could exist under specified sets of assumptions. The state-of-the-art practice in ecological risk assessment is an expert judgement process (U.S.EPA, 1992). Combined with political, engineering, social and economic information, it can be useful for guiding decisions about risk reduction.

3.2.1 Problem Formulation

Problem formulation is the planning stage of assessment. Goals are set, data gaps are identified and a conceptual framework for assessment is adopted. Identifying the actual values to be protected (assessment endpoints) and selecting ways in which these can be measured and evaluated (measurement endpoints) are the most important steps in this process (Suter & Barnthouse, 1993).

The conceptual framework describes how the characteristics of ecological systems (endpoints) are affected by exposure to stressors. There is no commonly accepted set of valued ecosystem components, attributes, processes, or relationships, that is used either as the focus of the assessment or to define its scope. Although selection and articulation of goals and endpoints is critical to the success of any assessment, there is no guidance given on how this should be done or whom to involve in the process (Menzie-Cura, 1996; U.S.EPA 1994).

Ecological risk assessments typically evaluate the effects of stressors on individual organisms. Only rarely are the effects at a biochemical, individual, population or community level evaluated in terms of the consequences for the ecosystem as a whole. Community changes are ecologically relevant, but may only be detectable after a long time lag, may be difficult to reverse, and may be the result of changes that are difficult to define. At the other extreme, biochemical responses happen quickly, and can more often be related to specific causes, but may have little ecological relevance and are easily reversed. The exact nature of the changes being monitored depends on the endpoints that will be used in management decision-making. However, it is important to develop an assessment approach that balances protection and detection with reversibility and relevance (Munkittrick, 2004). Society needs sufficient warning to adapt to any unanticipated consequences before they become irreversible.

How are problems defined and how big a change warrants action? A consensus is needed on the nature of changes that are socially or economically unacceptable. For example, loss of a commercially valuable fish species or contamination that prevents consumption are obvious problems. Ecosystems where fish cannot grow or reproduce at a normal rate or survive a normal lifespan are less obvious. Significant changes in growth, reproductive development, and energy storage and age distribution are a warning signs that fish populations may be at risk to significant damage, which could threaten the survival of the species (Munkittrick, 2004).

If the problem is defined incorrectly or too narrowly, time and effort will be spent exploring and implementing solutions that are inadequate, less effective or more costly than need have been. It is now recognised that the analyst should collaborate with risk managers and stakeholders in formulating the assessment problem, taking into account the economic, social and political considerations related to the questions being addressed (Commission on Risk Assessment and Risk Management, 1997; Menzie-Cura, 1996; EC, 1996). Stakeholders are more likely to accept and implement decisions in which they have had a role, and to bring to the table important information, knowledge, expertise, and insights for crafting workable solutions. If they do not participate in formulating the assessment problem, the analysis is less likely to provide useful information for decision-making.

3.2.2 Analysis of Exposure and Effects

The analysis stage of ecological risk assessments involves consideration of exposure and effects. The potential sources of exposure, pathways of contamination (e.g., air, water, soil and sediment) and ultimate fate in the environment are determined. As well, the spatial and temporal patterns of exposure are investigated. Susceptibility and linkages with adverse effects are evaluated. Stress-response relationships are quantified. Ecological risks are more complex than threats to human health because they involve multiple endpoints, sources, and pathways of exposure. Moreover, ecological risks are often interdependent. Consequently, the results of the analysis are frequently uncertain. A high degree of professional judgement is required to interpret them, and preliminary conclusions must often be revisited when new findings cast light on earlier deliberations and decisions. Therefore, a tiered or iterative approach to assessment is now recommended (Commission on Risk Assessment and Risk Management, 1997; Menzie-Cura, 1996; EC, 1996). There is no longer any pretence that ecological risk assessment provides "hard" answers or is "free" of outside influences.

3.2.3 Risk Characterization

In risk characterization, the likelihood that adverse ecological effects could occur as a result of exposure to stressors is evaluated. The significance or consequences of the risks may also be addressed. Unfortunately, there is seldom enough information to quantify stress-exposure-response relationships. So risk assessors must use a combination of scientific information and their best judgement to characterize risks. Considerable professional judgement is called for in evaluating the underlying data and studies for accuracy, reliability and relevance. There is no consensus on how to evaluate the "weight-of-evidence" (Commission on Risk Assessment and Risk Management, 1997; Menzie-Cura, 1996). Experts are largely responsible for deciding how much importance to assign to differences in probability versus differences in magnitude of harm, and how to account for qualitative differences in outcome (Graham and Hammitt, 1996). Their choices of risk metric, time frame and context have an important bearing on decision-making. Often the approach adopted reflects an individual's professional point of view, and the process and conclusions may not be transparent to others.

Ecological risk assessments involve a high degree of uncertainty. Sources of uncertainty include the following: the inherent randomness of the phenomena being studied (stochastic); imperfect or incomplete knowledge (ignorance); and outright mistakes (error). From a decision-maker's perspective, the level of uncertainty in ecological risk estimates rarely receives due consideration. Stakeholders may react differently to uncertainty in decision-making. For example, risk managers' may fear "paralysis by analysis". Industry sometimes denies responsibility and demands "proof" of the linkage between cause and harm. The public frequently is less concerned about proof than the need for "prudent action".

The assessment of ecosystem risk includes value judgements about more than the probability and consequences of ecological effects (Kunreuther & Slovic, 1996). Ecological risk assessment depends on expert judgements at every stage of the process, from the initial structuring of the risk problem, to deciding what consequences (endpoints) to include in the analysis and what constitutes harm. Every way of presenting information is a frame that has a strong influence on decision-making.

Persistent policy disagreements about risk acceptability have their origin in different value or belief systems: how to define risk and related concepts, how much weight or importance to attach to the different dimensions being considered, how to frame or structure the decision or problem (Vaughan & Seifert, 1992). Unless a common framework is negotiated, a consensus or agreement may not be possible. Moreover, when dissimilar frameworks are used, more information, regardless of its quality, will do little to narrow differences because information judged to be important from one perspective might be deemed to be worthless from another.

Expert judgement contributes operational definitions and measurements of assessment values and management goals. Measurement endpoints are characteristics or attributes that may be affected by exposure to a stressor (Suter, 1990). Ideally endpoints should be policy relevant, operationally defined and measured, using a standard procedure with a documented performance and low measurement error. Measurement endpoints should be interpretable: that is to say, it should be possible to distinguish acceptable from unacceptable conditions in a scientific and legally defensible way. They should be timely, providing information quickly enough to initiate management action before unacceptable damage occurs.

Industry and public interest groups have completely different perspectives on evaluating evidence. Industry groups tend to be risk takers who want the offsetting benefits of risky activities taken into account. Public interest groups tend to be risk averse, and frequently want multiple criteria taken into consideration.

De minimus or zero levels of risk may not be achievable or measurable. Even the notion of a threshold level of exposure may be a fiction. Damage often occurs at lower levels of exposure, especially to the more sensitive members of a population or vulnerable components of an ecosystem. In fact there may be no threshold level of exposure for many environmental pollutants. Optimal allocation and limited budget criteria suggest that efforts to reduce risk beyond a certain level may not be worthwhile because the costs may be prohibitive or the returns negligible.

Many of the environmental issues dealt with in ecosystem risk analysis are inherently uncertain and perhaps unknowable. The public is not likely to be concerned about an environmental issue until it feels that it is directly threatened or can actually observe the effects of such changes. Due to the way in which the ecosystem responds to human intervention (long lag times or feedback loops), by the time it is possible to observe these effects, the ecosystem is already under major stress and significant adverse changes have already taken place. It is therefore very difficult to muster stakeholder and public support for action during the initial stages of the stress-response curve. Early in the life cycle of an issue much can be learnt, non-reversible changes can be avoided, and more expensive risk management can be put off. We are often forced to act and learn from experience. Therefore, experts may be called upon to help policy makers choose an appropriate interim response strategy based on the current state of knowledge before all the necessary evidence have been assembled.

Environmental decision-making faces several challenges. Decision-makers are forced to allocate time, money, and effort on an ongoing basis to resolving a broad range of environmental issues. At any given time, knowledge about many of these issues is incomplete or highly uncertain. Because knowledge is acquired incrementally, it is critical not to foreclose future options and to leave room for mid-course adjustments. Moreover, if budgetary constraints are a paramount consideration, the tendency to waste resources on innocuous concerns or to allocate an inordinate amount of resources to controlling small risks must be curbed.

3.3 The Context for Environmental Decision Making

It was only in the early 1970s that the environment was recognized for the first time as a distinct focus of public policy and domain of constitutional jurisdiction. An ecological perspective was explicitly adopted in describing the need for better stewardship of the environment:

> "Only when the source and effects lie within a particular jurisdiction, does a government have the incentive and jurisdiction to deal effectively with environmental issues. Because the effects of many problems spill over jurisdictional boundaries or the source lies outside but the effects are felt within its boundaries, it was recognized that joint action by one or more jurisdictions, domestic and foreign, is now required to deal effectively with most environmental issues. Moreover, for the first time, a danger to the environment of a state was recognized as a threat to its security.
>
> "Man and all living things are subjects of a global system. This global system has many component ecosystems, all interdependent; all tied together by an infinite web of linkages... the biosphere, the living part of the land, water and atmosphere of the planet... A thin envelope circling the globe... sustains a hierarchy of millions of plant and animal species, including man, all interconnected and dependent upon one another for life support. It is this living system that is threatened... in discussing the pressure of human activities on air, land, water and other resources, the primary concern is always with the side effects of this pressure on the biosphere and especially on human health. Furthermore there are four characteristics of global ecological systems, which at the time appeared to be central, both to the relationship between human activity and environmental quality, and indirectly to the appropriate role of government in environmental management. These are the fact of a finite planet, (our dependence on the products of) photosynthesis, biological magnification

(of chemical contaminants in the food chain) and the rising level of the by-products (of combustion) in the atmosphere."

(MacNeill 1971 pp.10-11).

In Canada, when the federal environmental ministry became a reality in 1971, the focus on ecosystems and the health of the biosphere was forgotten, and the ministry was organized along traditional resource management lines. Existing services (e.g., weather, fisheries, forestry) were simply repackaged.

Conservation activities concentrated on the establishment of protected areas (e.g., new parks). An environmental protection service was established for the first time. It reflected the industrial organization of the economic sectors it regulated and typically concurred with the prevailing consensus about what was technologically and economically feasible. Source-oriented discharge levels and effects-based environmental quality targets (for air, drinking water, soils and sediments, fish and game) were set for the more common pollutants, reflecting notions about how much contamination could be absorbed without lasting harmful effects.

In response to a series of mega-projects, such as the James Bay dams and diversions, and the McKenzie Valley pipeline, the public insisted that the government conduct impartial environmental impact assessments of major development projects (such as dams and diversions, pipelines), and that their more significant impacts be mitigated throughout the project's design, construction or operations. Public review of persistent, bioaccumulating, toxic chemicals was also undertaken and independent regulatory action initiated. In a country as large and diverse as Canada, the uneven distribution of its population and industrial development has resulted in a "brown field - green field" effect. Remedial action plans were undertaken to clean up the most significant contaminated sites and natural systems (e.g., Great Lakes action plans.) The loss of wildlife habitat and "charismatic mega-fauna", such as grizzly bears, and wolves continues to be a source of public concern.

After all this effort and expense, why are governments and industry still struggling to get a passing grade on their environmental report cards? These initiatives dealt primarily with the effects rather than the sources of environmental problems. Population growth, household formation, consumption and lifestyle choices continue to be the source of overwhelming pressure on environmental resources. Economic policies and decision making (e.g., energy and food production) often undermine attempts to achieve environmental quality goals.

As well, these initiatives failed to recognise the existence of complex linkages and feedback loops in nature. For example, even where parks and protected areas have been created, species are struggling for survival because only part of the ecosystem necessary for their survival is protected or because of the impact of competing human use. Resource management activities, such as budworm spraying, have often made natural systems more vulnerable to catastrophic change. Everywhere, due to the global cycling of pollutants, we can find traces of chemical contamination, even in pristine systems, such as the high Arctic, where we least expect it. Finally, the declining marginal returns from piecemeal efforts to protect the environment are a source of frustration to those who want a clean environment, and also want a competitive economy.

4.0 ECOSYSTEMS AT RISK

If one judges from the debate in the scientific literature, where ecosystems were once thought to be the unifying concept in ecology (Odum, 1953), many now think the concept is fading from sight (Worster, 1990), or perhaps should be buried with "full military honours" (O'Neil, 2001). Others question the existence of ecosystems (e.g., Fitzimmons, 1999) or claim that the concept is simply not very useful (Suter, 1998). However, the world's leaders seem to disagree.

The Millennium Ecosystem Assessment (MEA) was called for by United Nations Secretary-General Kofi Annan in 2000 in his report to the UN General Assembly, *We the Peoples: The Role of the United Nations in the 21st Century.* The achievement of the UN's millennial development goals is jeopardised by the sorry state of the world's ecosystems. Governments subsequently supported the establishment of an international assessment panel, through decisions taken by three international conventions, and the MEA was initiated in 2001.

The goal of the MEA is to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The premise of the assessment is that people are integral parts of ecosystems, and that a dynamic interaction exists between them and other parts of their ecosystems. Changing human conditions are driving, directly and indirectly, changes in ecosystems, which impact human well-being.

The Millennium Ecosystem Assessment (in press) will synthesize information from the scientific literature and relevant peer reviewed datasets and models. It incorporates knowledge held by the private sector, local communities, and indigenous peoples. The MEA did not aim to generate new primary knowledge, but instead sought to add value to existing information by collating, evaluating, summarizing, interpreting, and communicating it in a useful form. It recognised that the scientific and assessment tools and models needed to undertake a cross-scale integrated assessment and to project future changes in ecosystem services are only now being developed.

Ecosystem services in the MEA's terms are the benefits that humans obtain from ecosystems. They include the provision of food, fuel, fibre and water; non-material benefits such as aesthetic appreciation, recreation, and spiritual renewal; the regulation of ecological processes such as climate, flood, drought and disease; and the maintenance of basic processes such as soil formation, nutrient cycling, and primary production.

The demand for ecosystem services has become so great that trade-offs among services have become the rule (Samper, 2003). For example, a country can increase its food supply by converting a forest to agriculture, but in doing so, it decreases the supply of services of equal or greater value, such as clean water, timber, flood regulation or drought control. There are many indications that human demands on ecosystems will continue to grow in the coming decades. Current estimates of 3 billion more people and a quadrupling of the world economy by 2050 will escalate the consumption of natural resources and the scope and severity of the associated environmental impacts.

> The bottom line
>
> At the heart of this assessment is a stark warning. Human activity is putting such a strain on the natural functions of the Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted.
>
> The provision of food, fresh water, energy, and materials to a growing population has come at considerable cost to the complex systems of plants, animals, and biological processes that make the planet habitable.
>
> As human demands increase in coming decades, these systems will face even greater pressures - and the risk of further weakening the natural infrastructure on which societies depend.
>
> Protecting and improving our future well-being requires wiser and less destructive use of natural assets. This in turn involves major changes in the way we make and implement decisions.
>
> (MEA Board, 2005)

The Millennium Ecosystem Assessment (2005) has reached four main conclusions:

1) Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fibre, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.
2) The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs, have often exacerbated the poverty of disadvantaged groups of people, and have increased risk of non-linear changes. Examples of non-linear changes include:
    - Disease emergence
    - Eutrophication and hypoxia
    - Fisheries collapse
    - Species introduction and losses
    - Regional climate change

    These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.
3) The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals of the United Nations.
4) To reverse the degradation of ecosystems while meeting and increasing demands for their services requires significant changes in policies, institutions, and practices that are not currently under way.

What are the most critical factors causing adverse ecosystem changes? The MEA (2005) uses the term drivers to describe the factors causing adverse changes in ecosystems. Others have used the terms "pressures" or "threats". The MEA identified the following drivers:

Direct Drivers

- The most important direct drivers of change in ecosystems are habitat change (land use change, physical modification of rivers, or water withdrawal from rivers), overexploitation, invasive species, pollution, and climate change:

- For terrestrial ecosystems the most important drivers have been land use changes and the application of new technologies
- For marine systems, the most important driver has been fishing.
- For freshwater ecosystems, the most important drivers have been modification of water regimes, invasive species, and pollution.
- For marine, terrestrial, and freshwater systems excessive nutrient loading is one of the most important direct drivers of ecosystem change

Indirect Drivers:

- Demographic drivers – global population growth, migration and settlement
- Economic drivers – industrial production, and changes in the structure of consumption

Humans are re-engineering ecosystems on a planetary scale with little understanding of the consequences for themselves and other living things. Most of the driving factors identified in the MEA are critically reviewed and discussed in this chapter. The chapter provides the context for this study of the different expert conceptions of ecosystem risk.

4.1 Human Population Growth and Consumption

Current estimates of the world's population exceed six billion people. During the twentieth century the world's population increased 3.7 fold (Cohen, 1995). The world's population doubled in the second half of the twentieth century; never before has the world's population doubled in anyone's lifetime. In absolute terms, putting the first billion people on Earth took from the beginning of time to about 1830 and adding the last billion took about twelve years (Cohen, 1997; Keyfitz, 1989).

The world's urban population increased from about 0.2 billion to 2.9 billion in the twentieth century (Population Reference Bureau, 2004; UN Development Program, 2000). Over the last forty years the urban share of the world's population has increased from a third to almost one half of the global total. Fifty percent of the world's population inhabits less than three percent of the available land area at average densities of greater than 300 people/km^2 (Small, 2001). In 1960, only New York and Tokyo had more than 10 million people, but by the end of the twentieth century there were more than fifteen mega cities. The number of cities with populations in excess of 1 million increased from 17 in 1900 to 388 by the year 2000.

Cultural breakthroughs have resulted in three surges in human population growth. Each breakthrough helped increase human population more than ten fold. Between 200,000 and 40,000 years before present, humans organized into bands of hunter/ gatherers and through language passed on to each succeeding generation the knowledge of how to build shelters and fires, and how to make clothing and tools, allowing them to live in diverse habitats and spread throughout the world. The emergence of agriculture and the rise of towns and cities, about 12,000 years before present, helped humans to increase the carrying capacity of various habitats. Finally, the industrial and agricultural revolution, as well as improved medicine and sanitation, helped humans sidestep most of the limiting factors to population growth. Adding another billion people to the world's population is taking less and less time (see Table 4.1).

Table 4.1 Human Population Growth throughout History

Elapsed time	Year	Human Population
~2,000,000 years	~10,000 BC	5 - 10 million
10,000 years	1 A.D.	170 million
1,800 years	1800	1,000,000,000
130 years	1930	2,000,000,000
30 years	1960	3,000,000,000
15 years	1975	4,000,000,000
12 years	1987	5,000,000,000
6 years	1999	6,000,000,000

Source: McMichael 1993, Gibbons 1963, Deevey 1960

Notes: On October 12, 1999 the population of the Earth reached 6,000,000,000 - "Y6B"
World Population Clock: http://opr.princeton.edu/popclock/

Of the 6 billion people currently living, about half live in poverty and at least one fifth are severely under-nourished. The rest live out their lives in comparative comfort and health. Present estimates are that the world's population will reach 8 to 12 billion before the end of the twenty-first century (Sustainableworld.Com 2004; UN Population Division 2002; U.S. Census Bureau International Data Base 2000).

Nearly 99 percent of all the projected population increase is taking place in poor nations, while population size is static or declining in the rich nations. Among major industrialized nations, currently only the United States now has significant population growth. The World Population Data Sheet (2004), for example, suggests that the world population could rise 45 percent to nearly 9.3 billion by mid-century. While the population of developed countries would rise 4 percent to over 1.2 billion, the population in developing nations would surge by 55 percent to over 8 billion. Countries in Africa and south Asia would see the largest increases.

The global population growth rate peaked at 2.1 percent per year in the late 1960s and has since fallen to 1.4 percent (Population Reference Bureau, 2004). However, if every couple on the planet decided to have only two children today, human population would keep growing for another sixty years because a third of the world's population is about to enter their reproductive years.

Since the mid-1990s the number of environmental refugees has outnumbered those from war, and could double in the next in the next ten years (Myers, 2002; UNFPA, 2001). Population projections do not take explicit account of possible environmental feedbacks on mortality. First, there is no consensus on the limiting factors to population growth or the human carrying capacity of the environment. On the contrary, the range of these estimates has widened over time (Cohen, 1995). Second, even if there were a consensus about the relevant factors it may be too difficult to project the future impact of these factors on population growth (Keyfitz, 1982). Third, even if these factors could be reliably predicted, their effects are mediated through economic, political, and cultural systems in ways that are not possible to quantify with confidence (Cohen, 1998).

A global population of six billion for our species is extraordinary. For most of human history, until the agricultural revolution started about 10,000 years ago, humans were apparently about as rare or abundant as carnivores or omnivores of comparable weight. Cohen (1997) thought that the allometric relationship between body size and population density could provide insight into whether the pre-agricultural population of 2 to 20 million people or the current population of 5 to 6 billion people is unusual. Generally the more a typical adult weighs the fewer numbers of individuals per unit land area at any one time. Therefore, if humans took on the role of large tropical herbivores, as the result of inventing agriculture, Cohen (1997) thought their global abundance should currently fall between 91 million and 190 million.

There are no easy answers to the question: "How many people can the earth support (and of course at what level of well-being)?" Cohen (1995) suggested we think in terms of three possible but nonexclusive strategies:

1. Make a bigger pie: Increase human productive capacities through technology and innovation
2. Put fewer forks on the table: Reduce numbers and expectations of people through such means as family planning and vegetarian diets
3. Teach better manners: Change the terms of people's interactions through improved planning and government to enhance social justice.

Humans are by far the main threat to the world's ecosystems. The wealthiest billion people consume the most and generate the most waste. The poorest billion are destroying their resource base in the daily struggle to avoid starvation. In addition, there are the billions of people in between who are doing their best to increase their own standard of living, largely through increased consumption.

Overall, human beings now consume between 35 and 40 percent of the net primary productivity of global ecosystems (Pauly & Christensen, 1995; Vitousek et al., 1986). More recently Pimm (2001) claimed that humans now monopolize 40 percent of annual plant growth, and 35 percent of the oceans' continental shelf production.

4.2 Land Use Conversion

For most of the 10,000-year history of settled agriculture, the environmental effects of land-use change have been scattered in time and space. According to Houghton (1994), half the world's croplands were added in the last 90 years, and the land used productively by humans today now comprises 32 percent of the Earth's land surface. Soil erosion is now a common problem with soil loss exceeding soil formation rates by a factor of ten (Pimentel, 1993).

Since 1950, the so-called Green Revolution has placed a brake on further land use conversions, increasing yields three fold while the world's population doubled (Trewavas 2002). Current agricultural technology permits one person to be fed from food grown on no more than 2000m^2 of cropland, where in Malthus's time it took almost 20,000 m^2 of cropland (Evans, 1998). To meet projected population increases and demands for diets richer in cereals and meat using current technology, the global agricultural land base in fifty years will have to increase by 18 percent, representing a world-wide loss of natural ecosystems greater in area than the United States (Tilman et al., 2001).

In the last century, half the world's forests and wetlands were also lost in the quest for food, fuel, and fibre (Johnson, 2001). Plantations provide an increasing percentage of the global harvest of round wood, amounting to 35 percent of the global harvest in 2000. However, fuel wood is still the primary source of energy for heating for some 2.6 billion people. Fuel wood is 55 percent of global wood consumption. Although Africa only accounts for 7 percent of the world's energy use, 40 percent of its energy needs are met through the use of fuel wood and charcoal. (See MEA, 2005.)

Sixty percent of Canada's forestlands (340 million hectares) have been untouched by logging activities for at least fifty years, and large enough (at least fifty thousand hectares) to conserve all their naturally occurring species and ecological processes. This amounts to 25 percent of the untouched wild forestlands left in the world (see www.globalforestwatch.org). Over 40 percent of the old growth in southern or temperate parts of Canada has already been harvested.

4.3 Water Diversions and Use

Humans use between 45 and 50 percent of the world's readily available freshwater (Vitousek et al., 1997; Postel et al., 1996). Between 1960 and 2000, reservoir storage capacity quadrupled. As a result, the amount of water stored behind large dams is estimated to be three to six times the amount held by natural river channels (this excludes natural lakes). Water withdrawals from lakes and rivers for irrigation, household, and industrial use have also doubled in the last 40 years (MEA, 2005). Water shortages already exist in many regions (water is considered to be scarce when its availability drops below one million litres per capita), and more than one billion people do not have adequate drinking water (Pimentel et al., 2004). Twenty percent of the world's population lack safe drinking water. Moreover, ninety percent of the infectious diseases in developing countries are water-borne. Agriculture requires about seventy percent of all fresh water used by humans; for example, on average approximately 1000 litres of water are required to produce one kilogram of cereal grain, 1600 litres of water to produce one kilogram of rice and 43,000 litres to produce one kilogram of beef (Pimentel et al., 2004). New water supplies are now more likely to come from conservation, recycling, and improved water-use efficiency rather than from large-scale development projects such as dams and reservoirs.

4.4 The Spread of Monocultures

In 1982, the Food and Agricultural Organization (FAO) concluded that by the year 2000, 64 countries (29 of them in Africa) would not be able to feed themselves if they continued to use subsistence farming techniques. Of these countries, 36 would not be able to feed themselves with intermediate farming technology (some fertilisers, pesticides, improved seeds) and 19 would not be able feed them selves even with advanced agricultural technology. As bleak as the FAO projections were, they have proven to be too optimistic (Pulliam & Haddad, 1994).

Thanks in a large part to the tripling of fertiliser use, a one-third increase in the amount of irrigated land, and the development of high-yielding cereal varieties, many developing nations have realized impressive gains in the production of rice, wheat, and maize. But the focus on the production of grains for sale in commercial markets has had the unfortunate consequence of reducing the diversity of traditional cropping systems. Farmers have adopted simpler rotations of the higher yielding and more profitable grains, and abandoned lower calorie foods that were nonetheless generally higher in protein and micronutrients. The increasing production of these staples has displaced the production of local fruits, vegetables and legumes that were once a vital source of micronutrients. More than two billion people, about forty percent of the world's population, now face debilitating diseases because their diets are dangerously low in micronutrients that are important for growth and development (Welch et al., 1997).

As well, varieties selected for greater yields, or resistance to pests or adaptability to different climates, do not always have the ability to uptake nutrients at the same or a faster rate. Davis, Epp, and Riordan (2004) examined 48 varieties of garden crops and found a consistent decline in nutrient content between 1950 and 1999. For example, today's tomato has 40% less proteins, vitamin C and minerals.

In the course of human history people have utilised about 7,000 plant species for food. They now rely on about 20 plant species for food, although at least 75,000 plant species have edible parts (Wilson, 1989). Just three plant species, rice, wheat, and maize, supply sixty percent of the world's food supply (PCAST, 1998). The viability of these crops depends on the maintenance of high genetic diversity, which allows for the development of strains that are resistant to emerging and evolving diseases and pests (Fehr, 1984). However, FAO (1996) estimates that since the beginning of this century 75 percent of the worldwide genetic diversity of agricultural crops has been lost.

4.4.1 Biotechnology

The risks to biodiversity posed by recent developments in biotechnology are largely uncharted. More than sixty plants, a dozen animals and hundreds of microorganisms have been genetically engineered thus far (de Kathen, 2000). The most common applications are genetically modified herbicide-tolerant and insect-resistant crops. Very few biotechnology applications have been designed to improve diet or alleviate hunger (Dannigkeit, 1999).

Industrialized countries have adopted plant biotechnologies faster than developing countries, planting three quarters of the transgenic crops (James, 2001). The United States produces over two-thirds of the transgenic crops. The next largest producers, Argentina (22%) Canada (6%) and China (3%) collectively have less than half the area the Americans have planted in transgenic crops.

Globally, 11 percent of the area planted in canola, 7 percent of area planted in corn, and 46 percent of the area planted in soybeans is sown with transgenic crops (James 2001). The relative share of each crop area in Canada varies considerably. The three most significant transgenic crops in Canada are canola, corn and soybeans. In 2001 transgenic varieties accounted for 76 percent, 40 percent and 28 percent of the area in Canada planted to each of these crops. The seed technology of one company, Monsanto, has captured 91percent of the world market.

Thus far, development of plant biotechnology has focussed on the development of genetically modified products that reduce the cost of pest and weed control. The supposed advantages of biotechnology for the consumer (such as increased nutritional values, and the reduction of toxins), for farmers (such as lower input costs and higher yields), and for the environment (reduced use of pesticides and other chemical inputs) have not been extensively documented or properly explained (Wolfenberger & Phifer, 2001; Leisinger, 2001; Kalaitzandonakes, 1999). In contrast, the alleged risks of plant biotechnology (such as the Losey et al., 1999 study of Monarch butterfly larva) have received extensive press coverage. (See also Rissler & Mellon, 1996.)

Transgenic crops can pose several risks to biodiversity. The risks include the possibility a genetically modified organism may become an invasive species; gene flow from transgenic plants to their wild relatives; direct non-target effects on beneficial or native organisms; and indirect effects on species that depend on weeds/seeds as food sources (Wolfenbarger & Phifer, 2001; Rissler & Melon, 1996). Until recently, risk assessments for commercial release of transgenic crops did not consider their indirect effects on biodiversity. The earliest comparative studies that considered biodiversity effects were undertaken in 1998 (Johnson & Hope, 2000). Transgenic crops may also exacerbate the ecological problems associated with the introduction of monoculture agriculture (Alteri & Rosset, 1999).

It has been argued that growing genetically modified herbicide tolerant crops uses less herbicide, and those broad-spectrum herbicides have a lower environmental impact than conventional herbicides. This may be true if these herbicides are replacing persistent chemicals such as the triazines, but in terms of their impact on biodiversity, genetically modified herbicide-tolerant crops systems increase pressure on already beleaguered wildlife in farmed landscapes. For example, genetically modified herbicide-tolerant crops are resistant to broad-spectrum herbicides, such as glyphosate and glufinosate. If herbicide tolerant crops are planted, these herbicides can be sprayed at will without affecting the growth of the crop. Because these herbicides have a broad range of action, their use may reduce weed and invertebrate populations upon which birds and other wildlife depend (Hails, 2000; Watkinson et al., 2000).

In contrast to North America, with its extensive areas of natural wilderness, much of the wildlife in Europe, North Africa and South East Asia depends on farmed landscapes. In tropical countries, traditional farming methods sustain large populations of over wintering birds that feed on the invertebrates living within wet fields (Johnson & Hope, 2000). From extensive research on arable systems in North America and elsewhere (McLaughlin & Mineau, 1995; Freemark, Boutin, and Keddy 1995; Tucker & Heath, 1994), it is becoming increasingly clear that the use of herbicides is a major factor in the decline of farmland biodiversity.

The greatest concerns, however, are about the potential environmental release of transgenic animals because we cannot yet identify potential environmental problems early on nor easily assess the feasibility of their remediation. Released animals may also compete with native species for limited resources causing population declines. The likelihood of a living modified organism establishing itself in the wild is dependent on three factors. The first factor is fitness, its ability to survive and reproduce successfully. From a population genetics perspective, if a transgenic organism is fitter than its wild relatives in a receiving environment, then it will eventually replace its cousins, and if their fitness is similar, both may persist in the wild. The second factor, is its ability to escape, disperse or become feral. Third, the ability of the transgenic organism to establish itself in the wild depends on the characteristics of the receiving community itself. (See Pew Initiative on Food and Biotechnology, 2004; Vandenburgh et al., 2002)

Selective breeding is based on a polygenetic inheritance, where the end result is the cumulative effect of many, perhaps hundreds of genes, each with a small effect. In contrast most trans-genetic modifications involve one or two genes that have a major effect. Genetically modified native organisms are potentially cross-fertile with native species, greatly increasing the risks of gene transfer. Genetic traits that increase adaptability such as growth, physical tolerance or disease resistance cause the greatest concern. Transgenes that increase fitness and adaptability have a negative impact if they spread to pest populations. The introgression of genes decreasing fitness would also pose a near term risk to a small receiving population. Until we obtain more information about how "risky" transgenes might affect wild populations of native species, it would seem prudent to delay commercial release of transgenic native species.

For the purpose of risk management, there is a need to distinguish between organisms engineered for deliberate release and those that are engineered for confinement and are inadvertently released. Genetically engineered animals that are used to manufacture valuable by-products such as high tensile strength fibre and pharmaceuticals are domestic animals that are kept in close confinement and if they escaped they would be unlikely to survive in the wild. However, in aquaculture, for example, the risk factors are high because (1) cultured fish and shellfish are not far removed from their wild relatives; (2) aquaculture production systems are located in ecosystems containing wild populations of the same species; (3) aquatic organism exhibit great dispersal abilities; and (4) aquaculture organisms are often marketed live. (See Goldburg & Triplett, 1997.)

Muir and Howard (2000) have proposed a Trojan gene hypothesis to describe three ways in which a transgene could pose an extinction hazard: 1) when the transgene increases mating success and decreases adult viability, 2) when the transgene increases adult viability but decreases male fertility; and 3) when the transgene increases both male mating success and adult viability but reduces male fertility. They found that release of transgenic fish that were larger and therefore had a higher mating success but which had a shorter life expectancy could drive a wild population extinct in as few as forty generations. As one lowers the fertility of genetically modified organisms, the timeline to extinction is shorter. Hedrick (2001) also found that if a transgenic species has a mating advantage and a general viability disadvantage, then the conditions for its invasion into a natural population are very broad. He found that for two-thirds of the possible combinations, the transgene would increase in frequency and for fifty percent of the combinations it would go to fixation, thereby reducing the viability and increasing the probability of extinction of the natural population.

4.5 Declining Fisheries

Less than seven percent of the ocean, primarily the continental shelves, generates 85 percent of the global fish catch. All the world's continental shelves are being trawled for bottom fish, and purse-seined for open-water fish. Global fish catches began to decline in the late 1980's and any extrapolations of present trends suggest that large-scale fisheries will collapse in the next few decades throughout most of the world, inducing losses for which aquaculture will be unable to compensate (Pauly, 2004; Pauly, et al., 2002).

Marine aquaculture (Pauly, 2004), as it is currently practised, consists primarily of feedlot operations in which carnivorous fish are fattened on a diet rich in fishmeal and oil. These operations generate a lot of pollution and are extremely vulnerable to infestations and outbreaks of disease. They make commercial sense because the farmed fish fetch a higher price than the fish they consume, but they are also another source of pollution and pressure on wild fish populations.

Seventy-five percent of the world's commercial fisheries are fully or over-exploited or in a state of decline (Johnson, 2001; FAO, 2000; Vitousek, et al., 1997). In addition to threatening populations with extinction through over-exploitation, fishing may also change the evolutionary characteristics of populations by selectively removing the larger fast-growing individuals (Pauly, 2004). Commercial fishing reduces the abundance of target species and simplifies food webs (Pauly, et al., 2002). Size-selective fishing also drastically alters the average size, age-class and genetic diversity of surviving fish (Botsford, et al., 1997). For example, over the last sixty years the average size of a Chinook salmon has declined by fifty percent and the average age at maturity has declined by about two years (Upton, 1992). Northern cod caught in 1960 weighted about nine kilograms, and today weigh only 2.5 kilograms (Rosenberg, et al., 2005). Moreover, the fishing gear used in many cases is non-selective, resulting in very large by-catch, which must be discarded because of commercial considerations or legal constraints. The gear used may also damage fishery habitat (Botsford et al., 1997, McAllister, 1995, Upton, 1992). Extensive bottom trawling of world's marine coastal shelves has been blamed for a decline in the ratio of longer living demersal (bottom-dwelling) fish to the shorter-lived pelagic (open-water) fishes (Watling & Norse, 1998). Over-fishing precedes all other reasons for extinctions and the global decline of fisheries (Jackson et al., 2001).

Industrialised fisheries typically reduce community biomass by as much as eighty percent within 15 years of exploitation, and compensatory increases in fast-growing species are often reversed within a decade (Myers & Worm, 2003). The reduction of fish biomass to very low levels compromises the sustainability of fishing and in heavily depleted communities this may lead to the extirpation of populations, especially those which take longer to mature. Myers and Worm (2003) suggest that fully ninety percent of the large predatory fish in global oceans have already been lost. Worm and others (2005) have also found that the variety of species has also declined between 10 and 50 percent.

Pauly and others (1998) have described the impact of fishing pressure of this magnitude as "fishing down the food web" because the average trophic level of the species caught in commercial fisheries has declined since 1950. This effect has been most pronounced in the North Atlantic, where the average trophic level of the fishes caught declined by two-thirds during the latter part of the twentieth century (Christensen et al., 2002).

Andy Rosenberg and others (2005), examining the collapse of the Grand Banks cod fishery, found that cod stocks on the Scotian shelf have plunged 96 percent since the 1850's. Cod stocks have declined from 1.26 million metric tons in 1852 to less than 50,000 metric tons today. Only 3,000 metric tons of adult fish remain: barely enough to fill the holds of 16 of the sailing schooners that used to frequent the Grand Banks in the nineteenth century. Will the cod come back? Rosenberg thinks not. All that productivity that used to support the cod stocks has gone elsewhere. Through a trophic cascade, other species have rushed in to take the cod's place. He also wonders if the Scotian shelf is as productive an ecosystem as it once was.

Between 1989 and 1998, commercial landings of fish in Canada have declined by sixty percent (F&O, 2002.) Most of the decline can be attributed to the collapse of the Atlantic cod stocks. Nonetheless, Pacific Coast landings also declined by 25 percent during the same period. Aquaculture production increased over four fold during this period (F&0, 1998) but it was not enough to offset these losses. Aquaculture production amounted to less than ten percent of the lost commercial fish landings. Over half of Canadian aquaculture production is now located in British Columbia.

4.6 Industrial Production and Waste

Since 1900, the world economy has expanded 20 times, the consumption of fossil fuels has grown by a factor of 300, and industrial production has increased by a factor of 50 (MacNeill, 1989). The global production of chemicals has increased from less than one million tonnes in 1930 to over 400 million tonnes today (Commission for European Communities, 2001). The consumption of natural resources by modern industrial economies remains very high (WRI, 2000), in the range of 45 to 85 metric tons per person annually when all materials (including soil erosion, mining wastes, and other ancillary materials) are counted. Use of renewable resources has grown to levels estimated to 20 percent above the Earth's biological capacity (WWF, 2000). It currently takes about 300 kilos of natural resources to generate US$100 of income in the world's most advanced economies. Studies show that in North America (Rachel, 1989), only seven percent of industrial throughput winds up as product, only 1.4 percent is still product after six months, and per capita waste has doubled over the last generation.

Although Canada's population is relatively small compared to its land-base, its level of consumption and standard of living are among the highest in the world. Canada's economy is characterized by a reliance on energy and natural resources. Exports are dominated by raw materials and semi-finished goods. Because of the ready availability of energy, water, land, and mineral resources, Canada is competitive in industrial sectors using these resources intensively. Harvesting, extraction, food production, primary processing, energy generation and transportation industries are generally more stressful to the environment than secondary manufacturing or service industries. The ratio of waste and contaminants to resource recovery is very poor. Disposal, dispersion and dilution (end-of-pipe and end-of-stack solutions) are still the pollution management approaches most commonly in use (Statistics Canada, 2000; 1991).

4.7 Pollution

Human activity may now also be disrupting the planet's natural cycles (Bruce, Lee & Haites 1996).

4.7.1 Climate Change

The scientific consensus is that greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperature and subsurface ocean temperatures to rise (Oreskes, 2004).

Since 1750, the start of the Industrial Revolution, the atmospheric concentration of carbon dioxide has increased by about 32 percent (from about 285 to 380 parts per million in 2000), primarily due to the combustion of fossil fuels and land use changes (Watson et al., 2000; Vitousek et al., 1997; Ehrlich & Ehrlich, 1992a; Schneider, 1989).

For example, prior to the industrial revolution, fluxes between pools of carbon dioxide in the atmosphere and ocean of living and dead matter were approximately in balance. Photosynthesis removed about as much carbon dioxide from the inorganic atmospheric and oceanic pools as plant and animal respiration and decomposition returned to them.

But now the balance has shifted, because fossil fuel combustion, deforestation, fertiliser use, and agricultural practises are adding carbon to the atmospheric pool faster than natural processes remove it (Ehrlich & Ehrlich, 1992a). Fossil-powered energy systems, in particular, may be locked in a positive feedback cycle with evolving natural ecosystems (Houghton et al., 1995; Bormann, 1976) which up to now have generally kept climatic changes sufficiently gradual that life-forms could adapt to them.

In the last 25 years (from 1975-2000) atmospheric concentrations of CO^2 have increased by 45 parts per million, more than half the total increase over the entire industrial era (Friedlingsten & Soloman, 2005). Atmospheric scientists say that atmospheric concentrations of CO^2 could hit 550 parts per million by 2050, even if all the planned reductions are implemented. If the atmospheric concentration of CO^2 increases from 285 to 550 parts per million, we are going to be living in a very different post-industrial world.

The Intergovernmental Panel on Climate Change Second Assessment Report (Houghton et al., 1996) estimated that atmospheric concentrations of carbon dioxide could only be stabilized if emissions were reduced fifty to seventy percent. Currently world average emissions of carbon are four tonnes per capita. The North American average is nearly twenty tonnes per capita, while average African emissions are less than one tonne per capita.

4.7.2 Nutrient Cycling

Nutrients are mineral elements such as nitrogen, phosphorus, and potassium that are essential as raw materials for organism growth and development. Ecosystems regulate the flows and concentrations of nutrients through a number of complex processes that allow these elements to be extracted from their mineral sources (the atmosphere, hydrosphere, or lithosphere) or recycled from dead organisms. The capacity of terrestrial ecosystems to absorb and retain the nutrients supplied to them either as fertilizers or atmospheric deposition has been undermined by the radical simplification of many ecosystems into large-scale, low diversity agricultural landscapes. Excess nutrients leak into the groundwater, rivers, and lakes and are transported to the coast. Treated and untreated sewage released from urban areas also adds to the nutrient loading.

The rate of nitrogen fixation as a result of human activity has doubled and now exceeds the contribution of natural processes (Galloway & Cowling, 2002; Smil, 2000; Vitousek et al., 1997). The biodiversity and intricate webs of life found in nature are the result of intense competition among many different life forms, which have evolved under nitrogen-limited conditions (Galloway & Cowling, 2002). Many ecosystems are now subject to conditions of excess nitrogen.

In 1913, the invention of the Haber-Bosch chemical process provided the means to convert atmospheric nitrogen into ammonia, creating for the first time an unlimited supply of nitrogen fertiliser that could be used to grow food (Galloway and Cowling, 2002). Today over half the world's food is grown using fertiliser manufactured using the Haber-Bosch process (Smil 2000). There has been a nine-fold increase in the production of nitrogen since 1913, compared to 3.5 fold increase in population (Galloway and Cowling, 2002).

About half the nitrogen and phosphorus produced is captured in harvested crops, and about seventy percent of the harvested crops are fed to livestock (Tilman et al., 2001). Much of the nitrogen and phosphorous from chemical fertilisers and animal wastes eventually enters surface and groundwater. The potential consequences include eutrophication of freshwater ecosystems. For example, nitrogen concentrations in the Mississippi are now two to three times what they were fifty years ago and as a result a gigantic dead zone over twenty thousand square kilometres in size forms every summer in the Gulf of Mexico (McIsaac et al., 2001). The excess phosphorus accumulating in agricultural soils has been called a "chemical time bomb" (Stigliani, 1991).

4.8 The Biodiversity Crisis

Many ecologists argue that the continued growth in human population and consumption is incompatible with many ecological processes, including the persistence of large predators, the continuation of the annual migration of birds, speciation of large organisms, and the protection and maintenance of native biota (Soulé, 1991).

The success of our species in transforming landscapes and commandeering resources to meet human needs in an evolutionary blink of an eye has been phenomenal. Survival rates have risen and life spans increased. Our numbers have grown from fewer than four million, 10,000 years ago, to over six billion today. Humans are now withdrawing so much energy, water and resources, and discharging so much pollution and waste to many ecosystems that we threaten the survival of our own and other species. The most obvious threats humans pose to Nature's storehouse of biodiversity have been well documented (Heywood, 1995). Less obvious are human impacts on evolutionary processes.

Land-use change is expected to have the largest global impact on biodiversity by 2100, followed by climate change, nitrogen deposition, biological invasions and elevated atmospheric concentrations of carbon dioxide (Sala et al., 2000). For freshwater systems, biological invasions are the most important, followed by runoff and climate change. According to the authors, changing any of the parameters of the assessment by ± 10 percent would not alter the outcome of this forecasting exercise.

The domestication of arable landscapes results in the convergence of landscape properties such as soil characteristics, water and nutrient cycles. Domestication also dampens disturbance regimes (Western, 2001). As domesticated landscapes expand, they reduce the range of many native species, and ultimately lead to population declines of native species excluded from their former habitat by human activity. Human actions threaten to reduce and may virtually eliminate some biomes, notably tropical forests, coral reefs and wetlands, which have always been major sources of biodiversity.

Nearly half the world's vascular plant species and one third of the terrestrial vertebrates are endemic to 25 hotspots (Myers et al., 2000). Using the IUCN Red Lists, Brooks and others (2002) found between one-half and two-thirds of the threatened plants and 57 percent of all threatened terrestrial vertebrates are hotspot endemics.

One of the greatest challenges for conservation are hot spot endemics (Brooks et al., 2002) because 1) they have small range sizes increasing their probability of extinction by chance alone; 2) endemic species with small range also tend to be scarce within those ranges; and 3) consistent mechanisms underlie evolution in small ranges so most endemic species co-occur. Centres of endemism are disproportionately threatened by human settlement and economic activities (Cincotta, Wisnewski, & Engelman, 2000).

Since the age of exploration, biogeographical barriers have been breached that have protected biota for aeons. Invasive species now contribute to the progressive depletion and further homogenisation of native biota (Mooney & Cleland, 2001). Twenty percent or more of the species in many countries' floras are now exotic species (Vitousek et al, 1996). Only a small fraction has so far have become pests (Williamson, 1996).

Overharvesting of big species is our most ancient and persistent trademark. Removal of keystone species influences species richness and habitat patchiness. Downsized communities accelerate population, energy and nutrient turnover rates (Calder, 1984). The impact of any disturbances will be magnified as the internal feedback linkages dominated by larger life forms weaken. As biodiversity declines and the number of functional groups decreases, resistance to invasive species and pathogens will fail. Practices that change functional diversity and composition are likely to have the greatest impact on ecological processes over the long term (Tilman et al., 1997).

Since the 1960s there has been widespread public concern about the loss of "charismatic megafauna" such as whales, dolphins, eagles, tigers, pandas, and primates. These creatures are often large, warm-blooded, aesthetically attractive, and regarded as having the capacity for feeling, thought, or pain (Kellert, 1986). Perpetuation of diversity requires the maintenance of a more or less natural balance between predators, their prey, and their plant food resources. The over-harvesting or loss of species high in the food chain may trigger a population explosion of undesirable species. Similarly, harvesting or the loss of organisms low on the food chain may also cause collapse of valued species that consume them (Orians, 1990; Terborgh, 1989; Wilson, 1987).

Although scientists usually think of biodiversity in terms of the four levels of the biological hierarchy (genetic, species, ecosystem, and landscape diversity), more attention has been paid to species loss. However, we do not know even to the nearest order of magnitude the number of species or organisms on Earth (Wilson, 1989; May, 1988). Estimates range from 10 to 100 million.

Species extinctions will alter biodiversity as well as the evolutionary processes by which biodiversity is created with consequences that could persist for millennia (Myers & Knoll, 2001). Habitat fragmentation imposes barriers to dispersal and gene flow. Species with low population densities and poor dispersal abilities are especially vulnerable to extinction (Soulé, 1980). If between one-third and two-thirds of the species that now exist are lost as expected, these losses will be accompanied by major population declines of other species. The reduction of population sizes of these species will further deplete the natural gene pool. Natural selection will favour opportunistic (r-selected) species that are able to exploit the production cycles in domesticated landscapes or heavily harvested natural resource areas. Human-dominated areas will become characterized by a pest-and-weed ecology and their further expansion could spell the end to the speciation of large vertebrates (Myers & Knoll, 2001; Soulé, 1991).

Approximately 1.4 million species of plants, animals and organisms have been given scientific names (Ehrlich & Wilson, 1991) and an overwhelming number of them are flowering plants (220,000 species) and insects (750,000 species). An average day sees the formal description of about 300 new species (Heywood, 1995). Moreover, the rate at which taxonomists split previously recognized species into two or more new species exceeds the rate at which they lump different species together, especially in taxa that are of particular concern to conservationists (Purvis & Hector, 2000). Nonetheless, the most recent International Union for the Conservation of Nature (IUCN, 2000) global biodiversity estimate of 12.1 million species vastly exceeds its own update of the number (1.75 million) of species that have been identified and scientifically described thus far. Therefore, most of the catastrophic extinction scenarios are based on numbers of species that no one has ever seen (Nelson & Serafin, 1992; Mann, 1991).

If 99 percent of all the species that have ever existed on Earth are now extinct, then why is it so urgent that we reduce the numbers of species extinctions? The usual answer is that the accelerated rate and unprecedented scale of these extinctions is cause for concern (Norton & Ulanowicz, 1992). All estimates of current extinction rates are higher than the rates at which natural evolutionary processes compensate for losses. It has been claimed that current extinction rates are 40 to 400 times the last mass extinction, 10,000 times the extinction rate before the agricultural revolution, and 150,000 times the natural background rate of extinction (Ehrlich & Ehrlich, 1992b). Others claim that current rates of extinction are 100 to 1000 times greater than pre-human rates (Pimm et al., 1995; Lawton & May, 1995). However, the most recent IUCN (2000) estimate of human-induced extinction is fifty times the natural rate of extinction.

Around 71,000 species of wild animals and plants have been recorded in Canada, and scientists think another 68,000 species have yet to be discovered and classified (Environment Canada, 2000; Mosquin et al., 1995). Canadians understand the ecological function, status, trends and survival needs of less than 3 percent of the recorded species (Environment Canada, 2000). The number of endangered species in Canada has increased from 178 in 1988 to 380 in 2001(see http://www.cosewic.gc.ca). About 612 species overall are considered to be at risk (CESCC, 2001). Less than five percent of terrestrial and freshwater species are endemic to Canada because most species re-established themselves here following the last great period of glaciation (McAllister, 2000).

In conclusion, most estimates of the total number of species today lie between 5 million and 30 million, although the overall total could be higher than 30 million, if poorly known groups such as deep-sea organisms, fungi, and micro-organisms, including parasites, have more species than currently estimated (MEA, 2005). The natural process of evolution, and particularly the combination of natural barriers to migration and local adaptation of species, led to significant differences in the types of species in ecosystems in different regions of the world. The distribution of species on Earth is becoming more homogenous. The differences between the set of species at one location on the planet and the set at another location are, on average, diminishing. Across a range of taxonomic groups, either the population size or range or both of the majority of species is currently declining. The number of species on the planet is declining.

The most obvious impacts of human activity on ecosystems, such as the loss of wild habitat, have been extensively documented. Harder to gauge are human impacts on ecosystem properties, such as nutrient cycles and disturbance regimes, and on the processes governing global climate and hydrology. Ecosystems everywhere within decades could be affected by changes in temperature and rainfall. The rapidity of climate change and human imposed barriers to migration and dispersal will challenge species adaptation and survival. The consensus is that every major planetary process in the biosphere, lithosphere, hydrosphere or atmosphere has already been altered by human activity.

4.9 Sustainable Development

The combined destructive impacts of a poor majority struggling to stay alive, and the lifestyle of an affluent minority, are inexorably eroding the buffer that has always existed, at least on a global scale, between human consumption and the planet's productive capacity (McNeely et al., 1990.)

Many observers have become alarmed at the unprecedented effects of industrialisation on the environment and believe that future human welfare and survival may depend on uncoupling economic growth from energy and material use. The Brundtland Commission (WCED, 1987) recognised the need to integrate environmental considerations into business planning and decision-making in order to steadily reduce the energy and resource content of future growth. What is called for is a transformation of human economic activity, on the order of the first Industrial Revolution.

Since the Industrial Revolution, a once-through model of industrial production has been employed which relies on cheap abundant resources and inexpensive waste disposal. Most industrial processes are fossil-fuelled, make intensive use of energy and materials, involve high temperature and pressures, and contain multiple steps where harmful substances can be discharged to the environment. Products are mass-produced, have limited useful lives, are not easily repaired and are cheaply discarded. Producers' responsibility for their products ends at the plant gate.

Industrial production and mass consumption are still largely linear processes. Production, use and disposal often occur without substantial reuse or recovery of energy or materials. The industrial system is still driven by inputs of virgin materials, and waste continues to be generated and disposed of outside the economic system. However, if internal recycling is incorporated into production processes, the throughput of materials and energy will decrease. By integrating the life cycles of diverse processes and products so that the waste stream from some becomes the feedstock for others, the materials and energy cycle may also be extended. Manufacturers could avoid waste through better design, and make reusable products, instead of short-lived discards. Nonetheless:

> If every factory in the world shifted to the cleanest production available (or even the cleanest plausible technology), the larger environmental crises would be at best be deferred a few years...As long as the material component of products is still largely based on the use of virgin resources, while the energy is largely derived from fossil fuels, clean is an impossible dream...indeed sustainability will be a distant receding goal.
> (Ayres, 1993)

Environmental sustainability at the most basic level is a function of the state of ecosystems, the stresses on those systems, human vulnerability to environmental change, and the capacity of human institutions to respond to these challenges and provide global stewardship of environmental resources (ESI, 2002). Human success in influencing these aspects of their environment in a lasting manner will affect our species chances of survival and the quality of life of succeeding generations.

The ecosystem approach challenges the prevailing notion that economic growth is not constrained by biophysical factors (Rees, 1994). Consumption of energy and material resources must not exceed natural rates of renewal. Waste generation should not exceed the assimilative capacity of the environment. Human activity must not jeopardise the replenishment of biological resources that maintain critical life support functions of the biosphere. This "natural" capital must be maintained as a precondition of sustainability. From these preconditions flow considerations of equity: the demands for society to meet the basic needs of its members, for procedural fairness, for citizens' participation in decisions that affect their lives, and for fairness to future generations.

Prior to the Brundtland Commission, most decision makers were preoccupied with the optimal or efficient use of natural resources. Few were interested in the potential welfare effects of resource use. The Brundtland Commission defined sustainable development, as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). This definition implied that the goal of sustainable development is to maintain a constant non-diminishing level of human welfare. Humans should live off the interest provided by our natural resources, not the principal. David Pearce (1988) introduced the metaphor of natural capital as a way of integrating environmental considerations into economic thinking, and to spark public interest in the value of nature. A number of efforts have been made to value the ecological goods and services provided by nature, with mixed results (Costanza et al., 1997; Pimental et al., 1997).

Without joining the debate about the best way to describe or value ecosystem functions, goods and services, one has to go no further than point out the obvious. The Canadian economy depends largely on our so-called natural capital. For example, Canadians obtain \$59B annually from our forests, \$35B from primary agriculture, \$22B from our oceans, and we spend \$12B on nature related tourism and recreational activities (SC Special Tabulations, 2004). Canada's trade surpluses largely depend on export of natural resources.

Sustaining these economic benefits requires a better understanding of how ecosystems function and renewed efforts to reduce and manage human impacts on ecosystems. The natural environment provides these benefits freely to all. However, when ecosystems are damaged by human activities or intervention, ecological goods and services are extremely costly to replace or restore. Sometimes it is simply not feasible. Canada's natural capital is a source of future opportunities. Sustaining Canada's natural capital – water, air, land and wildlife – is critical to ensuring Canadians long-term economic security, survival, and well-being.

5.0 KEY CONCEPTS

Cognitive science is the interdisciplinary study of thinking, learning, and problem solving. This research draws upon the conceptual foundations laid by many others. The key concepts necessary to understand the analysis and interpretation of the survey findings are presented and discussed here. First, the role and functioning of mental models are described. Research into mental models is based on the assumption that experts do not reason solely in terms of abstract logical rules. They also draw upon their accumulated experience. Second, experts often think metaphorically, using their understanding of a familiar domain, as an analogy for drawing inferences about a less well-understood domain. Mental models of risk help them think about the world in a simplified manner, and even to simulate future events. Third, mental models incorporate worldviews, strongly held beliefs about how the world works, that may influence problem solving. Lastly, personal constructs provide the framework for eliciting and interpreting expert mental models of risk.

5.1 Mental Models

Social psychologists use mental models to explain how humans handle complex cognitive tasks such as perception, learning, and problem solving, and to provide insight into how people understand a particular domain of knowledge (Gentner & Stevens, 1983).

The idea that people form mental models to help them describe, explain and predict what is going to happen originated with Kenneth Craik (1943). He believed that individuals reason by analogy with their past experience in order to anticipate future events. For Craik, mental models were simplified ways of organizing and representing human knowledge and experience. He thought that everyone carries with them mental models of virtually every aspect of their life. We can verbalise them and they influence our behaviour. (See Collins & Gentner, 1987.)

There are different views about how mental models function, as causal models and as working memory constructs, but they are not mutually exclusive (Markman & Gentner, 2001).

The causal interpretation stresses that mental models are simplified sets of distinctions that individuals make about the world that help them to interpret what they observe, to generate inferences, and to solve problems in a particular domain (Kempton, Boster & Hartley, 1995; Rouse & Morris, 1986). Causal mental models are domain-based, involve causal mechanisms and draw on long-term memory structures (Gentner & Stevens, 1983).

Mental models influence how people think about a particular domain. For example, mental models have been used to explain reasoning about ecology (Kempton, Boster and Hartley, 1994). They help explain differences in the way people draw inferences. In a series of experiments with serial and parallel combinations of batteries and resistors, Gentner and Gentner (1983) showed that subjects relying on a "flowing water" mental model were more likely to spot the differences between two kinds of battery combinations, and those with a "moving crowd" model were more likely to see the difference between the two kinds of resistor combinations. There is also evidence that mental models can influence real-life environmental decision-making. For example, Kempton (1987) found that people had two distinct mental models of their home heating systems, which affected the way they used their thermostats.

Experts use mental models of the world to frame discussions and evaluate choices (Carley & Palmquist, 1992). They can portray mental models in a variety of ways: argument forms (Toulmin, 1958), concept maps (Novack & Gowan, 1984), scenarios (Jungermann, 1985), semantic networks (Sowa 1991) or influence diagrams (Bostrom, Fischoff & Morgan, 1992). Typically a hierarchical means-ends framework is used to capture the concepts and relationships necessary to structure a decision. These constructs are called "expert mental models of risk" (Bostrom, 1990). Comparisons of different mental models can help determine the extent to which people share the same knowledge and ideas (Morgan et al. 2002).

Mental models are highly simplified, cannot exceed the capacity of our working memory, and are difficult to generalize (Bostrom, 1990). However, a mental model can be used to simulate the future behaviour of a system. The explanatory power of a mental model lies in the plausibility of its assumptions, and the accuracy of its predictions. A mental model can be evaluated in terms of its:

- Generality – applicability to other situations

- Simplicity – ability to generate significant propositions from a small number of assumptions
- Power – provision of reliable and valid observations (Hart, 1977).

The second view of mental models is that they are working-memory constructs or sketches that support immediate comprehension and logical reasoning (Johnson-Liard, 1983). In the process of learning, people do not just add new information to a random accumulation of facts in their heads. They reason by analogy with familiar situations rather than by abstract logical rules (Johnson-Liard, 1983). The mental constructs they create allow them to cope with unfamiliar situations based on seemingly incomplete information.

Research on mental models is strongly influenced by theories about the organization of human memory. According to some, human memory is organized around frames or schemas, constructed by individuals from prior experience, and from information they have picked up from other sources (Kleindorfer et al. 1993). These constructs influence the acceptance and assimilation of further information, and subsequent behaviour. In a novel situation, individuals will recall from their memory the necessary frames or schemas or construct them. These frames or schemas are filters through which people see the world.

There is no need for mental models to be correct and in fact, they are often highly inaccurate. For example, Kempton, Boster, and Hartley (1994) found that individuals often perceived global warming to be the result of atmospheric pollution from the use of aerosols such as chlorofluorocarbons (CFCs).

Although evidence suggests that experts' mental models are fundamentally different than lay mental models, experts' models are not necessarily more elaborate or accurate (Rouse & Morris, 1986). Expert models may contain naïve and possibly incorrect notions. Prior views that are incorrect will not necessarily be discarded when the correct information is provided.

People are capable of holding two or more inconsistent models of the same domain. For example, Collins and Gentner (1987) found that people gave different explanations of what causes a towel to dry in the sun, and what causes a puddle of water to evaporate failing to see any connection between the two phenomena.

Mental models are representations of real, hypothetical or imaginary situations. Like any form of scientific conjecture, mental models help people make sense of what they see and are also tested through experience. They can be recalled from memory, learned from experience or acquired through training and instruction. Mental models usually start with an analogy; employ metaphors, incorporate acquired beliefs and causal assertions; and depend to some extent on memory and recall mechanisms (Bostrom, 1990).

We are often not consciously aware of effects our mental models have on our reasoning and behaviour. The problem with mental models is not whether they are right or wrong. They are by definition simplified and incomplete representations of the world. That is why surfacing, testing and improving our mental models of how the world works promises to be a key to breakthrough thinking (Senge, 1994).

5.2 Metaphors

One of the building blocks of mental models is metaphor. Metaphors permeate language, and are fundamental to thought (Lakoff and Johnson, 1980). They structure our perceptions and understanding of our world. However, metaphors do not tell the whole story about an action, event or experience. They only evoke certain aspects of it.

Metaphors are derived from our senses of touch, taste, sight, hearing, and smell (e.g., greenhouse effect, sound waves). Metaphors are also shaped by culture. We live in a world of space, time, energy and matter. In Western culture, for example, time is money, a valuable commodity, and a limited resource that we use to accomplish our goals. These are metaphorical concepts. There are cultures where time is none of these things. Metaphors can also provide spatial orientations. For example, more is up and less is down. The use of metaphors is so widely understood in everyday life, that in many cases, observers may be unaware of their significance (Lakoff & Johnson, 1980).

Although reductionist science has tried to abandon symbolic and analogical modes of thinking, in favour of quantitative analysis, metaphors live on. The use of metaphors is commonplace in the language of science (Eisenberg, 1992). Metaphors may provide insights leading to new discoveries or may be used as teaching tools to convey difficult concepts. Since metaphors allow for the substitution of ideas across different areas of study, they are often considered to be an interdisciplinary Rosetta stone.

Scientific metaphors are used primarily for explanatory-predictive purposes rather than expressive-affective purposes (Gentner, 1982). When scientific metaphors are used to help us understand one conceptual domain in terms of another they are considered to be analogies (Gentner et al., 2001; Gentner & Holyoak, 1997; Gentner & Jeziorski, 1993).

Typically scientific metaphors employ a more concrete or familiar subject domain as their source and a more abstract less well-known target domain as their predicate (Gentner & Holyoak, 1997; Gentner, 1983). A conceptual domain is any coherent way of organizing experience. Conceptual domains consist of entities, attributes, and relationships. Analogical reasoning implies that the system of relationships that hold among the base entities also holds among the target entities.

Knowledge can be represented as a propositional network of subject nodes and relational predicates. The nodes represent concepts treated as wholes, and the predicates applied to the nodes express propositions about the concepts (Markman & Gentner, 2001; Gentner, 1983.)

Metaphorically linking two domains alters one's view of one or both domains and makes inferences about the target domain possible (e.g., the linkage between human and ecosystem health). Researchers who study metaphor face the difficulty of separating the conventional meaning of a metaphor from what the expert's use of the metaphor suggests (Gentner et al., 2001). The strongest possibility is that metaphors create meaning (Lakoff, 1990). The target domain is organized and structured in terms of conceptual systems borrowed from the more readily observable base domain. People actively use the metaphorical base domain to think about the target.

Gentner (1982) evaluates scientific analogies on the basis of their specificity, clarity, richness, abstractness, scope and validity. The most important feature of a scientific analogy is that the base domain be well understood and fully specified. The better analysed the base, the clearer the candidate set of important relations. To be clear, scientific analogies have to have one-to-one mappings, while everyday metaphors may have one- to-many mappings. For example, if a base node maps to two or more target nodes, or if two or more base nodes map to the same target nodes, then invalid inferences may be drawn. Richness describes how many predicate mappings are made. There is a trade-off between richness and clarity. A true scientific analogy is a system of interconnected knowledge, not an assortment of facts. Abstractness has to do with how interrelated or tightly constrained by the analogy the mapped predicates are. Lower order predicates should be derived from higher order predicates. A scientific metaphor should apply to a number of cases to be useful (scope) and it should lead to the correct inferences (validity) in the majority of cases.

5.3 Worldviews

Expert mental models incorporate worldviews, acquired beliefs and causal assertions. These beliefs usually describe alternative views of what the world is like or of some preferred future. Shared causal assertions link possible policy options with desired outcomes. In the present research, we are trying to make explicit the values and beliefs associated with particular mental models of risk. By making these beliefs explicit, they are open to re-evaluation.

Worldviews are often characterized by different storylines or discourses (Haas, 2002; Thompson 2000, Rayner 1992). Persons with different worldviews argue from different premises. They often offer starkly different diagnoses of the world's ills and propose different remedies. These discourses institutionalize cognitive frames of reference that identify issues as problems for decision makers (Haas 2002).

Each worldview generates a storyline that is contradicted from other perspectives, and yet often distils elements of experience that are missed by others. Problems defined from one perspective may be compounded by solutions offered from another perspective. Worldviews rest on different assumptions, goals, and policy options. It is the mutually exclusive quality of different worldviews, and the lack of mechanisms for reconciling conflicting worldviews, that make them problematic to decision makers.

Worldviews include shared preferences about social relations (ways of life) risk-taking and decision-making (Thompson, Ellis, & Wildavsky, 1990). They also shape perceptions of what is considered rational, feasible, moral or just (Dake, 1990). Worldviews justify different ways of behaving and engender distinct representations of what is considered hazardous (e.g. Dake, 1992; Wildavsky & Dake, 1990).

Experts live and work in very different occupational and institutional contexts. Membership in different reference groups, with distinctive patterns of social relations, generates distinctive ways of looking at the world, and distinctive representations of what constitutes risk (see Kempton, Boster, & Hartley, 1995).

Worldviews acquire a taken-for-granted quality because experts are socialized into accepting arguments that are expedient for achieving their goals (Haas, 2002: "the lazy thinker often acquires them in graduate school").

Dietz, Stern, and Rycroft (1989) hypothesize that risk professionals acquire values and interests through their work for different institutions or organizations that influence their views of environmental policy conflicts. They found that gender/age cohort and professional identification have less influence on risk professionals' views than institutional affiliation. Three types of institutional settings seem to be important in shaping environmental policy positions: a competitive market orientation is typical of industry; a hierarchical bureaucratic orientation is characteristic of government; and an egalitarian communal orientation describes many environmental organisations. Each kind of institution has developed an internal consensus about how the policy process should function. Each has different perspectives on the role of market mechanisms, economic growth, technological progress, human consumption, citizen participation, ties between government and industry, and the role of science in decision-making.

Different institutional cultures also provide the context for the social definition of environmental risks and of policy conflicts (Dietz, Stern, and Guagnano, 1998). People who work for government or industry tend to view knowledge differentials as the source of policy conflicts. The great majority of the general public is thought to be ignorant at best, and at worst to be prone to unreasonable fears and expectations. Experts are thought to understand risk well, have realistic expectations, and are in a better position than most to make judgements about how safe is safe enough. People who work in environmental organisations are more likely to mistrust experts and to see environmental conflicts as based on vested interests or value differences, views that are consistent with the democratic and participatory norms of the environmental movement.

Under conditions of uncertainty, institutional context or professional background strongly influences the formation of shared mental models of risk (Denzau & North, 1993). Organizations, professions and disciplines share beliefs that facilitate or limit learning and development (see Beail, 1985 and Eden & Jones, 1984). Experts working in particular institutions such as government, industry, and public interest groups, and having a common disciplinary or professional background may share similar mental models of risk (e.g., Dietz, Stern, and Guagnano 1998).

Worldviews describe the basic beliefs, ideals and institutional practices of an epoch (Rodman, 1980). Worldviews are resistant to change. This may explain why people have difficulty updating their mental models or discarding worn out metaphors. New ideas fail to get put into practise because they conflict with deeply held beliefs about how the world works that limit us to familiar ways of thinking and acting (Senge, 1994).

Mental models of risk are not solely matters of individual cognition (Slovic et al., 1997) but may also correspond to worldviews, deeply held concerns and beliefs about society, its functioning, and potential fate (Kempton, Boster, & Hartley, 1995; Senge, 1994; Dake, 1991). These concerns are debated within the context of people's understanding and (dis)satisfaction with society and their understanding of their place within it (Dake, 1991). They may distinguish one group of people from another. Public discourse suffers because our society only has mechanisms for resolving conflicting interests rather than conflicting views of reality, and there is no basis for deciding which of the prevalent worldviews, if any, is most useful, let alone which is right or wrong (Lovins, 1977).

5.4 Personal Constructs

Memory and learning processes underpin the emergence of metaphors and mental models of risk. Kelly's (1995) personal construct theory provides the framework in this research for eliciting, and interpreting expert mental models of risk. Kelly postulated that people build up representations of their experience that he called personal constructs, and use them to anticipate what is going to happen next. Constructs are our personally acquired interpretations of experienced events. They subsume our understanding of repeated events with which we are familiar. Through shared constructs we can appreciate someone else's interpretation or construction of the same events.

Constructs are the only primitives in Kelly's psychology (1955). They are not concepts. Humans organize and classify the elements of their experience through a process of making distinctions about their environment. Personal constructs are dichotomous distinctions that describe how an element (an entity, process or event) is similar to or different from others. We need to know both the expressed and implicit poles of a construct before we can understand the circumstances (range of convenience) in which it applies. People recognise regularities and recurring patterns of events in their experience by means of contrasts, not absolutes. We do not know what is safe without being aware of what is harmful. Constructs are used to anticipate a finite range of events and are revised in the light of experience if they prove to be unreliable. Through the intersection of a number of distinctions, other distinctions may be implied which humans can also use to anticipate or react to future events.

For example, Kelly (1955) thought a young woman might describe a suitable marriage partner in terms of distinctions such as age and wealth (see Figure 5.1). Although the intersection of these distinctions defines the characteristics of her ideal husband, the young woman herself must generate an auxiliary commitment or rule when she makes her choice (e.g., If Joe is young and rich then he is a suitable marriage partner). Inferential rules play a similar role in expert models or computational systems by generating recommendations for decision or action. (See Shaw & Gaines 1992)

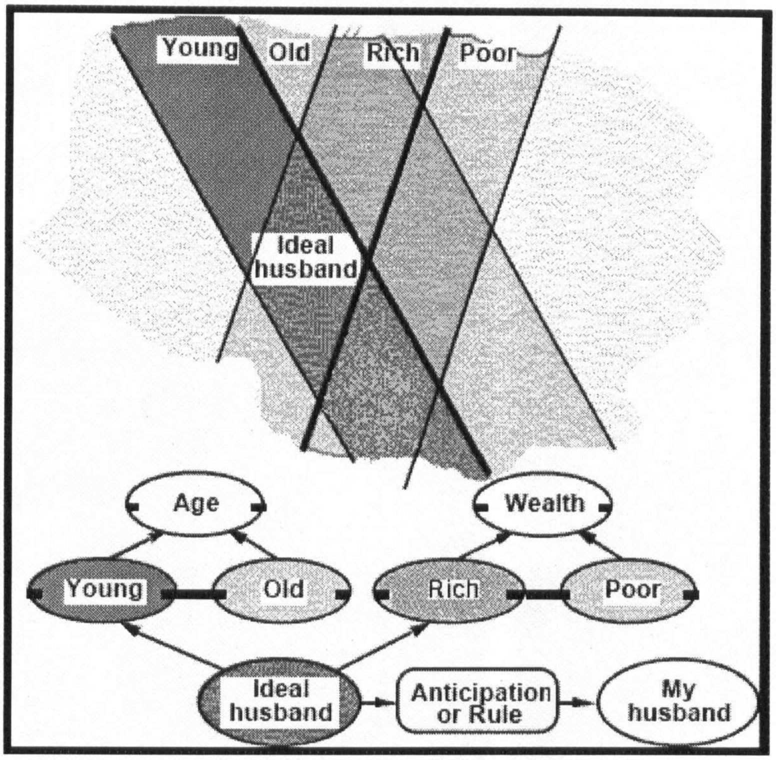

Figure 5.1 Logic of Anticipation through Rules (Shaw & Gaines 1992 Fig. 7)

Personal constructs represent not only how people classify past experience but also how people perceive the future - the framework through which they interpret or construe future events (Stewart, 1998.) Constructs are continuously revised in light of experience, which shows them to be right or wrong. Although their construct system reflects an individual's past experience, it also influences their expectations and future behaviour. A person's construct system represents the truth, as they understand it. It is a reflection of the fact they've had different experiences, react to their world differently, and find that different things are important.

Hinkle (1965) was the first to point out that the meaning of personal constructs lies in what each implies. In some sense, superordinate constructs are more abstract versions of the constructs that are subordinate to them and are more likely to be resistant to change. Moreover, the meaning of superordinate constructs is defined by these subordinate constructs. Therefore a grid can be thought of as a hierarchical network of implications. These implications can be detected in repertory grids. (See Smithson, 1987, Shaw & Gaines, 1982.) Implications may also create dilemmas or logical inconsistencies. For example, when examining the relationships between the following constructs (depressed-happy, sensitive-insensitive, and desirable-undesirable) happiness is considered to be desirable, but if it implies being insensitive, this is considered to be undesirable.

The anticipatory process is a hierarchical set of distinction making processes (Gaines, 1988). It is a social process encompassing multiple sources of expertise that may not be consistent and in fact may be in outright conflict.

Expert mental models and theoretical reasoning emerge from the cognitive process of making distinctions. At the most primitive level, the most basic type of distinction that humans make is to recognise and respond to the same event again in the same way. If the same distinction yields the same interpretation in a variety of contexts, humans are able to classify or categorize their experience (Gentner et al., 2001). Humans are able recognise patterns or relationships among their mental constructs and to recall "chunks" of information (e.g. Rosenbloom & Newall 1986; Simon, 1974), which Kelly called derived distinctions.

Humans can categorize their experience in terms of exemplars or prototypes. Contemporary experimental evidence suggests experts are more likely to use exemplars (rules specifying the necessary and sufficient conditions for category membership) than prototypes (models or benchmarks) to classify examples (Dobkins & Gleason, 1997). However, the controlled experiments performed were generally rather simplistic tasks of assigning objects to categories. In real life, humans are called upon to make comparisons of complex physical systems that involve many uncertainties, and unknowns. The best they can hope for in many cases are good prototypes, which may share only a few properties in common.

Humans reason symbolically. They use metaphors to draw on their experience (x is like y) to explore the unknown and mental models to anticipate the future (if x then y). This view does not accord with the standard set theoretical approach (e.g., Tversky, 1977) that claims we define and understand things in terms of sets of inherent properties (i.e. shared attributes.) The capacity to recall distinctions and to apply them outside their original context is the next level of cognitive complexity. Models and other forms of abstract reasoning emerge when the distinctions made are no longer primarily based on personal observations or experience. This capacity, to generate and share distinctions, allows humans to develop a much greater repertoire of anticipatory responses to cope with changes in their environment. (See Figure 5.2.)

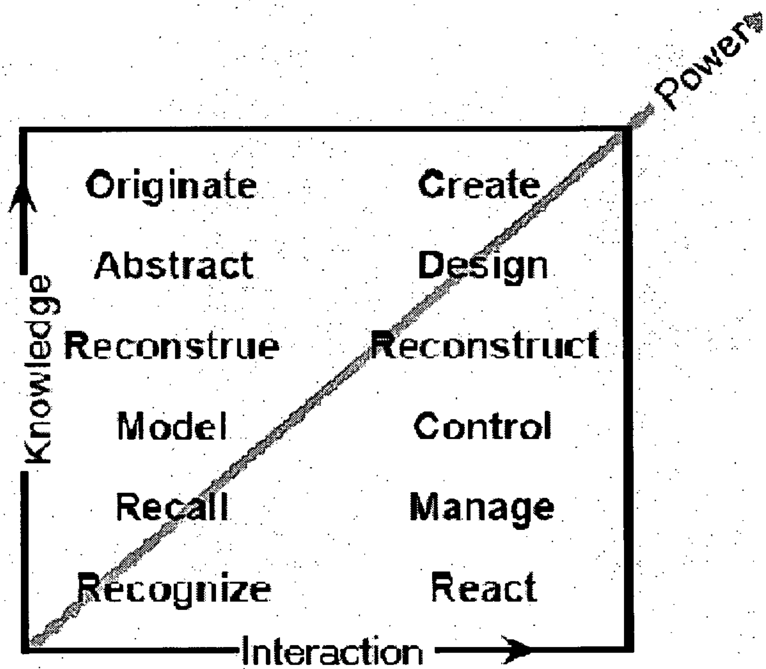

Figure 5.2 Anticipation as a Hierarchy of Decision-Making Processes **(Gaines 1989b Fig. 5)**

Surprise flows up the ladder of inference and choices or preferences flow down. (See Klir, 1985) Surprise arises when distinctions are not comprehensive enough to capture all relevant events, too inaccurate to predict events, or too simple to adequately explain events. The process itself generates a reflexive loop. The assumptions and conclusions that we make from our observations and experience generate beliefs about the world. We take actions based on our beliefs and they affect the data we select next time.

Scientific reasoning, both theoretical and instrumental, tells us what to expect, and help us see it when it happens. In Kelly's view (1970) we are personal scientists, who derive hypotheses (expectations) from our theories (experience) – we subject these hypotheses to experimental testing (we bet on them behaviourally by taking risks) – we observe the results of our experiments (we live with or die from the outcome of our behaviour) – we modify our theory (we change our minds and ourselves or we go extinct) and so the cycle continues. Although personal constructs underlie preference formation and decision-making personal construct theory does not presuppose a rational mode of decision-making. For example, if a subject wants to buy a green product, eliciting the subject's personal constructs will help describe their underlying decision-making criteria, and help anticipate their choices (see Figure 5.3).

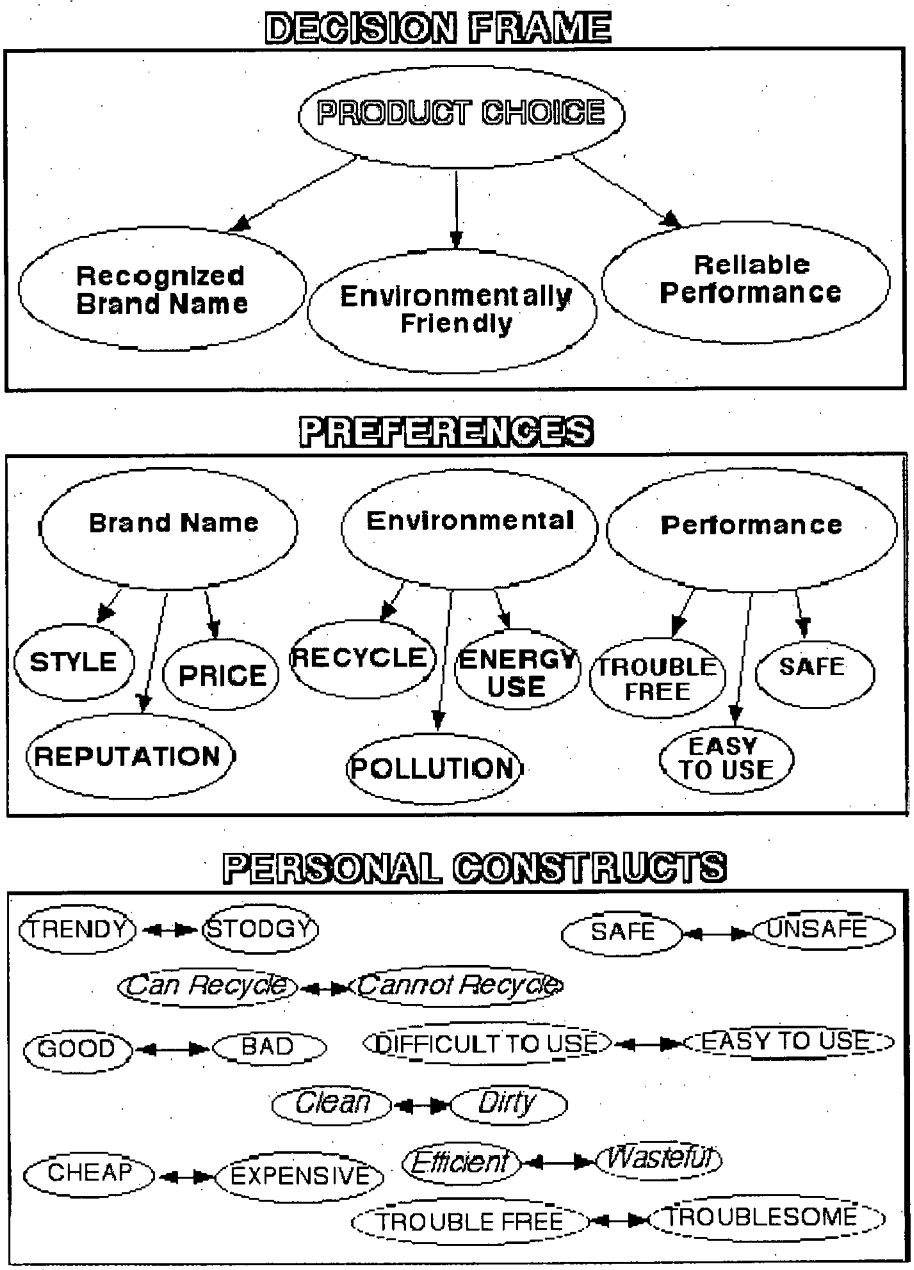

Figure 5.3 Role of Personal Constructs in Preference Formation and Decision Making

Daniel Kahneman and Amos Tversky (1981) used the term 'decision frame' to describe the decision-maker's conception of the preferences, outcomes and contingencies associated with a particular choice.

People are highly sensitive to how choices are presented or framed. Framing limits the definition of the problem itself, the options considered to be possible solutions, and influences the eventual choice of the preferred option. According to Kahneman and Tversky's prospect theory (Kahneman & Tversky, 1979) people assign different values to perceived gains and losses. For example, when asking people about a program to combat a deadly disease, Kahneman and Tversky (1979) found dramatic differences in people's choice of program options, depending on whether the program was framed in terms of how many lives it would save or how many people would die. People will pay a premium to avoid losses and less to achieve gains. They are more influenced by perceived gains or losses than by the overall final outcome.

People are also more likely to rely on their prior beliefs, and the perceived similarity of the decision situation to other situations they have experienced before, than on statistical probabilities, when they make decisions (Kahneman, Slovic, & Tversky, 1982; Kahneman & Tversky, 1973). For example, Kahneman and Tversky (1973) found that telling subjects a described event had either low or high probability of occurrence had little or no effect on their choices.

Mental models or decision frames are conceptual systems that people inadvertently create to simplify and organize their understanding of the world. They often include many decision-making ingredients such as problem definitions, criteria (goals), and alternatives (options). They also include:

- Boundaries which control the scope of the problem,
- Reference points, elements critical to success or failure,
- Implicit yardsticks used to measure success or failure, and
- Metaphors and analogies used to interpret the situation at hand.

Personal construct theory anticipates the findings of psychologists like Kahneman and Tversky. We may solve the wrong problem because our mental model or decision frame prevents us from seeing the best options and important objectives. Bad metaphors or analogies may provide a misleading understanding of the problem situation. Our judgements may be biased and our choices may be ill advised. Personal constructs are simply the basic distinctions, underlying our preferences, and in most circumstances can be used to simulate our choices.

6.0 RESEARCH METHODS

Three methods were used to elicit the expert metaphors and mental models of ecosystems: 1) textual analysis, 2) direct questioning, and 3) the performance of a task. The first step was to conduct a key word search of the scientific literature on ecosystem risk to identify commonly used metaphors and mental models. NVivo, computer assisted qualitative data analysis software was used to develop a framework and typology of experts mental models of risk. This formative evaluation provided the basis for the design of the subsequent interview survey. Second, interviews with key informants helped identify what experts thought was important about ecosystems, and worthy of protection, conservation, or management in most circumstances. The elicited constructs were used to develop a repertory grid that experts could use to compare different concepts or types of ecosystems. Then the relationship between the experts' mental models and worldviews was tested using a composite semantic differential scale comprised of thirty statements. Finally, during the web-based stage of the survey, the experts were asked to use the repertory grid to operationally define the meaning of different concepts of ecosystem risk.

6.1 Data Collection

Data was collected by means of a literature review, expert interviews and an Internet-based survey.

6.1.1 Literature Review

The first step of the textual analysis was to define the scope of the scientific literature about ecosystem risk assessment and management.

This survey of the scientific literature was conducted using keywords in context. Initially, the terms ecosystem and health, sustainability, integrity and carrying capacity were used. Adaptive management, resilience and the ecological footprint were later added to the search criteria.

The initial search of the University of British Columbia catalogue yielded fewer than fifty references. Then Internet searches were conducted, every six months over a four-year period, using the following search engines: Alta Vista (http://www.altavista.ca/), Excite (http://www.excite.com/), Google (http://www.google.com/), Lycos (http://www.lycos.com/), and Yahoo (http://www.yahoo.ca/). Copernic (http://www.copernic.com), a research tool for Windows-based systems, was also used near the end of the survey to conduct searches of the Internet. It relies on multiple search engines and keeps a log of the results, which can be later edited and updated.

Most of the journal articles were downloaded from several online electronic collections of journal articles. The CPI.Q is the electronic version of the Canadian Periodical Index covering 415 periodicals published in English and French (http://www.galegroup.com/). It provides the full text of articles published since 1995 for 165 of these periodicals. The Online Computer Library Centre Electronic Collections Online (ECO) database also provides the full text of many journal articles (http://oclc.org/oclc/menu/eco.htm). The National Library of Canada and the Library of Congress helped locate many of the books cited.

The search retrieved material encompassing the full range of humanities, social, and natural sciences. As these terms are quite widely used, additional criteria were used to select the material retained for further consideration. The selected items either had to explain the structure and functioning of ecosystems, or debate the meaning and significance of any of the selected terms, or address the assessment or management of risks to actual ecosystems. Over seven hundred references were retained for in-depth analysis from the initial search and subsequently reviewed.

The second step was to clarify the underlying conceptual distinctions between various mental models of risk. A framework was developed and used to compare different mental models of risk. This involved identifying experts'

- Beliefs about what is important and worthwhile about ecosystems
- Thoughts about the driving forces of environmental change
- Views of the role of science
- Social concerns
- Choice of valued ecosystem components, attributes, and relationships
- Choice of measurement and decision-making criteria, and
- Metaphors employed

The final step was to describe these mental models and to try to capture the gist of the controversy about their use. These findings were subsequently used in the design of the interview and questionnaire surveys.

6.1.2 Expert Interviews

Ecosystem risk is an unbounded intellectual domain. There is no sampling framework from which we can draw a sample of experts who think and act in terms of ecosystems. Ecosystem experts are found in many disciplines and contexts.

An expert is someone who is widely recognized as a reliable source of specialized knowledge or skill, whose judgement is recognised by the public and his or her peers. Experts may have advanced training and/or prolonged experience. There is no need for an individual to have professional or academic qualifications to be accepted as an expert.

An exhaustive review of the literature helped to identify the relevant institutional and disciplinary contexts in which experts concerned about ecosystems risk can be found. In order to ensure the study population was as broadly representative as possible, the first goal was to ensure that all points of view were represented (i.e., every metaphor and potential mental model of risk), and that all groups with a potential interest in ecosystem risks were canvassed (e.g., academics, resource managers and regulators, business and consultants, community groups and activists.) Finally an effort was made to ensure that the respondents were not drawn exclusively from one region or institutional setting.

Potential subjects were identified from their published work (e.g., academics & journalists), their management responsibilities (e.g., conservation, protection or resource management activities), their participation in conferences (e.g., EMAN – Ecological Management and Assessment Network), and professional or organizational directories (e.g., CEN – Canadian Environmental Network).

Over one hundred potential interview subjects were identified from their involvement with ecosystems or their contribution to the literature.

A sample size of thirty interviews was thought to be sufficient during the first stage of the survey to compare and contrast three to six different mental models of ecosystem risk. For knowledge elicitation purposes a small sample of four to six respondents has proven to be adequate and to perform as well as larger data sets (Gaines, 1989), permitting rapid prototyping of expert systems. Experience has shown that larger numbers of interviews will simply produce redundant information (Hill, 2002 citing Bostrom, 2000).

The interview subjects were first approached by e-mail (see Appendix 1). Because of the travel and logistics involved, the mailings were staggered so that interviews could be wound up in one region before they commenced in the next. When a subject agreed to an interview, they were contacted by phone within ten days to make the necessary arrangements. A running account of completed interviews was kept to ensure that professionals and knowledgeable persons drawn from different institutional contexts (government, industry, consultants, academia, and public interest groups) were interviewed. An extra effort was made to reach women, activists, and business people, when it became apparent that the numbers of interviews with these subgroups lagged behind other groups.

Each person who agreed to an interview was asked to sign a consent form (see Appendix 2). They were asked for their permission to identify them as one of the persons interviewed. An audio recording was made of each interview.

In the interview, (see Appendix 5) the respondents were asked to describe what they thought was important about ecosystems – to identify entities, processes, and relationships that they thought were worthy of management, conservation or protection in most instances. Next they were asked to suggest corresponding assessment criteria. They were asked to compare and contrast different eco-concepts. After they had selected their preferred eco-concept, they were asked to describe it, using the eco-assessment criteria they had selected.

During the next phase of the interview the respondents were asked to identify what they thought were the main threats to ecosystems today and the extent to which they agreed or disagreed with some common beliefs about society and the environment.

In closing, the respondents were asked to provide some basic personal background information so that their responses could be compared to those of other respondents.

6.1.3 Internet-based Questionnaire Survey

Respondents were asked to rate a common set of eco-concepts using the same assessment criteria, a task which should have taken around thirty minutes to complete. These concepts and criteria were derived from the expert interviews. Two versions of the questionnaire were posted on the web (see Appendices 8 & 9).

An e-mailed cover letter was used to contact respondents and an HTML form was used for data collection. Modern e-mail packages automatically convert universal resource locators (URL) or web-addresses in the text of e-mail into hyperlinks. Placing the URL of the survey form in the covering e-mail allowed to the respondent to "click" their mouse on the URL to display the survey form and subsequently fill it out.

The original interview respondents were contacted again by e-mail and asked to complete a version of the survey using the WebGrid software (www.repgrid.com). Both user help notes and context sensitive help were provided to help respondents use the WebGrid software. WebGrid facilitates a free-form response. The respondents could edit and modify their response, adding or deleting concepts or criteria if they chose. (See Appendix 8.)

A fixed form of the questionnaire was posted on the web (see Appendix 9). This version of the survey was programmed using HTML, and input data into an Access database where it could be downloaded for analysis. A request to participate in the survey was circulated to several e-mail discussion lists, inviting a wide range of subjects to respond to the survey (see Appendix 10). The preface to the web-based questionnaire provided background information about the survey, covering the same topics as the interview request and consent form. It guaranteed the subjects' anonymity. However, this time, the respondents were told they would be considered to have given their consent to participate in the survey by filling out the web-based questionnaire and submitting their answers to the survey database. The subjects participating in the second stage web-based survey were self-selected.

The respondents to the web-based survey provided background information such as gender, age, education, professional identification and institutional affiliation. By embedding the survey in a website, it was also possible to track the respondents' origin. The respondents rated a common set of eco-concepts using the same assessment criteria. The respondents could not modify the concepts or criteria used. Nor could they revisit or compare their ratings of any of the concepts once they had completed the task of rating each of the concepts. Since they didn't participate in the first stage of the survey, they were then asked to indicate the extent to which they agreed or disagreed with the same set of statements that were used during expert interviews to elicit the respondents' worldviews.

6.2 Analysis

The literature, interview, and Internet surveys were analysed using a mixture of qualitative and quantitative data analysis techniques.

6.2.1 Qualitative data analysis

NVivo data analysis software (Richards, 2000) was used to analyse qualitative data from the literature review and expert interviews. Computer-assisted qualitative data analysis software helps researchers form an accurate and transparent picture of interview or textual data while providing an audit of the data analysis process as a whole—something that is often missing in accounts of qualitative research. For reviews of the various software packages that are available, see CAQDAS online (http://caqdas.soc.surrey.ac.uk), and for discussions of the use of this software in qualitative research, see the Forum for Qualitative Social Research (http://www.qualitative-research.net/fqs/fqs-eng.htm).

NVivo imports textual documents directly from word processors. These documents can be easily coded on screen. One can easily view any coded data in context alongside other data that has been coded in the same way. Any data retrieved following coding identifies the source of the data and is linked to the original document. One can also use online memos to link text in different documents, building up themes across the data.

NVivo was used mainly as an organizing tool. NVivo organises documents and coding categories or filters into sets or nodes. A hierarchical tree structure can be used to summarise and display the coding categories. For example, the valued ecosystem entities, attributes, and relationships were organized according to levels of biological organization (i.e. landscape, community, population, and organisms). It was easy to group observations and to eliminate redundancies. The list of categories can readily be reviewed and modified as the analysis proceeds. Coding and coding categories can be more readily modified using NVivo than a word processor.

NVivo supports advanced searches of qualitative data (e.g., use of Boolean operators and strings). It can also be used to explore and test relationships in the data. Patterns, associations and relationships may be suggested and explored by using logical or contextual searches. NVivo was also used to summarise the data in tabular form.

6.2.2 Statistical data analysis

The repertory grid data was downloaded from an online cache (for the WebGrid survey instrument) and from an Access database (for the Web-based survey instrument) and incorporated in a common Excel spreadsheet. The interview subjects' personal background data and response to the worldview questions were added to the same spreadsheet. The data was analysed using Microsoft Excel and SPSS (Statistical Package for the Social Sciences).

A variety of statistical techniques were used to analyse the data. Romney and his associates (2000) examined a variety of statistical techniques for comparing different semantic domains. These methods included: comparing mean correlations within and between subgroups, principal components analysis (PCA), analysis of variance (ANOVA), and simple visualization techniques. For example, there are N(N-1)/2 pairs of informants in any study. The mean pair by pair correlation or matching score can be used to estimate the degree of expert consensus about a given domain (Romney, Weller & Batchelder, 1986). Alternatively, measuring the amount of agreement using covariance would completely avoid the problem of response bias because covariance is invariant under different levels of response bias. They concluded that all these techniques can be appropriately applied to partitioning shared knowledge into the following segments: (*1*) a universal portion shared by all subjects, (2) portions shared by specific subgroups, and (3) a residual portion accounting for sampling variability, measurement error, and true differences among subjects. All of the methods produce comparable results, although each contributes unique insights about the data.

Underlying relationships in the data were tested for significance. If differences were found, an effort was made to determine whether they could be attributed to differences in the respondents' personal characteristics, professional background or work experience.

6.3 Repertory Grids

Repertory grid methodologies were used to elicit the conceptual structures of experts (see Jankowicz, 2004; Fransella, Bell and Bannister, 2004; Stewart, 1998; Shaw & Gaines, 1987).

Kelly (1955) developed the repertory grids technique as a means to bypass people's cognitive defences and to gain access to their underlying conceptual thinking by asking them to compare and contrast relevant examples. The power of the technique is remarkable because it only takes a few critical cases described in terms of a few relevant attributes to completely define any subject matter domain (Gaines, 1989b).

A repertory grid is a matrix, a two-way classification of data, cross-referencing an individual's personal observations and experience with a subject matter domain and their personal interpretation or classification of that experience. Kelly's repertory grid is a way of representing personal constructs as a set of distinctions made about elements in a problem domain.

Elements are examples drawn from experience that can be used to define the knowledge domain being explored. The universe of discourse is determined by the choice of elements. Investigators usually start with six to 12 elements (see Miller, 1956). Elements can be concrete or abstract entities, should span the topic as fully as possible, and should be the same type and level of complexity. Any example used should be as specific as possible. Duplication or overlap should be avoided. All examples should carry equal weight and be equally representative of the element class. An element class should be homogeneous.

Constructs are terms that describe the way in which the elements are similar or different from each other. Constructs are elicited as dichotomies or bipolar opposites. They may also be more-or-less-than continuums. Constructs describe dimensions of thinking that are important to the subject. Each cell contains the constraints or a range of values within which these distinctions apply. The bipolar attributes in repertory grids can be treated as a pair of predicates defining fuzzy sets and the rating of an entity on an attribute can be regarded as defining the degree of membership of the entity in each of these sets.

The repertory grid is a matrix of elements (entities), constructs (attributes) and values. (See Figure 6.1.) The constructs or distinctions made about the elements in a particular domain form the rows of the matrix. The elements or entities, which make up the domain, form the columns of the matrix.

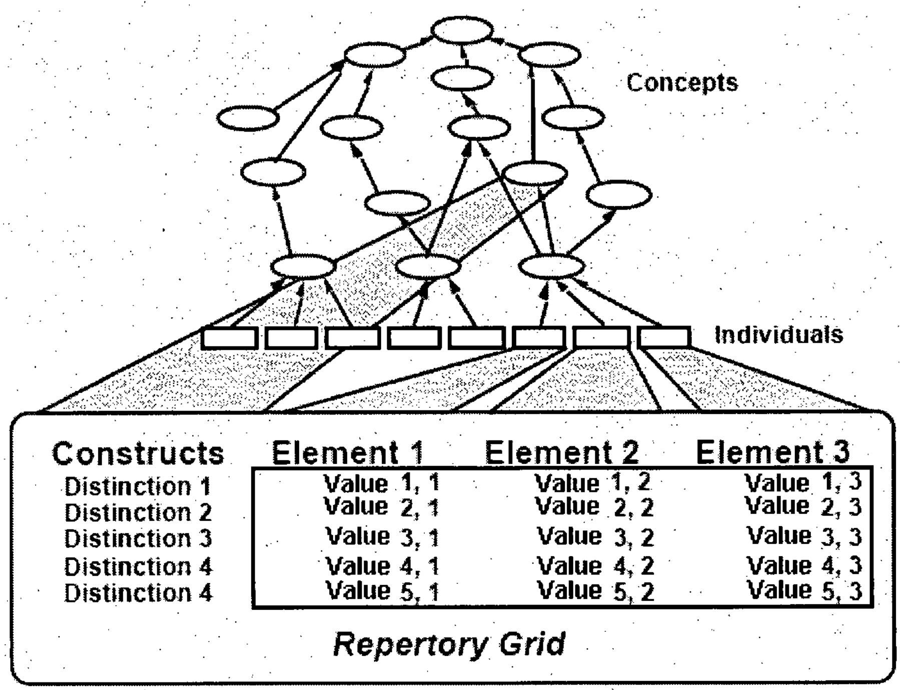

Figure 6.1 Repertory Grids (adapted from Gaines & Shaw 1993 Fig. 10)

The resultant data structure is one in which the expert has specified the terms for the elements and their constructs, and assigned values to the constructs. The elements are usually concrete items in the domain whose nature, definition and names can be supplied by most experts. Constructs are used and labelled idiosyncratically because they reflect the differences in experts' personal conceptual systems.

The constructs and elements used in a repertory grid must be independent of one another (Slater, 1969). The function of the repertory grid is to provide a technique for deriving an individual's conceptual structure without direct elicitation of concepts or their structures and relationships. The assumption is that it may be easier for experts to compare individual examples in the domain of interest, and then to state in fairly concrete terms how they would distinguish between them in terms of properties relevant to the purpose of eliciting the grid.

The elicited conceptual structure is defined by a set of basic distinctions, and by intersections (derived distinctions). The constructs elicited will not fully specify the underlying conceptual structure. However, it is possible by using suitable analysis techniques to approximate the structure from the data provided (Gaines & Shaw, 1986).

Repertory grids have been used in a variety of applications. Gaines & Shaw first suggested in 1980 that repertory grids would be a useful development tool for expert systems, and later published a validation study of the elicitation of expertise from accountants and accounting students (Shaw & Gaines, 1983b). Boose (1984) in an independent study reported success with this technique in developing a wide range of expert industrial applications. Other applications of repertory grids can be found in education and counselling (Roulet, 1998, Pope & Shaw, 1981) and personnel evaluation (Preiss, 2000; Dunn, Pavlak, & Roberts, 1987); in clinical psychology (Shepherd & Watson, 1982); in the development of expert systems (Ford et al., 1993, Gaines & Shaw, 1993), modelling neural networks (Domany, Hemin & Schulten, 1999), software requirements engineering (http://ksi.cpsc.ucalgary.ca/SERN/) and the deployment of information technology (Tan, 1999); in assessing different communities' responses to policy changes (Coakes, Fenton, & Gabriel, 1999); in comparing geographers' preferences about mapping techniques (Shaw & Woodward, 1988); in construction management (Halcrow-Bristol, 2001); in the evaluation of investment opportunities (Harris,1999); in marketing (Eden & Jones, 1984; Sampson, 1972); and in studies of risk perception and communication (Shepherd, Frewrer, & Howard, 1996; Raats, Sparks & Grugeon,1994).

- *Eliciting Repertory Grids*

The knowledge expressed in a mental model may depend on the elicitation context or method (Caputi & Reddy, 1999; Carley & Palmquist, 1992). Mental models elicited by interviews may vary significantly if questions are framed differently. For example, Thüring and Jungermann (1986) found that groups who were asked questions about the causes and consequences of California earthquakes in slightly different ways generated different mental models about the same problem. Sevón (1984) found that even the temporal characteristics of a task influence the ways in which mental models are expressed. By comparing mental models generated in relation to past and future events, she found that subjects' explanations of past events were more complex than those of future ones.

Kelly (1970) was interested in developing interviewing techniques (see Stewart, 1998) that did not impose the researcher's own frame of reference and worldview on the respondent and at the same time would reliably elicit the respondent's cognitive structure. Open-ended unstructured interviews do not impose the researcher's cognitive frame on the respondent but unfortunately they often fail to elicit valid and reliable perceptions from the respondents. Repertory grids are a structured way to elicit the cognitive structure that an expert imposes on a subject domain; that is to say, the expert's own frame of reference. These interviewing techniques attempt to solve the problem of researchers trying to force the respondent's perceptions of phenomenon into the cognitive structure of the researcher (Reger, 1990).

Repertory grid interviews can be used to elicit different conceptual structures for the same domain without distortion. In this study, two types of information were elicited: the distinctions made among the relevant elements that comprise the domain; and the constructs used to describe these distinctions. The interviewing techniques used in the expert survey are described in full in the interview guide provided in Appendix 4.

Several strategies were used to elicit a set of elements from the experts to define the subject domain under study. Element nomination strategies included providing the respondent with a set of examples prepared in advance, describing an element class, and then asking the respondent to provide their own examples. Another strategy was to ask a series of questions where the respondents' answers helped develop the element set. When you resort to questioning, the questions have to be structured so that the interviewer samples all aspects of the element class. With a prepared list, it is easier to compare different experts' responses. However, the respondents may not be familiar with all of the elements in the list and some may wish that other elements had been included. If the interviewer asks the respondent to provide examples of particular classes of elements, they may respond with more familiar examples and omit others. It also may be more difficult to explore the boundaries of the domain.

Constructs were elicited by comparing two or three elements at a time (dyads or triads). The most common form of eliciting constructs is the triad method. Elements were presented in groups of three, being the smallest number that will produce both a similarity and a difference. Subjects were then asked in what way two are alike and different from the third. This elicited the emergent or expressed pole of the construct. The implicit pole was elicited by the difference method (the subject could be asked to describe the way in which the example differs from the pair) or by the opposite method (what would be the opposite of the description of the pair).

In dyadic elicitation, respondents were asked to consider whether two elements are alike or different in some way. Once they described the similarity or difference, they were asked to provide a contrasting word or phrase opposite to the phrase they initially provided. In triadic elicitation respondents are asked to consider in which way two elements are similar yet different from a third. The contrasting word or phrase elicited in this instance described the way in which the pair is different from the third member of the triad.

Another process that was introduced into the interview is laddering. Laddering-up is a process by which the interviewer can derive more general and inclusive constructs, and laddering-down is a process by which the interviewer can derive more detailed and precise constructs. Laddering-up has the interviewer take a construct and ask which pole of the construct is preferred in terms of the purpose of the interview, and why. The interviewer can then ask for the reasons underlying the preference, and then ask the subject to elaborate each of the reasons. This process takes you deeper into the construct system and eventually leads to what are known as core constructs - deeply held values and beliefs which the person adheres to strongly. Laddering down has the interviewer take a construct and ask for some details about how one pole of the construct differs from the other - asking for more observable and behavioural detail about the construct. These laddered-down constructs nearly always appear as clusters in the final grid.

After a number of constructs had been created, the next stage was to rate all the elements on all the constructs, thereby forming a matrix that can be analysed by a number of different statistical methods. The resulting matrix or repertory grid represented the respondents' construct system for the domain of enquiry in the language respondents use to describe and classify the elements.

Repertory Grids can be elicited manually or through the use of a microcomputer. The advantage of computer-assisted elicitation is that it reduces the time needed to elicit constructs and complete the grid. The Internet can also be used to reach many potential subjects. The disadvantage is that many potential subjects either may not be computer literate or may be averse to using a computer. If they lack the necessary computer skills or understanding of the software they use, the respondents may make many errors, become frustrated, and give up. Another significant issue may be software glitches or problems with the programming.

- *Repertory Grid Elicitation and Analysis Tools*

The Personal Construct Psychology (PCP) web site provides an overview of the available repertory grid programs (http://www.pcp-net.de/info/comp-prog.html). Only two programs support both elicitation and analysis: Idiogrid (http://www.idiogrid.com/) and WebGrid III provide access to repertory grid elicitation and analysis tools (http://www.repgrid.com/). Other programs support either elicitation (e.g. Enquire Within http://www.enquirewithin.co.nz/) or analysis (e.g. InGridx - Wingrid http://homepages.ihug.co.nz/~income/tutor.htm) functions only.

WebGrid-III is a toolset for the elicitation, analysis, and sharing of different repertory grids over the World Wide Web that resides on the server of the University of Calgary. It is publicly available at no cost and can be used by anyone who has a Microsoft or Netscape browser. Grid data are stored in the HTML data input form itself, in hidden input fields, so that the user may save the file locally, on their own personal computer or home page, reload it at any time, and continue the transaction. The embedded data is readily extracted for use in other stand-alone applications, such as RepGrid2 (CPCS, 1990) and Statview. The WebGrid-III server also converts computed graphics to a GIF format, and returns them to the client where they can be examined and shared with others. WebGrid also facilitates the exchange of grids between different users, and the online administration and caching of grid data. An update to WebGrid-IV is currently in preparation, and the RepGrid software package is now available for Windows XP as well as OS X systems (http://www.repgrid.com/).

This research relied on WebGrid-III and RepGrid2 (CPCS, 1990), an earlier stand-alone version of the software package, to perform the analysis.

The Repertory Grid tool set (see Figure 6.2) includes modules that help analysts elicit and exchange repertory grids; that sift and sort the elements and constructs in the repertory grid using hierarchical and spatial clustering (FOCUS and PrinCom); that enable them to make semantic comparisons (SOCIO) of the experts' usage of relevant concepts and terminology; and that facilitate conceptual structuring, and induction (ENTAIL or INDUCT) which can be used to analyse the grid as a logical structure of classes and rules.

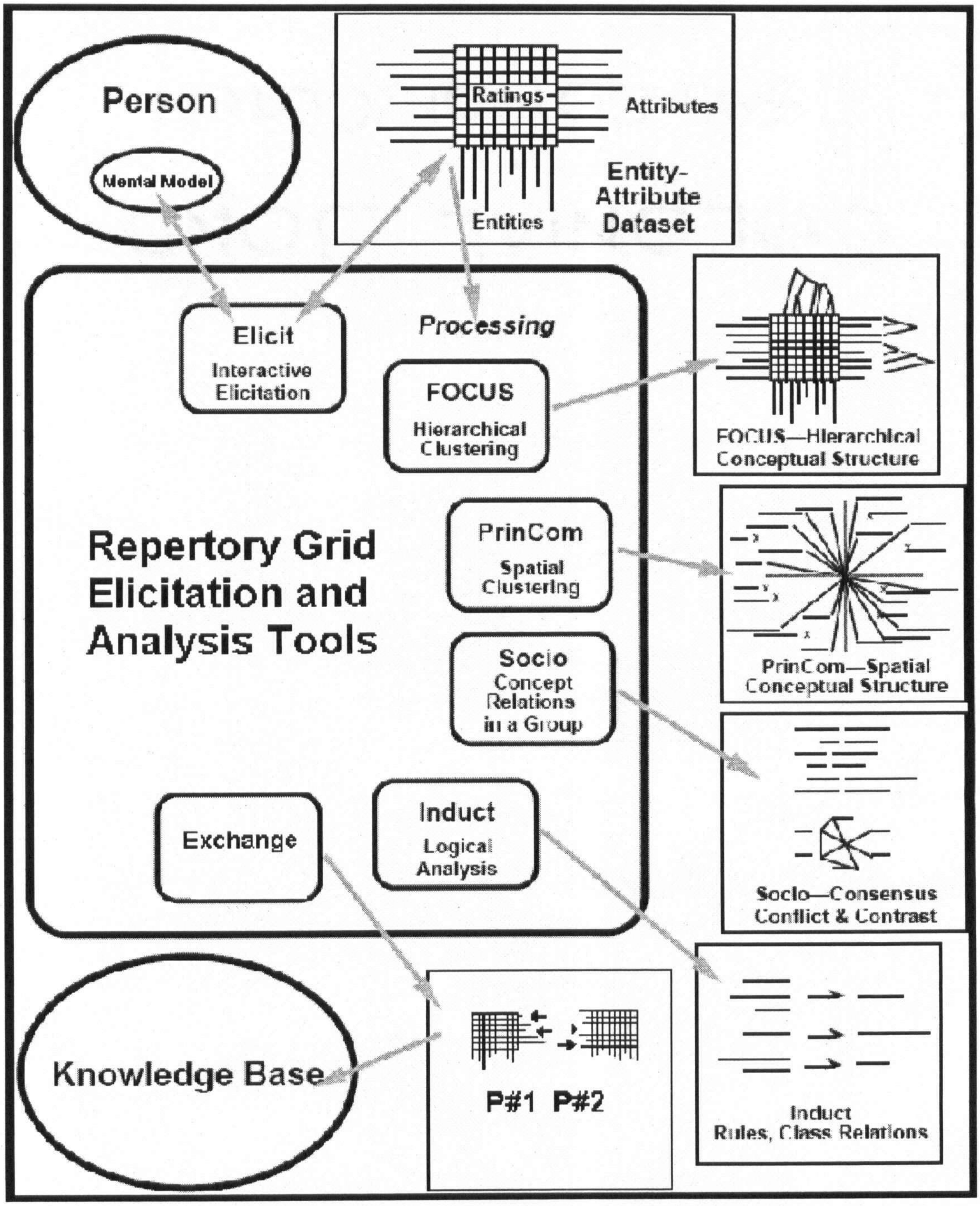

Figure 6.2 The Repertory Grid Tool Set (adapted from Gaines & Shaw 1993)

- *FOCUS*

The FOCUS algorithm (Shaw, 1980) is a distance-based hierarchical cluster analysis technique that reorganizes the original repertory grid by the similarity of the element and constructs ratings.

The FOCUS algorithm computes two matrices of inter-element and inter-construct distances. Elements are arrayed from 0-100% based on degree of similarity and constructs are arrayed from -100% to +100% based on their degree of similarity. Then the sets of elements and constructs are sorted so that similar elements and constructs are grouped together.

Clusters are computed by selecting the highest matching scores from the resulting element and construct matrices. This process is continued until all the elements and constructs have been incorporated. Tree diagrams (acyclic graphs) showing these clusters are then imposed on the re-sorted original data, revealing the underlying dependencies (see Figure 6.3).

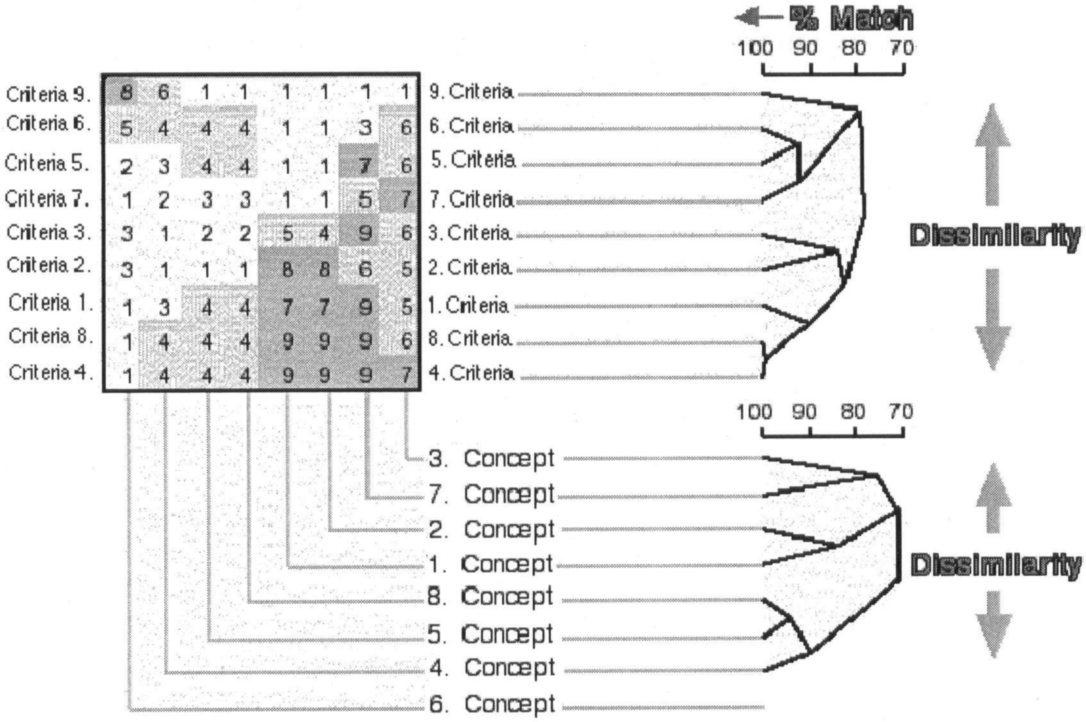

Figure 6.3 FOCUS Cluster Analysis Diagram

The major criterion for forming clusters is the linear reordering of the constructs and elements so that the resulting grid displays a minimum total distance between all adjacent pairs of rows and columns. This often results in a pattern of like responses being displayed diagonally across the grid (see Figure 6.3). Both the reordered constructs and elements are numbered for easy reference.

A cluster is a subset of points (elements or constructs) where the distance between any points in the cluster is less than the distance to any point not in the cluster. For example, constructs that are zero distance apart are in some sense similar or equivalent constructs.

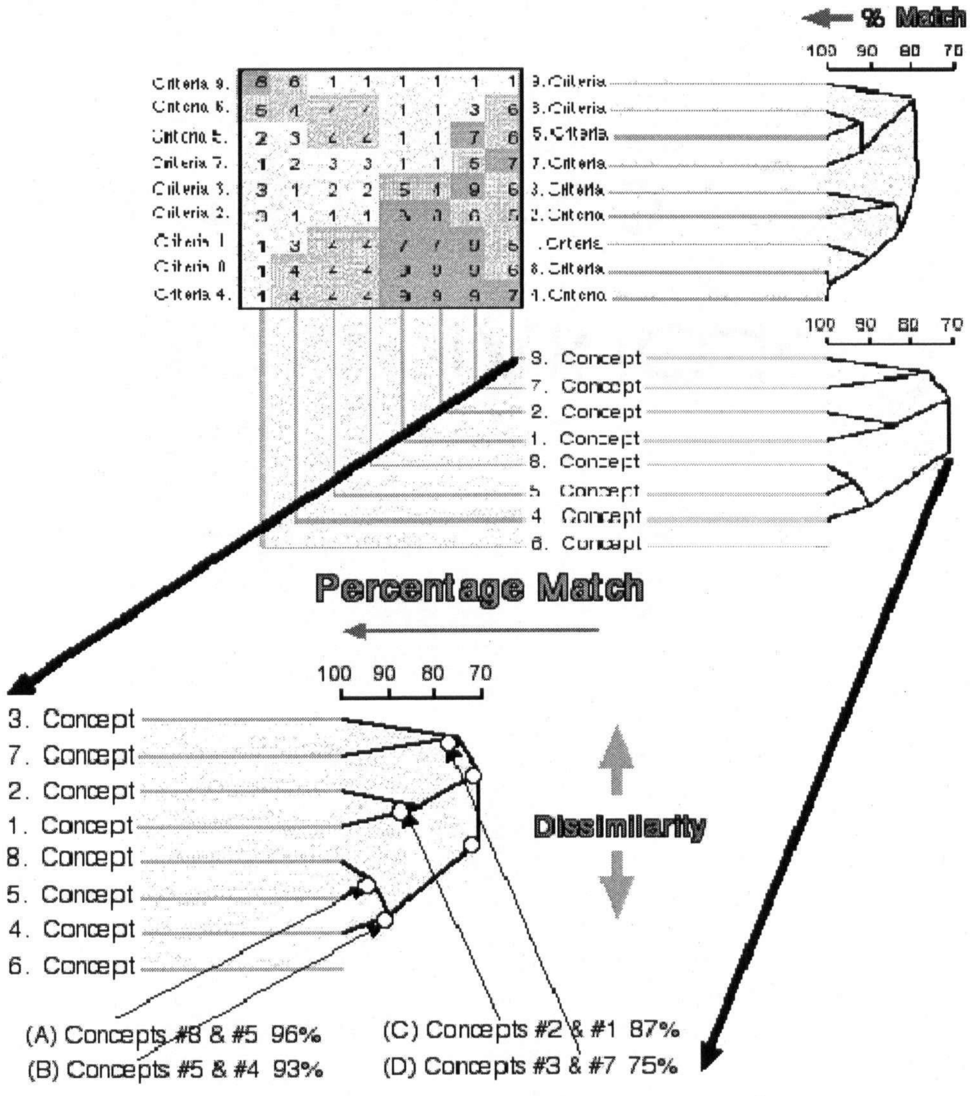

Figure 6.4 Interpreting Focus Clusters

In each FOCUS cluster diagram there are two acyclic graphs that display the resulting clusters of constructs and elements. The scale above each graph displays the degree of similarity, matching score, for closely linked constructs or elements. The matching score is a measure of overlap between sets. For example, in Figure 6.4, Concept #8 and #5 have a matching score of 96% and Concept #5 and #4 have a matching score of 93%. Set (A) & (B) also form a distinct cluster. In FOCUS analysis, these sets are sometimes also called links. In Figure 6.4 clusters A and B are very similar and the least like cluster D. Concept #6 in contrast is not included in any cluster.

- *PrinCom*

PrinCom, another distance-based algorithm, is a variant of principal components analysis, first used by Slater (1964) to process repertory grids. Principal components analysis is used to reduce the number of variables necessary to explain the overall variation in the data, to classify variables, and to locate the main dimensions in the data.

Principal components analysis is a technique for finding a set of weighted linear composites of original variables such that each composite (principal component) is uncorrelated with the others (Bell, 2004a). The first principal component is such a weighted linear composite of the original variables with weights chosen so that the composite accounts for the maximum variation in the original data. The second component accounts for the maximum variation that is not accounted for by the first, and so on. These weights are found by a matrix analysis technique called eigen-decomposition that produces eigenvalues (which represent the amount of variation accounted for by the composite) and eigenvectors (which give the weights for the original variables).

There are several tests that could be applied to determine whether to retain or discard a component from the analysis. Kaiser's rule is to only retain components with an eigenvalue greater than one because it does not make sense to retain a component that explains less variance than a variable. The second possibility is Catell's scree test. Plot successive eigenvalues, and look for a point where the plot abruptly levels out. For the more statistically inclined, there is always Bartlett's test. What the Bartlett test tells you is whether after a component has been extracted, the remaining dispersion is within the limits of sampling error. Because of the small non-random samples used in repertory grid analysis, statistical tests of significance are generally not thought to be appropriate.

PrinCom uses a spatial map to represent the grid in a minimum number of dimensions (Shaw & Gaines, 1998; Gaines & Shaw, 1993.) The numeric ratings of any given construct in the grid may be regarded as a vector of values. From this point of view, each construct becomes represented as a point in multidimensional space, whose dimensions are the numbers of elements involved. For the entire constellation of constructs, PrinCom projects a set of axes, such that the first axis accounts for most of the distance between them, and the second axis accounts for most of the remaining distance. If the constructs are zero distance apart, it can be inferred they are being used in the same way.

In PrinCom the elements (or subjects) are arranged according to the descriptions provided by the constructs (predicates). Subjects with similar descriptions are plotted in close proximity. The constructs appear as lines with the degree of collinearity between two lines being a measure of the constructs' dependence. Perpendicular constructs can be construed to be independent of one another. The length of the lines is some indication of the polarity of the constructs. For example, any constructs whose subjects are clustered at the extremes of the scale would be displayed with extended lines.

The PrinCom display can be used to identify elements described in similar ways, and to identify the constructs attributed to each element (see Figure 6.5). In Figure 6.5 the elements (concepts) are represented by x and the constructs (criteria) by squares. Criterion 6 is closely related to Criteria 4 and 5, but appears to be largely independent of Criteria 1-3. Criteria 4 to 6 largely describe Concept #3. Concept #3 is the converse of Concept #4 because it is negatively associated with the same criteria.

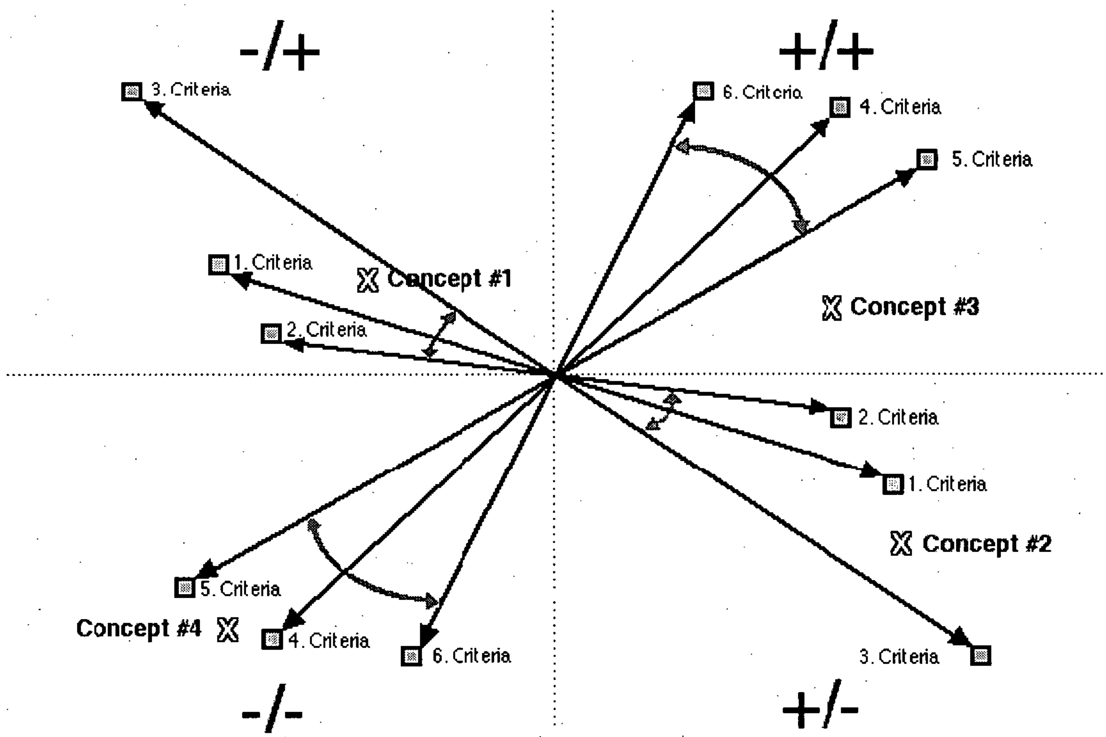

Figure 6.5 Interpreting the PrinCom Map

- *SOCIOGRIDS*

SOCIOGRIDS (Shaw, 1980) maps one grid onto another and produces a matrix of the degree of similarity between the two grids. The SOCIOGRID analysis module provides the tools for comparing different experts' conceptual systems for the same domain, (repertory grids with a common set of elements), allowing us to identify their similarities and differences. If the grids have common element and construct names, the FOCUS "minus" algorithm can be used to highlight the differences. Zeros indicate agreement and increasing values indicate the degree of dissent. Each construct used is listed in order of how highly matched it is across all grids. Mode grids consist of the most commonly used constructs. Similarity is not determined based upon literal similarity but upon the ordering of the construct set. Elements or constructs where there is the least amount of agreement can be deleted from the grid. Only core elements and constructs, where there is some degree of consensus and common understanding, need be retained for further consideration.

SOCIOGRIDS' Entity-Attribute Compare functions were used to identify the degree of conflict and consensus in the group (Shaw, 1994; Shaw & Gaines 1989). For example, the Entity-Attribute Compare function can be used to identify matching or dissimilar values, and the Entity Compare functions can be used to identify the closest matching elements of the grids. The Mode, Entity and Attributes function can be used to extract highly matched elements and constructs from the majority of grids.

Figure 6.6 illustrates the compare function. In comparing the repertory grids of two different persons, the constructs and elements are sorted so that those that are most similar are on the top and left respectively. The numbers on the right of the graph show the matching scores and the numbers in parentheses show the cumulative percentage of items matching at that value or greater. For example, Person #1 and Person #2 only agree on Concept 3 and Criteria 4-6 if a cut-off value of eighty percent is used.

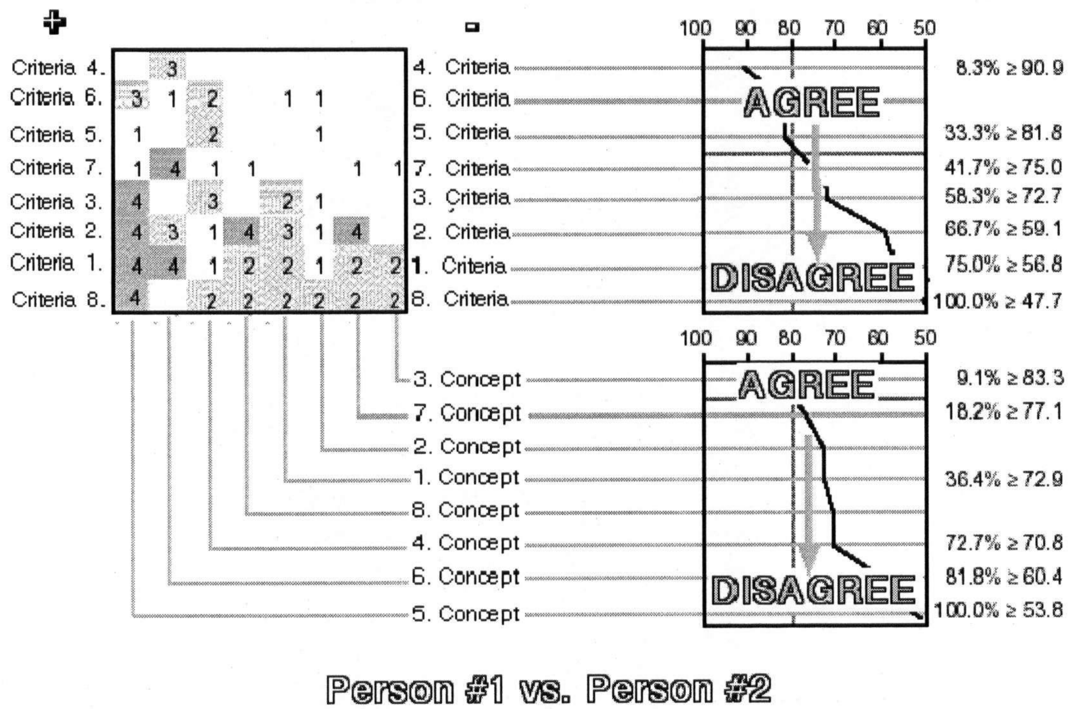

Figure 6.6 SOCIO Compare Functions

The SocioNet functions also help to identify subgroups of experts who think and act in similar ways. SocioNets are extracted from the matrix of similarity measures. The highest related pair and subsequent pairs (linkages) are extracted on the basis of their rank ordering on the similarity measures. Every pair of grids is compared using the FOCUS algorithm to reveal the linkages among constructs in the grids. These functions help show the degree to which each expert is able to make the same distinctions as other experts, even though they may use different terminology. SocioNets exposes the members of the group that have most in common and those with strongly idiosyncratic viewpoints.

- EXCHANGE Grids

The analysis relied primarily on Shaw and Gaines' (1989) methodology for comparing the conceptual systems of experts. A common or modal repertory grid derived from the interview survey was exchanged amongst survey respondents. A modal grid of ecosystem concepts and criteria was derived from the expert interviews, and the survey respondents were asked to rate eight different eco-concepts using a common set of criteria. Comparisons of the original grids allowed correspondence and contrast to be modelled, while comparisons of the exchanged grids allowed consensus and conflict to be modelled.

Repertory grid methodologies can be applied to domains where there is still no consensus about the relevant distinctions and terminology, and the primary sources of knowledge are still the conceptual structures of individual experts. In these circumstances, it is important not to assume that there is a 'correct' conceptual framework or terminology and to be able to highlight the differences among experts. It is only possible to compare the conceptual structures of experts as long as the experts agree on the elements or entities that comprise the domain they are studying.

The primary consideration in modelling the knowledge structure of groups is a linguistic one - tracking the terminological differences among experts. The recognition of consensual concepts is important because it establishes the basis for communication using shared concepts and terminology. By identifying conflicting concepts, it is possible to avoid confusion when different concepts are labelled with the same term. When we are aware of contrasting concepts, it can help identify those aspects of knowledge about which communication and understanding may be very difficult.

Attributes \ Terminology	Same	Different
Same	***Consensus*** Experts use terminology and concepts in the same way	***Correspondence*** Experts use different terminology for the same concepts
Different	***Conflict*** Experts use same terminology for different concepts	***Contrast*** Experts differ in terminology and concepts

Figure 6.7 Comparing the Conceptual Structures of Experts (Shaw & Gaines 1989 Fig. 2)

As Figure 6.7 illustrates, where there is consensus, shared concepts and terminology provide the basis for communication among experts. Different terms may have a corresponding use in describing the same concept, and one can be substituted for the other. Where experts use the same or corresponding attributes to describe the entity, there is a basis for mutual understanding of any underlying concepts, and for professional collaboration. In instances of conflict, confusion can be avoided if one realises that different concepts are labelled with the same term. Finally, when experts use contrasting terminology and concepts, communication may not be possible. Discussion of these differences is itself an important goal of the knowledge elicitation process. (See Shaw & Gaines, 1989; Gaines & Shaw, 1989.)

- INDUCT

Repertory grids are useful knowledge elicitation tools. However, their 'flat' entity-attribute-value structure seems to preclude their use in developing hierarchical knowledge structures common in semantic networks and decision analysis. FOCUS cluster analysis is a sound tool for deriving hierarchical structures underlying a flat grid (Shaw & Gaines, 1998). WebGrid provides another option called INDUCT. INDUCT does not look at a grid as a set of vectors in space but as an assignment of truth-values to logical predicates. For example, if we consider that the elements or entities being rated are the subjects, the ratings of constructs or attributes may be considered to be the predicates describing the subject. Gaines and Shaw (1986; 1980) were the first to use fuzzy sets to analyse the entailments in repertory grids based on rating scales.

The INDUCT algorithm is derived from fuzzy set theory (Gaines & Shaw, 1986; Shaw & Gaines, 1984; 1983; 1982). INDUCT represents the conceptual system implied by the grid as a logical structure of classes and rules. It proceeds by applying a decision tree algorithm to the constructs attributed to a particular element of the grid. It analyses logical dependencies in the data. Three values are provided: (1) the truth-value 1-100%, (2) the possibility of hypothesis being true, and (3) uncertainty reduction, which can be used to prune trivial assertions. The output can be used to create a directed graph in which the strength of the inferences can be expressed as conditional probabilities.

INDUCT infers the rules (with exceptions) necessary to generate complex decisions from fairly small grids – allowing knowledge to be elicited fairly efficiently compared to rule induction from databases (Gaines 1989a). The rules can be converted directly into a decision tree expressing the relationship between the experts' premises and their conclusions. INDUCT generates both Exception Directed Acyclic Graphs (EDAG) which may be read as sets of rules with exceptions (Gaines 1996) and Ripple-Down Rules (RDR) that minimize interactions between rules (Gaines & Compton 1995). INDUCT combines the features of manual and inductive approaches to knowledge elicitation.

6.3.1 Case Studies

The following hypothetical case studies demonstrate the functionality of the software, and illustrate the various types of analysis that may be undertaken.

JOB Case Study.

The goal of this particular case study is to gain insight into the subject's job preferences. Using the elicitation process described earlier, the subject was asked to compare and contrast their current job with their ideal job, a possible transfer, and a recent job offer. Eleven criteria were elicited. The subject was then asked to use these to rate each job option on a 5-point scale (see Figure 6.8).

		1	2	3	4	
High Salary	*1*	1	4	4	1	*1 Low Salary*
Flexible Working Hours	*2*	1	4	3	2	*2 Fixed Working Hours*
Long Holidays	*3*	2	1	1	2	*3 Short Holidays*
Good Working Conditions	*4*	1	3	2	2	*4 Poor Working Conditions*
Supportive Boss	*5*	1	4	2	2	*5 Boss not supportive*
Private office	*6*	2	3	3	2	*6 Open office*
Pension Scheme	*7*	2	1	1	2	*7 No Pension Scheme*
Interesting work and colleagues	*8*	1	4	3	1	*8 Would be bored out of my mind*
Good prospects for promotion	*9*	1	5	3	2	*9 No prospects for promotion*
Opportunity for travel	*10*	1	4	3	1	*10 Never get to leave the office*
Educational Leave	*11*	2	5	4	2	*11 Training-on-the-job*
		1	2	3	4	

New Job Offer
Job Transfer
Current Job
Ideal Job

Figure 6.8 Display of Repertory Grid Elicited from the Subject Comparing Job Options

FOCUS can be used to conduct a cluster analysis of the subject's job options and preferences. The cluster analysis (see Figure 6.9) shows that the new job offer is most like the subject's ideal job (matching score of 91%) and the subject's current job is most like the proposed transfer (79.5% match). When we examine what the subject thinks is important in a job, the elicited criteria break down into the following clusters:

1. Pension and holidays (100%)
2. Interesting job, good salary, supportive boss, flexible working hours and prospects of promotion (93.8%)
3. Private office, good working conditions, interesting work and an opportunity to travel (87.5%)
4. High salary and an opportunity to advance one's education (81.2%)

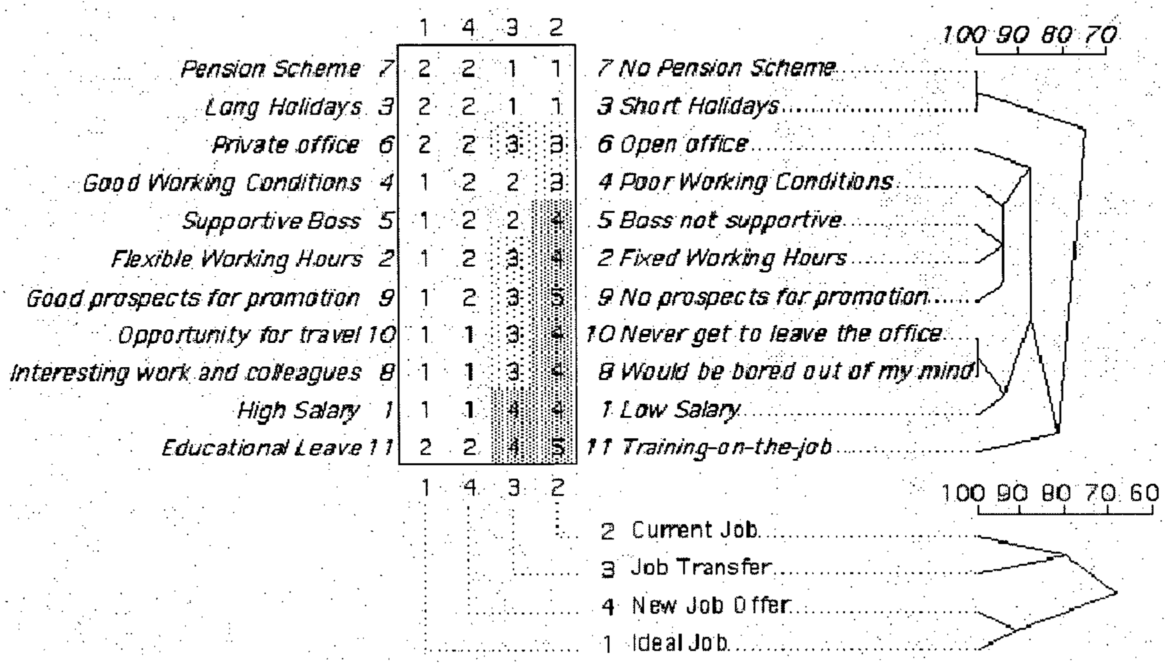

Figure 6.9 FOCUS Cluster Analysis of the Criteria Used by the Subject to Evaluate Job Options

Next PrinCom was used to represent the grid in a minimum of dimensions (see Figure 6.10). The constructs used by the subject to evaluate their job prospects are bi-polar opposites, and allow us to contrast the subject's job options. For example, the subject's current job is the exact opposite of their ideal job. When it comes to the new job offer and a potential transfer, the picture is more mixed, but the new job is described largely in positive terms, while the transfer is described in more negative terms. The new job is closer to, and therefore more alike the subject's ideal job. It is also worth noting, for example, that criteria like interesting work and colleagues, opportunity to travel, and educational leave are for all intents and purposes equivalent terms in the subject's evaluation scheme because they are zero-distance apart.

One component accounts for 93% of the variance (see Table 6.2). Examining the construct loadings on each component, the first component could be described as Job and Fringe Benefits. For example, the most important contributing variables to the first component were salary, promotional opportunities, interesting work and co-workers, travel, and personal development. The second component accounts in a minor way for the working environment. The subject's relationship with the supervisor and office working conditions appear to be a very minor consideration.

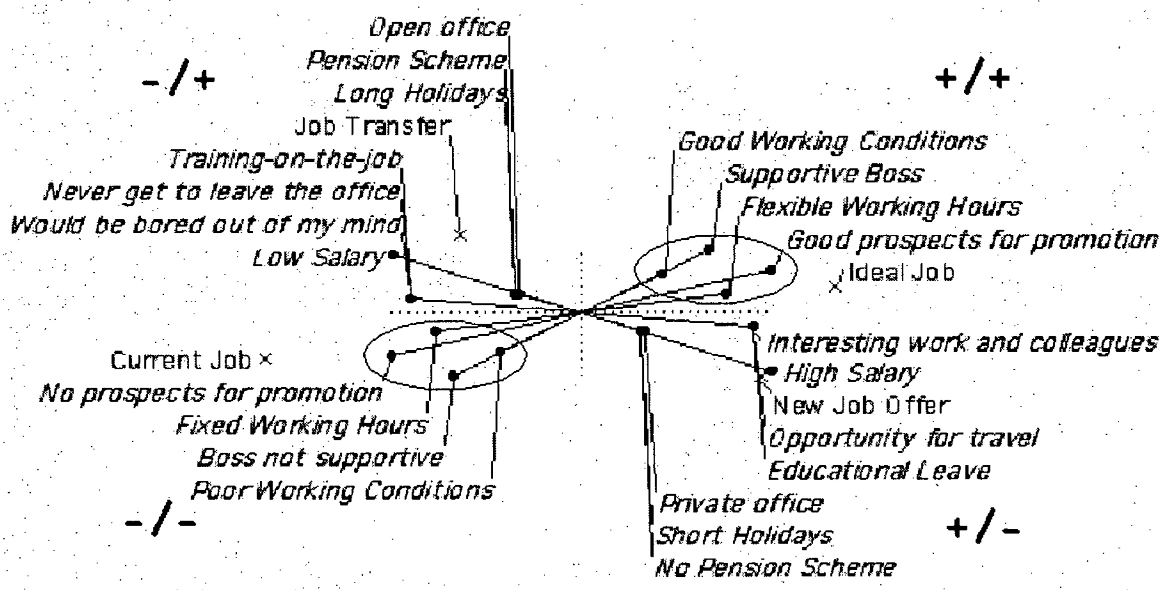

Figure 6.10 PrinCom Map of the Subject's Evaluation of Their Job Options

Table 6.1 Principal Components Analysis of Subject's Job Selection Criteria

% of variance accounted for by each component	* 1 2 3
	* 92.91 6.35 0.74

Construct loadings on each component		*	1	2	3
Salary	1	*	0.710	-0.235	-0.057
Hours of work	2	*	0.547	0.078	-0.083
Holidays	3	*	-0.237	0.078	0.019
Working conditions	4	*	0.311	0.156	-0.064
Supervisor	5	*	0.482	0.253	0.027
Office accommodations	6	*	0.237	-0.078	-0.019
Company pension	7	*	-0.237	0.078	0.019
Interesting work & co-workers	8	*	0.645	-0.060	0.052
Promotional opportunities	9	*	0.719	0.175	0.007
Travel	10	*	0.645	-0.060	0.052
Personal development	11	*	0.645	-0.060	0.052

EXPERTS Case Study.

Repertory grids can be merged to examine the intersection of ideas, by exploring mixed clusters of concepts to see if one can find common ground. In the following hypothetical case study we have sifted and sorted through grids elicited from a wilderness activist, fisheries biologist, land use planner, and commercial forester, using the SOCIOGRID functions to choose a common set of assessment criteria. Each of the participants contributed some of the criteria used to construct the modal grid. They were then asked to use the same modal grid to rate what was important in ecosystem management.

The Focus Cluster analysis (Figure 6.11) shows that the participants used the criteria with roughly the same level of consistency (inspect the acyclic graph in the lower right hand corner). All had matching scores in mid 70 % range.

Several distinct clusters of assessment criteria were identified (review the acyclic graph on the upper right hand side of the diagram). For example,

100% Match

1. Nutrient cycling, population growth, vigour & viability (Criteria 1,10,11)
2. Range, species composition, disturbance regime (Criteria 9,12,13)
3. Ownership, size and state of the area (Criteria 2,8)

93.8% Match

4. Reproductive success, natural ecological processes, habitat connectivity (Criteria 6, 7, 16)
5. Logged, farmed or settled, dams or roads, artificial boundary (Criteria 3, 4, 5)

87.5% Match

6. Species at risk (Criterion 14)

75.0% Match

7. Plants, fish, and wildlife unfit for human consumption (Criterion 15)

Although clusters may have similar matching scores, each cluster may be characterised by a distinctive response pattern. For example, even though clusters one and three have a 100% matching score they have very different response patterns (Inspect the list of criteria. Compare criteria 1, 10 and 11 that make up cluster 1, and then contrast them with criteria 9, 12 and 13 that make up cluster 2.)

The acyclic graph shows that most of the clusters of criteria in this list may be grouped into more inclusive clusters. For example, clusters 2&4 and 3& 5 may be grouped into more inclusive clusters. The resulting clusters appear to contrast human-induced and other ecological changes.

The PrinCom Map (Figure 6.12) helps to identify the principal underlying dimensions in the data. Each of the participants was sensitive to a different set of assessment criteria. The wilderness activist was most like the biologist and least like the commercial forester in his use of the criteria. The activist's use of the assessment criteria is the polar opposite of the forester. The wilderness activist and fisheries biologist were more preoccupied with conserving the natural character and functioning of the area than either the forester or the land use planner, who were perhaps less concerned about human impacts and more interested in the area's potential use.

The length of lines in the PrinCom Map indicates the relative polarity of the constructs. For example, where the forester and planner may be indifferent, the activist and biologist prefer large intact, naturally bounded areas with native species. Ownership, the construction of dams and roads, and whether or not the area has been logged, farmed or settled before are other polarizing issues that discriminate among the individuals.

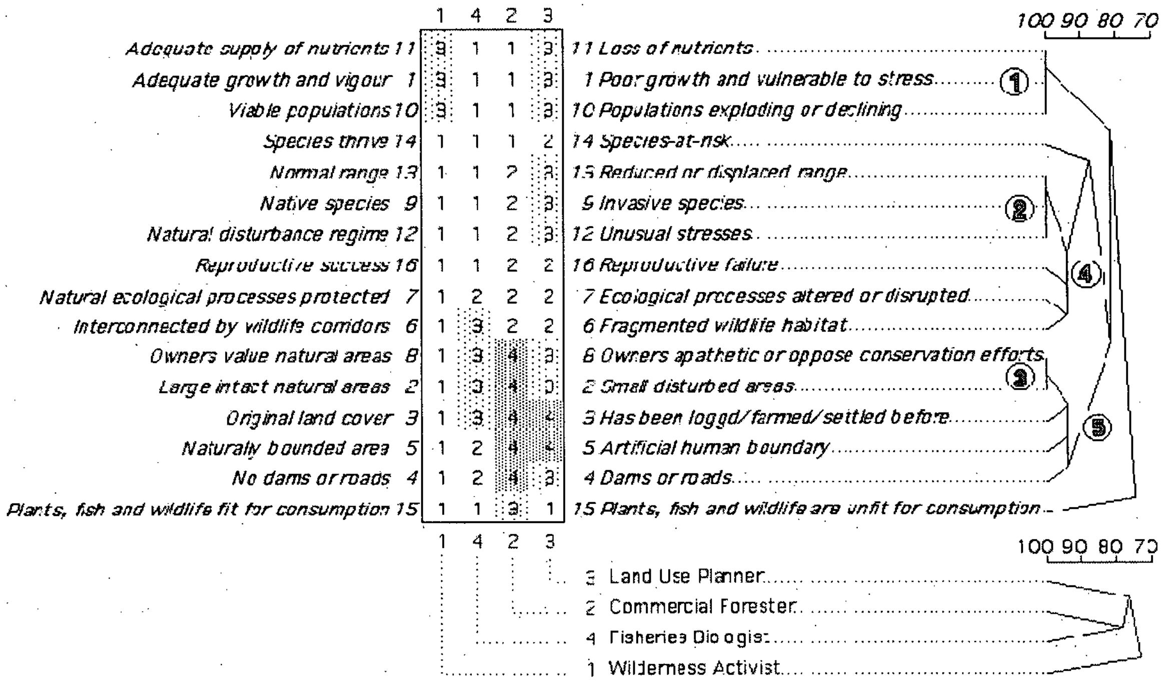

Figure 6.11 FOCUS Cluster Analysis of the Participants' Use of the Assessment Criteria

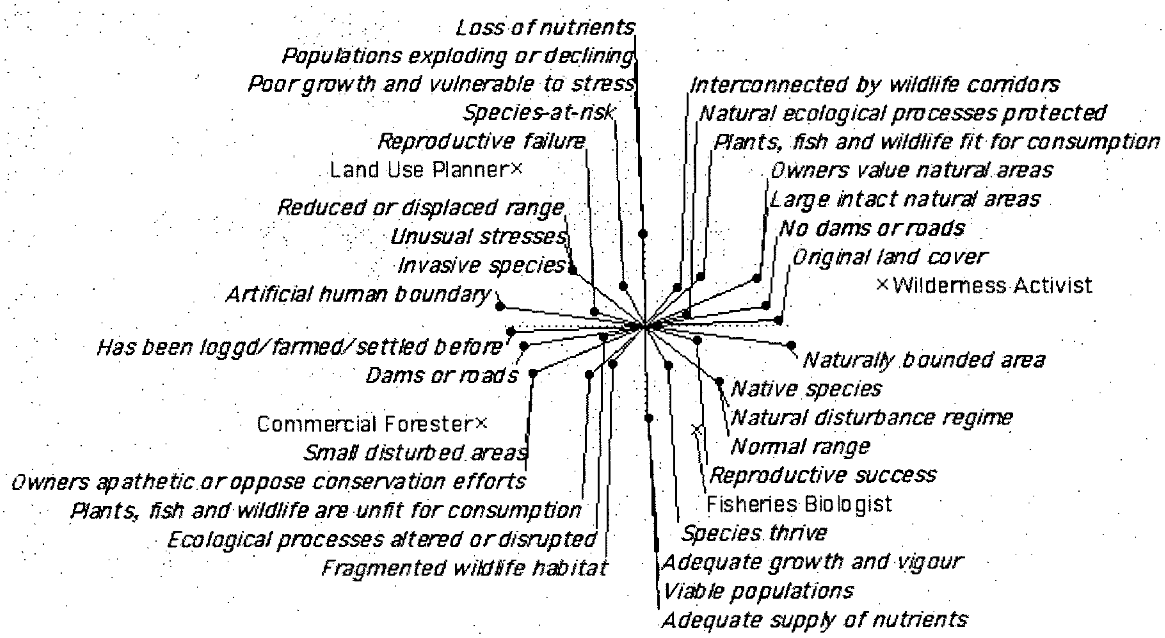

Figure 6.12 PrinCom Map of Participants' Evaluation of Relative Importance of the Criteria

6.3.2 Repertory Grid Descriptive Statistics

A variety of summary statistics can be used to describe the repertory grids themselves (Bell, 2003; Preiss, 2000; Reger, 1990; Dunn, et al. 1986). Collective frames of reference (such as knowledge networks or epistemic communities) can be represented by matrices of shared constructs. For example, element or construct preferences were determined from their average ratings. The perceived similarity or difference of the elements was computed from a cluster analysis and pair-wise comparisons of inter-element distances.

Construct centrality describes the relative importance of the construct and was measured from its average correlation with other constructs. Differentiation describes the number of constructs generated. Experts tend to have a more differentiated construct system than lay people.

Cognitive complexity describes the number of unique constructs generated by a respondent. Where elements of a grid are construed in a similar fashion, construct organization is simple. If the constructs are highly inter-correlated, each construct contributes very little additional information about the elements, and will lead to similar choices and outcomes. More complex construct systems are inter-correlated to a lesser extent, and each construct independently contributes more information about the elements. If the elements are construed in less related ways, then the more complex conceptual organization may lead to more uncertain outcomes. Of course, if the elements are construed in totally unrelated ways then we could have chaos.

6.4 Worldview Scales

This research aimed to determine whether or not the experts' belief systems play a role in framing their views of ecosystem risk. As well, it examined the influence of different personal background characteristics on these belief systems. Following a discussion of the literature on risk perception, the rationale for development and testing of the worldview scales used in this study is explained.

Building on Simon's concept of *bounded rationality* (Simon 1955) and Tversky and Kahneman's work on *cognitive heuristics and biases* (Tversky & Kahneman, 1974), Slovic and his coworkers (Slovic, Fischoff & Lichtenstein, 1978) argued that faulty perceptions of risk could be explained in terms of the cognitive limitations of human beings. Through multivariate analysis they showed that many risk characteristics were highly correlated, and could be reduced to two or three factors at most (e.g. type of consequence, nature of exposure, and lack of knowledge) that explained the majority of the variance in risk judgements. The derived factor space provided a cognitive map of risk perceptions that has been called the psychometric paradigm. This approach has been replicated many times, and it has been frequently possible to show that the factor structure is invariant. Psychometric research has provided the justification for a model of decision-making that seeks to insulate rational expert judgement from contamination from irrational public fears (Jasnoff, 1998).

Dake (1991) developed an alternative approach to the study of risk perception based on the grid-group theory of Douglas & Wildavsky (1982). This approach is premised on the notion that risk perception is conditioned by group membership. Dakes (1991) cultural bias scales have been used in a number of studies (Sjoberg 1998; Marris, Langford & O'Riordan 1996). Researchers found that each cultural bias was associated with a distinct set of beliefs, and concern about a distinct set of risks. This research suggests that risk communication practice would benefit from a shift in attention from message construction to audience analysis.

However, when the two approaches were compared, these researchers found that the psychometric approach explained a far greater percentage of variation in risk perception than the cultural approach (e.g. Marris et al, 1996, found the psychometric approach explained 50% of the variance in risk perception, and only 14% of the variance in risk perception was explained by the cultural approach). Sjöberg, and his associates have reviewed the psychometric and cultural approaches to risk perception and found both of them wanting (Sjöberg, Moen & Rudmo, 2004; Sjöberg, 2002; Sjöberg, 1995). They claim either approach explains only a small percentage of variation in risk perception.

The psychometric approach treats qualitative risk characteristics as inherent attributes of the hazards themselves rather than as the respondent's own mental constructs (Marris, Langford and O'Riordan, 1997). Its explanatory power is largely due to the inclusion of dread items in the list of explanatory variables (Sjöberg, Moen & Rudmo, 2004). However, dread is not a cause but more likely a consequence of perceived risk (Gregory & Mendelsohn, 1993). Furthermore the psychometric correlations in aggregate data tend to disappear when analyzed at the level of individuals (Sjöberg, Moen & Rudmo, 2004; Marris, Saunderson & O'Riordan, 1998). As well, the psychometric approach does not distinguish between groups, other than lay persons or experts.

One could discard Dake's cultural bias scales simply because researchers have not obtained good results using them. (e.g. Sjöberg, 1998; Marris, Langford and O'Riordan, 1997). What is more, context free questions do not provide the means to analyze group relations (Marris, Langford and O'Riordan, 1997). On closer examination it is also clear that the Dake's questions do not tap the underlying distinctions made by cultural theory (e.g. Thompson, Ellis & Wildavsky, 1990; Douglas & Wildavsky, 1982) or the distinctions used by other researchers to compare the worldviews of different reference groups (e.g. Haas, 2002; Dunlap et al., 2000; Hofsetter, 1998; Stern & Dietz, 1994; Merchant, 1992). Marris, Langford and O'Riordan (1997) also note that a better mix of quantitative and qualitative research methodologies would generate better insight into who might defend these viewpoints in different circumstances, whether there are only four mutually exclusive worldviews or not, and how these views are related to patterns of social solidarity, judgement or institutional trust.

Many writers have argued that our current environmental problems stem from a constellation of beliefs they call the dominant social paradigm (Dunlap & van Liere, 1978). These beliefs include our support for the status quo; continued economic growth; our faith in science and technology, progress, and future prosperity; and opposition to government intervention in our lives. They claimed that if disaster is to be avoided society must embrace a new ecological paradigm (e.g., Daly, 1973, Meadows, Meadows & Behrens, 1972, and Commoner, 1971).

One of the most widely used measures of environmental beliefs is the New Ecological Paradigm (NEP) scale (Dunlap et al., 2000, Dunlap & Van Liere, 1978). NEP claims to measure the extent to which people believe human actions help or harm the environment. The NEP taps beliefs that people have about their impact on the balance of nature, the need for limits to growth, human domination of nature, and the potential magnitude of the current eco-crisis. It is not rooted in social or psychological theories of attitude formation. Dunlap and Van Liere (1984) found that the dominant social paradigm and the new ecological paradigm were negatively correlated. The NEP has been replicated in many countries and from the available evidence it appears that the

Canadian public shares most of the beliefs described by the NEP (e.g. Blake, Guppy, & Urmetzer, 1997).

Contrary to Douglas and Wildavsky's (1982) grid-group theory, there is no a priori basis for saying there are only four worldviews. Regardless of what you call them (e.g. worldviews, paradigms, visions or discourses) depending on the source used, from two to five worldviews are described in the literature. For example, Dunlap and his co-workers refer to the new ecological paradigm and the dominant social paradigm (Dunlap et al. 2000; Dunlap & van Liere, 1978); O'Riordan (1995) refers to ecocentric and technocentric worldviews; and Gagnon, Thompson and Barton (1994) to ecocentric and anthropocentric worldviews. Costanza (2000) uses two worldviews, technological optimist and technological skeptic, from which he generates four visions (i.e. Star trek, Ecotopia, Big Government, and Mad Max). Even Dake (1990) at one point describes worldview (a) and worldview (b). Examples of tripartite breakdowns include: Hofstetter (1998) technosphere, ecosphere, and valuesphere; Axelrod (1994) egocentric, homocentric, and ecocentric; Stern and Dietz (1994) egoistic, altruistic, and biospheric; and Merchant (1992) bio-centric, socio-centric and ego-centric. Douglas and Wildavsky's (1982) grid-group theory included four worldviews: hierarchy, egalitarianism, individualism, and fatalism (e.g. Dake 1990). Haas 2002 also identified four dominant environmental discourses: cornucopian, malthusian, sustainable development, and radical/postmodern. Other authors added a fifth worldview to the base set proposed by Douglas and Wildavsky. For example, Thompson added autonomy (Thompson, Ellis & Wildavsky 1990), and Krewski added technological enthusiasm (Krewski et. al. 1995).

In the present research, three clusters of beliefs were chosen to represent social, environmental and economic viewpoints or discourses. Neither Dake's nor Dunlap's scales represent the full spectrum of beliefs described in the literature on worldviews. Dake's is biased towards egalitarianism and Dunlap's excludes the dominant social paradigm. Ten different clusters of beliefs were identified from the worldview literature described above. (See Table 6.2)

Table 6.2 Experts' Worldviews

WORLDVIEW	Discourse #1	Discourse #2	Discourse #3
Orientation	Aesthetic and moral – Fairness to future generations	Public good – Social order	Self interest – Equality of opportunity
Concerns	Inequality -	Safety & Security -	Personal freedom -
Perceived Risks	Environment & Technology	Violence, Deviance	Business failures, Debt
Myths of Nature	Fragile – unforgiving	Resilient within limits	Robust – benign
Other Species	Coexist	Wise use	Dominate
Resource Management	*Can manage neither resources nor needs*	*Can manage resources but not needs*	*Can manage resources and needs*
Social Control	Community consensus and cooperation	Bureaucratic standards and regulation	W ell-functioning markets and competition
Experts	Misuse scientific knowledge in short-sighted ways	Map & manage boundaries of acceptable risk	Creativity & innovation is critical to our survival
Learning & Decision Making	Precautionary – Participatory	Rules - Defer to authority	Trial & error-Negotiation
Risk Taking	Risk Averse -continued economic growth will ultimately lead to environmental disaster	Risk/Benefit –opportunity cost for creating wealth, a stronger society and a safer future	Risk Taker - growth and innovation leave people better-off in the long run

Each bundle or cluster of beliefs in Table 6.2 should be internally consistent and contrast with the others. These discourses are typical of different groups such as government officials and regulators, academics, community and activist groups, and business groups. Underlying experts' worldviews are different value orientations, concerns, perceptions of risk, myths of nature, relationship with other species, notions of resource management, preferences with respect to social controls, ideas about the role of experts, conceptions of environmental learning, and approaches to risk taking.

Worldviews consist of a common set of shared beliefs and causal assertions that distinguish one group of people from another. Both the interview and survey respondents were asked to state the degree to which they agreed or disagreed with the statements in Table 6.3 (which follows) using a five point semantic differential scale. The statements were selected from previous surveys (primarily Dunlap et al. 2000, and Kempton, Boster & Hartley 1995) using the framework provided by Table 6.2. The statements were selected because of their known power to discriminate between groups with different worldviews and were adapted for use in this expert survey after a pre-test.

Scaling, like index construction, creates a summary measure from a set of indicators of an underlying construct. The working hypothesis was that if respondents shared a particular worldview they would endorse or endorse more strongly a particular subset of these statements. Likert indexes (average ratings of each subset of questions) were calculated for the three different clusters of beliefs. These summary measures were used to test the hypothesized relationship between experts' mental models of risk and their underlying worldviews.

The validity and reliability of a scale can be determined in a variety of ways. A scale has logical or face validity if it adequately defines or describes the concepts or domain being studied. Do different observers agree on the meaning of the items or recognise the imagery being used? The theoretical rationale for the selection of items has been explained above. Construct validity was established by selecting representative test items for each domain. Where the items selected discriminate between known groups or predict differences in experts' mental models they have criterion validity.

A good scale or index should be internally consistent.

Indexes are constructed from a set of test items that are thought to represent a latent variable, such as a worldview. Items (e.g. the statements) representing a latent variable (such as a particular worldview) should be more strongly interrelated with each other than with the items that are thought to represent other latent variables (different worldviews).

Scales are ordinal indexes that describe greater or less than relationships. Although the items (e.g., statements) used in a worldview scale are often expressed in ordinal terms using a semantic differential scale (i.e., the subject may strongly agree through to strongly disagree with a statement) each set of items (describing different worldviews) are not necessarily ordinal with respect to each other.

Table 6.3 Typical Beliefs about Society and the Environment

WORLDVIEW	Belief Statements		
	Discourse 1	Discourse 2	Discourse 3
Orientation	• We have to protect the environment for our children & grandchildren, even if it means reducing our standard of living today.	• In this country we should return to more traditional values and way of life.	• Continued economic growth & technological innovation is the key to improving human welfare.
Concerns	• If wealth and opportunity were more fairly distributed in this country we would have fewer environmental and social problems.	• We cannot rely on the functioning of markets or the goodwill of individuals to protect our health and the environment.	• Governments should not restrict peoples' personal freedom or their lifestyle choices.
Perceived Risk	• Modern technology poses serious risks to the environment.	• The so-called "environmental crisis" facing humankind has been greatly exaggerated.	• Human ingenuity will insure that we do NOT make the Earth unliveable.
Myths of Nature	• The balance of nature is very delicate and easily upset.	• Nature is resilient but it can only absorb so much damage.	• Nature will recover in the long run from any harm caused by humans.
Other Species	• Plants and animals have the same right as humans to exist.	• As long as the same species exists elsewhere in the world, humans have the right to use plants and animals to meet their needs	• If humans do not have a particular use for species, they shouldn't worry about it becoming extinct.
Resource Management	• We should voluntarily adopt a simpler less materialistic way of life in order to save the environment.	• We are approaching the limit of the number of people the Earth can support.	• The Earth has plenty of natural resources, if we can just learn how to develop them.
Social Control	• Communities know better than government or industry what needs to be done to protect the environment.	• Companies won't protect the environment until the law forces them to do something.	• Private enterprise is more likely than the government to find solutions to environmental problems.
Role of Experts	• There is so much disagreement among experts that it is hard to know who to believe about the environment.	• We should leave the tough decisions about the environment to the experts.	• We should rely on our own common sense rather than the opinions of experts about environmental issues.
Learning & Decision Making	• It is often less costly to prevent environmental problems than to fix them.	• Humans will eventually learn enough about how nature works to be able to control it.	• Environmental choices always involve trade-offs.
Risk Taking	• It is unfortunate but acceptable if some people lose their jobs or have to change their line of work for the sake of protecting the environment.	• The public should be prepared to accept some environmental risks if they want to have a more prosperous economy.	• In a fair society, people who invest and take greater risks should be rewarded.

Cronbach's alpha or reliability coefficient is the most common test of whether or not the test items are sufficiently interrelated to justify their combination in an index. It is not a test of significance, rather a measure of internal consistency. Alpha measures the extent to which item responses correlate highly with each other. Though widely interpreted as such, strictly speaking alpha is not a measure of unidimensionality. In most social science applications a reliability coefficient of .80 or higher is considered acceptable. When alpha is .70, the standard error of measurement will be over half (0.55) a standard deviation.

Cronbach's alpha (1951) is defined as the mean correlation between each of a set of items, all of which have been measured for every member of a sample, with the mean of all the other items. The higher the proportion of variance due to individual responses rather than the items used, the higher Cronbach's alpha. If the deletion of an item causes a considerable increase in alpha then investigators should normally consider dropping the item from the scale.

A set of items can have a high alpha and still be multidimensional. This happens when there are separate clusters of items (separate dimensions) that are highly intercorrelated, even though the clusters themselves are not highly icorrelated. Also, a set of items can have a low alpha even when it is unidimensional, if there is high random error.

In addition to estimating internal consistency or reliability from the average correlation, the formula for alpha also takes into account the number of items on the assumption that the more items, the more reliable a scale will be. That is, when the number of items in a scale is higher, alpha will be higher even although the average correlations may be similar. As the number of items rises, alpha rises.

Also, the more consistent within-subject responses are, and the greater the variability between subjects in the sample, the higher Cronbach's alpha will be. Finally, alpha will be higher when item variances are relatively homogeneous than when they are not.

Reliability answers the question of whether or not a scale or index will yield the same result if used again. Other researchers have used the items that comprise the proposed scales successfully.

Test-Retest reliability was determined by using the worldview scales in the expert interviews, and then by using them again in the internet-based survey, and by comparing the results.

6.5 Research Approach

The literature review helped identify and describe different expert mental models of risk. This information provided the framework for the expert interviews. The experts were asked to identify important ecosystem entities, attributes, and relationships they thought should be managed, conserved or protected. The elicited constructs were coded, grouped and classified by different levels of biological organization, using NVivo. WebGrid was used to further sift and sort through the contributed constructs to create the modal grid that was used in the subsequent Internet survey.

Respondents were asked to describe an ecosystem concept (eco-concept) that best captured their mental model of risk. Their worldview was determined from a series of semantic differential questions designed to capture their beliefs about society and the environment. Indexes for three discourse or clusters of beliefs were calculated from their response to these questions. These indexes were then used to determine the extent to which a particular worldview was associated with a given mental model of risk. The possible influence of the respondents' personal and professional background and previous work experience were also assessed.

During the second stage of the survey, the respondents were asked to rate several eco-concepts using a common set of assessment criteria. WebGrid was used to assess differences in the way they used the criteria to define different eco-concepts. The degree of consensus or conflict in the group was determined. Finally an attempt was made to logically structure their responses and to draw some general conclusions about ecosystem risks.

The background characteristics of respondents were then assessed to determine whether the survey sample was representative and to identify any contributed form of bias.

7.0 EXPERT METAPHORS AND MENTAL MODELS OF RISK

The use of metaphors and different mental models of risk is commonplace and controversial in ecosystem science. Scientific metaphors are analogies (Gentner, 1982) that help us understand one domain in terms of another. The target domain is organized and structured in terms of conceptual systems borrowed from the more readily observable base domain. People use the base domain to think about the target. Conventional metaphors, in contrast, are used for expressive purposes and are designed to evoke a reaction. The conventional view of mental models is that they are simplified set of distinctions that individuals make about the world to help them to interpret what they observe, generate inferences, and solve problems in a particular domain (Kempton, Boster, & Hartley 1995; Rouse & Morris, 1986). Typically a hierarchical means-ends framework is used to capture the concepts and relationships necessary to structure a decision. These conceptual structures are called "expert mental models of risk" (Bostrom, 1990). An alternative position is that mental models of risk are simply working memory constructs or sketches that support immediate comprehension or logical reasoning. Simply put, more often than not, people reason by analogy with familiar situations rather than by abstract logical rules.

One approach is to create a formal scientific model as a template for phenomena, and use it to evaluate the assumptions and conclusions reached by individuals (Morgan et al., 2002). Another approach is to try to understand how individuals think about particular phenomena. The latter approach was adopted for this study

A comprehensive survey of the literature was conducted in an effort to learn more about how experts think about ecosystem risk. The goal of the review was to identify different mental models of ecosystem risk and to develop a framework for comparing them. The review identified three mental models of ecosystem risk, carrying capacity, biological integrity, and ecosystem health.

7.1 Carrying Capacity

The carrying capacity of the ecosystem is the population of a given species that can be supported indefinitely in a given habitat without permanently damaging the ecosystem upon which it depends (Rees, 1995, Postel, 1994). Others have described the carrying capacity of the environment as the final limiting and sustaining abundance (Botkin, 1990). The policy focus of this mental model of ecosystem risk is the reduction of pollution and waste. Limits to growth (Meadows et al., 1972) or the ecological footprint (Wackernagel & Rees, 1996) are the predominant metaphors used to describe this mental model of risk. Human population growth and consumption are claimed to be the driving forces of ecological change.

The major assessment concerns of this mental model are the loss of resource productivity or buffering capacity (sink functions) of the environment. Decision-makers rely on expert input to estimate maximum sustained yields or threshold limit values of ecosystems. Supporters of this mental model believe there are limited sets of choices that will maximize output or minimise risk.

From a functional or energetic perspective (Barrett & Odum, 2000), carrying capacity is reached when respiration on average does not exceed production (P/R is approximately 1). The notion of limits is fundamental to the concept of carrying capacity. Carrying capacity has been used in a variety of contexts where it has acquired different meanings. It has been defined in terms of limits to population growth, the sustained yield of renewable natural resources, and threshold limit values or critical deposition loadings for pollutants.

Carrying capacity is commonly used to describe the maximum population that an area can support year after year, without damage to the environment (Hardin, 1986), or without reducing the capacity of the area to support the same species in the future (Daily & Ehrlich, 1992). Even when carrying capacity is used this way, ecologists often do not agree on its meaning. Leopold (1933), for example, described carrying capacity as a characteristic of habitat whereas Odum (1953) equated carrying capacity with the parameter K in a logistic population growth curve - the upper bound beyond which no major population increase could occur.

The more useful sense of the term is a limit set to population size by the availability of resources (Pulliam & Haddad, 1994). When carrying capacity is used this way it can be measured independently of population size. Carrying capacity may be above or below the predation stable point and/or the threshold for disease transmission. Predation often keeps many prey populations from becoming so abundant that the prey over-consumes its own resources. The spread of disease and pathogens will also be constrained when there is limited contact among various population members. Behavioural factors such as dominance and territoriality also appear to be significant factors in the regulation of many populations.

Carrying capacity is also used to describe the threshold level of exposure to pollutants below which there is unlikely to be serious health damage inflicted on any member of a population or there are unlikely to be serious long lasting ecological effects. This approach has defined regulatory science for over half a century (e.g. Environment Canada, 1996). It is based on a series of fictions (i.e. conventions of dubious validity.)

First, these levels of exposure have been set based on acute short-term exposure to lethal dosages of a single pollutant. The more typical exposure scenario is long run chronic exposure to low doses of multiple pollutants. Damage does occur at lower levels of exposure, especially to sensitive members of the population (e.g., children, the aged and chronically ill are more sensitive to air pollution). The Canadian critical deposition loading for acid rain, for example, was set to protect the most sensitive commercially valuable species of fish but not the food chain on which these fish depend.

Second, threshold levels of exposure are in fact averages that typically do not target the most sensitive ecosystems, life stages, and seasons where the greatest amount of damage is done..

Third, there may be no threshold level of exposure for many pollutants: one exposure may be sufficient to do irreparable harm or some damage will occur at any level of exposure.

Finally, control targets such as threshold exposure levels, critical deposition loadings and ambient air quality objectives are often negotiated compromises. For example, the Canadian control target for smog is set at twice the level of exposure where recognised health effects occur, and the American control target is set at three times the level of exposure where health effects occur. Another way in which carrying capacity is used is to describe the loss of an ecosystem's productivity (source functions) and buffering capacity (sink functions). For example, Rees (1994a) defines carrying capacity as the maximum rate of resource harvesting and waste generation that can be sustained indefinitely without progressively impairing the productivity and functional integrity of ecosystems. Elsewhere Rees (1992) has stated that carrying capacity is equivalent to Hicks' sustainable income - the level of consumption that can be maintained from one period to another without reducing productive wealth (Hicks, 1945). Barrett and Odum (2000) also think that the carrying capacity is equivalent to an optimal economic welfare threshold, because it is the point at which increasing return to scale switches to decreasing returns to scale.

Human carrying capacity is the maximum population, equipped with a particular technology and form of organization, which can be supported indefinitely by a given environment (Catton, 1997/98; Ehrlich & Ehrlich, 1990; Duncan, 1961). Social carrying capacity is always less than biophysical carrying capacity, which pressed to the extreme, would imply an undesirable factory farm style of existence (Daily & Ehrlich, 1996). For other species, individual variation in resource demand is minimal so that population size alone provides a reasonable indication of typical environmental impacts. Per capita human demand can vary from one culture to another and from one social class to another by as much as a hundred to one. Resource exploitation and consumption have leaped ahead of population growth as the industrial mode of development has been adopted around the world (Ehrlich & Ehrlich, 2002). The effective balance between population and resources rarely lasts for very long for any culture or in nature. It is possible for any population to overshoot the carrying capacity of its habitat for a short while by consuming the resource base itself (Catton, 1982). Cultures have died off in the past (Wright, 2005; Diamond, 2004; Ponting, 1991). Industrial technology and modern organization have helped humans to occupy so many ecological niches that global carrying capacity may now be threatened. The spatial and temporal scale of human disruption of ecosystems may no longer be compatible with evolutionary change (Barrett & Odum, 2000).

Ecological footprint analysis inverts the carrying-capacity ratio. Instead of asking how many people a particular area might support, it asks what area is required to support a particular population (Rees, 2003). A population's ecological footprint is the area required to produce the resources that it consumes and to assimilate its waste. It is the area of land and water required to support a society or economy at a specified standard of living (Wackernagel and Rees, 1996). Ecological footprints do not overlap. The carrying capacity appropriated by one economy is not available to another. Area communicates the finite character of the world in readily understandable terms, and is roughly proportional to its photosynthetic potential for low entropy biomass production. Area-based environmental quality indices could also be used to characterize the productive capacity of ecosystems. The ecological footprint is a simple benchmark that can be used to compare human consumption with nature's limited supply to help focus public attention on the challenge of sustainability (Wackernagel et al., 1997).

For example, Rees (2003) estimates that the world's average human eco-footprint is about 2.3 ha, even though there is only 1.9 ha of productive land and water per person on Earth. Humans are compromising the welfare of future generations. He says the eco-footprint challenge for both the natural and social sciences in the twenty-first century is to engineer the means by which human beings can live peaceful, comfortable and satisfying lives on the biological life-support provided by less than two hectares per capita (1.3 ha by 2050), while taking into account the needs of other species. The alternative is resource wars and a descent into geopolitical chaos.

7.1.1 The Limits to Growth

Throughout the post war era, environmental choice has been defined primarily in terms of the assimilative or carrying capacity of the environment. Those who are concerned about the effects of harvesting and use want to maintain ecosystems as source of the energy, food, fibre and other commodities that humans need to survive. They want to ensure that human resource consumption does not exceed rates of natural renewal or technological substitution. Those who are concerned about pollution want to prevent the transmission of disease or to maintain the ecosystem's capacity as a sink for human waste. Wise use of nature is often seen as multiple use or multipurpose use that usually involves a succession of compromises allowing new and more intensive uses through time that shift ecosystems away from their original state. The notion that experts can determine the capacity of the environment to provide what we need and to absorb our wastes remains the dominant perspective of regulatory science and public policy (e.g. allowable catches, threshold limit values).

In 1969 Eugene Odum wrote that succession is an orderly process of community development that is reasonably directional and therefore predictable and that the process of succession will culminate in a stable ecosystem. Botkin (1990) argues that both those for and those against economic growth share this worldview or belief. One side tries to exploit this capacity and engineer solutions to common environmental problems, while the other emphasizes the benefits of doing nothing at all, assuming nature knows best. Our beliefs are out of step with current knowledge of the biosphere and are an impediment to progress on environmental issues, blinding us to the possibility of constructive change. Botkin (1990) wrote that:

> Nature undisturbed by human influence seems more like a symphony whose harmonies arise from variation and change over every interval of time (p. 62) ... ecological succession is nature's melody played against the changing chords of storms, fires and short-term climatic changes, all of which are heard against the ponderous themes of glaciation and soil change. Nature's melody, however, does not result in one final chord that will sound forever. (p. 116)

Until the 1970s ecologists relied on two working hypotheses about population growth: the logistic curve, and the Loka-Volterra equations (Botkin 1990). Although populations have a capacity for exponential growth, ecologists believed that they would grow along an S-shaped curve, called a logistic curve, until they reached the ecosystem's carrying capacity. The sustained yield, the point of maximum growth, is half as large as the carrying capacity, so in theory, any growth above that level could be harvested. The Loka-Volterra equations described the relationship between predator and prey. Predator and prey populations were thought to oscillate, dampening to constant abundance.

These working hypotheses have been conclusively falsified. David Lack (1954), for example, found that variations in population size are the rule, and that animal populations do not reach a stable equilibrium. Moreover, the Loka-Volterra equations were long ago conclusively falsified in lab experiments (Gause, 1934). Nonetheless, these notions persist as common beliefs or assumptions even today. As well, there is a tendency to assume that ecological change will be smooth and continuous, allowing plenty of time for human adaptation, and that human loadings may be approaching but have not yet reached carrying capacity (Catton, 1994), even though there is considerable evidence of overshoot.

Experience has shown that management policies and practices that apply fixed rules for achieving constant yields (e.g., constant carrying capacity) independent of scale have created ecosystems that gradually have lost their resilience over time and broken down in the face of disturbances that could have previously been absorbed (Holling, 1986). Resource management premised on maximum sustained yield has also failed repeatedly because it created a ratchet effect by which pressures on the resource have actually increased. Large levels of natural variability often mask the effects of over exploitation until it is severe and often not reversible. Optimum levels of exploitation must be learned by trial and error. Ecosystems are moving targets with multiple potential futures that are uncertain and unpredictable. Therefore management has to be flexible, adaptive, and experimental at scales compatible with the scales of critical ecosystem functions (Walters, 1986). Experience has shown that short-term actions that are reversible and robust to uncertainty should also be favoured (Ludwig et. al., 1993; Holling, 1978).

7.1.2 Resilience

The Resilience Alliance (http://www.resalliance.org/) is a multidisciplinary research group that is exploring the dynamics of complex adaptive systems in an effort to discover the foundations for sustainability.

Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes (Carpenter et al., 2001; Holling, 1973). The traditional view of resilience reinforces the dangerous myth that the variability of natural systems can be controlled with predictable consequences and that sustained production is an attainable goal. Unlike the traditional view of resilience, this definition emphasizes conditions, far from any steady state, where a system can suddenly flip into another behavioural regime. Clear lakes can suddenly turn into turbid anoxic pools, grasslands into shrub deserts, and forests into grasslands. Broecker's (1999; 1997) work on global ocean circulation, for example, has demonstrated the vulnerability of the Gulf Stream to climate change.

Resilience can be enhanced through adaptive resource management policies. The less resilient the system, the more vulnerable it is to change. Managing for resilience is not only a question of maintaining options for development, now and in the future, but also a question of developing the institutional capacity to cope with environmental change. Adaptive management is a tool to learn about natural systems rather than to control them. It calls for us to use the best available information to generate risk averse management strategies, which can be modified as new information becomes available (Walters, 1986; Holling, 1978). Resilience can also be enhanced by the conservation of biodiversity, because it provides functional redundancy, and high response diversity. Resilience analysis identifies two important sets of information: crucial (slow) driving variables that exhibit threshold effects, and the processes that determine how these variables change. This set of drivers and their determinants may suggest a corresponding set of policies and management actions that will promote resilience, and adaptability.

Just as the Cheshire Cat's smile survived his demise, resilience perpetuates the notion of the balance of nature and the conviction that ecosystems are self-organizing and will ultimately regenerate themselves, although in a different form. Whether an ecosystem is showing resilience by not changing or fragility by changing depend entirely on the observer and assessment criteria that are used.

7.1.3 Limitless Growth

Increasing resource scarcity generates price signals in a market economy, which provide incentives for increased resource exploration, efficiency, recycling and substitution. However, market prices fail to provide real measures of scarcity (resource depletion or thresholds below which stocks cannot renew or replenish themselves) or their functional role in maintaining critical life-support systems and the risks associated with their loss (Wackernagel & Rees, 1996; Pearce, 1988; Rees, 1994a).

Economic growth refers to an increase in value, not volume. Sagoff (1995) suggests that we need to examine well-defined problems rather than simply the issue of size or scale. Some forms of throughput are worse than others. Where we can minimise the environmental risks associated with human economic activity, whether or not an activity is environmentally sustainable is largely indeterminate or may be unknowable. We can minimise energy and material through puts. We can reduce and often contain waste discharges. We can substitute plentiful for scarce resources and harmless substances for toxic inputs. We can extend the useful life of products. We can postpone the inevitable, but we have no assurance that our lifestyle and consumption will be sustainable within a time frame that matters.

7.2 Biological Integrity

Angermeir and Karr (1994) define biological integrity as an ecosystem's capacity to sustain the native biological communities that have adapted to a region through natural evolutionary processes. This definition of biological integrity of ecosystems rests on arguments that other naturally evolved systems in the region can be used as benchmarks to distinguish stress-induced changes from natural fluctuations (CCME, 1996). This second mental model focuses on the widespread loss of biodiversity (genetic, species and habitat). Advocates employ wilderness preservation or species rights metaphors to describe their point of view. The dominant metaphor of integrity or wholeness is drawn from images of pristine wilderness or nature largely undisturbed by humans.

They distinguish biological integrity from biological diversity in several ways. Integrity focuses on whole landscapes rather than particular species or populations. Although introducing species into vacant or unexploited niches of an ecosystem may enhance biodiversity, it would violate the ecosystem's integrity. Integrity refers to the loss of native biological components and the breakdown of ecological processes that generate future diversity, whereas diversity only refers to changes in an ecosystem's composition. Consequently some authors prefer to use the term ecological integrity (Woodley, Kay, & Francis, 1993). In this study, the terms are used interchangeably.

Loss of habitat and the contamination or collapse of food webs is thought to be among the leading causes of species loss. The capacity of ecosystems to support self-regenerating population levels flows from maintaining naturally functioning ecological processes (e.g. energy flux, nutrient cycling and primary production) that support adequate food webs. (See CCME, 1996) Suitable abiotic (e.g. soil, micro climatic) conditions are also necessary to maintain the biological integrity of ecosystems (Kimmins, 1993).

Experts choose natural benchmarks, representative species or typical least impacted areas, to provide criteria which are used to guide decision-making. Some allowance is made for public education and consultation, in order to promote better stewardship of natural resources. Expert judgement is needed to identify natural benchmarks used to assess human impacts on the environment. Experts are urged to rely on the weight of evidence rather than strict scientific proofs. Decision-makers are also encouraged to exercise precaution, and to achieve a safe minimum standard of protection.

Aesthetic qualities such as naturalness, and moral values such as equity and fairness to future generations, dominate this perspective. Like Aldo Leopold (1949), supporters of this point of view believe that a thing is right when it tends to preserve the integrity, stability and beauty of the biotic community and that it is wrong when it tends otherwise. Existence and option values are also important considerations. Economic and human health concerns are often downplayed or discredited in their crusade to save nature. Activists are unlikely to make trade-offs. In the spirit of Leopold (1953) they believe that the first rule of intelligent tinkering is to keep all the parts ("every cog and wheel").

James Karr (1981) first conceived of an index of biological integrity as a way of addressing the shortcomings of regulatory science, which at the time focussed almost exclusively on chemical indicators. He used biological endpoints to describe a gradient of ecological conditions (Karr & Yoder, 2004, Chu & Karr, 2001). When properly defined, he felt that biological integrity could be used as a benchmark against which other sites could be evaluated (Karr, 2003). He also thought that the concept could be used to help clarify human relationships with their surroundings (Karr, 2000). Biological integrity refers to the condition of places at one end of a continuum of human influence that still have the capacity to sustain the full range of organisms and processes that have evolved in the region. When acceptable value-based land-uses are no longer sustainable' a threshold is crossed where the system becomes unhealthy and unsustainable.

The frame of reference for biological integrity is derived from experts' judgments about the characteristics of natural, pristine or unimpaired ecosystems (CCME, 1996). The preference for natural over artificially cultured features is based on the belief that the valued attributes of ecosystems derive from natural evolution, and cannot be manufactured or replaced by technology (Angermeir, 2000). Benchmarks for assessing naturalness ideally reflect conditions free of human influence (Anderson, 1991). The typical reference period chosen for the western hemisphere often predates European settlement (Mosquin, 2000).

Our notions of nature are culturally laden metaphors that we derive from society (Williams, 1980; Collingwood, 1945). Given our limited knowledge of many ecosystems and extensive human presence and disruption of ecosystems around the world, defining what is natural may no longer be feasible. However, the concept of a natural or acceptable range of variation has proven to be a useful construct for setting benchmarks for conservation efforts (Landres, Morgan, and Swanson, 1999; Swetnam, Allen, & Betancourt, 1999). While the chosen range of variation most likely does not replicate pre-human conditions, it is chosen in the expectation that it will ensure the long-term persistence of the conservation target.

In sum, ecological integrity encompasses biotic composition (measured in terms of an inventory of items) and ecological processes (measured as rates of change) over multiple levels of biological organisation. It is assessed in comparison with naturally evolved conditions in a region (Angermeir & Karr, 1994). For example, ecological integrity can be measured in comparison to the historic variety and numbers of native species (Callicott, Crowder, & Mumford, 1998) and by how well habitats maintain their ecological processes following natural disturbances (Covich et al., 1995). An ecosystem with integrity can adjust to natural disturbances without human intervention (Karr, 1990). Conservation of ecological integrity includes representation of ecosystems across natural ranges of variation; protection of total native diversity (species, populations), and the ecological patterns and processes that maintain that diversity; maintenance of natural disturbance regimes; conservation of viable populations of native species, and reintroduction of native, extirpated species (Grumbine, 1994).

Two features distinguish ecosystem integrity (Callicott, 1995a). Integrity focuses on the community level of organization. The concept is more likely to be applied to natural areas where human influences are minimal or have been excluded. As the Parks Panel expressed the concept in plain language:

> Ecosystems have integrity when they have their native components (plants and animals and other organisms) and processes (such as growth and reproduction) still intact. The goal of conserving ecological integrity is best addressed by maintaining or restoring the diversity of genes, species, and communities native to the region. It is a simple strategy consistent with the vision of integrity, which is wholeness. If parts are missing, the ecosystem is not whole. This definition also justifies active management. It does not mean managing for a steady state or trying to turn back the clock. By managing for historic ranges of variation, processes that may take the ecosystem into the future will also be conserved. It also implies thresholds below which some kinds of human use are compatible and appropriate, and above which conservation agencies could just say "no."
>
> (Parks Panel Vol II, 2000 p. 1-15)

Conserving biodiversity, even in protected areas, is going to be an intractable policy problem. The causes of genetic, species and ecosystem loss are extremely diffuse. The root causes are population growth and consumption, and the scale of industrial production and monoculture. The proximate causes are habitat loss and fragmentation, overexploitation, introduction of exotic species and diseases, pollution and climate change (Soulé, 1991). The thresholds at which ecological processes begin to break down and the magnitude of the downward spiral are unknown. These losses may not be reversible. We cannot be sure whether or not our actions will make a difference. The benefits of our actions may not be apparent for generations, if not centuries. Most of all, there is a lack of consensus about goals, priorities, and the means by which we can conserve biodiversity.

7.2.1 Conservation at the Crossroads

The fight to preserve the last remaining wild places on Earth has engaged the attention and efforts of many parties, yet our thinking is not all that new. Simply setting aside more protected areas or trying to save species-at-risk may not be enough. Protecting the ecological integrity of Canada's ecosystems poses new challenges for policy and decision-making.

At the dawn of the twentieth century the North American frontier was fast disappearing under the axe and the plough, and successive waves of human migration and settlement. When Theodore Roosevelt became President of the United States in 1901 on the assassination of President McKinley, he made resource conservation the cornerstone of his domestic policy.

The battle lines were drawn between Gifford Pinchot, the Chairman of the United States Conservation Commission, an advocate for wise use, and John Muir, a naturalist and outdoorsman, who was an advocate for preservation. Pinchot (1910) argued from a utilitarian scientific perspective in the Fight for Conservation for the sustainable harvesting of natural resources ("conservation means the greatest good to the greatest number for the longest period of time" p. 48). He also recognised the obligation of the present generation "to use what we need so that our descendants are not deprived of what they need" (p.80). John Muir, on the other hand, argued for the preservation of wilderness as a place of beauty, quiet contemplation, and spiritual renewal. In 1911 John Muir wrote in My First Summer in the Sierra, a reflective memoir embodying his vision of the beauty and integrity of nature, that "when we try to pick out anything by itself, we find it hitched to everything else in the universe" (p.211). Even today, those who work to protect the ecological or biological integrity of natural areas share the wilderness perspective of Muir rather than the resource management perspective of Pinchot.

Canadian participation in Roosevelt's North American Conservation Conference led directly to the creation of the Canadian Commission of Conservation (1909) by Sir Wilfrid Laurier. By the time the Commission ended its work in 1921, it laid the foundation for twentieth century conservation, urban and regional planning in Canada. It was the first body (1915) to propose the principle that "each generation is entitled to the interest on our natural capital but the principal should be handed on unimpaired to future generations."

The most noteworthy legacy of the Conservation Commission was its lasting influence on wildlife conservation. At the time, most migratory birds, large game animals and fur-bearing animals were on the verge of extinction. The Commission succeeded in getting the commercial sale of game banned. The approach to wildlife conservation which Charles Gordon Hewitt (1921) outlined then, is still followed today:

> A species of animal must not be destroyed at a rate greater than it can increase. Further preservation of any part of our native fauna depends upon the maintenance of sufficient of its normal range to permit unmolested feeding and breeding. In other words killing for recreation or food must be wisely regulated, and the provision of refuges is indispensable (Hewitt 1921, p. 19).
>
> ...Of such protective measures, by far the most important is the establishment of wildlife preserves, refuges or sanctuaries in which native mammals and birds are protected. Such wildlife reserves should include a sufficient area to provide ample summer and winter range for wildlife they intend to protect. They should be as a rule unsuitable for agricultural development. Nor should they include mining or other commercial properties that are likely to interfere with their purpose. So far as possible the boundaries of such reserves should be well defined, and the necessary steps should be taken within the reserve areas for the required protection to the wildlife they contain, and all protective measures should be rigidly enforced
>
> (Hewitt 1921, p. 235).

Unlike modern approaches to conservation, which concentrate on human threats to wildlife, Hewitt (1921) thought that "any rational system of wildlife protection must take into account the control of predatory species of mammals and birds - wolves, eagles, falcons and hawks, and inferior rapaces such as loons and kingfishers that feed on fish" (p.193).

The Canadian Commission of Conservation also helped create the Dominion Parks Branch in 1911. Within parks and other reserves, it promoted practices such as fire suppression, the extermination of predators such as wolves, and the introduction of sports fish (put and take fisheries) for the pleasure of tourists. The Commission also helped establish the network of wildlife sanctuaries, forest reserves, and experimental farms that exists today.

The 1930s Parks Act subsequently dedicated National Parks for the benefit, education, and enjoyment of the people of Canada and provided that such parks shall be maintained and made use of so as to leave them unimpaired for future generations. It reinforced the notion of parks as game sanctuaries and recreational playgrounds. National Parks were promoted as world-class tourism destinations.

In the postwar years public visitation grew steadily, and from 1968 to 1978, ten new national parks had to be created to satisfy the growing demand for outdoor recreation. Tourism and outdoor recreation were promoted as a compatible uses of national parks. During this period of expansion, Parks Canada developed an extensive network of roads and visitor facilities whose existence may not be compatible with the goal of protecting the ecological integrity of national parks.

Public concern has also led to a profound change in the policies and approaches governing protected natural areas. The 1988 amendments to the Parks Act (the first since the 1930's) formalised the requirement to protect ecological integrity in park zoning and visitor use management. Ecological integrity was defined as minimising human impact on the natural processes of ecological change. Parks Canada was also required to report periodically on the state of the parks. Similar measures to examine and foster the integrity of Migratory Bird Sanctuaries, National Wildlife Areas, and other wildlife areas have not yet been taken.

The first State of the Parks Report (Parks Canada, 1997) showed that Canadian national parks are undergoing profound change. The authors attributed changes in species composition within established parks to their proximity to settled areas, accessibility by road, wilderness fragmentation, overuse, fire suppression, invasion by exotic species, and pollution. Even though attention is currently focussed on completing a national system of protected areas by acquiring remote wilderness areas, and by establishing marine refuges, the real challenge Canadians now face is conserving the ecological integrity of protected areas in more settled regions.

Existing parks and protected areas are a reflection of their history and in some ways a prisoner of their past. They have been created through an opportunistic process, reflecting the whims and tastes of the time. Outstanding areas of scenic beauty, for example, do not necessarily include within their boundaries the habitat necessary to sustain the native species typical of the area, nor do they exclude harmful influences threatening the existence of these species.

Parks and protected areas have undergone major changes over many years because of the elimination of previous human uses, the incursions of tourists, and the effects of the policies and practices associated with the planning and management of the protected areas themselves. Conservation and protection are not the sole objectives of national parks, and certainly not of many provincial and regional parks or of wildlife or biosphere reserve areas.

Dealing with a plurality of values, interests and expertise is inevitable in planning and managing protected areas. For example

> What does it mean to protect and maintain biodiversity in parks and protected areas? Does it mean following the wilderness philosophy in which a park landscapes or ecosystem is largely left alone to evolve in a natural manner, largely devoid of human influence? Does it mean removing people without assessing the effects of their activities on the biophysical characteristics of the area? Or does it mean more active management or intervention through controlled burning, culling of animals or other programs intended to protect and enhance biodiversity and other objectives? If it means the latter, how will biodiversity be defined, and by whom? And what is to be done, if the various definitions that are offered prove to be incompatible?
>
> (Nelson & Serafin, 1992 p. 216)

Ironically, those holding the most extreme positions in conservation and economic development share a worldview (Botkin, 1990). From the engineering perspective the tractability of nature should be exploited and from the preservationist perspective nature should be left alone. Following in the footsteps of people like Pinchot and Muir, (Norton, 1995b), it is increasingly difficult to find common ground between advocates of wise use, and those who would lock up nature and exclude humans. The view of national parks and related reserves as fortresses that can fence-off natural areas and wall-out unwanted changes is being challenged by the call for a coordinated or integrated set of public and private conservation programs (Nelson, 1991). Moreover, there has been a growing recognition that the ecological integrity of protected areas cannot be maintained in isolation from regional planning and decision-making processes (CCEA, 1991). The ideal of natural parks as pristine benchmarks in a changing world may be an unattainable dream.

7.2.2 The Path Forward

What is the best conservation strategy to pursue in the circumstances? Some place-based suggestions include:

- Specialized niches of endemic species
- Hotspots with rich biological inventories of species
- Habitats of keystone or umbrella species
- Ecosystems-at-risk

Endemic species are rare because they have a low adult survival rate and limited range or specialized niche. Although endemic species are more vulnerable to extinction (Pimm, 1997), the strategy of trying to save endemic taxa is like saving living fossils, scientific curiosities unlikely to help protect the evolutionary processes or environmental systems that will generate future biodiversity (Erwin, 1991).

Loss of the largest, most abundant, or fastest growing species is likely to have a bigger impact than loss of rare or endangered species. Remove those species that are hogging the resources, and other species may increase their resource use, minimizing the net functional impact of the species loss (Baskin, 1994).

Another approach has been to try to save the hotspots, areas rich in species. These systems have been thought to be resilient to change, and have often been managed for relatively stable states (Poiani et al., 2000; Chapin, Sala, & Burke, 1998). However, many systems need periods of instability in order to maintain natural biodiversity (Lemons, 1995). Areas rich in species may not provide adequate habitats for larger vertebrates and some long-lived plant species (Lemons, 1995).

It is also widely believed that by protecting the habitat of the largest, longest-living or dominant species, other species will be protected (Lister & Kay, 2000). For example, an area designed to protect large carnivores, with large and diverse habitat requirements, may also maintain prey populations, small carnivores, and the majority of native plants and animals. However, populations of different species fluctuate in complicated ways. In shifting the focus of conservation efforts from single species to guilds or keystone species, we still cannot be sure that all the needs of the desired species will be met because the habitat requirements of different species rarely coincide. As well, the minimum viable population size needed for different species to survive natural stochastic and human-induced events varies considerably. Some would argue that it would be a serious mistake to conserve only the species we perceive to be critical because we are ignorant of the role or existence of most species, while others would argue that many species are more or less redundant (Simberloff, 1998).

Conserving biodiversity at the ecosystem level means setting whole landscapes and seascapes aside, and protecting their physical structure and their characteristic energy flow and nutrient cycling patterns (Lemons, 1995). With the exception of naturally species-poor environments such as boreal forests, where species loss could erase entire functional groups, the diversity of landscapes is more likely to be damaged by land use conversion than the extinction of species (Baskin, 1994). If an ecosystem is protected adequately then the assumption is that all of its resident species will also be protected. Therefore the best way to minimise species loss may be to maintain an ecosystem's functioning (Walker 1995). Soulé (1996) argues that what's wrong with maintaining or restoring ecological processes is that they are generic and can be performed by "weedy" species. An ecosystem-based strategy may also not be precise enough to ensure the survival of endemic species. However, this strategy avoids the destruction of biological assets whose value may not yet be fully understood but which some day may be appreciated.

It has also become a widely held tenet of conservation that biodiversity is crucial to the maintenance of earth's "life-support systems" and a hedge against catastrophe: as we lose species, we also alter the integrity of processes that maintain soil fertility and water quality, provide natural checks on pest outbreaks, convert carbon dioxide into plant tissue, and support the complex food webs upon which we and other creatures depend (Baskin, 1994). The species that have the biggest impact on function are likely to be the ones that change the amount of water or nutrients available to a community or the frequency of fire, disease or other major disturbances.

The redundancy hypothesis suggests that the highest conservation priority be given to functional groups of species where there is little or no redundancy, because redundancy is thought to contribute to an ecosystem's resilience to change (Ehrlich & Walker, 1998; Walker, 1995; 1992). Risser (1995) also argues that changes at regional spatial scales from a hundred metres to a hundred kilometres, and at time scales of years to decades, are most likely to drive the relationship between biodiversity and ecosystem function. Goldstein (1999) criticizes this conservation strategy for its failure to provide a consistent criterion for identifying important ecosystem functions or processes, and its failure to link them to the life history requirements of species.

A diversity of points of view and controversy characterize ecosystem management, not so much because of the principles upon which it is based, as the state of science and supporting activities, such as monitoring, research and analysis. Some scientists are preoccupied with the distribution and abundance of species. They look at ecosystems as patch works of living biological communities. Others focus on the ecological processes, structures and components that are necessary to sustain life. They look at ecosystems from a broader landscape and seascape perspective. Underlying these differences in points of view is the claim by some that evolution and natural selection operates exclusively at the level of the individual organism (Williams, 1966) and therefore conservation plans should be tailored to the life history requirements of species (Goldstein, 1999).

7.2.3 Building a New Consensus

There is no consensus among scientists about the desired or preferred conditions they are trying to achieve for the world's ecosystems (Lackey, 1997). For example, scientists realise the value of protecting all levels of biodiversity but their goal is still not clear: protecting a representative sample of communities; the most diverse communities of species; or the rarest (Reid, 1999). Ecological integrity must be operationally defined before we can assess alternative conservation strategies or learn from future conservation efforts.

Many of our assumptions about environmental change need to be reconsidered. In any ecosystem multiple agents (e.g. pollution, human harvesting, habitat loss, and invasive species) are at work contributing to the loss of biodiversity. If we believe the crisis rhetoric, efforts to set aside more areas for nature, and to protect species-at-risk, will be overwhelmed by human settlement, energy and resource demands, and pollution. Like economic analysis, which treats the environment as an externality, ecology often treats humankind as an externality, even though humans have become a keystone species in practically every ecosystem (O'Neill, 2000). We ignore the contribution of humans to global change at our peril.

In today's global economy, natural systems are under assault and are breaking down. Moreover, if anything remotely resembling the sustainable development scenarios envisioned by Brundtland Commission (WCED, 1987) were realised, most of the world's biodiversity seems destined to disappear (Ehrlich & Wilson, 1991). The Biosphere 2 mission, a $2 million experiment which attempted to design, construct and operate a 3.15 acre artificially enclosed ecosystem, demonstrated that it was well nigh impossible for us to supply the needs of eight people for an extended period of time using technological means (Daily et al., 1997).

By definition any system has integrity (Kimmins, 1997). Ecological integrity is nature's way of allowing a variety of living things to survive and evolve in different places. The strength of interactions within an ecosystem must differ by orders of magnitude from interactions with the rest of the biosphere for the system to be able to shelter and nurture biodiversity (O'Neill, 2000). Attempts to manage ecological variables that normally fluctuate has led to the creation of spatially homogeneous ecosystems over landscape scales that are more likely to suffer catastrophic declines, brought on by disturbances that could previously be absorbed (Walters, 1986; Holling, 1978). Ecosystems can exist in any of a variety of conditions called seral stages. Natural processes or disturbances may bring about a transition from one seral stage to another (Kimmins, 1997).

A new conservation policy is needed for the 21st Century. Current environmental policy is based on the notion that it is feasible to trade off an ecosystem's productivity against its diversity or capacity to buffer the harmful effects of change. If the vision of maintaining and restoring the ecological integrity of protected areas is going to be realised, thinking and acting in terms of ecosystems will have to become a more broadly accepted intellectual perspective in conservation.

A conservation agenda for the new century would have at least four fundamental objectives:

- Representing the natural range of variation in ecosystems and seral stages of community succession in a system of protected areas
- Sustaining viable populations of native species in natural patterns of abundance and distribution
- Maintaining ecological processes such as natural disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions
- Managing landscape changes in a way that retains critical habitat characteristics

(Noss & Cooperrider, 1994)

This agenda unites the competing perspectives of different disciplines. For example, conservation biologists are more likely to focus on species survival, including gene pool and related habitat considerations. Landscape ecologists, on the other hand, would focus on mapping large landscape units, understanding their processes, and managing the stresses that affect them. This agenda also recognises the importance of biotic and abiotic factors. It incorporates all levels of biological organisation, implicitly recognising that many issues may have to be dealt with within different temporal and spatial frameworks (Norton and Ulanowicz, 1992; O'Neill et al., 1986).

We cannot turn back the clock nor can we predict the future. There are no longer any ecosystems that are unaffected by human activities (O'Neill, 2000). We suffer from what Reichman and Pulliam (1996) have called the last pioneer syndrome. Each generation accepts the world as it was when they arrived including the built environment, but is intolerant of any substantial changes during its life span. Returning regional ecosystems to pre-settlement conditions is not a realistic goal. Nor is it realistic to expect that we will be able to reduce human population growth and consumption to the levels that existed prior to the agricultural revolution. Ultimately the success of our conservation efforts will be judged by the continued survival and the adaptation of people and other living things to environmental change

7.3 Ecosystem Health

Health is a concept that transcends scientific definition (Ehrenfield, 1992). It embodies not only the absence of disease or injury but also the notion of a state of complete physical and social well-being (WHO, 1948). Ecosystem health is a socially determined or constructed concept (Callicott, 1995a). Qualities judged desirable by society are used to define what is healthy. Ecosystem health as a goal involves consideration of biophysical constraints and societal preferences that may be objectively measured to some degree.

This last mental model is based on a medical or public health metaphor (see Costanza, 1992; Calow, 1992; Ryder, 1990, Rapport, 1989). It describes diverse attempts to link ecological commodities and processes to the health and well being of human populations and the economic welfare of communities (Daily et al., 1997; CCME, 1996; Costanza, 1992).

For many people the protection of human health is the most important goal of environmental management (IJC, 1991). Since the 1970's the protection of human health has been the predominant concern of environmental policy making. It is only within the last decade that agencies such as the US EPA have been told to attach as much importance to reducing ecological risk as it does to reducing human health risk and that these very close linkages between human health and ecological health should be reflected in national environmental policy (U.S.EPA, 1990). Canadian public agencies have also promoted the idea that our personal health and economic well-being depend on the state of the environment (HC, 1997; HWC, 1992). These actions reflect the widespread public belief that healthy economies and societies require healthy ecosystems: a notion that cannot be demonstrated by its proponents or falsified by its critics.

There is a great difference between public perception of ecosystem health and the use of the term by most scientists. Scientists tend to look at any ecosystem as healthy or sick depending on how close it is to a desired state. Even then scientists accept what they know as the norm and the baselines chosen by scientists have shifted over the generations (e.g. Pauly 1995). Scientists believe that the cumulative effects of human activity can be diagnosed from the response of valued ecosystem entities, attributes, and relationships to the stresses placed on them. This approach calls for the identification of risk factors, potential threats from exposure to known stresses. Stressors may be physical, chemical or biological in origin. Progress is measured by setting targets for action and by using diagnostic indicators to report on the state of the environment. Supporters of the ecosystem health concept also claim that ecosystems exhibit the signs and symptoms of a non-specific distress syndrome and respond in a predictable pattern to human induced stress (Rapport, 1989; Schindler, 1987; Bormann, 1985; Odum, 1985). They have already begun to build diagnostic tool kits (e.g., Herricks, 1992).

In contrast to the preceding approaches, the ecosystem health model relies heavily on public input. Stakeholder and public co-operation are needed to set overall goals, targets and a timetable for action. In different contexts, cultural, symbolic, and historic values may also be important. These goals reflect the interplay of what is possible and desirable. Decision-making is based on negotiated compromises involving trade-offs. Multiple criteria are used to evaluate options.

Ecosystem health is a goal, a sustainable state for ecosystems used by people (Karr, 2003). It describes acceptable or preferred states of sites heavily used for human purposes. Integrity in an evolutionary sense cannot be a goal in these places. However, humans should try to avoid practices that so damage these places that we cannot continue to use them for their designated purposes (Chu & Karr, 2001). Karr (2000) thinks that health as a word and a concept in ecology is useful precisely because it is a concept familiar to the public. It is an effortless intuitive step from health to ecological health. Granted, we must operationally define the term and find ways to measure it. But as a policy goal, protecting health – whether landscapes, wildlife or children – has a fighting chance of engaging the public.

Value judgements are implicit in the definition of health at the individual, population or ecosystem level (Rapport et al., 2000; Rapport, 1995). Health is a social rather than a scientific construct whose defining characteristics evolve with time and circumstance (Rapport et al., 2000). Conservation programmes often ignore human values and focus on biophysical conditions necessary for sustaining wildlife. Seldom is the question raised explicitly: what ought to be sustained for what purpose (Rapport et al, 1998)? These are questions of societal values (Norton, 1995a). Societal values provide behavioural norms and help judge the acceptability of environmental conditions or outcomes. Values also arise in different contexts to describe ethical or moral principles governing a particular activity (e.g. a conservation ethic, the precautionary principle), or to describe the intrinsic properties or the socio-economic significance of environmental resources. The proponents of ecosystem health would say that the evaluation of ecosystem or landscape conditions is only meaningful relative to societal values expressing our aspirations (Rapport, 1995).

Aldo Leopold profoundly shaped commonly held ideas about ecosystem health. In his most famous work, The Sand County Almanac (1949), a posthumously published collection of essays, Leopold introduced the idea that humans are members of a "biological community" of inter-dependent parts, and proposed a "land ethic" that enlarged the boundaries of that community to include soils, waters, plants and animals. His viewpoint stemmed from the insight that people's beliefs and perceptions about the land influenced how they treat it and what they expect from it.

Leopold (1949) defined "health" as the capacity of the land for self-renewal. He associated land health with the stability and continuity of biological communities over long periods of time.

Leopold (1941) also introduced the concept of land "sickness" that suggested while land doctoring is being practised with vigour, the science of land health would be a job for the future. Signs of land sickness included soil erosion, loss of fertility, hydrological abnormalities, and the occasional eruptions of certain species and local extinctions of others, as well as qualitative deterioration in farm and forest products, the outbreak of disease and pest epidemics, and boom-and-bust wildlife population cycles (Birkett & Rapport, 1998).

Ecosystems provide food, fibre, energy, and the other commodities that humans need for survival, and maintain clean air, pure water, and other vital life support functions (Daily et al., 1997; Westman, 1977). The state of the ecosystem worries us because it determines the "basket of benefits" available to satisfy human needs. Ecosystem health is a normative concept, describing an envelope or range of possible sustainable system conditions that will support life (Rapport et al., 1998; Rapport & Regier, 1995).

When the notion of health is applied to ecosystems, the focus of effort shifts from assessing how they work to assessing their contribution to human goals (Rapport, 2002). Indeed health, whether it is applied to the health of organisms, populations, or ecosystems cannot be defined independently from human goals (Rapport et al., 1998). Ecosystem health broadens the concept of ecosystems to include humans because they dominate most ecosystems in the world today.

Ecosystem health is a metaphor for the states of the system, which satisfy human wants and needs (Rapport & Moll, 2000). A metaphor helps defines the type of scientific information required by decision makers (Lackey, 2001). The ecosystem health metaphor suggests that ecologists can distinguish between healthy and diseased systems, and that maintaining ecosystem health is possible and as necessary as maintaining the health of humans or the economy (Ross et al., 1997). The cumulative effects of human activities on the attributes of ecosystems can be diagnosed as response syndromes from stresses placed on them. All practitioners have to do is to diagnose the situation and recommend measures to restore the "health" of degraded ecosystems (Francis, 1994).

The ecosystem health metaphor is also readily understood and generally embraced by the public. The term has considerable value as a risk communication tool (CCME, 1996).

7.3.1 The Diagnostic Approach

Ecosystem health calls for criteria that can be used to judge the capacity of ecosystems and landscapes to supply the goods and services society wants (Rapport, 1997). In this context it means evaluating how our land and resource use decisions affect humans, plants, animals and the natural systems themselves. Consequently decision makers must rely on multiple criteria rather than a historical baseline or a single desired state. The goal of the approach is to optimize the array of goods and services that ecosystems provide, while maintaining or increasing their capacity to produce those things in the future (WRI, 2000). As well, the ecosystem approach tries to maintain future management options to accommodate changes in societal values (Rapport et al., 1998).

Ecosystem health assessments have been based on the ecosystem's productivity (vigour), organization, and resilience (Mageau, Costanza, &. Ulanowicz, 1995; Costanza, 1992). Others describe signs of ecosystem distress syndrome (Rapport 1995; Schaeffer et al. 1988; Rapport, Regier & Hutchinson, 1985; Odum, 1985). A critical indicator of ecosystem health is the capacity of the system to rebound from disturbances (Rapport & Regier, 1995; Rapport, 1992; Stebbing, 1981). The breakdown of ecosystems under stress can also be linked to declining economic opportunity and risks to human health (Rapport, Costanza, & MicMichael, 1998).

Ecosystem health appears to be the conservation norm for the parts of the planet where humans live and work (Costanza, 1995). Ecosystem health is defined by some as the preferred state of ecosystems modified by human activity, and ecosystem integrity is used to describe the condition of ecosystems largely unaffected by human activity (Karr, 2003; Rapport et al., 1998). However, others still use the two terms interchangeably.

However, the choice of ecosystem-level indicators depends upon whether health or integrity is employed as the assessment concept. Ecosystem health indicators focus on the achievement of specific societal goals, while ecological integrity indicators focus on maintaining naturally evolved biological components and processes. Ecosystem health permits substitutions for natural components (i.e. non-native and domestic species for indigenous ones), provided that these substitutions do not significantly reduce the efficiency of processes that sustain the system over time or diminish the flow of ecosystem services satisfying societal values (Daily et al., 1997). For example, the massively degraded Great Lakes would have to be managed for ecosystem health rather than biological integrity. The health of the system is defined by the parameters within which an ecosystem may be used without a major change in ecosystem functioning.

Deciding what is normal is the central criterion of ecosystem health, as deciding what is natural is central for ecological integrity (Callicott, Crowder, & Mumford, 1998). Although ecosystems are loosely organized, they have adapted somewhat to recurring natural disturbances such as fire, floods, and drought. Alteration of the normal disturbance regime (e.g., reducing or increasing the frequency and/or intensity of the disturbance) or the introduction of any combination of physical/thermal, biological or chemical stressors, if prolonged or intense, can result in the eventual breakdown of the functioning of the ecosystem (Rapport & Regier, 1995; Schindler, 1990). Ecosystems, despite their diversity, respond to stress in similar ways (Rapport et al., 1998; Rapport, Regier, & Hutchinson, 1985). Even if recovery results in a new or altered state of functioning, healthy regenerating ecosystems are more likely to be resilient when perturbed and to retain the functional integrity characteristic of mature ecosystems (Rapport et al., 1998; Rapport, 1995a).

Ecosystem health may be assessed by the presence or absence of signs of ecosystem distress syndrome (Rapport, 1995a). Ecosystem health can be operationally defined using objective criteria (Mageau, Costanza, & Ulanowicz, 1995). Moreover, it is possible to assess the relative condition of ecosystems compared to their historic states or to desired objectives using a wide variety of scientific methods (Rapport, Gaudet & Calow, eds. 1995). The major human pressures or stressors that can transform an ecosystem from healthy to pathological states include physical restructuring, over-harvesting, waste disposal, and the introduction of exotic species (Rapport et al. 1998; Rapport, Regier, & Hutchinson, 1985; Rapport & Friend, 1979).

Signs of an ecosystem-level distress syndrome include changes in nutrient cycling, productivity, the size and longevity of dominant species, declining species diversity, and a shift in species composition to opportunistic short-lived life forms (Davies, Rapport, & Brady, 1992; Rapport, Regier, & Hutchinson, 1985). In terrestrial ecosystems the signs include the leaching of nutrients and a decline in primary productivity, and in aquatic systems, the loading of nutrients and an increase in primary productivity because aquatic systems are a sink for terrestrial run-off (Birkett & Rapport, 1998). When an ecosystem loses its buffering capacity the circulation of contaminants increases. Widespread loss of top predators and harsh environmental conditions encourages the selection of opportunistic pests and pathogens across a wide taxonomic range of plants and animals. As a result, the prevalence of disease increases (Epstein, 1995; Miller, 1989). Furthermore, the population levels of different species may start to fluctuate wildly.

Ecosystem health goals are broad-based narrative statements that describe the desired long-term state of the ecosystem, and ecosystem objectives provide targets for management action (Bertram & Reynoldson, 1992). Examples of ecosystem goals for the Great Lakes include fishability, swimmability and drinkability (IJC, 1997). Ecosystem health indicators quantify habitat characteristics, the magnitude of the stress, the degree of exposure to the stressor or the degree of the ecological response (Hunsaker & Carpenter, 1990). This type of indicator has often provided the basis for federal or provincial environmental quality guidelines. Critical ecosystem characteristics include enough habitats for desired diversity and reproduction; adequate nutrient cycling; sufficient buffering capacity and decomposer activity; and the effects of stressors on productivity and biomass (Ramade, 1995; Schaeffer et al., 1988).

The stress-response framework employed by practitioners to diagnose signs of the "ecosystem distress syndrome" has found widespread use in the development of environmental indicators (OECD, 1993; UNEP, 1991; Bird & Rapport, 1986; Rapport & Friend, 1979). It provides a well-defined taxonomy of the stresses human activity places on the environment. By classifying ecosystem disorders, the framework facilitates remedial action. A detailed knowledge of the underlying mechanisms of ecological change is not required to use this approach (Rapport et al., 1998).

The Forest Health Network (1999) completed an inventory of the condition of Canada's forests using a simple set of indicators. Canada's forests cover 418 million hectares and span 13 of Canada's 15 terrestrial ecozones. The Forest Health Network was able to determine that long term changes in plant succession and tree species composition are occurring, and that forest management practises such as harvesting and fire suppression are changing the basic ecological structure of some forest ecosystems. In the Rocky Mountains (Montane Cordillera Ecozone), for example, fire suppression has resulted in the development of older stands of Lodgepole pine and Douglas fir increasing the risk of infestations of mountain pine beetle, Douglas fir tussock moth, and Amillara root rot. Moreover the accumulating ground debris increases the possibilities of major wildfires. Approximately 27percent of the rainforest in British Columbia (Pacific Maritime Ecozone) has been logged. Although most of the logged rainforest is regenerating, over half the trees in the remaining unharvested forest are more than 250 years old. In Ontario, (Boreal Shield EcoZone) the combination of clear cutting and fire suppression favours establishment of species such as trembling aspen and white birch to the detriment of existing conifer species such as black and white spruce and jack pine. The Carolinian hickory-sugar maple and basswood-sugar maple forest ecosystems (Mixed Wood Plains Ecozone) are rapidly disappearing due to fragmentation, agricultural uses and land use conversion. As these examples demonstrate, this approach helps set a variety of environmental changes in context.

While this framework has served well for the purpose of screening for very obvious environmental threats, it has not proved to be very useful for detecting the early warning signs of emerging issues (Rapport 1995c). It has generally provided an after the fact confirmation of ecosystem breakdown but rarely early warning signs of degeneration (Whitford, Rapport & de Soyza, 1999). As well, a diagnostic approach seems to presuppose a curative rather than a preventative mode of action.

7.3.2 Can Ecosystems Be Healthy?

Some critics think the ecosystem health perspective presupposes that an ecosystem has a biological structure analogous to an organism (Lancaster, 2000; Calow, 1992). That view has not been commonly held in ecology since Clements' (1916) time. Nor do the majority of ecologists believe today that ecosystems tend towards a stable state (parts resist change and return to the norm) or optimal state (parts actively serve the well-being of the whole). These outmoded views have largely been displaced in the scientific literature about ecosystems. The functioning of ecosystems represents a trade-off among all the forces acting on them, and as complex systems, they demonstrate emergent dynamic behaviour (Schneider & Kay, 1994). Other critics claim that health is a property of organisms (Suter, 1993). However, health has long been applied at the population and community levels of biological organization and appropriate indicators have already been developed for those levels of biological organisation (Rapport, 2002; Rapport & Moll, 2000).

Ecosystem health suggests that ecosystems are only healthy when they are in a climax state (Hunter 2000). Critical to the definition of ecosystem health is the notion that ecosystems have the capacity to rebound from disturbances (Rapport & Regier, 1995; Costanza, 1995; Kay, 1991; Stebbing, 1981). Ecosystems are open systems that exhibit considerable spatial and temporal variability. When natural disturbances open up space in an ecosystem, the pattern or sequence of regeneration will depend on the colonizing ability of the remaining species. Natural selection will favour species that are able to maximize their use of available resources, even if it is at the expense of the rest of the system (Calow, 1995). Although a degree of functional stability may eventually be achieved where input equals output, this state is not linked to a particular species composition. In open (non-equilibrium) systems, process and outcome is less than predictable. Only long-range data sets may be able to capture ecosystems' normal range of variability (Kelly & Harwell, 1989). The notion of a single climax state has given way to the realisation that for many ecosystems there exist alternative stable states that may be self-perpetuating. For example, Lake Erie flips between clear benthic and turbid pelagic states, which have different feedback systems that limit or maintain the amount of phosphorous in the water column. Kay (2001) provides another example. The closed soft maple swamps of southern Ontario may shift to either an upland forest community, grassland or marsh ecosystem, depending on the amount and duration of water flows during periods of drought and flooding.

Ecosystems often exhibit highly variable, even chaotic behaviour. Under these conditions, it may be very difficult if not impossible to establish norms (Calow, 1992; Kelly & Harwell, 1989). There are insufficient replicates by which to establish the normal range of variability for key ecosystem parameters (Minns, 1992; Calow, 1992; Kelly & Harwell, 1989). Ecosystems are not as well integrated as other levels of biological organisation, such as populations and individual organisms. It is difficult to identify the different effects of the stress caused by human activity and natural events (Carpenter, 1990). Some think that it is not possible to develop integrative measures or indicators of all the effects of disturbances or to reach a consensus about the expected values of various indicators used to characterize ecosystem health (Minns, 1992; Kelly & Harwell, 1989).

Critics also claim that the ecosystem health approach does not provide an objective basis for assessment. Health always implies an element of subjectivity because it calls for value judgements about what is important. The belief that maintaining qualities judged desirable by society will somehow maintain the health of the ecosystem is not based on scientific theory or evidence (Wicklum & Davies, 1995). Even when we know what we want the ecosystem to provide, we are often unable to choose a management option that will reliably achieve those results (Reid 1999). The relationship between ecosystem health and the services an ecosystem provides should be documented (Rapport, Gaudet, & Calow, eds. 1995; Cairns & Pratt, 1995). There is also still a need to generate testable hypotheses about ecosystem health and to validate diagnostic protocols and indicators (Rapport, Regier, & Hutchinson 1985; Odum, 1985).

Many scientists are uncomfortable when asked to extend their field of inquiry beyond natural phenomena to incorporate social values and consideration of human heath (Rapport & Moll, 2000). There is also lingering doubt about whether it is possible to integrate knowledge over such disparate domains (the natural, social and health sciences). However, at least four universities (e.g., Western Ontario, Guelph, Hawaii, and John Hopkins) have established programs encompassing human and ecosystem health (Wilcox 2001).

What is healthy often depends on the perspective of the observer. For example, ecosystem health is defined as much by social and economic values, what people want from the forest, as it is by a scientific assessment of forest health (Kimmins, 1997). Professional foresters have used forest health to describe the growth and vigour of trees (Kolb et al., 1994). In defining forest health, for example, McLaughlin and Percy (1999) concentrate on the capacity of the forest to supply and allocate water nutrients and energy in ways that increase or maintain the forest's productivity while maintaining its resistance to stress. A forest is healthy when the trees are free from infestation and growing at a maximum rate. It is unhealthy if trees are dead or dying.

Scientists today recognise that natural disturbances are a normal part of a well-functioning forest ecosystem (Peters, Frost, & Pace, 1996). Wildfire, disease, and insect infestations help regenerate the forest, cycle nutrients, and maintain a patchwork of stands across the landscape that provide habitat for wildlife and birds. It is only when these disturbances exceed the historic range of variability that they become a cause for concern and can be considered to be unhealthy (Dalms & Geils, 1997).

Science cannot adjudicate conflicts about values and preferences (Lancaster, 2000; Kapustka & Landis, 1998). For example, the forestry industry has tried to maximize overall tree growth and timber production, often at the expense of other values such as water quality or fisheries.

The health metaphor breaks down when you consider that healthy ecosystems are not necessarily free of disease. Ask a hundred people to view a forest that has recently experienced a crown fire, and few will say that they are looking at a healthy ecosystem. However, from the perspective of a woodpecker or bark beetle, a forest with hundreds of dead trees may look very healthy indeed (Hunter, 2000).

Ecosystem health may simply be an attempt to grab the moral high ground. The real policy debates are about values, not about science (Grumbine, 1997). The use of metaphors is part of a social agenda (Suter, 1993). Normative concepts like ecosystem health shroud difficult and painful tradeoffs. The use of the term actually obscures societal values and preferences by not forcing an explicit choice from competing policy options (Lackey, 2001). The interplay between what is possible and what is desirable defines ecosystem health. The first priority for research that would make a difference would be to determine public values and priorities for ecosystems (Lackey, 1995). The alternative is that values of scientists and other technocrats will be used as surrogates for societal values and preferences (Russow, 1995).

7.4. Concluding Comments

Three mental models of ecosystem risk were identified from this analysis of the scientific literature (see Table 7.1). The proposed typology provides a basis for comparing different mental models of risk. Why were only three and not more mental models of risk chosen? In addition to carrying capacity (e.g. Barrett & Odum, 2000; Catton, 1994; Daily & Ehrlich 1992; Hardin 1986), biological or ecological integrity (e.g. Angermeir & Karr, 1994; Woodley et al., 1993) and ecosystem health (e.g. Costanza et al. 1992; Rapport 1989), other potential mental models can be found in the literature, such as ecological footprints (e.g. Rees, 1992), sustainability (e.g. ESI, 2002; Salwasser 1990) and resilience (e.g. Carpenter et al., 2001; Holling, 1973). The NVivo analysis showed there was considerable duplication and overlap in the usage of these terms. Ecological footprints are defined as a form of "appropriated' carrying capacity. Ecosystem health is defined in terms of sustainability. Resilience is common to all the mental models. The mental models in the typology are neither mutually exclusive nor exhaustive of the possible mental models. In some cases they may represent a continuum of thought and action.

The carrying capacity model is based on a limits-to-growth metaphor and arises from concerns about population growth and rising consumption. The biological or ecological Integrity model is based on a wilderness preservation metaphor and arises from concerns about the loss of biodiversity. The ecosystem health model is based on a health metaphor and concern about how we are going to meet human needs

These divergent mental models are also premised on different convictions about the driving forces of change. The carrying capacity model blames human population growth and consumption. Over harvesting and use, habitat loss and invasive species are considered to be the driving forces of change in as far as the biological integrity model is concerned. Human wants and needs drive the ecosystem health mental model.

Table7.1 Typology of Experts' Mental Models of Ecosystem Risk

MENTAL MODELS	Carrying Capacity	Biological Integrity	Ecosystem Health
Metaphor	Limits to Growth, Ecological Footprint	Wilderness Preservation, Conservation Ethic	Medical Diagnosis, Sustainability
Public Concerns	Pollution and Waste	Biodiversity, Extinction	Human wants & needs
Driving Force of Change	Population growth and consumption	Habitat loss/fragmentation, Over-harvesting, Exotics	Industrial production, Monocultures, Trade
Stressors	Chemical, Physical	Biological, Physical	Chemical, Biological, Physical, Societal
VEC	Populations-Individuals	Communities – Species	Ecosystems – Landscapes
Assessment criteria	Sustained yield, TLV's Critical deposition loadings	Natural benchmarks or Ranges of variability	Targets for action or Diagnostic indicators
View of Science	Reductionist	Reductionist/Holistic	Holistic
Decision Making Criteria	Optimal Choice	Safe Minimum Standard	Multi-Criteria -Trade-offs

These mental models also focus on ecosystem responses to different combinations of chemical, physical and biological stressors.

The carrying capacity model focuses on processes that affect individuals or populations, the biological integrity model focuses on risks to communities or species, and the ecosystem health model is employed when dealing with ecosystems-at-risk.

The assessment criteria used vary. The carrying capacity model proposes threshold limits, critical loadings or sustained yields as decision-making criteria. Notions of biological integrity rely on naturally occurring benchmarks. Ecosystem health is premised on the normal functioning of the ecosystem.

Underlying these mental models are different attitudes to public, and stakeholder input. With the exception of ecosystem health, the other mental models do not envision a role for public input.

Supporters of the carrying capacity mental model have a reductionist view of science, while the adherents of the other mental models have a more holistic systems point of view. They do not agree on whether the parts or whole are more important. Reductionism has been the dominant mode of inquiry in Western science. By reducing questions to more manageable parts, scientists wind up providing answers to very different questions. Holling expressed the differences underlying these conflicting points of view best:

> Reductionist science emerges from a tradition of experimental science, where a narrow enough focus is chosen in order to pose hypotheses, collect data, and design critical tests in order to reject invalid hypotheses – the goal of the science of the parts is to narrow uncertainty to the point where acceptance of the argument is essentially unanimous (provide the building blocks but not the design).
>
> The other is science of integration…the goal is to narrow the range of possibilities by invalidating alternative hypotheses – the scales chosen are dictated by the question not by the practical limits of experimentation … multiple lines of evidence are sought that progressively invalidate alternatives. There is deep concern that useful hypotheses might be rejected…rather than…accepting false hypotheses. The premise of the second stream is that knowledge of the system we deal with is incomplete. Surprise is inevitable. There will rarely be unanimity of agreement among peers, only increasingly credible lines of tested argument. Not only is the science incomplete, the system itself is a moving target, evolving because of the effects of management and the progressive expansion of the scale of human influence on the planet.
>
> (Holling, 1996 p. 734)

Ultimately these mental models reflect underlying differences in attitudes to risk and decision-making. Where is the common ground for experts intent on achieving the best possible solution in the circumstances, for others bound by moral imperatives, and for the pragmatic few that are not averse to trade-offs?

This initial typology of experts' mental models of risk helped to formulate the interview questionnaire. Repertory grid methods were used to elicit the subject's mental model of ecosystem risk. Unlike direct questioning, the knowledge elicitation process allowed the research subjects to

- Use their own frame of reference in describing an ecosystem (e.g. scope, scale or timeframe);
- Chose their own response categories, selecting what was important about ecosystems (e.g. entities, attributes, processes, and relationships); and
- Draw their own inferences (e.g. telling us what was threatened or at risk).

The subjects were free to describe and label the constructs in their own mental model in an idiosyncratic manner.

8.0 EXPERT SURVEY ANALYSIS

This chapter presents the results of the survey analysis.

The first stage of the survey was used to describe ecosystems and elicit assessment criteria from experts describing those aspects of ecosystems they felt should be conserved, managed, or protected. The experts were asked to identify threats to regional ecosystems and to evaluate the relative importance of different driving forces of ecological change. They were also asked to identify eco-concepts they would prefer to use to assess risks to ecosystems. The experts were asked to choose an eco-concept that described their mental model of risk and to compare and contrast it with others.

This approach contrasts with the second stage of the survey where an attempt was made to derive the experts' mental models analytically from their use of elicited assessment criteria. The extent to which the findings of the questionnaire survey confirm the results of the expert interviews increases confidence in the validity of the research findings.

An attempt was also made to assess the influence of the experts' worldviews, background, and experience on their choice of mental model of risk.

During the second stage of the survey, the respondents were asked to define what these eco-concepts meant to them using a common set of assessment criteria developed from the expert interviews. FOCUS and PrinCom (Shaw, 1980) were used to analyse the repertory grids elicited from experts. FOCUS represents the underlying conceptual structure as a tree diagram revealing the underlying dependencies, and PrinCom uses a spatial map to represent the grid in a minimum number of dimensions. By ordering and clustering the concepts and criteria in terms of their similarities and differences, it was possible to determine the degree of expert consensus and the extent to which the usage of one concept corresponds to another. The SocioNet functions (Shaw, 1980) were used to identify sub-groups of experts who shared similar mental models of risk, and made similar conceptual distinctions.

The background characteristics of respondents and non-respondents were assessed to determine how representative the study population is of professionals engaged in ecological risk assessment.

In closing, the survey findings are summarized and reviewed.

8.1 What Is an Ecosystem?

The subjects were asked to agree or disagree with a set of statements about ecosystems (see Table 8.1). Most of the experts interviewed thought of an ecosystem as a dynamic set of processes and functions. However, they were also prepared to characterize an ecosystem as a physical-biological entity or as a real place. Geographers and landscape ecologists, for example, were inclined to think of ecosystems as something that was reasonably fixed in place, while biologists and community ecologists were more inclined to think of an ecosystem as something that was more variable in time and space. Ecologists in particular were the most averse to thinking of an ecosystem as a physical biological entity.

Although the term holistic was controversial, over 70% of the subjects were inclined to think of an ecosystem as a holistic understanding of the relationship between living things and their environment. A majority did not think of an ecosystem as a problem solving approach. Few (only three) thought the definition of an ecosystem was problem- or action-specific. Most subjects added the clarification that the characteristics described were conceptual distinctions they applied to phenomena, and 11 stated explicitly that ecosystems were purely mental constructs.

Table 8.1 Experts' Support For Different Views Of Ecosystems

Agreement with statement that ecosystems are a	N=51	%
• Dynamic set of processes and functions	47	92
• Holistic understanding of relationship of living things and their environment	37	73
• Physical - biological entity	36	71
• Real place	35	69
• Problem solving approach	18	35
• Mental construct	11	22
• Definition – problem-action specific	3	6

8.2 What Is Important about Ecosystems?

The subjects were then asked what they thought was important about ecosystems (see Table 8.2). They were asked to identify observable entities, processes or relationships that they considered in most cases to be worthy of management, conservation or protection. The subjects also contributed two other sets of distinctions, describing an ecosystem as a system with emergent properties, and describing its social significance.

Each expert contributed on average contributed six suggestions. The most frequent choices were entities (40.5% of the suggestions) and processes (24.3% of the suggestions).

Over two-thirds of the experts thought of an ecosystem primarily as some combination of entities, processes or relationships. A quarter thought of an ecosystem in terms of entities or processes and their social significance. Only one in five thought of an ecosystem as a system *per se*.

Table 8.2 lists what the experts thought were the most important components of an ecosystem. Generally experts chose components of biodiversity, the cycling of materials and energy, and important functional relationships. They suggested biotic components such as species, populations and organisms more often than they suggested abiotic components such as habitat. It is also worth noting that biogeochemical processes such as nutrient cycling and the water cycle were selected more frequently than climatic factors. On the social side of the ledger, they described the use and abuse of ecosystems, human knowledge about ecosystems or lack of it, and the impact of human actions. In particular, they emphasized the need for better management of our relationship with the earth's ecosystems. When they contributed system properties, they often suggested properties that stress stability and continuity over change.

Table 8.2 Elicited Ecosystem Entities, Attributes & Relationships

	N=51	%
ENTITIES	43	84%
• Species – Taxa	28	55
• Populations	26	51
• Habitat	22	43
• Biodiversity	15	29
• Guilds-Assemblages	9	18
• Keystone species	9	18
• Organisms	5	10
• Biomass	5	10
• Landscapes	3	6
PROCESSES	40	78%
• Nutrient cycling	17	33
• Water cycle	16	31
• Climate change	13	26
• Disturbance regime	13	26
• Decomposition	8	16
• Evolution & natural selection	6	12
RELATIONSHIPS	32	63%
• Trophic structure	15	29
• Connectivity	9	18
• Redundancy	7	14
• Trends	3	6
SOCIAL	31	61%
• Governance	9	18
• Benefits desired by society	9	18
• Harvesting & use	7	14
• Human knowledge & perceptions	7	14
• Pollution	6	12
SYSTEM	27	53%
• Resilience	8	16
• Naturalness	7	14
• Integrity	6	12
• Physical structure	5	10
• Self-organizing & regulating	4	8
• Complexity	4	8

8.3 Experts' Eco-Concepts and Assessment Criteria

The interviewees were asked to suggest assessment criteria that could be used to evaluate the condition and functioning of ecosystems (Question 4) and then to compare and contrast the meaning of different ecosystem concepts such as Ecosystem Health, Biological/Ecological Integrity, and Carrying Capacity (Question 5-7). The order in which the respondents introduced different eco- criteria varied. They required little prompting. They did not have to discuss all the eco-concepts provided and were free to introduce new eco-concepts to the interview.

Question 4 was designed to elicit assessment criteria that could be used to assess the condition or functioning of ecosystems. The criteria were grouped by level of biological organization and classified using NVivo. The criteria provided the constructs for a composite repertory grid. The mode, entity and attribute functions of RepGrid were used to extract highly matched elements and constructs (i.e. entities and attributes) from the majority of grids. The resulting assessment criteria are described in Table 8.3.

Different levels of biological organization were used to classify the suggested assessment criteria (see Table 8.3). Abiotic factors are non-living physical and chemical factors that limit the survival of living organisms. Examples of abiotic factors include temperature, moisture and the availability of soil nutrients. Communities or guilds are clusters of fish, plants and animals that exploit the same ecological niche, and are understood to be functionally linked in some way. A community or guild is an assemblage of a variety of species, while a population is a collection of organisms of a particular species. Populations are capable of interbreeding and are usually reproductively isolated from other populations of the same species. Organisms are living things that are usually sensitive to stimuli, and capable of movement, respiration, feeding, growth and reproduction. Most of the criteria assigned to the residual category correspond to stresses imposed by humans on ecosystems.

Several rules were applied to sift and sort through candidate eco-assessment criteria. Only criteria that apply to ecosystems were considered. Assessment criteria that do not vary were excluded from further consideration. If the proposed criteria could apply to several levels of biological organization, the highest level of biological organization was chosen. Representative criteria were chosen for each level of biological organization.

Table 8.3 Elicited Eco-Assessment Criteria

CONSTRUCTS	EMERGENT	IMPLICIT	N
PHYSICAL-ABIOTIC			**43**
• Physical structure	Complex	Simplified	24
• Connectivity	Interconnected	Fragmented	23
• Nutrient cycling	Retention	Leakage	21
• Patch size	Large	Small	20
• Climate	Minimum variability	Warming/Cooling	15
• Disturbance regime	Minor	Extensive/Severe	11
• Decomposition	Decomposition	Bio-accumulation	10
• Resilience	Resilient	Vulnerable	10
COMMUNITY-GUILDS			**44**
• Species abundance	Survive & Thrive	Species –at-Risk	29
• Trophic structure	Stable	Unstable/Shifting	24
• Invasive species	Native	Exotic & Invasive	15
• Food webs	Complex-Robust	Simplified-fragile	13
• Succession	Regenerate	Composition changing	13
• Productivity	Production	Respiration	12
• Biomass	Constant-Increasing	Decreasing	9
• R-k strategists	Larger-longer lived	Smaller-shorter lived	7
POPULATIONS			**35**
• Population dynamics	Stable-Viable	Growing or declining	30
• Range	Normal	Reduced or displaced	14
• Age-sex distribution	Balanced	Skewed	8
• Niche specialization	Plentiful-dispersed	Rare-endemic	8
ORGANISMS			**22**
• Genetic diversity	Increased	Decreased	14
• Metabolic processes	Normal	Disrupted	7
• Reproductive success	High	Low	6
• Disease/deformities	Absent or rare	Spreads/present	6
• Mortality	Low	High	5
OTHER			**25**
• Harvesting/use	No direct impacts	Substantial use/impacts	11
• Pollution	Low level	High level	8
• Affinity	Care about/enjoy	People indifferent	6
• Familiarity	Grew up with	Don't know	5
• Fresh water	Adequate	In short supply	5
• Land use changes	Minimum Small scale	Profound Large-scale	5
• Human population	Constant-declines	Grows	2

Each expert contributed from two to seven suggestions. Even though the suggestions were quite evenly distributed across the various levels of biological organization, there were fewer suggestions for organisms, about half the average for other levels of biological organization. When the experts suggested criteria, the interviewer elicited both emergent and implicit poles of the constructs (i.e. preferred and contrasting conditions of the ecosystem) from the respondent (see Table 8.3). These assessment criteria were subsequently used to elicit and compare different mental models of ecosystem risk.

All the experts said they were familiar with the meaning of the various eco-concepts that were discussed. Tables 8.4.1 to 8.4.6 summarise the terminology used to describe the differences and similarities between different ecosystem concepts. Each respondent was free to suggest as many constructs as they wished.

Ecological Integrity and Ecosystem Health drew more comments than other eco-concepts (see Table 8.4.1 & 8.4.2). Contrary to what the literature review suggested, many felt Ecological Integrity and Ecosystem Health were not really different concepts. In fact several quipped when asked to explain the distinction between Ecological Integrity and Ecosystem Health that one was favoured at Guelph and the other at Waterloo, the universities which are the most vigorous exponents of these concepts. When describing Ecological Integrity, the respondents were most likely to use language such as natural or pristine, complete, intact, self-organizing or regenerating. In describing Ecosystem Health, they were most likely to use language such as managed, human goals, benefits, wants or needs. Some thought the public more easily understood Ecosystem Health than Ecological Integrity. Both were thought to be report cards or snapshots of the state of the environment. While the respondents thought Ecological Integrity was a measurable benchmark or reference state, they thought Ecosystem Health was based on subjective preferences.

Table 8.4. Elicitation of Eco-Concepts

8.4.1 Eco-Integrity	Constructs	N = 51
	• Natural-Pristine-Undisturbed	11
	• Similar to Ecosystem Health	7
	• Self-organizing - regenerating – evolving	7
	• Complete-Intact	6
	• Benchmark – Reference State	5
	• Minimum Human Intervention	5
	• Retain Biodiversity	5
	• Not understood by the public	2
	• Snapshot in time	2

8.4.2 Eco-Health	Constructs	N= 51
	• Similar to Ecological Integrity	17
	• What people want; people's perceptions	10
	• Managed ecosystem	7
	• Human goals and benefits	4
	• Understood by the public	4
	• Multi-states healthy	4
	• Subjective not measurable	3
	• Medical analogy	3
	• Report Card	3

Sustainability, like Ecosystem Health, is a management or societal goal. Sustainability (Table 8.4.3) is expressed through the imagery of a steady state economy, or constant natural capital. It calls for a level of human use that will permit resource regeneration, and reconciling conflicting human demands in a way that will permit us to meet the needs of future generations. The experts thought that Sustainability and Ecosystem Health were similar concepts.

8.4.3 Sustainability	Constructs	N =51
	• Societal or management goal	7
	• Persist through time	7
	• Meet needs of future generations	6
	• Steady State – Constant wealth	6
	• Focus on human society or economy	5
	• Take only what we need	5
	• Resource use permits regeneration	5
	• Reconcile conflicting demands	5
	• Sustainable is similar to healthy	3

Carrying Capacity (Table 8.4.4) is expressed in the language of limits to growth, maximum population density or yields.

Table 8.4 Elicitation of Eco-Concepts (continued)

8.4.4 Carrying Capacity	Constructs	N=51
	• Max. Population that can be supported	20
	• Single Species or Population density limits	6
	• Max. Production or Yields	6
	• Limits to growth/consumption	6
	• Wildlife resource management term	6
	• Measurable indicator	4

The Ecological Footprint (Table 8.4.5) is described in terms of the space humans use or take up, and their withdrawals from ecosystems.

Some thought Carrying Capacity and Ecological Footprints were technical measures more likely to be estimated and understood by specialists. Eco-concepts, such as Sustainability and Ecosystem Health, are notions that are open to public debate and discussion. What is thought to be sustainable or healthy in a particular context may vary or be the result of a negotiated compromise.

8.4.5 Eco-Footprint	Constructs	N=51
	• Space humans use or take up	15
	• Human impacts on ecosystems	14
	• What we take out of ecosystems	9
	• Measurable spatial index	8
	• Inverse of Carrying Capacity	4

Not many respondents mentioned Resilience (Table 8.4.6). Like Sustainability it was thought to describe the ecosystem's trajectory encompassing current and future states of the environment.

8.4.6 Resilience	Constructs	N=51
	• Withstand disturbances	5
	• Understand future changes / states	3

8.4 Preferred Eco-Concept

The experts were asked to select the eco-concept that described how they would compare risks to different ecosystems (Question 9). Their overwhelming preference was Ecological Integrity (47%) followed by Sustainability (16%), Ecosystem Health (12%), Resilience (10%) and Carrying Capacity (6%). Five persons (10%) had other preferences or no preference at all.

Subjects who chose Ecological Integrity as their preferred concept were less likely to have a PhD. Only fifty percent had a PhD compared to 85 percent of the respondents who chose other eco-concepts or none at all. They were also younger (38% were under the age of 45 compared to19% of the other respondents), and had less work experience (only 58% had over twenty years of work experience compared to 78% of the others). In terms of other background characteristics they were similar.

The difference in response pattern may be accounted for by a number of factors. Ecological integrity may be the preferred ecological concept because it is the most recent eco-concept to enter into popular usage. Greater age, education, and experience are associated with greater specialization and differentiation. The outcome of this process of maturation might be a greater variety of choices in how the experts would compare risk to different ecosystems.

Could the experts' choice of eco-concept be a function of the sample composition? The characteristics of the population of ecosystem experts are unknown. Certain groups, such as women, activists, and business professionals were underrepresented in the survey sample. There is some indication that persons preferring ecological integrity as an ecosystem concept were less likely than other experts with different preferences to respond to the survey. However, the sheer diversity of the respondents' backgrounds lends credibility to the conclusion that ecological integrity was the experts' preferred choice of eco-concept.

The next step was to examine the underlying distinctions between the eco-concepts. A common set of relatively simple qualitative distinctions was selected from the interviews and used to compare the eco-concepts. These elicited constructs included:

- *Natural-Human* – describing a relatively pristine undisturbed area contrasted to areas that are managed for human use or benefit
- *Measurable-Subjective* – contrasting observable conditions or trends with human goals and preferences
- *Present-Future* – a snapshot or report card versus a trend or possible outcome
- *Single-Multiple States* – a benchmark or desired state contrasted with many possible states or outcomes
- *Popular-Technical* – easily or generally understood ideas compared to difficult hard to understand technical concepts
- *Fuzzy-Clear Cut* – concepts leaving room for interpretation and that are open for public discussion and debate compared to more precise estimates and indicators that can only be calculated and interpreted by specialists

Shaw's (1980) FOCUS and PrinCom (principal components) algorithms were used to represent the elements and constructs (eco-concepts and criteria). FOCUS was used to cluster the concepts in the form of a tree to help identify underlying dependencies. PrinCom was used to locate the eco-concepts in a common conceptual space, and to represent them in a minimum number of dimensions.

The FOCUS Analysis (Figure 8.1) isolates what appear to be two distinct conceptual clusters. The first cluster consists of popular concepts such as Sustainability, Ecosystem Health and the Ecological Footprint. The second cluster consists of scientific and technical concepts such as Ecological Integrity, Resilience and Carrying Capacity. The only eco-concepts that are strongly associated are Ecosystem Health and Sustainability (83% match). The other eco-concepts fall below the minimum cut-off point of 75 percent. Nevertheless the eco-concepts appear to fall into two distinct categories.

Figure 8.1 shows that Naturalness, Understanding, Observable, and Clarity are the most tightly clustered criteria (matching scores of 83%). Time and States is also weakly clustered (66.7% match). When the linkages among the assessment criteria are examined it appears that the two conceptual clusters could be described in starkly different terms.

The first set of concepts appears to apply to human impacted areas, while the second set applies to pristine areas. In the former case the concepts reflect popular understanding, and in the latter case, only specialists may only understand the terms. With the exception of the Ecological Footprint, the first set of concepts is thought to be subjective, and the remaining set is thought to be measurable. With respect to time and end-state, the groupings are less clear but Sustainability and Resilience potentially refer to multiple future states, and Ecological Integrity and Carrying Capacity usually refer to current conditions.

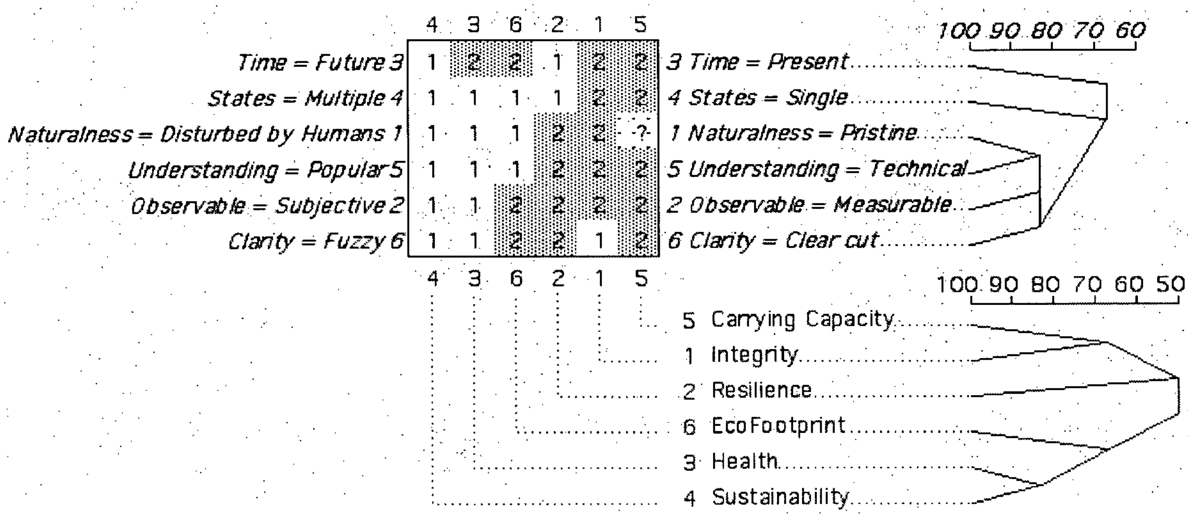

Figure 8.1: Preliminary FOCUS Cluster Analysis of Eco-Concepts & Criteria

The PrinCom Map (Figure 8.2) also extracted the primary dimensions underlying the data. The first three principal components appear to be significant

Naturalness, Observable and Understanding are tightly aligned with the X-axis suggesting that these criteria are not really independent. Time, State, and Clarity are highly collinear with this first set of criteria. The PrinCom graphic suggests that there are at least two dimensions underlying the data. The criteria exhibit a high degree of polarity (evident from the length of the lines) with the implication that each of the concepts received strongly contrasting ratings.

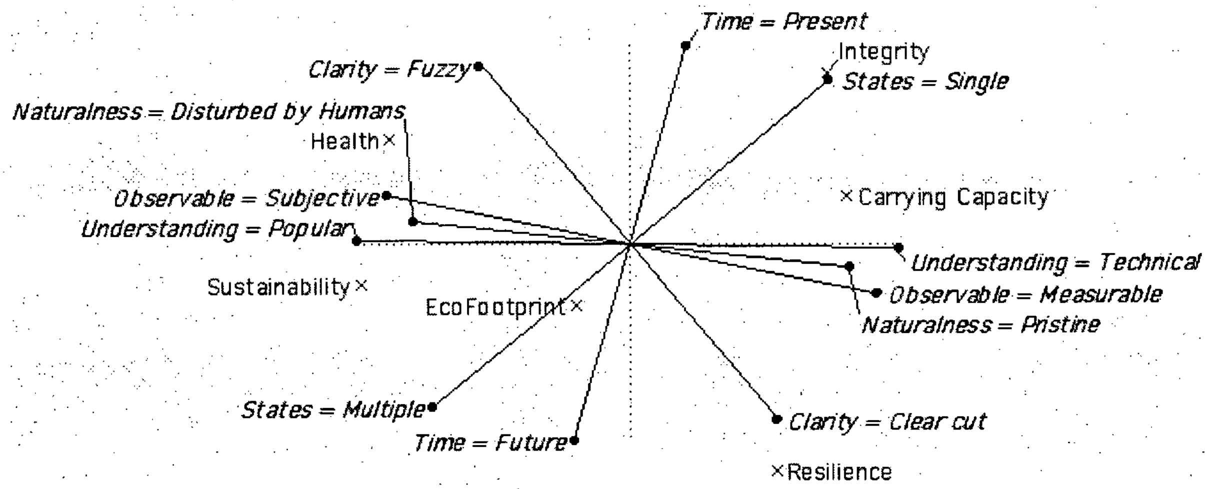

Figure 8.2 Preliminary PrinCom Mapping of Eco-Concepts & Criteria

The First component accounted for 54% of the variance (see Table 8.5). Sustainability and Ecosystem Health had the highest positive loadings on the First component. In contrast, Carrying Capacity, and Ecological Integrity had high negative loadings. Observable and Understanding were the criteria with the highest loadings on the First component. However, while Observable was positive, Understanding was negative. That is to say, subjective and popular was contrasted with measurable and technical. Naturalness also had a high positive loading on this component. The First component appears to contrast natural and human-impacted ecosystems. At the same time it contrasts a scientific with a more popular understanding of ecosystems.

The Second and Third components each account for about twenty percent of the variance.

The most positive concept loading on the Second component was Resilience. Ecological Integrity had a high negative loading. The criteria, Time, Clarity, and States had the highest loading on this component. The Second component appears to contrast ecosystem structure and function.

The most positive concept loading on the Third component was the Ecological Footprint. Time and Clarity also had high loadings on this component. Clarity was positive, while Time was negative. The Third component seems to reflect uncertainty as to the outcome of human activities.

Table 8.5 Preliminary Principal Components Analysis of Concepts and Criteria

Percentage of variance accounted for by each component	*	1	2	3	4	5
	*	53.88	22.20	18.86	3.50	1.56

Concept loadings on each component	*	1	2	3	4	5
1 Biological/Ecological Integrity	*	-0.852	-0.733	-0.435	0.202	0.119
2 Resilience	*	-0.632	0.968	-0.379	0.127	-0.101
3 Ecosystem Health	*	1.030	-0.454	0.065	0.121	-0.233
4 Sustainability	*	1.146	0.172	-0.506	-0.226	0.150
5 Carrying Capacity	*	-0.931	-0.211	0.339	-0.376	-0.077
6 Ecological Footprint	*	0.238	0.258	0.916	0.153	0.143

Criteria loadings on each component	*	1	2	3	4	5
1 Naturalness	*	0.927	-0.096	0.518	–0.261	0.058
2 Observable	*	1.035	-0.209	-0.354	–0.197	-0.234
3 Time	*	0.245	0.845	-0.712	–0.186	0.137
4 States	*	0.848	0.700	0.077	0.325	-0.116
5 Understanding	*	-1.148	0.018	-0.382	–0.089	-0.166
6 Clarity	*	-0.630	0.752	0.704	–0.179	-0.099

Figure 8.1, the FOCUS Cluster Analysis, revealed two apparent conceptual clusters. The first cluster consisted of popular concepts such as Sustainability, Ecosystem Health and the Ecological Footprint. The second cluster consisted of more scientific and technical concepts such as Ecological Integrity, Resilience and Carrying Capacity. The PrinCom map (Figure 8.2) and the Principal Component Analysis (Table 8.5) suggested that this conceptual array might reflect an assessment continuum that ranges from undisturbed natural ecosystems to human impacted ecosystems. Applying INDUCT to this repertory grid data confirmed that the experts thought that the first set of eco-concepts (Sustainability, Ecosystem Health and the Ecological Footprint) were popular terms used to describe human-disturbed ecosystems. Experts thought that the second set of eco-concepts (Ecological Integrity, Resilience and Carrying Capacity) were technical terms used to describe pristine ecosystems. Whereas experts thought Ecosystem Health and Sustainability were fuzzy and subjective terms, they thought that Resilience, Carrying Capacity, and the Ecological Footprint were clear-cut and measurable terms. Although they thought Ecological Integrity was measurable, they did not think it was a clear-cut term. Temporal orientation and state

of the ecosystem were even less crisp distinctions. Experts thought that Ecological Integrity and Carrying Capacity refer to a current state of the ecosystem, and that Resilience potentially refers to multiple future states of the ecosystem. They also thought Ecosystem Health and the Ecological Footprint refer to the present and Sustainability to the future. These findings were revisited in greater depth during the second stage of the survey in an effort to validate and build upon these conclusions.

8.5 Worldviews

Each expert was asked the extent to which they agreed or disagreed on a scale of one to five with a battery of thirty statements about society and the environment (Question 12). The experts' worldviews were determined from their relative agreement or disagreement with specific subsets of these statements (see Table 6.3). Each subset of statements describes a discourse or cluster of contrasting beliefs. Likert indexes were calculated for each discourse. A Likert index is the average semantic differential rating assigned by the respondent.

All 51 persons who were interviewed completed this question. The same battery of statements was also incorporated into the second stage of the survey and an additional 27 respondents who completed the web-based portion of the survey answered this question. Each administration of the question yielded equivalent results increasing confidence in the reliability of the worldview scale.

Almost eighty percent of the respondents supported the dominant discourse #1 (see Table 8.6). They were less likely to have a PhD (58% of the respondents who supported the dominant discourse had PhD's compared to 75% of those who shared other discourses) and more likely to be younger (61% of the supporters were over 45 years of age compared to 69% under 45). Three-quarters of the supporters of discourse #1 were most likely to disagree with the component beliefs of discourse #3. Almost twenty percent of the supporters of the dominant discourse were also likely to disagree with the component beliefs of discourse #2. The remainder of the supporters of the dominant discourse were evenly divided in their disagreement with the remaining discourses.

Support for discourse #1 was statistically significant (using the T-test) in the majority of cases (14 cases were significant at .01, 13 cases were significant at .05, and 10 cases were significant at .1). Disagreement with discourse #3 was also significant (using the T-test) in many cases (2 cases were significant at .01, 10 cases were significant at .05, and 5 were significant at .1).

Discourse #1 was the dominant worldview. Ninety-five percent of those who supported Ecological Integrity as a mental model of risk were more likely to agree with the statements in discourse #1. The level of support for discourse #1 fell off among supporters of other mental models of risk: 85 percent of those who supported Ecosystem Health, 75 percent of those who supported Sustainability and 60 percent of those who supported Resilience agreed with the statements in discourse #1.

Cronbach's alphas were calculated for each index. The indexes for each discourse were reasonably internally consistent (i.e. Discourse #1 = .83, Discourse #2 = .64, and Discourse #3 = .78).

Nonetheless, respondents were likely to reject the notions implicit in discourse #1 (statements 25 & 26) that nature is fragile, and that expert disagreement was a problem. They supported only two statements (9 & 29) in discourse #3, that environmental choice always involves trade-offs, and that people who invest and take greater risks should be rewarded. Moreover, they also disagreed with many of the statements in discourse #2 (statements 7, 12, 27, & 28): that the environmental crisis has been greatly exaggerated, that humans have a right to use other species to meet their needs, that the tough decisions about the environment should be left to the experts, and that humans have the ability to control nature.

Table 8.6 Respondents' Worldviews by Personal Background

EDUCATION	Total		Discourse #1		Others	
Less than PhD	30	38.5%	26	41.9%	4	25.0%
PhD	48	61.5%	36	58.1%	12	75.0%
TOTAL	78		62		16	

DISCIPLINE	Total		Discourse #1		Others	
Ecology	21	26.9%	16	25.8%	5	31.2%
Other Eco-Sciences	39	50.0%	32	51.6%	7	43.8%
Social & Health Sciences	18	23.1%	14	22.6%	4	25.0%
TOTAL	78		62		16	

WORK EXPERIENCE	Total		Discourse #1		Others	
Academic	27	34.6%	21	33.9%	6	37.5%
Other	51	65.4%	41	66.1%	10	62.5%
TOTAL	78		62		16	

CURRENT POSITION	Total		Discourse #1		Others	
Academic	42	53.8%	33	53.2%	9	56.3%
Professional & Consulting	24	30.8%	19	30.7%	5	31.2%
Advocacy & Other	12	15.4%	10	16.1%	2	12.5%
TOTAL	78		62		16	

YEARS OF EXPERIENCE	Total		Discourse #1		Others	
Under 20 years	37	47.4%	29	46.8%	8	50.0%
20 years and over	41	52.6%	33	53.2%	8	50.0%
TOTAL	78		62		16	

AGE	Total		Discourse #1		Others	
Under 45 years	35	44.9%	24	38.7%	11	68.8%
45 years and over	43	55.1%	38	61.3%	5	31.2%
TOTAL	78		62		16	

GENDER	Total		Discourse #1		Others	
Male	63	80.8%	52	83.9%	11	68.8%
Female	15	19.2%	10	16.1%	5	31.2%
TOTAL	78		62		16	

Responses to some of the statements varied: by gender, discipline, experience, age or years of work experience.

The most significant background characteristic was gender. Females were more likely to agree: that we are approaching the limits of the number of people that the earth can support (Statement 3, F-test significant .05), that companies won't protect the environment until the law forces them to do something (Statement 14, F-test significant .05), and that modern technology poses serious risks to the environment (Statement 22, F-test significant .05). They were more inclined to disagree with the statements that people who take risks should be rewarded (Statement 9, F-test significance .05), and the public should be prepared to accept some environmental risks if they want to have a more prosperous economy (Statement 16, F-test significance .01).

Ecologists and other ecosystem scientists were more inclined than social scientists to believe that you cannot rely on the functioning of markets or the goodwill of individuals (Statement 6, F-test significance .01) and the opinions of experts (Statement 20, F-test significance .05) to protect the environment. Persons with a business background were more inclined to believe that we will eventually learn enough about how nature works to be able to control it (Statement 12, F-test significance .05), and that as long as the same species exists somewhere else in the world, humans have the right to use plants and animals to meet their needs (Statement 28, F-test significance .05).

Older respondents were more inclined to disagree that we should leave tough decisions about the environment to the experts (Statement 7, F-test significance .05). More educated respondents were more likely to believe that nature may be resilient but it can only absorb so much damage (Statement 4, F-test significance .05). With increasing experience, respondents were more likely to believe that if humans do not have a particular use for a species they should not worry about it becoming extinct (Statement 23, F-test significance .01).

Gender was the most pervasive background influence on the respondents' worldview. However, it was a factor in the response to only five of the thirty statements used. Eight of the twelve statements that had a different response set were drawn from the set of questions designed to elicit discourse #2. This suggests that from many perspectives, beliefs implicit in discourse #2 are likely to be the most contestable.

In real life, individual responses to these statements are unlikely to fall neatly into any one category of this or any other typology of worldviews. The respondents may more or less support any of these discourses. The worldview typical of any group is more likely to be a composite, drawing from all the belief sets. Moreover their worldview is likely to be influenced by contextual considerations.

Table 8.7 describes the typical worldview of the respondents. The average score was calculated for the response to each statement, and the set of statements with most significantly different responses (usually two for agree, and four for disagree) were selected. The typical respondent is likely to agree with the left-hand list of statements and disagree with the right-hand list of statements.

Table 8.7 Typical Worldview of Respondents

WV. BELIEFS	AGREE (2.0)	DISAGREE (4.0)
Orientation	Q17 We have to protect the environment for our children and grandchildren, even if it means reducing our standard of living today.	Q10 Continued economic growth and technological innovation is the key to improving our living standard.
Concerns	Q6 We cannot rely on the functioning of markets or goodwill of individuals to protect our health or the environment.	Q18 Governments should not restrict peoples' personal freedom or their lifestyle choices.
Perceived Risk	Q22 Modern technology poses serious risks to the environment	Q27 The so-called "environmental" crisis facing society has been greatly exaggerated.
Nature	Q4 Nature may be resilient but it can only absorb so much damage	Q13 Nature will recover in the long run from any harm caused by humans.
Other Species	Q11 Plants and animals have the same right as humans to exist.	Q23 If humans do not have a particular use for a species they shouldn't worry about it becoming extinct.
Resource Management	Q5 We should voluntarily adopt a simpler less materialistic way of life in order to save the environment.	Q1 The Earth has plenty of natural resources, if we can just learn how to develop them.
Social Control	Q14 Companies won't protect the environment until the law forces them to do something.	Q30 Private enterprise is more likely than government to find solutions to environmental problems
Role of Experts	Q26 There is so much disagreement among experts that it is hard to know who to believe about the environment.	Q7 We should leave the tough decisions about the environment to the experts
Learning & Decision-Making	Q8 It is often less costly to prevent environmental problems than to fix them.	Q12 Humans will eventually learn enough about how nature works to be able to control it.
Risk Taking	Q24 It is unfortunate but acceptable if some people loose their jobs or have to change their line of work for the sake of the environment.	Q16 The public should be prepared to accept some environmental risks if they want to have a more prosperous economy

Four sets of statements contrast discourse #1 with discourse #2. They are perceived risk, role of experts, learning and decision-making, and risk taking. These statements reflect opposition to what has been called the dominant social paradigm or business as usual.

Another set of statements, orientation, other species, and resource management, contrast discourse #1 with discourse #3. These statements reflect a strong commitment to conservation and protection as opposed to economic growth.

The remaining statements, concerns, nature, and social control, reflect support for or opposition to rules protecting the environment. These statements contrast discourse #2 and discourse #3

The findings suggest that if ecosystem experts have a common worldview, then risk communication with groups who do not share that worldview may be difficult.

The respondent's current position (One-way ANOVA, F-test significant .02) and previous employment (One-way ANOVA F-test significant .01) were the only significant indicators of the respondents' inclination to agree or disagree with the statements in Table 8.7. This suggests that the institutional and professional contexts in which experts work have a significant bearing on the formation of their worldviews.

The interview subjects were also asked whether or not values, moral or ethical concerns had any role to play in scientific assessment (Question 9). Almost 90 percent of the experts said they thought values had a role to play. Although they thought science was only a tool, in their experience, assessment sciences were value-based, and experts were called upon to make value judgements in their work. They thought that experts should do a better job in making these values explicit. Only 10 percent thought science should be value-free. They were uncomfortable with scientists acting as advocates, and thought risk assessment and risk management should be separate phases of decision-making.

8.6 What are the Major Threats to Ecosystems?

The experts were invited to comment on what they thought were the driving forces of environmental change and whether or not they were significant, globally, nationally or within their local region (Question 11).

Table 8.8 Driving Forces of Ecosystem Change

THREATS	N	%	Scale
• Population Growth	36	71	Global
• Lifestyles & Consumption	33	65	National–Local
• Climate Change	25	49	Global
• Pollution – air & water	20	39	Global
• Over harvesting fish & wildlife	19	37	Global–National
• Land use conversion	19	37	National–Local
• Biological invasions	16	31	Global
• Resource depletion	15	29	Global–National
• Poverty & hunger	14	28	Global
• Urban sprawl	14	28	National–Local
• Public attitudes	14	28	National
• Energy use	12	24	Global
• Overuse of fertilisers	11	19	National–Local
• Solid waste disposal	9	18	National–Local
• Trade	9	18	Global
• Industrialization	8	16	Global

Population growth and consumption were identified by most as the main threats to ecosystems and the driving forces of environmental change (see Table 8.8.) Many respondents who chose population growth and consumption said that all other threats to the environment were derived from them. Some respondents also contrasted western lifestyles and consumption with the poverty and hunger in the third world. Climate change was another major preoccupation, with about fifty percent of the respondents selecting it. What is clear is that most of the experts thought that the driving forces of environmental changes are now more likely to be global or national than strictly regional in scale.

8.7 Eco-Mental Models of Risk - One or Many?

During the second stage of the survey, the respondents were asked to define what eight different eco-concepts meant to them. These eco-concepts were discussed during the first stage of the survey, and are commonly used in the literature of assessment sciences without any clear or consistent definitions. The respondents were asked to use a common set of assessment criteria to describe how several eco-concepts or types of ecosystems differed from one another (see Table 8.3). These criteria were developed during the first stage of the survey.

Each assessment criterion was presented as a range of values between two contrasting conditions. Conventional semantic differential scales usually ask you to say how much you agree or disagree with a particular statement or how important something is to you. Instead, a repertory grid scale contrasts two different conditions. When some people think about habitat, for example, they may think that a certain amount of connectivity is necessary and that habitat fragmentation is something we should avoid. Connectivity is contrasted with fragmentation. So for example, in thinking about an eco-concept such as Biological or Ecological Integrity, they may think that a habitat with integrity is more likely to be interconnected rather than fragmented. In thinking about an urban or industrial area, they may think that habitat in such an area is more likely to be fragmented than interconnected. The respondents rated each concept on 32 criteria using a five-point scale (see Table 8.3).

The second stage of the survey produced 42 completed elicitations. Thirty-three respondents completed the web-based version of the survey, and nine experts who were previously interviewed used the web-grid software to complete the survey. There was no significant difference in the response to either form of the survey; that is to say, the responses from each form of the survey were highly consistent with the overall results described below.

Each pair of grids was compared to determine the amount of consensus or conflict. Figure 8.3 provides an example of grid comparisons for respondents 176 and 80. The matrix summarises the differences in the ratings they assigned to each of the eco-concepts. Zeros indicate consensus. Complete disagreement would be indicated by differences of three or more points in the scores assigned to particular criteria. The graphics that accompany the matrix show that there is over eighty percent consistency in the way the respondents used the assessment criteria, and in their ratings of the eco-concepts.

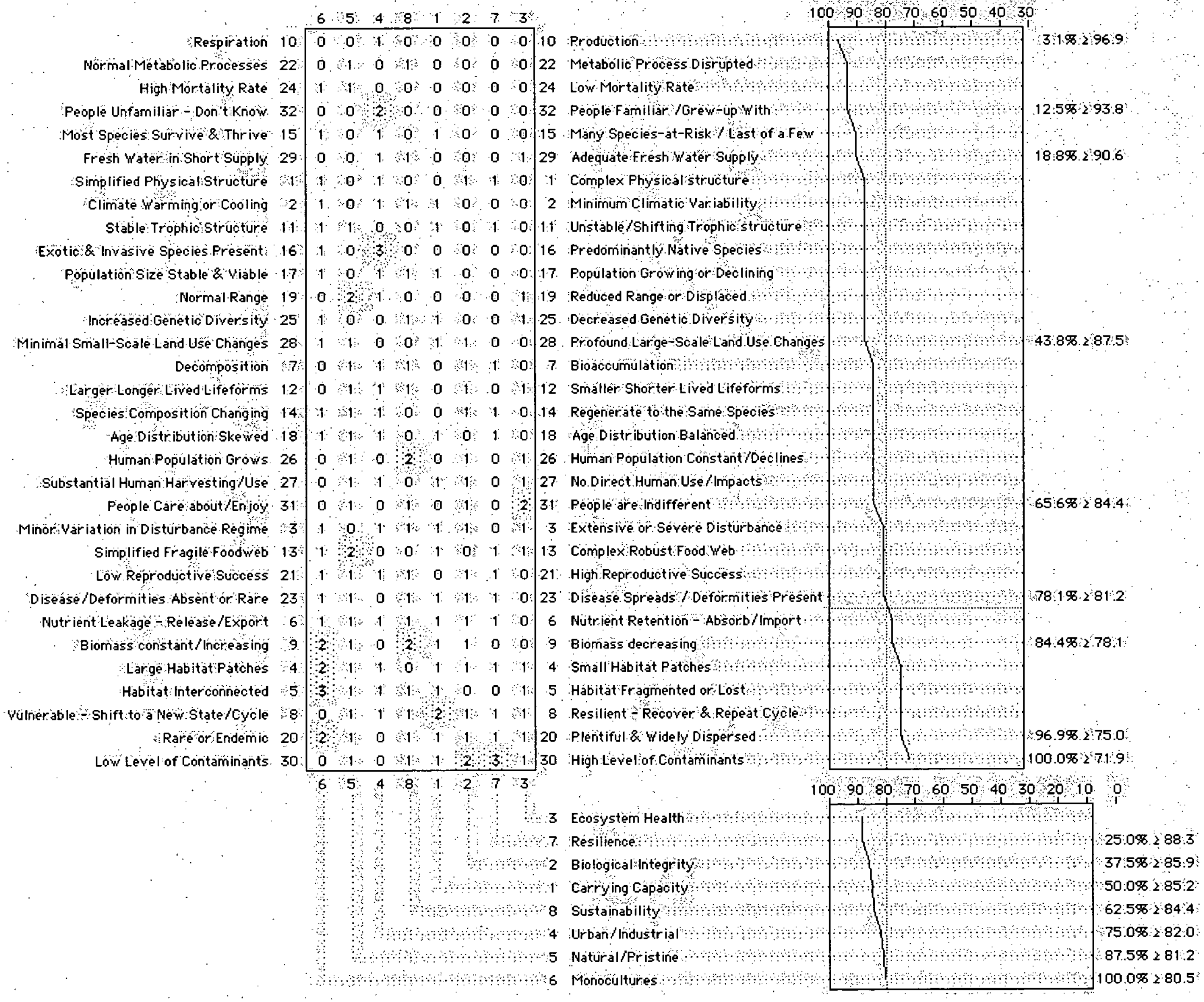

Figure 8.3 Comparison of the Grids Elicited from Respondents 176 and 80

The respondents in general described the eco-concepts in a highly consistent way, indicating there is a high degree of consensus about what each of the concepts meant. Table 8.9 shows that with one exception there was over eighty percent agreement in the way each concept was rated. This finding indicates that there was substantial consensus about the meaning of each eco-concept.

Table 8.9 Expert Agreement[1] in the Use of the Assessment Criteria to Describe the Eco-Concepts

ECO-CONCEPTS	Mean	Minimum	Median	Maximum
Natural	83.4%	75.8%	84.4%	89.9%
Eco-Integrity	83.6%	80.9%	84.4%	90.3%
Eco-Health	81.4%	81.3%	81.9%	93.0%
Sustainability	82.8%	82.5%	83.6%	92.6%
Resilience	81.2%	77.4%	80.9%	90.6%
Carrying Capacity	81.7%	77.0%	81.9%	91.1%
Monocultures	71.2%	69.9%	70.8%	82.8%
Urban/Industrial	81.5%	75.0%	81.8%	90.2%

1. For each pair of grids there had to be at least 80% agreement in the use of the 32 criteria to rate the same concept

The eco-concepts are themselves highly interrelated (see Table 8.10). For example, Ecosystem Health has matching scores 96.1 percent with Sustainability, and Carrying Capacity. That is to say the respondents, using a common set of assessment criteria, rated these concepts in very similar ways. Urban/Industrial is most strongly related to Monocultures, and not to the other eco-concepts.

Table 8.10 Percentage Agreement Among Eco-Concepts[1]

Eco-Concepts	*	1	2	3	4	5	6	7	8
1. Carrying Capacity	*	100	58	96	95	84	91	93	52
2. Monocultures	*		100	59	59	45	62	54	82
3. Ecosystem Health	*			100	96	85	91	92	50
4. Sustainability	*				100	86	92	95	51
5. Natural/Pristine	*					100	83	90	37
6. Resilience	*						100	88	52
7. Ecological Integrity	*							100	45
8. Urban – Industrial	*								100

1 The matching score for a pair of eco-concepts is the percentage agreement in their ratings on 32 assessment criteria

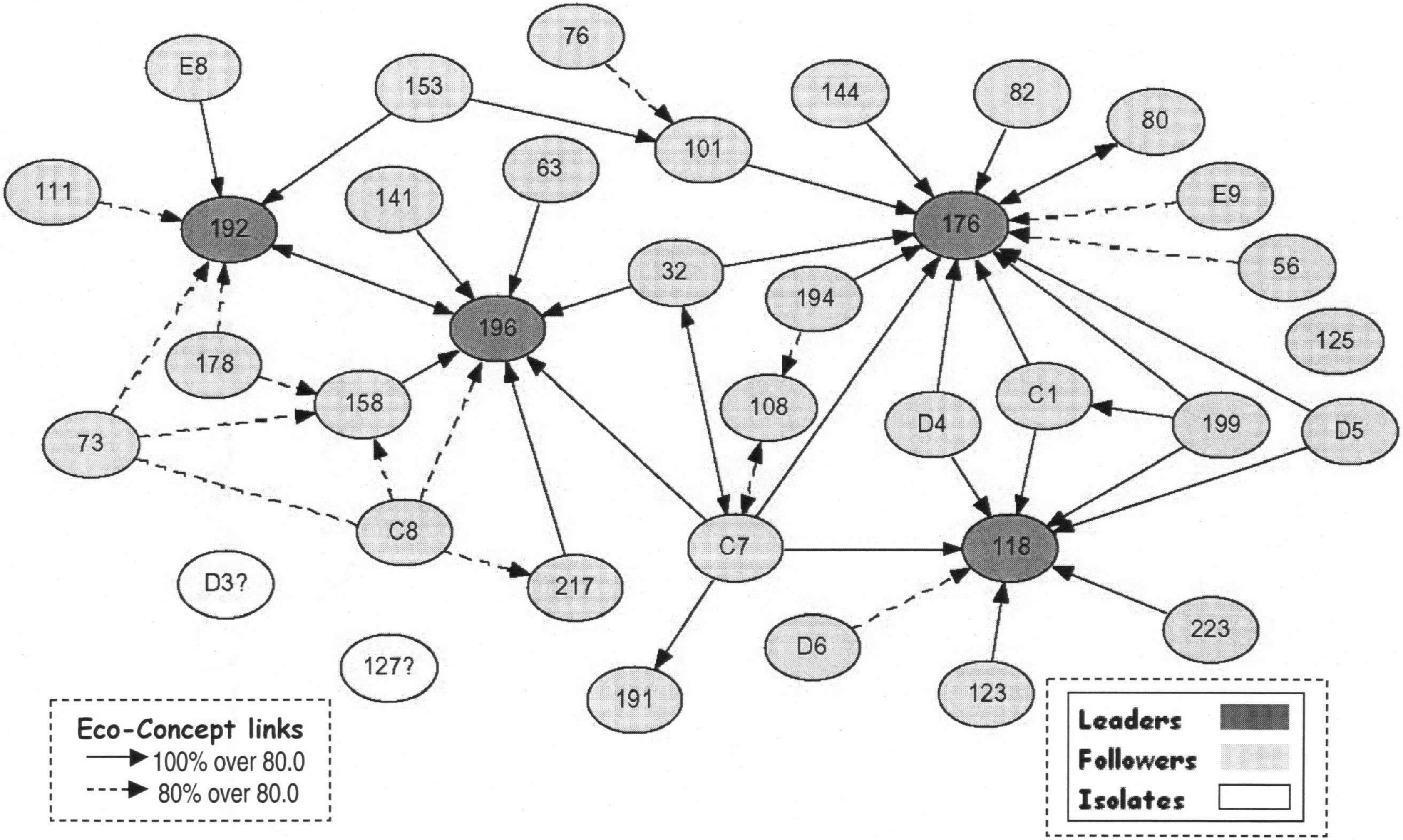

Figure 8.4 Socio-Network Diagram of the Correspondence among Respondents' Assessment of the Eco-Concepts

Even with a substantial consensus about the meaning of the concepts and use of the assessment criteria, experts may still use them in different ways. The SocioNet functions of RepGrid were used to examine the linkages among the respondents' repertory grids in an effort to identify subgroups of like-thinking individuals who made similar distinctions about the concepts, and to identify individuals with strongly idiosyncratic viewpoints who fell outside any grouping.

The SocioNet analysis was only based on the complete responses of 35 individuals because the outcome would be strongly influenced by the respondent's decision not to rate a particular eco-concept or to leave a particular criterion blank. Figure 8.4[1] reveals that there were four distinct groupings centred on respondents 176, 196, 118, and 192. The linking arrows indicate which respondents rated the concepts in a corresponding manner. A solid line indicates that there was an 80 percent correspondence for 100 percent of the linkages between the eco-concepts, and a broken line indicates that there was an 80 percent correspondence for only 80 percent of the linkages. Although respondent 125 fell just below the cut-off point, he would be linked to respondent 176. However, respondents D3 and 127 were not strongly linked to other respondents.

It is possible to make some limited comparisons of the patterns of linkages within each group. For example, the strongest linkages among members centred on respondent 176 were for Ecological Integrity and Ecosystem Health. In the case of the group centred on respondent 118, the predominant linkages were for Carrying Capacity. The linkages for Sustainability and Resilience were also strong. For almost all the respondents linked to respondent 196, the strongest linkages were for Natural/Pristine. The linkages among the remaining grouping, centred on respondent 192, were a mixture of Natural/Pristine, Ecological Integrity, and Ecosystem Health, without any conceptual preference being clearly dominant.

The FOCUS cluster analysis (Figure 8.5) examined whether or not there was a hierarchical structure of relationships among the eco-concepts and assessment criteria. The analysis showed that the concepts and criteria were very tightly clustered and therefore very strongly related. The linkages fell for the most part within a range of 90% to 100%.

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1 Interview subjects are identified by alpha-numeric designations, and survey respondents are identified by numeric designations.

Construct (left pole)	5	7	4	3	1	6	2	8	Construct (right pole)
Niche Specialization = Plentiful & widely dispersed 20	2	2	2	2	3	2	2	4	20 Niche Specialization = Rare or endemic
Patch Size = Large habitat patches 4	2	2	2	2	2	2	3	5	4 Patch Size = Small habitat patches
Biomass = Biomass constant/increasing 9	2	2	2	2	2	3	3	4	9 Biomass = Biomass decreasing
Affinity = People care about / enjoy 31	1	2	2	2	2	3	3	4	31 Affinity = People are indifferent
Metabolism = Normal metabolic processes 22	1	2	2	2	2	2	3	4	22 Metabolism = Metabolic processes disrupted
Resilience = Resilient - recover & repeat cycle 8	1	2	2	2	2	1	4	4	8 Resilience = Vulnerable - shift to new state/cycle
Fresh Water Supply = Adequate fresh water supply 29	1	2	2	2	2	2	4	4	29 Fresh Water Supply = Fresh water in short supply
Species Abundance = Most species survive & thrive 15	1	2	2	2	2	2	4	4	15 Species Abundance = Many species at risk/last of a few
Range = Normal range 19	1	2	2	2	2	2	4	4	19 Range = Reduced range or displaced
Age Distribution = Age distribution balanced 18	2	2	2	2	2	2	4	4	18 Age Distribution = Age distribution skewed
Nutrient Cycling = Nutrient retention - absorb/import 6	2	2	2	2	2	2	4	4	6 Nutrient Cycling = Nutrient leakage - release/export
R-k Strategists = Larger longer lived life forms 12	2	2	2	2	2	2	4	4	12 R-k Strategists = Smaller shorter lived life forms
Population Dynamics = Population size stable & viable 17	2	2	2	2	2	2	4	4	17 Population Dynamics = Population growing or declining
Disease/Deformities = Disease / deformities absent or rare 23	2	2	2	2	2	2	4	4	23 Disease/Deformities = Disease spreads / deformities present
Trophic structure = Stable trophic structure 11	2	1	2	2	2	2	4	4	11 Trophic structure = Unstable/shifting trophic structure
Genetic diversity = Increased genetic diversity 25	2	2	2	2	2	2	5	4	25 Genetic diversity = Decreased genetic diversity
Food Webs = Complex robust food web 13	1	1	2	2	2	2	5	4	13 Food Webs = Simplified fragile food web
Physical Structure = Complex physical structure 1	1	1	2	2	2	2	5	4	1 Physical Structure = Simplified physical structure
Invasive Species = Predominantly native species 16	1	2	2	2	2	2	5	5	16 Invasive Species = Exotic & invasive species present
Disturbance Regime = Minor variation in disturbance regime 3	1	2	2	2	2	3	4	5	3 Disturbance Regime = Extensive or severe disturbance
Pollution = Low level of contaminants 30	1	2	2	1	2	2	4	5	30 Pollution = High level of contaminants
Connectivity = Habitat interconnected 5	1	1	2	2	1	2	4	5	5 Connectivity = Habitat fragmented or lost
Land Use Change = Minimal small-scale land use change 28	1	2	3	2	2	4	5	5	28 Land Use Change = Profound large-scale land use change
Harvesting / Use = No direct human use or impacts 27	1	2	3	3	3	3	5	5	27 Harvesting / Use = Substantial hunan harvesting / use
Human Population Dynamics = Human population constant / declines 26	2	2	2	3	3	3	4	5	26 Human Population Dynamics = Human population grows
Climate Change = Minimum climate variability 2	2	2	2	3	3	3	3	4	2 Climate Change = Climate warming or cooling
Mortality = Low mortality rates 24	2	2	3	3	3	2	3	4	24 Mortality = High mortality rates
Reproductive Success = High reproductive success 21	2	3	3	3	3	2	3	4	21 Reproductive Success = Low reproductive success
Succession = Regenerate to same species 14	3	3	3	3	3	2	2	4	14 Succession = Species composition changing
Productivity = Production 10	3	3	3	3	3	3	2	4	10 Productivity = Respiration
Decomposition = Bioaccumulation 7	3	3	3	4	3	3	2	3	7 Decomposition = Decomposition
Familiarity = People familiar - grew up with 32	3	3	3	3	2	3	3	2	32 Familiarity = People unfamiliar - don't know

8 Urban/Industrial
2 Monocultures
6 Resilience
1 Carrying Capacity
3 Ecosystem Health
4 Sustainability
7 Biological/Ecological Integrity
5 Natural/Pristine

100 90 80

100 90 80 70 60

Figure 8.5 FOCUS Clustering of Eco-Concepts and Criteria

The graphic in the lower right hand corner of Figure 8.5 shows that Ecosystem Health, Sustainability, Carrying Capacity, Ecological integrity, Resilience and Natural/Pristine were very tightly clustered (with a matching scores over 90 %) and therefore very similar concepts. Urban/ Industrial and Monocultures formed another cluster that was not as tightly related (with a matching score of 82%). This cluster analysis suggests that the eco-concepts describe ecosystems that are either relatively undisturbed or those that are heavily impacted by human activity. It appears that the eco-concepts function as members of two contrasting metaphoric categories.

Twelve clusters of assessment criteria were identified (see Table 8.11). FOCUS computes the inter-construct distances and arrays the constructs by their degree of similarity. The linkage between the pairs of criteria, in most cases, does not seem to be spurious, and appears to have face validity. The criteria themselves do not appear to be redundant. The assessment criteria are so highly interconnected that individual criteria may contribute very little additional information to decision-making and may lead to similar choices and outcomes.

The structure of relationships among the eco-concepts assessment criteria is flat rather than hierarchical, meaning that they function as a classification scheme rather than an inductive model.

Table 8.11 FOCUS Clusters[1] of Assessment Criteria	
100% Similar	
Cluster # 1	• Reduced range and species-at-risk • Water in short supply and species-at-risk
Cluster # 2	• Nutrients released or exported and age distribution skewed • Smaller shorter lived life forms and nutrients released or exported • Smaller shorter lived life forms and population growing or declining • Population growing or declining and disease spreads
Cluster # 3	• Physical structure simplified and food webs simplified
96.9% Similar	
Cluster # 4	• Decreasing biomass and people indifferent • Metabolic processes disrupted and people indifferent
Cluster # 5	• Vulnerable – shift to new cycle and fresh water in short supply • Range reduced and age distribution skewed • Trophic structure unstable and disease spreads
Cluster # 6	• Low reproductive success and high mortality rates • Respiration and species composition changing
93.8% Similar	
Cluster # 7	• Metabolism disrupted and resilience • Simplified physical structure and invasive species • Decreased genetic diversity and an unstable trophic structure • Decreased genetic diversity and simplified food webs • Invasive species and extensive or severe disturbance • Extensive or severe disturbance and high level of contaminants
Cluster # 8	• Climate warming or cooling and human population grows • Climate warming or cooling and high mortality rates • Low reproductive success and species composition changing • Decomposition and respiration
90.6% Similar	
Cluster # 9	• Species rare or endemic and small patch size • Habitat fragmentation and high level of contaminants
Cluster #10	• Profound large scale land use change and substantial human harvesting & use • Population growing or declining and substantial human harvesting and use
87.5% Similar	
Cluster # 11	• Decomposition and people unfamiliar/don't know
81.2% Similar	
Cluster # 12	• Habitat fragmentation and profound large scale land use changes

1 FOCUS computes the inter-construct distances and arrays the constructs by their degree of similarity.

The principal components analysis (Figure 8.6) shows that all the natural scientific eco-concepts, such as Ecological Integrity, Ecosystem Health, Sustainability, Carrying Capacity, and Resilience are tightly clustered, and therefore very similar. Together with Natural/Pristine they fall very close to one of the principal axes. Urban/Industrial and Monocultures are distinct concepts because the spread from the principal axes is greater. Because of the bipolar nature of the criteria, the meaning of Natural/Pristine, Resilience, and Sustainability appears to contrast with that of Urban/Industrial. The meanings of Biological/Ecological Integrity, Ecosystem Health, and Carrying Capacity appear to contrast with the meaning of Monocultures. Because the natural scientific concepts are clustered around the horizontal axis, a more likely interpretation is that the set of criteria on the right hand side of the diagram more or less describes all of these concepts. The same interpretation will hold for the criteria on the left hand side of the diagram to a lesser extent because the spread between the concepts is greater. This finding were pursued in greater depth in the INDUCT analysis.

The first component of the principal components analysis accounted for 85 percent of the variance (see Table 8.12) and seems to contrast natural and human impacted ecosystems. Urban/Industrial and Monocultures had the highest positive loading. Natural/Pristine and Biological/Ecological Integrity had the highest negative loadings. The following assessment criteria had loadings of over seventy percent on the first component. Positive loadings included: 1) predominantly native species, 2) complex physical structure, 3) complex robust food web, 4) no direct human use or impacts, 5) resilient. Negative loadings included: 1) habitat fragmented or lost, 2) large scale land use change, 3) high level of contaminants, 4) extensive or severe disruption, and 5) decreased genetic diversity.

The other components were not significant. Monoculture was the primary concept associated with the second component and Resilience was associated with the third component. None of the assessment criteria had significant loadings on the second or third components.

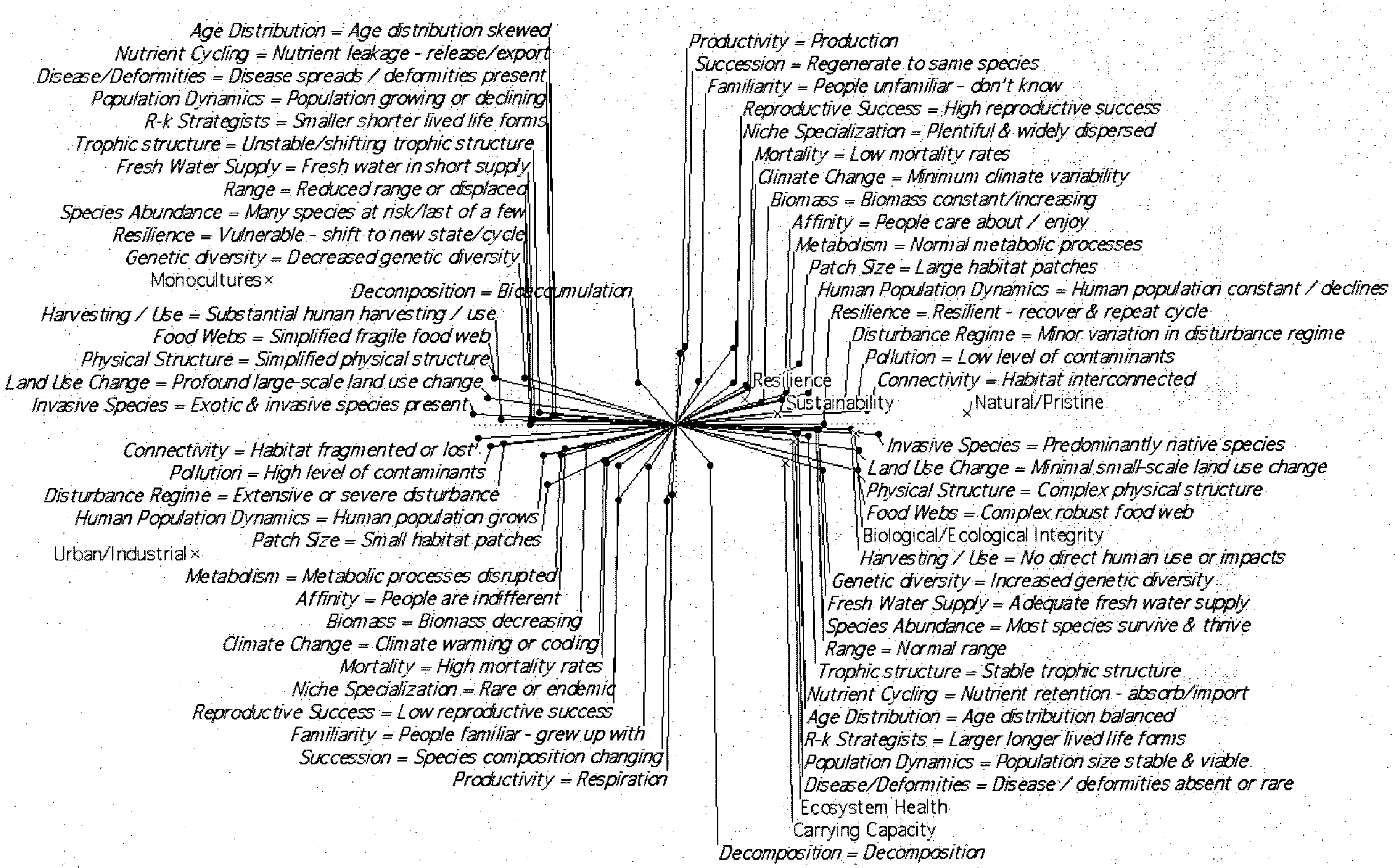

Figure 8.6 PrinCom Map of the Respondents' Use of the Assessment Criteria to Define the Eco-Concepts

Table 8.12 Principal Components Analysis of the Respondents' Use of the Assessment Criteria to Define the Eco-Concepts

The percentage of variance accounted for by each component	*	1	2	3	4	5	6	7
	*	84.99	6.15	3.42	2.12	1.67	1.00	0.63

Eco-Concept loadings on each component	*	1	2	3	4	5	6	7
1. Carrying Capacity	*	-0.541	-0.190	0.094	0.239	-0.047	0.304	-0.048
2. Monocultures	*	1.972	0.710	0.141	0.021	-0.003	0.035	0.024
3. Ecosystem Health	*	-0.577	-0.086	0.037	0.307	-0.180	-0.184	0.144
4. Sustainability	*	-0.510	0.057	-0.022	0.126	0.149	-0.159	-0.233
5. Natural/Pristine	*	-1.437	0.057	0.291	-0.347	-0.216	-0.013	-0.030
6. Resilience	*	-0.351	0.122	-0.640	-0.120	-0.074	0.042	0.017
7. Biological/Ecological Integrity	*	-0.888	-0.050	0.079	-0.098	0.388	0.012	0.137
8. Urban/Industrial	*	2.331	-0.619	0.020	-0.128	-0.017	-0.037	-0.010

Criteria loadings on each component	*	1	2	3	4	5	6	7
1. Physical Structure	*	0.888	0.226	0.032	0.110	-0.105	0.021	-0.046
2. Climate Change	*	0.356	-0.175	-0.113	0.083	-0.166	0.078	0.093
3. Disturbance Regime	*	-0.828	0.095	0.202	0.050	-0.042	-0.009	-0.051
4. Patch Size	*	-0.617	0.294	-0.069	0.158	0.026	0.047	0.006
5. Connectivity	*	-0.950	0.065	0.042	0.059	0.089	0.217	0.034
6. Nutrient Cycling	*	0.593	0.046	0.110	-0.093	-0.019	-0.002	0.021
7. Decomposition	*	-0.175	-0.204	-0.036	0.125	-0.087	-0.138	0.096
8. Resilience	*	0.716	0.001	0.230	0.110	0.123	-0.020	0.032
9. Biomass	*	-0.433	0.104	0.157	0.155	0.054	-0.002	-0.016
10. Productivity	*	0.025	-0.340	-0.042	0.065	-0.007	-0.045	-0.027
11. Trophic Structure	*	-0.654	-0.059	-0.083	0.050	0.210	0.009	0.088
12. R-k Strategists	*	-0.593	-0.046	-0.110	0.093	0.019	0.002	-0.021
13. Food Webs	*	0.888	0.226	0.032	0.110	-0.105	0.021	-0.046
14. Succession	*	0.049	-0.371	0.178	-0.012	0.030	-0.072	-0.041
15. Species Abundance	*	-0.691	-0.032	-0.011	-0.058	-0.086	-0.006	-0.045
16. Invasive Species	*	0.988	0.055	0.066	0.011	0.077	0.005	0.056
17. Population Dynamics	*	-0.593	-0.046	-0.110	0.093	0.019	0.002	-0.021
18. Age Distribution	*	0.593	0.046	0.110	-0.093	-0.019	-0.002	0.021
19. Range	*	-0.691	-0.032	-0.011	-0.058	-0.086	-0.006	-0.045
20. Niche Specialization	*	0.284	-0.366	0.046	-0.007	-0.039	0.146	-0.054
21. Reproductive Success	*	0.284	-0.204	0.126	0.148	0.134	-0.041	0.002
22. Metabolic Processes	*	-0.556	0.150	0.038	-0.049	-0.088	0.016	-0.026
23. Disease/Deformities	*	-0.593	-0.046	-0.110	0.093	0.019	0.002	-0.021
24. Mortality	*	0.345	-0.191	0.099	0.191	-0.056	-0.049	-0.107
25. Genetic diversity	*	-0.728	-0.228	-0.159	0.084	0.021	-0.020	-0.040
26. Human Population Growth	*	0.652	-0.151	-0.057	0.037	-0.175	0.077	0.103
27. Harvesting/Use	*	0.852	0.030	-0.116	0.252	0.002	0.007	-0.040
28. Land Use Changes	*	-0.904	-0.132	0.381	0.039	-0.077	0.043	0.103
29. Fresh Water Supply	*	0.691	0.032	0.011	0.058	0.086	0.006	0.045
30. Pollution	*	-0.892	0.105	-0.005	0.132	-0.167	-0.099	0.078
31. Affinity	*	-0.532	0.118	0.257	0.004	-0.052	-0.010	-0.040
32. Familiarity	*	-0.123	0.207	-0.039	-0.048	0.031	-0.169	0.046

WebGrid's INDUCT module does not look at a grid as a set of vectors in space but uses fuzzy set theory to assign truth-values to logical predicates. The concepts can be considered to be subjects and the criteria can be considered to be predicates describing the subjects. The INDUCT analysis of the eco-concepts and criteria represents them as sets of classes and rules that can be drawn as a directed graph. In preparing Figure 8.7, a cut-off point (truth-value of 100%) was used. There were no differences in the assignments made through simple induction, EDAG (rules with exceptions), or RDR (ripple-down rules). There was only one error in assignment.

INDUCT assigned the eco-concepts and criteria to two mutually exclusive categories corresponding to human impacted and natural ecosystems. Urban/industrial and monocultures shared 21 criteria in common. The other natural scientific eco-concepts shared 20 criteria in common.

Urban/Industrial ecosystems were distinguished from other eco-concepts by the following criteria:

- *Climate warming or cooling*
- *Small habitat patches*
- *Biomass decreasing*
- *Respiration*
- *Species composition changing*
- *Rare or endemic species*
- *Low reproductive success*
- *Metabolic processes disrupted*
- *High mortality rates*
- *People are indifferent*

Only three criteria uniquely distinguished Monocultures from other eco-concepts:

- *Bioaccumulation*
- *Production*
- *Regenerate to the same species*

Natural/Pristine accounted for 8 out of 10 of the remaining scientific criteria. Moreover the residual criteria that distinguished Ecological/Biological Integrity, Sustainability, and Carrying Capacity from other eco-concepts were overlapping subsets of the criteria used to characterize Natural/Pristine. Resilience also overlapped to some extent with the criteria used to describe Natural/Pristine but was uniquely distinguished by the one criterion: *Regenerate to the same species.* Ecosystem Health also overlapped with Natural/Pristine, and also had one unique criterion: *Decomposition.*

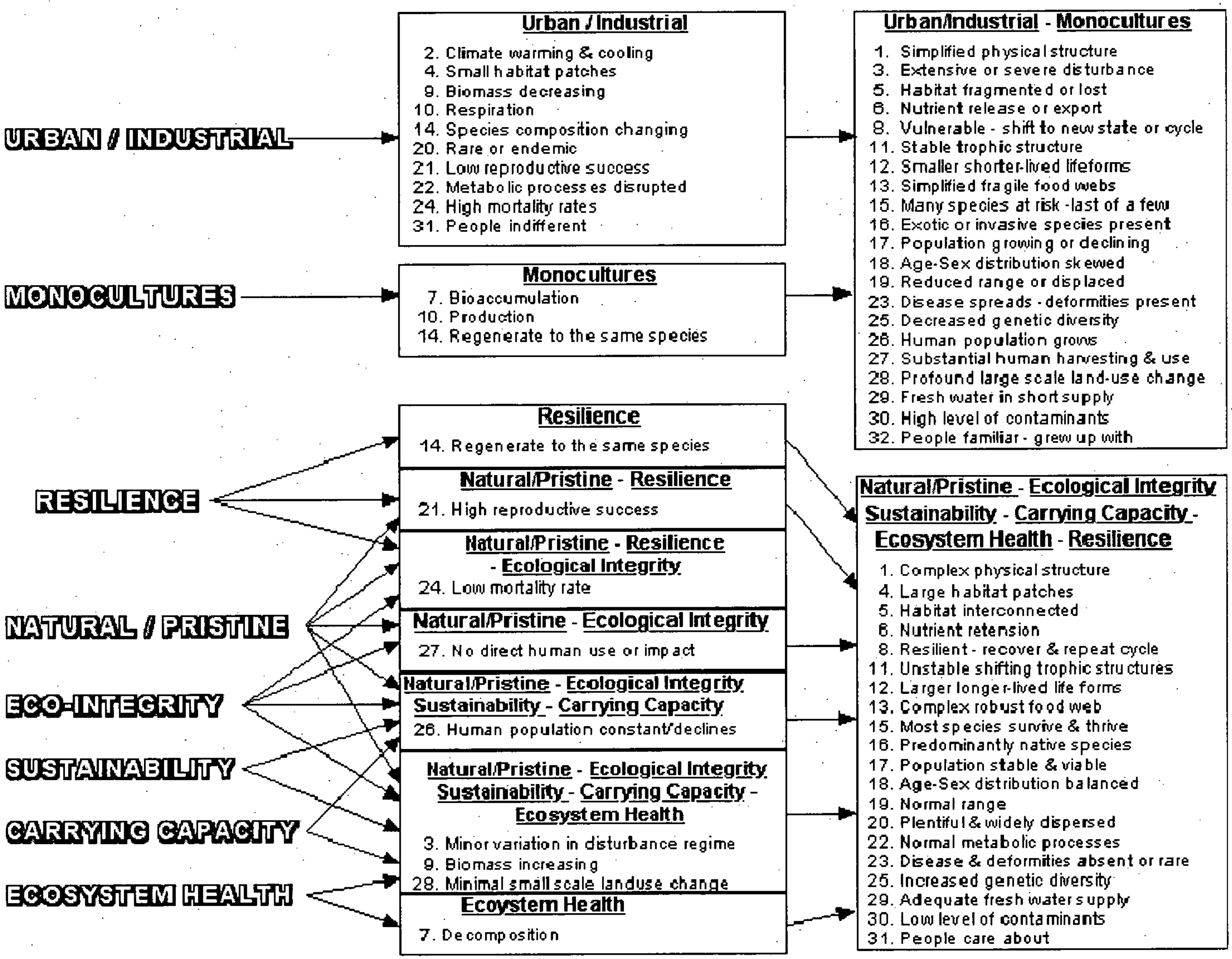

Figure 8.7 INDUCT Analyses of Eco-Concepts and Criteria

The criteria used to describe Natural/Pristine were

- *Minor variation in disturbance regime*
- *Biomass increasing*
- *Human population constant/declines*
- *High reproductive success*
- *Low mortality rates*
- *No direct human use or impacts*
- *Minimum small scale land use change*

8.8 Possible Effects of Survey Error and Non-Response

There are three sources of survey error (Groves, 1989). Sampling error goes to the survey coverage and how representative is the sample of the population about which you want to draw inferences. Measurement error addresses the issue of the reliability and validity of the data. Non-response deals with the potential for bias.

8.8.1 Coverage

Strictly speaking both the key informant interviews and web-based questionnaire surveys are convenience samples. In most cases, research of this type is undertaken with small groups, such as university students in a classroom setting, or in uncontrolled situations, where respondents self-select or volunteer to participate in the survey. Convenience samples are not randomly selected so it is well nigh impossible to draw statistical inferences or reach general conclusions. However, convenience samples are useful for developing research hypotheses, defining range of alternatives, and for qualitative data analysis. With certain assumptions, convenience samples can be useful for testing model-based inferences such as fuzzy membership functions and induction (Schonlau, Fricker & Elliott, 2002).

As described in chapter six, research methods, nothing much is known about the characteristics of the population of experts who think and act in terms of ecosystems. An effort was made to ensure that the interview subjects included as diverse group of experts, representing a cross section of viewpoints about ecosystem risk. Steps were also taken to ensure that a variety of regions and institutional settings were represented in the sample. A much broader group of respondents was reached during the second stage of the survey, through mailings to Internet discussion lists. The discussion lists were chosen because of their subject matter content and were selected from comprehensive Internet list servers or directories that are updated regularly (see Appendix 10). Internet surveys are well suited for larger survey efforts when the target population is difficult to reach. (Schonlau, Fricker & Elliott 2002)

Currently the biggest concern with web-based surveys is coverage bias (Solomon, 2001). The coverage is restricted to individuals with access to computers. For example university faculty, and students and government personnel are likely to have better access to the Internet than business people or community activists. Another potential source of bias is differences in the respondents experience and personal comfort level using Internet tools such as web browsers. For example, younger people may be more comfortable responding to the survey than older people. The self-selected nature of response to web page-based surveys may also affect the types of conclusions that may be drawn from them (Schillewaert, Langerak & Duhamel, 1998).

The Web is a public place and it is possible for anyone to respond to the survey. Moreover, respondents may mistakenly or purposefully submit multiple copies of their responses. These particular problems were dealt with through the survey programming. Respondents could only access the WebGrid version of the survey through blind splash page and their e-mail address was tracked. The fixed form of the survey also tracked the respondents e-mail address and did not permit the potential subjects to submit multiple responses

8.8.2 Validity and Reliability

The validity and reliability of the experts' mental models of ecosystem risk was determined in a variety of ways. The experts recognise and use the mental constructs discussed in this study in similar ways. This finding addresses any potential concerns about logical and face validity. Every level of biological organization in an ecosystem was described using a representative selection of eco-criteria thereby ensuring construct validity. The experts' mental model of risk is internally consistent. Test-retest comparisons between stage one and two of the survey yields similar results, increasing confidence in the reliability of the study's conclusions.

Experts recognised and agreed on the meaning of the discourses used to build the worldview scale, meaning that they have both logical and face validity. The statements used to represent each cluster of beliefs were drawn from the literature, have been used before, and reliably distinguish different groups. Discourse #1 and #3 are internally consistent and negatively correlated. Different respondents contested the statements in Discourse #2. The interview and Internet version of the worldview scale yielded virtually identical results.

8.8.3 Non-Response

Fifty-one interviews were completed during the first stage of the survey. The survey response rate was almost 75%. A total of 67 potential subjects were contacted from a mailing to 85 potential respondents (for a contact rate of rate of almost eighty percent.) Seventeen eligible respondents declined or could not complete the interviews (for a non-response rate of 25.4%).

Originally only thirty interviews were planned. Additional interviews were undertaken in an effort to achieve a more representative selection of subjects.

The interviews took place between the end of January and beginning of June 2004. Most of the interviews were conducted in person. Only seven of the interviews were conducted by phone. Interviews were conducted from coast to coast. The regional distribution of the interviews was as follows: Central Canada 28, Western Canada 11, Eastern Canada 7 and the United States 5. Experts from 18 different universities agreed to be interviewed. With one exception all the respondents agreed to the disclosure of their identity (see Appendix 7). Nine of the interview subjects also completed the second stage of the survey.

Unlike mail and phone surveys (AAPOR, 2005), a standardized method for calculating a non-response rate to a web-based survey has yet to be developed (Manfreda & Vehovar, 2002). The WebSM site (www.websm.org) is a resource on web survey methodology. Non-response to Internet based surveys can be described in terms of the contact rate, click-through rate, completion rate, and dropout rate. The contact rate is percentage of e-mailed invitations successfully delivered to valid e-mail addresses. The click-through rate refers to the percentage of those contacted, who actually access the questionnaire. The completion and drop-out rate refers to the percentage of potential respondents who complete or fail to complete the questionnaire

Forty-two responses were received to the second stage survey questionnaire, which was posted on the Internet from mid -September to the end of November 2004. From various sources, it was estimated that the initial invitation to participate in the second stage of the survey reached approximately 7,500 e-mail addresses. Approximately 600 potential respondents accessed the first page of the questionnaire for a click-through rate of eight percent. Survey professionals normally expect a click-through rate of 1 to 3 percent of the total contacts made for a web-based survey (MacElroy, 2000). Although almost two hundred (198) potential respondents provided personal background data. Only 42 of them completed the elicitation portion of the survey for a 21.2% survey response rate. Response rates to this type of survey can vary from 20 to 50 percent depending on the relevance and interest in the topic (MacElroy, 2000). Web-based surveys tend to have higher dropout rates than interviews or mailed surveys.

Twelve of the experts interviewed during the first stage of the survey but who did not complete the WebGrid questionnaire were contacted and asked why they did not respond to the second stage of the survey. They gave a lack of time and unfamiliarity with how to answer the questionnaire online as the main reasons they had not followed through.

During the web-based survey, seventy percent of the visitors to the questionnaire web page were from North America, fifteen percent were from Australia and New Zealand, ten percent were from Europe, and five percent were from elsewhere.

The personal characteristics of interview and questionnaire survey respondents differ (see Table 8.13). The interviewees were more likely to have completed a doctorate. Almost seventy percent had completed a doctorate compared to less than fifty percent (47%) of the survey respondents (1-tail test significant .02). The interview respondents were older: 73 percent were over 45 years of age, while two thirds of the survey respondents were under 45 years of age (1-tail test significant .0001). Males outnumbered females but a higher percentage of the survey respondents (38%) were female than of the interview respondents (12%). (The 1-tail test was significant at .0015.)

The respondents also differ in professional background and experience. Although the survey respondents were currently more likely to be academics (69% compared to 51% of the interviewees – 1-tail test significant .00003) paradoxically, they had had a broader range of work experience. For example, less than thirty percent of the survey respondents had only been academics, compared to over forty percent of the interview respondents (1-tail test significant .1). Over 25 percent of the survey respondents had business and other work experience compared to less than six percent of the interviewees (1-tail test significant .01). The respondents in both samples were evenly distributed among ecology, other ecosystem sciences, and the social and health sciences. However, persons with a social and health science background were somewhat more likely to have answered the survey questionnaires (33%) than to have been interviewed (26%). (The 1-tail test was significant at .2.)

The combined study population is more representative. The shortcomings of the first stage interview sample are offset to some degree by the second stage questionnaire survey sample. For example, the respondents in the combined sample are more evenly distributed in terms of age, education, discipline and years of experience. However, the study population is still biased in terms of gender (females are under-represented) and also in terms of past employment (persons with a business or environmental activist background are under-represented).

Table 8.13 Respondent Characteristics

EDUCATION	Total		Interviews		Survey	
BA or Less	18	21.5%	6	11.8%	12	28.6%
Masters	18	21.5%	10	19.6%	10	23.8%
Doctorate	48	57.0%	35	68.6%	20	47.6%
DISCIPLINE	Total		Interviews		Survey	
Ecology	24	28.6%	15	29.4%	13	30.9%
Other Eco-Sciences	37	44.0%	23	45.1%	15	35.7%
Social & Health Sciences	23	27.4%	13	25.5%	14	33.3%
TYPE OF EXPERIENCE	Total		Interviews		Survey	
Academic Only	27	32.1%	21	41.2%	12	28.6%
Government & Other	29	34.5%	18	35.3%	13	30.9%
Business & Other	13	15.5%	3	5.9%	11	26.2%
Advocacy & Other	15	17.9%	9	17.6%	6	14.3%
CURRENT POSITION	Total		Interviews		Survey	
Academic	48	57.0%	26	51.0%	29	69.1%
Professional & Consulting	24	28.6%	16	31.4%	9	21.4%
Advocacy & Other	12	14.4%	9	17.6%	4	9.5%
YEARS OF EXPERIENCE	Total		Interviews		Survey	
Under 20 years	42	50%	16	31.4%	30	71.4%
20 years and over	42	50%	35	68.6%	12	28.6%
AGE	Total		Interviews		Survey	
Under 45 years	38	45.2%	14	27.5%	28	66.7%
45 years and over	46	54.8%	37	72.5	14	33.3%
GENDER	Total		Interviews		Survey	
Male	64	76.2%	45	88.2%	26	61.9%
Female	20	23.8%	6	11.8%	16	38.1%
TOTAL	**84**		**51**		**42**	

It was also possible to assess the impact of non-response to the second stage of the survey by comparing the characteristics of 42 respondents with 156 non-respondents (see Table 8.14 above). The so-called "non-respondents" included everyone who started but failed to complete the web-based survey questionnaire. Respondents were more likely to have a PhD (48% percent of the respondents compared to 31% of the non-respondents – 1-tailed test significant at .02). They were older and more experienced (33% were over 45 years of age compared to 15% of the non-respondents – 1-tailed test significant .003 and 29% had over twenty years of experience compared to 15% of the non-respondents – 1-tailed test significant .0185). Survey respondents were more likely to be drawn from the social and health sciences, (33% compared to 17% of the non-respondents – 1tailed test significant .0115), and less likely to be drawn from other ecosystem sciences (36% compared to 56% of the non-respondents – 1-tailed test significant .0105). In other respects, the characteristics of respondents and non-respondents were similar.

Table 8.14 Comparison of Characteristics of Respondents & Non-Respondents to the Web-Based Survey

EDUCATION	RESPONDENTS		Non-Respondents	
Less than PhD	22	52.4%	108	69.0%
PhD	20	47.6%	48	31.0%
DISCIPLINE	RESPONDENTS		Non-Respondents	
Ecology	13	30.9%	42	26.9%
Other Eco-Sciences	15	35.7%	87	55.8%
Social & Health Sciences	14	33.3%	27	17.3%
TYPE OF EXPERIENCE	RESPONDENTS		Non-Respondents	
Academic Only	12	28.6%	33	21.1%
Government & Other	13	30.9%	48	30.8%
Business & Other	11	26.2%	38	24.4%
Advocacy & Other	6	14.3%	37	23.7%
CURRENT POSITION	RESPONDENTS		Non-Respondents	
Academic	29	69.1%	108	69.2%
Professional & Consulting	9	21.4%	35	22.5%
Advocacy & Other	4	9.5%	13	8.3%
YEARS OF EXPERIENCE	RESPONDENTS		Non-Respondents	
Under 20 years	30	71.4%	133	85.3%
20 years and over	12	28.6%	23	14.7%
AGE	RESPONDENTS		Non-Respondents	
Under 45 years	28	66.7%	133	85.3%
45 years and over	14	33.3%	23	14.7%
GENDER	RESPONDENTS		Non-Respondents	
Male	26	61.9%	89	57.1%
Female	16	38.1%	67	42.9%
TOTAL	**42**		**156**	

This type of research is typically based on a sample of university students or professional employees drawn from within a single organization. Both stages of the survey reached a broader cross section of experts than the typical knowledge elicitation study. The participants were drawn from a broad spectrum of disciplines and institutional contexts. They lived and worked in every corner of the globe. The interview and questionnaire survey to some extent offset each other's shortcomings. The survey provided more respondents with a non-academic background, business or other work experience. It also provided more respondents with a social or health science background. Nevertheless, females and persons with a business or activist background are still under-represented in the study.

Can we say with certainty that persons of one persuasion or another were more or less likely to respond to the survey? The answer is no, because we still do not know everything we would need to know about the characteristics of those who share a particular mental model of risk. However, our confidence in the survey, and the validity of its findings, is increased by size and diversity of the sample and the way in which it was drawn.

The respondents are largely drawn from the English-speaking world. Academic and government institutions are over represented. If there is any bias it is towards older formally educated male persons. Persons with little formal education whose expertise is based on extensive practical experience or traditional knowledge are under represented. Although business and environmental groups are underrepresented, many respondents had experience that crosscut multiple institutional spheres. The respondents were preoccupied with environmental rather than social or economic concerns about ecosystems.

8.9 Summary and Conclusions

The first stage of the survey was used to describe ecosystems and elicit assessment criteria from experts describing those aspects of ecosystems they felt should be conserved, managed, or protected. The experts were asked to identify threats to regional ecosystems and to evaluate the relative importance of different driving forces of ecological change. They were also asked to identify eco-concepts they would prefer to use to assess risks to ecosystems. During the second stage of the survey, the respondents were asked to define what these eco-concepts meant to them using a common set of assessment criteria developed from the expert interviews. The analysis of similarities and differences confirmed that the concepts have much in common.

Experts were more inclined to think of an ecosystem as a dynamic set of processes and functions than a real place. They were less inclined to think of it as a system. Experts proposed a wide range of assessment criteria, including biodiversity, the cycling of materials and energy, and important functional relationships. Social considerations and criteria applicable to organisms were less frequently mentioned.

Population growth, consumption and life styles were identified as the most important drivers of ecological change. Most of the threats to ecosystems were thought to be global and national rather than regional in scope

In comparing and contrasting different eco-concepts, the experts found more similarities than differences. The most important differences appear to be whether the ecosystem is either relatively pristine or impacted by human activity. Other important distinctions were whether the eco-concept is highly subjective or measurable or whether it is a popular or technical term.

Ecological Integrity was overwhelmingly chosen as the preferred eco-concept. Those who selected Ecological Integrity were younger, less likely to have a PhD, and had less work experience. Most respondents shared an egalitarian worldview. Those who shared other worldviews were more likely to prefer other eco-concepts. Professional background and current position were significant determinants of the respondents' worldviews.

Persons who endorsed the beliefs of discourse #1 were more likely to disagree with the beliefs of discourse #3. The beliefs of discourse #2 may be more contestable, because they drew a mixed response, depending on the respondents' personal background characteristics. If the experts do not share worldviews, risk communication may be more difficult.

Ecosystem experts generally believe that science is value-based and that scientists should do a better job of making these values explicit.

Despite the profusion of eco-concepts, the respondents appear to share a common mental model of ecosystem risk. There was over eighty percent consensus in the way the respondents used the assessment criteria. The assessment criteria were so highly interconnected that individual criteria contribute little additional information to decision-making and may lead to similar choices and outcomes in many circumstances. The relationship among the eco-concepts is flat rather than hierarchical. Consequently, the eco-concepts appear to function as a classification scheme rather than as an inductive model. Individual eco-concepts appear be members of two contrasting metaphoric categories, distinguishing natural from human impacted ecosystems. The only conclusion was that the experts were inclined to think in most circumstances that the various natural scientific eco-concepts have very similar meanings.

9.0 DISCUSSION

In this chapter the findings, strength and limitations of the study, and implications for future research are discussed.

9.1 Experts Share a Common Mental Model of Ecosystem Risk

The experts appear to share a common underlying mental model of ecosystem risk.

The FOCUS analysis identified two clusters of eco-concepts (see Figure 9.1). The natural scientific eco-concepts (i.e., carrying capacity, biological integrity, ecosystem health, and sustainability) are so tightly clustered (90%-100%) that they are more than likely equivalent concepts. Urban/ industrial systems and monocultures are less tightly clustered (85%). Resilience appears to bridge the two clusters.

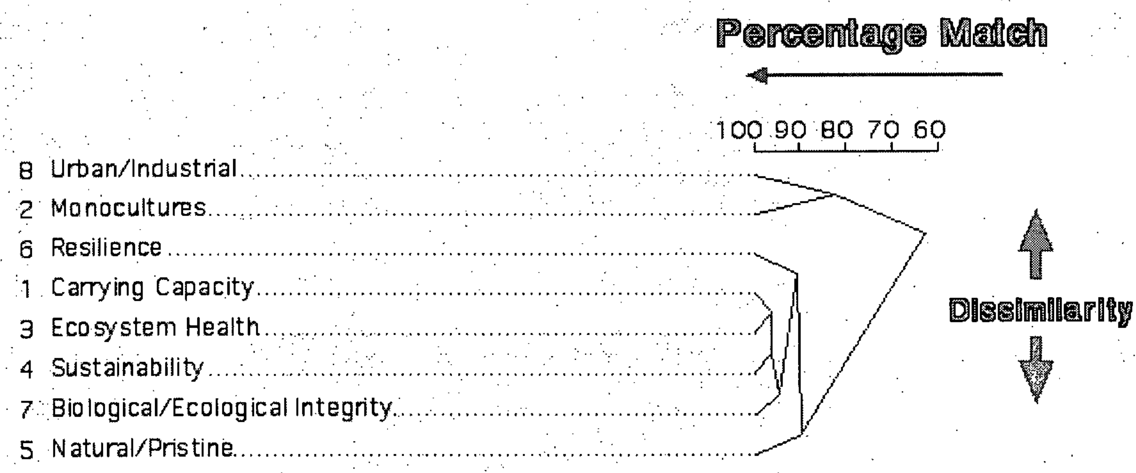

Figure 9.1 FOCUS Clusters of Eco-Concepts

One underlying component or dimension accounted for 85% of the variance in the data (see Figure 9.2). It appears to contrast natural and human-impacted systems. Most of the eco-concepts are very tightly clustered around the horizontal axis. The spread between urban/industrial systems and monocultures at the contrasting pole of the axis is greater.

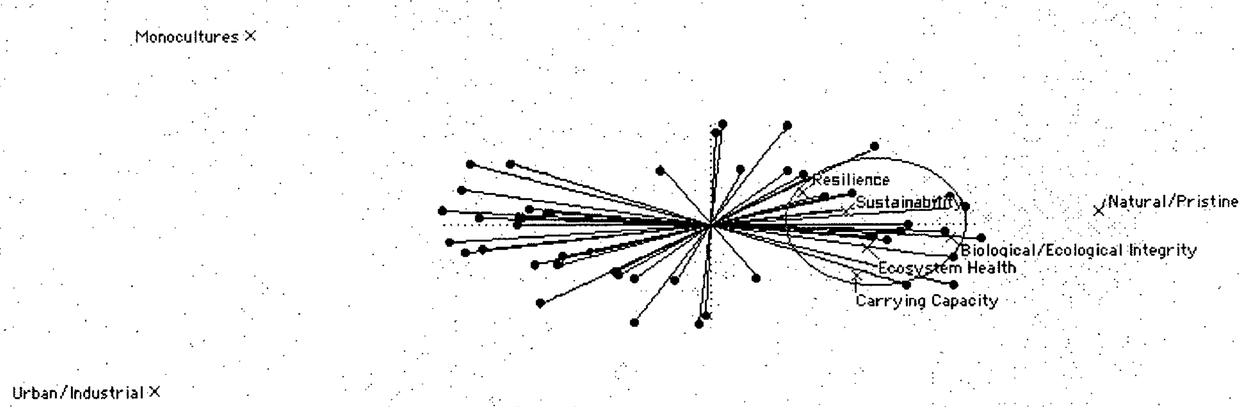

Figure 9.2 PrinCom Map of Eco-Concepts

The induct algorithm revealed the relationship between the eco-concepts and the criteria. The Eco-concepts can be assigned to two contrasting categories. That is to say, with one exception the assessment values of the eco-criteria describing one category are the opposite of the other category. Most of the criteria describing a category are shared in common by all the eco-concepts in that category. In particular, sustainability and carrying capacity are equivalent concepts. They are a subset of natural/pristine. Ecological integrity is also a subset of natural/pristine. Only a single criterion distinguishes each of the remaining eco-concepts, resilience and ecosystem health, from the other eco-concepts. For resilience it is the capacity to regenerate to the same species, and for ecosystem health it is decomposition.

The structure of relationships among the eco-concepts and assessment criteria is flat rather than hierarchical, meaning that they function as a classification scheme rather than an inductive model (see Figure 9.3). Consequently the eco-concepts generate few derived distinctions, and are unlikely to generate testable hypotheses.

There are two contrasting sets of eco-concepts. The members of the natural set of eco-concepts are proxies for a very similar type of ecosystem. They are not logically interrelated. Therefore Karr's claim (1996) for example, that ecosystem health and ecological integrity are not the same, and that they represent a continuum of ecosystems from relatively pristine to human impacted systems is not supported by the data.

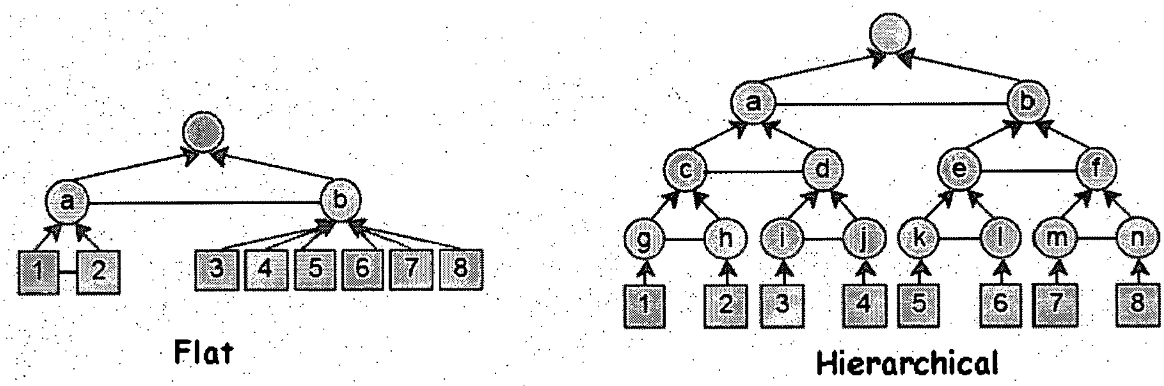

Figure 9.3 Metaphoric Categories or Inductive Models?

Thirty-two eco-assessment criteria were elicited as bipolar constructs. The criteria encompass all levels of biological organization, and provide a comprehensive guide to the assessment values of concern to experts. When the experts used the eco-assessment criteria to describe different eco-concepts, only two poles of the constructs were not in play: minimum climate variability and lack of familiarity or knowledge.

For the most part these constructs are effects-based. They provide a good basis for the development of monitoring and assessment endpoints or indicators. The exact selection of endpoints or indicators being monitored depends will depend on the values at risk. The role of the decision-maker is to decide whether or not these changes are acceptable. It is important to develop an assessment approach that balances protection and detection with reversibility and relevance (Munkittrick, 2004). Society needs sufficient warning to adapt to any unanticipated consequences before they become irreversible.

Although the assessment criteria do not appear to be redundant, they are so highly interconnected that individual criteria may contribute very little additional information to decision-making and may lead to similar choices and outcomes. Although ecosystems are complex systems, in most cases only a few criteria may be needed to detect significant changes in their structure or functioning. The Nature Watch approach (www.naturewatch.ca) to ecological monitoring (e.g. frog watch, plant watch, ice watch) may be a more appropriate strategy for detecting signs of emerging problems at this stage than more complex scientific assessments or modeling.

Because the experts use the eco-criteria in similar ways, and cannot distinguish one eco-concept from another they appear to share a common mental model of ecosystem risk.

9.2 Ecosystem Experts Share a Common Worldview

The experts also appear to share a common worldview. Eighty percent of the respondents endorsed the core beliefs of discourse #1. Over three quarters of them were also likely to oppose the core beliefs of discourse #3. These discourses contrast common environmental and economic belief sets. Consequently ecosystem experts may experience some difficulty in risk communications, when their audience does not support or share their beliefs.

Discourse #2 provoked the most controversy. Response to specific statements also varied by background characteristics such as gender. For example, females were more likely to agree that we are approaching the limits of the number of people the earth can support, that companies will not protect the environment until the law forces them to do something, and that modern technology poses serious risks to the environment.

The typical respondents' worldview incorporated beliefs drawn from all discourses. These beliefs reflect their opposition to business as usual, concern about the effects of sustained economic growth, and questioning of rules that govern the marketplace. These findings do not support the notion that the respondents' support for statements drawn from one discourse would necessarily exclude support for statements drawn from other discourses.

The typical worldview described in this study is compatible with Dunlap's New Ecological Paradigm scale (Dunlap et al., 2000).

Overall the respondent's worldviews were most heavily influenced by their current position and previous work experience. This suggests that workplace professional or disciplinary reference groups may be the primary influence shaping their mental models of ecosystem risk.

9.3 How do you distinguish a good from a bad metaphor?

Worldviews provide the root metaphors for mental models of risk. World hypotheses take an area of common sense fact and use this as a basic analogy with which to understand other areas of knowledge (Pepper 1942). No facts lie outside it and nothing can be rejected as irrelevant. The structural characteristics of these root metaphors provide the basic categories of explanation and description. World hypotheses can neither be verified nor falsified. The only requirement for a world hypothesis is consistency that it does not falsify itself, a requirement that many worldviews often fail to meet. Otherwise there is no basis for deciding whether a worldview is more useful than another, much less, whether it is right or wrong (Lovins, 1977).

Metaphors are cognitive tools that are important in creative thought and useful as mechanisms of discovery (Gentner, 2002; Markman & Gentner, 2001). Metaphors are developed through analogy, providing a bridge from the known to unknown. Through the use of metaphors one can exercise foresight, by applying past experience to future events. Metaphors are commonly used in communication and persuasion. Conventional metaphors also play an important role in memory recall and learning.

Through the use of metaphors one may draw attention to less obvious but important aspects of a domain, revealing communalities or differences, and helping to detect inconsistencies. These comparisons may lead to new conceptual developments. In a limited number of cases, metaphors may even provide the map for a new area of knowledge. Metaphors are an inescapable aspect of language and thought.

Metaphors are processed by means of structure-mapping comparisons between two subject matter domains that invite inferences from the base to the target domain (Gentner, 1983). Domains are psychologically viewed as systems of objects, object attributes, and relations between objects. Knowledge can be represented as a propositional network of nodes and predicates. The nodes represent concepts or any other subject matter, and the predicates applied to the nodes express propositions about the concepts. Attributes are predicates taking one argument, and relationships are predicates taking two or more arguments.

Scientific metaphors differ from conventional metaphors (Gentner, 1982). They aim to explain and predict where conventional metaphors aim to evoke or describe. Conventional metaphors provide richer descriptions with little attention to clarity or consistency. Scientific metaphors provide a relatively abstract, clear, and coherent description of a system of relations.

Gentner provides six evaluation criteria for analogies: 1) base specificity, 2) clarity, 3) richness, 4) abstractness, 5) scope, and 6) validity (Gentner, 1983). It is easier to identify the important relationships when the base is well understood. Clarity refers to how rigorously the object mappings are specified. A violation occurs, if a base node maps to two or more relationally distinct target nodes (the one-to-many case) or if two or more relationally distinct base nodes map to the same target node. Richness refers to the density or number of predicates that were imported for every target node. Abstractness refers to the extent to which higher order relations constrain lower order relations. A mapping is systematic to the degree that any predicate can be derived or at least is partly constrained by others. Scope refers to the number of different cases to which the metaphor applies. Validity refers to the correctness of the imported predicates.

The base domain for scientific metaphors should be well understood and fully specified. Good scientific metaphors should provide one-to-one, not one-to-many mappings. A useful metaphor should apply to a number of cases and lead to reliable and valid inferences in the majority of these cases.

Carrying capacity is the most specific scientific metaphor. It is premised on the notion of the balance of nature that suggests scientists can estimate predictable surpluses or loadings. Ecological integrity suggests that we can pick natural benchmarks or acceptable ranges of variation. Ecosystem health is the least specific, preferring to rely on diagnostic indicators. Carrying capacity is often the clearest, having a mathematical formulation. There is also an index of biological integrity. However, what ecosystem health or integrity lack in clarity, they often make up for by richness. Ecosystem health has a whole landscape or seascape scope, while ecological integrity focuses on the survival of biological communities, and carrying capacity focuses on population dynamics.

However, all three metaphors get a failing grade on the last two criteria, abstractness and validity. Abstractness means that we should be able to model one domain in terms of another, and generate valid inferences about the future. While it is true that these metaphors have shaped our perception of ecosystems, they do not help experts think about ecosystem risk in a simplified manner or to mentally simulate future events.

9.4 Mental Models or Mental Muddle

This study has shown that expert mental models of ecosystem risk conceal fundamental differences in concerns, scope, causal beliefs and views of science. For example the mental models of risk have different policy goals. The carrying capacity model is concerned with pollution and waste; the biological integrity model is concerned with the loss of biodiversity (e.g. species extinctions) and disruption of global cycles (e.g. carbon, nitrogen); and the ecosystem health model is concerned with how we are going to meet human wants and needs in the future. The mental models also have very different scopes. Carrying capacity focuses on populations and individuals; biological integrity focuses on communities and species; and ecosystem health focuses on ecosystems and landscapes. They also have very different notions of the driving forces of ecological change. Carrying capacity blames population growth, and consumption; biological integrity blames over-harvesting, habitat loss, and the introduction of exotic species; and ecosystem health blames monocultures, industrial production and global trade for our environmental ills. Consequently, the mental models provide shaky grounds for decision-making.

However, without an appropriate integrative assessment framework, it is impossible to judge the urgency of action or the consequences of inaction. For example, even with all planned mitigation measures in place, atmospheric concentrations of carbon dioxide will double over pre-industrial time. These estimates do not fully take into consideration the potential contribution of China and India, who have no obligations to reduce their greenhouse gases and who may add more carbon dioxide to the atmosphere than more developed nations plan to remove. Moreover, the lack of knowledge about the state of the world's ecosystems undermines any attempt to evaluate trends. For example, how can anyone claim that we are in the midst of an extinction crisis, when no one knows, even to the nearest magnitude, the number of species on Earth? Other drivers, such as excess nutrient loadings of nitrogen and phosphorous, have received limited attention. The amount of phosphorous in agricultural soils has been called a chemical time bomb that is just waiting to go off. What is needed is an assessment framework that will capture how these diverse driving forces of environmental change may play out from place to place.

The United States Environmental Protection Agency (U.S. EPA) has taken the first baby steps towards identifying a generic set of assessment endpoints (Suter et al., 2004). In ecological risk assessment, endpoints are explicit expressions of environmental values that should be managed, conserved or protected, operationally defined as the attributes of an ecological entity. U.S. EPA selected eight to twelve endpoints that can be estimated using existing assessment tools and that reflect current program goals of the Agency.

This study was also able to identify over thirty constructs describing important ecological endpoints, including many of the same endpoints identified by the US EPA. It is encouraging to note the high-level of consensus among the experts, about the entities and attributes they thought should be conserved, managed or protected, and about the use of appropriate assessment criteria. Experts were able to use these constructs to communicate among themselves. Moreover, use of these constructs would facilitate risk communication with a wider public audience. The values represented by these eco-criteria could be used as the basis for integrated decision making.

Value-focused thinking (Keeney, 1992) would represent the experts' values as a set of planning objectives, and define measures to evaluate the achievement of these objectives. The steps in the process include: (1) identifying the important concepts and relationships (2) clarifying the values they represent, (3) organizing them in a means-ends hierarchy, (3) suggesting possible evaluation criteria, (4) identifying important working hypotheses, (5) acting on them, and (6) learning from experience.

Objectives define what matters or what people care about in any decision-making context (McDaniels, 2000). They should clarify what is valued, suggest the direction of preference and provide a decision-making context. Ecosystem objectives should identify the entity or valued resource, the attributes to be protected and the desired state (Barton & Sergeant, 1998). Identification of these generic assessment endpoints or objectives of necessity involves human values and perceptions (Gentile & Harwell, 1998) and the final selection will reflect societal goals as well as ecological significance (US EPA, 1992).

The proposed set of objectives should cover everything that matters in making a decision, should only involve ends that somehow can be controlled or influenced by the choice of alternatives, and should be both measurable and meaningful to those who use them (Keeny, 1992). The set of objectives should comprise all the ends that are important for the decision but should exclude the means – otherwise the objectives would be linked (McDaniels, 2000). Because objectives comprise the fundamental motivations for making decisions, they can be used a number of ways: to compare alternatives, to create newer more attractive alternatives, and to identify decision opportunities.

9.5 Strengths and Limitations of the Study

Repertory grids and fuzzy logic are suitable tools for eliciting expert knowledge and modeling complex imprecise problems in uncertain domains. These methods work well with linguistic variables and poorly characterized parameters. They provide the opportunity to evaluate and communicate assessments using linguistic terms familiar to decision makers and the public. Moreover, approximate reasoning methods such as fuzzy arithmetic do not require well-characterized statistical distributions as inputs. Another key advantage of repertory grids and fuzzy logic is their ability work with quantitative and qualitative variables, and to cope with multiple objectives.

Over 55 hours of audio recordings of interviews with respondents were a rich source of insight. Qualitative analysis allows one to consider and weight the input of individuals in ways that are not possible in questionnaire surveys.

This study employed novel methods of elicitation and analysis in a survey setting. Repertory grids are normally elicited in a lab setting under controlled conditions. Respondents did not find it easy to apply each of the assessment criteria to all of the eco-concepts, one criterion at a time, much preferring to apply all the criteria to a concept at a time. The length of the survey, applying 32 criteria to eight concepts, created respondent fatigue, increasing the number of subjects who did not complete the questionnaire, and were eliminated from the analysis. (See discussion of non-response in Chapter 8.)

The Internet survey used interactive and fixed forms of elicitation. Computer literacy and time constraints were major factors affecting survey response, especially for older respondents using the WebGrid form of the questionnaire. Although the fixed form of the questionnaire was constructed used only basic HTML programming, many problems of compatibility were encountered due the wide variety of computer platforms (e.g., Microsoft, Apple-Macintosh) and multiple versions of the software (e.g., different editions of Explorer and Netscape browsers) employed by respondents. Finally, Internet security protocols in some cases prevented respondents from using active forms such as the WebGrid version of the survey or quarantined e-mails from discussion lists.

The sample composition and formal nature of repertory grid methods may perhaps contribute the impression that the study's conclusions apply only to the world of the professionally trained or conventional science. However, this is not the case. The methods used enabled us to elicit mental models of risk from a more diverse group of ecosystem experts than would have other wise been possible. Although the study population is not a true random sample it is vastly superior to the convenience samples normally used for studies of this type.

Business professionals and environmental activists are under-represented in the study population. There is some indication from the interviews that experts drawn from a business milieu are more inclined to practise reductionist science and to express an opposing worldview. Some activists were innately suspicious of the motives of the investigators and thought the value of ecosystems should not be up for debate or discussion. Activists are more likely to express the aesthetic, ethical or spiritual values of ecosystems. Greater diversity would have only strengthened the study's findings of a relationship between the respondents' background, worldview, and mental model of risk.

9.6 Implications for Future Research

Mental models of ecosystems are mental sketches typically based on longstanding beliefs that influence real life decision-making (Kempton, Boster & Hartley, 1994). They can be used to facilitate learning, (Gentner & Stevens, 1983) to help frame decisions (Kahneman, Slovic & Tversky, 1982), and to help design messages (Morgan et al., 2002).

The ecosystem concept should be explored in context and in greater depth. When people talk about ecosystems are they talking about the same things? Some people think about ecosystems as places (the Georgia Basin) or in terms of the parts (e.g., grizzly bears, salmon) or process (e.g. seasonal migration, fishing down food webs). If the concept is going to provide the basis for law and public policy, it is going to have to acquire more rigour.

For some we live in an age of ecological crisis, while others remain blissfully unconcerned. How do experts judge relative risk, the temporal scale, magnitude and severity of the changes to the Earth's ecosystems? Should we become concerned over the death of an organism, or the loss of a species or a guild? Is it the charismatic species of the world that matter (e.g., pandas) or the small creatures at the base of the food chain (e.g., diporeia or krill)? What do a couple of degrees of climate change here or there matter? At what point are these losses or changes not recoverable or reversible? Understanding the way experts frame these issues would help decision makers evaluate the urgency, possibility, and vigour of any response.

A small group setting in a lab would allow for a more in depth exploration of experts' conceptual systems. Experts drawn from different backgrounds should be asked to explain how a particular risk affects an ecosystem. They should be asked to evaluate a variety of ecosystem risks. The selection of risks should involve different levels of biological organization (e.g. landscapes, communities, species, populations, and individual organisms). The experts would then be asked to exchange their repertory grids with other experts and to see if they can reconcile their differences. This exercise would be repeated for a number of different types of risks. The experts would then be asked to fill out a common grid for each type of risk. Subsequently, the degree of conflict, contrast, correspondence, and consensus in the results would be determined. The experiment would allow the researcher to develop testable hypotheses about how ecosystems work.

Ecosystem thinking could potentially be a useful integrative concept for a broad spectrum of scientific research. Ecosystems, however defined, provide a manageable basis of action for conservation, protection, and resource management purposes. However, our lack of understanding of how ecosystems work, relative absence of ongoing ecosystem-scale studies, and non-existence of tools that provide timely feedback is worrisome. Policy makers should also be concerned about the current lack of appropriate institutions, policies, and response strategies in place to deal with the environmental problems that are now becoming all too apparent.

In the next fifty years three great transitions set in motion by the industrial revolution will reach their culmination.

The world will pass through a demographic transition (Cohen, 2005). Even at replacement levels, the human population will continue to grow for another sixty years. Judging from current trends, human population will plateau around nine billion people around the middle of this century. The anticipated increase in human population by 2.5 billion people by 2050 will exceed the total population of the world in 1950.

Before 2000, young people always outnumbered old people. From 2000 forward, old people will outnumber young people. The crossover in the proportion of young and old reflects both improved survival and reduced fertility. The average life span grew from perhaps 30 years at the beginning of the 20th century to more than 65 years by the start of the 21st century. From 2003 onward, the median woman will have too few or just enough children to replace herself and the father in the following generation.

The next half century will see an enormous shift in the demographic balance between the more developed regions of the world and the less developed ones. Whereas in 1950 the less developed regions had roughly twice the population of the more developed ones, by 2050 the ratio will exceed six to one. Until approximately 2007, rural people will outnumber urban people. From about 2007 onwards, urban dwellers will start to outnumber rural residents.

The second transition will be economic (Sachs, 2005). Almost everyone who ever lived was wretchedly poor. Humanity's sad plight started to change with the Industrial Revolution around 1750. Two and half centuries later more than five billion of the world's 6.5 billion people reliably meet their basic living needs. One out of six inhabitants of this planet, however, still struggles daily to meet some or all of their needs such as adequate nutrition, shelter, clean drinking water, and access to basic health care. Will we be able to meet the needs of another 2.5 billion people?

The future of humanity and the environment will be secured by thousands of mundane decisions made by ordinary people such as how many babies they are going to have, where they graze their cattle, and how they heat their homes.

Science and culture provide the context in which knowledge is pursued and used. Science provides the institutional setting, methods used, and standards of success. The goal of science is to expand our insight and knowledge of nature through a process of questioning, hypothesizing, and refutation. Scientific investigation is designed to inhibit premature consensus. Research is a prescription for raising new questions. Science is sufficiently diverse to support a range of viewpoints. The mental pictures it paints of nature and the human condition are only limited by our imagination. The challenge we face today is to frame the daunting environmental problems we face in a way that they can be resolved by the ordinary means available to us.

On January 10, 2005, the Biosphere 2 campus was put up for sale (see www.bio2.edu/). Biosphere 2 attempted to recreate seven so-called biomes (ocean, freshwater and saltwater marshes, tropical rain forest, savannah, desert, intensive agriculture and human habitat) in an effort to recreate the life support systems of the Earth (Biosphere 1). Over $150 million was spent to create a biosphere that could not support eight humans, even for a limited period of time. It is incomprehensible that greater effort has not been expended to understand the composition and functioning of the Earth's ecosystems.

REFERENCES

AAPOR (2005). Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys. Lenexa, Kansas, The American Association for Public Opinion Research.

Allen, T. F. H. and T. W. Hoekstra (1992). Towards A Unified Ecology. New York N.Y., Columbia University Press.

Allen, T.F.H., Bandurski, B.L. and King, A.W. (1993). The Ecosystem Approach: Theory and Ecosystem Integrity. International Joint Commission. (Report to the Great Lakes Science Advisory Board).

Altieri, M. A. and P. Rosset (1999). "Ten Reasons Why Biotechnology Will Not Ensure Food Security, Protect the Environment and Reduce Poverty in the Developing World." AgBioForum **2**(3&4): 155-162.

Anderson, J. E. (1991). "A conceptual framework for evaluating and quantifying naturalness." Conservation Biology **5**(3): 347-352.

Angermeier, P. L. (2000). "The Natural Imperative for Biological Conservation." Conservation Biology **14**(2): 373-381.

Angermeier, P. L. and J. R. Karr (1994). "Biological Integrity versus Biological Diversity as Policy Directives: Protecting Biotic Resources." BioScience **44**(10): 690-697.

Axelrod, L. J. (1994). "Balancing Personal Needs with Environmental Preservation: Identifying the Values that Guide Decisions in Ecological Dilemmas." Journal of Social Issues **50**(3): 85-104.

Ayres, R. U. (1993). "Cowboys, cornucopians and long-run sustainability." Ecological Economics **8**: 189-207.

Barnthouse, L. W. and G. W. Suter (eds.) (1986). User's manual for ecological risk assessment. Oak Ridge TN, Oak Ridge National Laboratory.

Barrett, G. W. and E. Odum (2000). "The Twenty-First Century: The World at Carrying Capacity." BioScience **50**(4): 363-368.

Bartell, S. M., R. H. Gardner, and R. V. O'Neill (1992). Ecological Risk Estimation. Boca Raton Florida, Lewis Publishers.

Barton, A. and A. Sergeant (1998). "Policy Before the Ecological Risk Assessment: What are we trying to protect?" Human and Ecological Risk Assessment **4**(4): 787-795.

Baskin, Y. (1994). "Ecosystem function of biodiversity." Bioscience **44**(10): 657-660.

Beail, N. (1985). An introduction to repertory grid technique. Repertory Grid Technique & Personal Constructs. N. Beail. Cambridge Massachusetts, Brookline Books: 1-26.

Beanlands, G. E. and P. N. Duinker (1983). An Ecological Framework for Environmental Impact Assessment in Canada. Halifax, Nova Scotia, Institute for Resource and Environmental Studies, Dalhousie University, and Federal Environment Assessment Review Office.

Bell, A. (1994). Non-Human Nature and The Ecosystem Approach: The Limits of Anthropocentrism in Great Lakes Management. Alternatives. **20:** 20-25.

Bell, R. C. (2003). An evaluation of indices used to represent construct structure. Psychological Constructivism and the Social World. G. Chiari and M. L. Nuzzo. Milano, Angeli (EPCA Publications).

Bell, R. C. (2004). Principal Components Analysis. The Internet Encyclopedia of Personal Construct Psychology, Jörn Scheer and Beverly Walker.

Bertram, P. E. and T. Reynoldson (1992). "Developing ecosystem objectives for the Great Lakes: policy, progress and public participation." Journal of Aquatic Ecosystem Health **1**: 82-95.

Bird, P. M. and D. J. Rapport (1986). State of Environment Report for Canada. Ottawa, Supply andServices.

Birkett, S. and D. Rapport (1998). "A framework for identifying and classifying ecosystem dysfunctions." The Environmentalist **18**: 15-25.

Blake, D. E., N. Guppy, and P. Urmetzer, (1997). "Canadian public opinion and environmental action." Canadian Journal of Political Science **30**: 451-472.

Bocking, S. (1994). Visions of Nature and Society: A History of the Ecosystem Concept. Alternatives. **20:** 12-18.

Bocking, S. (1995). "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory." Journal of the History of Biology **28**: 1-47.

Bocking, S., Ed. (2000). Biodiversity in Canada: Ecology, Ideas, and Action. Peterborough, Ontario, Broadview Press.

Boose, J. H. (1984). Personal construct theory and the transfer of human expertise. Proceedings AAAI-84, California, American Association for Artificial Intelligence.

Borman, F. H. (1985). "Air Pollution and Forests: An Ecosystem Perspective." BioScience **35**(7): 434-441.

Borman, F. H. and G. E. Likens (1967). "Nutrient Cycling." Science **155**(3461): 424-429.

Borman, F. H. et al. (1974). "The export of nutrients and recovery of stable conditions following deforestation at Hubbards Brook." Ecological Monographs **44**(225-277).

Bormann, F. H. (1976). "An inseparable linkage: conservation of natural ecosystems and the conservation of fossil energy." Bio Science **26**: 754-760.

Bormann, F. H. and G. E. Likens (1979). Pattern and Process in a Forested Ecosystem. New York, Springer Verlag.

Bostrom, A. (1990). A Mental Models Approach to Exploring Perceptions of Hazardous Processes. School of Urban and Public Affairs. Pittsburgh Penn., Carnegie Mellon University.

Bostrom, A. (1996). Risk Perceptions: "Experts" vs. "Lay People". Risk in the Republic: Comparative Risk Analysis and Public Policy - A Two-Day Joint Conference on the Science, Law and Ethics of Evaluating and Managing Risks to Health and Environment, Duke University, Durham, N.C.

Bostrom, A., B. Fischoff, and G. Morgan. (1992). "Characterizing Mental Models of Hazardous Processes: A Methodology and an Application to Radon." Journal of Social Issues **48**(4): 85-100.

Botkin, D. B. (1990). Discordant Harmonies: A New Ecology for the Twenty-First Century. Oxford, Oxford University Press.

Botsford, L. W., J. C. Castilla, and C.H. Peterson (1997). "The Management of Fisheries and Marine Ecosystems." Science **277**(5325): 509-515.

Broecker, W. S. (1997). "Thermohaline circulation, the Achilles heel of our climate system: Will manmade CO2 upset the current balance?" Science **278**: 1582-1588.

Broecker, W. S. (1999). "What If the Conveyor was to Shut Down? Reflections on a Possible Outcome of the Great Global Experiment." GSA Today **9**(1): 1-6.

Brooks, T. M. et al. (2002). "Habitat Loss and Extinction in the Hotspots of Biodiversity." Conservation Biology **16**(4): 909-923.

Brown, T. C. (1984). "The Concept of Value in Resource Allocation." Land Economics **60**(3): 231-246.

Bruce, J. P., H. Lee, and Erik Haites. Eds. (1996). Climate Change 1995: Economic and Social Dimensions of Climate Change - Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press.

Cairns, J. and J. R. Pratt (1995). The Relationship Between Ecosystem Health and the Delivery of Ecosystem Services. Evaluating and Monitoring the Health of Large Scale Ecosystems. D. J. Rapport, C. Gaudet and P. Calow. Eds. New York, Springer-Verlag. **NATO ASI Series Vol I - 28:** 63-76.

Calder, W. A. (1984). Size, Function, and Life History. Cambridge MA, Harvard University Press.

Callicott, J. B. (1995a). "A Review of Some Problems with the Concept of Ecosystem Health." Ecosystem Health **1**(2): 101-112.

Callicott, J. B. (1995b). "The Value of Ecosystem Health." Environmental Values **4**: 345-361.

Callicott, J. B., L. B. Crowder, and K. Mumford (1998). "Current Normative Concepts in Conservation." Conservation Biology **13**(1): 22-35.

Calow, P. (1992). "Can ecosystems be healthy? Critical considerations of concepts." Journal of Aquatic Ecosystem Health **1**(1-5).

Calow, P. (1995). Ecosystem Health - A Critical Analysis of Concepts. Evaluating and Monitoring the Health of Large Scale Ecosystems. D. J. Rapport, C. Gaudet and P. Calow. New York, Springer-Verlag. **NATO ASI Series Vol I - 28:** 33-41.

Canada Commission of Conservation (1910). Report of the First Annual Meeting, January 18-21, 1910. Ottawa, The Mortimer Co. Ltd.

Canada Commission of Conservation (1915). Report of the Sixth Annual Meeting, Ottawa January 19-20, 1915. Toronto, Bryant Press.

Caputi, P. and P. Reddy (1999). "A Comparison of Triadic and Dyadic Methods of Personal Construct Elicitation." Journal of Constructivist Psychology **12**: 253-264.

Carley, K. and M. Palmquist (1992). "Extracting, Representing and Analyzing Mental Models." Social Forces **70**(3): 601-636.

Carpenter, S. R. (1990). "Large-scale Perturbations: Opportunities for Innovation." Ecology **71**: 2038-2043.

Carpenter, S. R. et al. (2001). "From Metaphor to measurement: Resilience of what to what?" Ecosystems **4**: 765-781.

Carson, R. (1962). Silent Spring. New York, Houghton Mifflin.

Catton, W. R. (1982). Overshoot: The Ecological Basis of Revolutionary Change. Urbana Il., The University of Illinois Press.

Catton, W. R. (1994). "Carrying Capacity and the Death of Two Cultures: A Tale of Two Autopsies." Wild Earth **Summer**(73-83).

Catton, W. R. (1997/98). "What have we done to carrying capacity?" Wild Earth **Winter**(64-70).

CBD (2004). COP-5, Convention on Biodiversity.

CCEA (1991). A Protected Area Vision for Canada, Canadian Council of Ecological Areas.

CCME (1993). Environmental Scan: Evaluating Our Progress Toward Sustainable Development. Vancouver, Prepared by Peat Marwick Steveson & Kellogg for the Canadian Council of Ministers of the Environment.

CCME (1996). A Framework for Developing Ecosystem Health Goals, Objectives, and Indicators: Tools for Ecosystem-based Management. Winnipeg, Manitoba, Prepared by the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment.

CESCC (2001). Wild Species 2000: The General Status of Species in Canada. Ottawa, Canadian Endangered Species Conservation Council.

Chapin, F. S., O. E. Sala, and I.C. Burke (1998). "Ecosystem consequences of changing biodiversity." Bioscience **48**: 45-52.

Chociolko, C. (1995). "The Experts Disagree: A Simple Matter of Facts Versus Values?" Alternatives **21**(3): 18-25.

Christensen, N. et al. (1996). "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management." Ecological Applications **6**(3): 665-691.
Christensen, V. et al. (2002). Estimating Fish Abundance of the North Atlantic 1950-1999. Fisheries Impacts in North Atlantic Ecosystems: Models and Analyses. V. Christensen, Sylvie Guénette, Daniel Pauly. Vancouver B.C., Fisheries Centre, University of British Columbia. **Fisheries Centre Research Report 9:** 1-25.
Chu, E. W. and J. Karr (2001). "Concept and Measurement of Environmental Impact." Encyclopaedia of Biodiversity **2**: 557-577.
Cincotta, R. P., J. Wisnewski, and R. Engelman. (2000). "Letters to Nature: Human Population in the Biodiversity Hotspots." Nature **404** (27): 990-992.
Clements, F. E. (1916). Plant Succession: An Analysis of the Development of Vegetation. Washington D.C., Carnegie Institute.
Coakes, S., M. Fenton, et al. (1999). "Application of repertory grid analysis in assessing community sensitivity to change in the forest sector." Impact Assessment and Project Appraisal **17**(3): 193-202.
Cohen, J. E. (1995). How Many People Can the Earth Support. New York, Norton.
Cohen, J. E. (1997). "Population, economics, environment and culture: an introduction to human carrying capacity." Journal of Applied Ecology **34**: 1325-1333.
Cohen, J. E. (1998). Should Populations Projections Consider 'Limiting Factors' - and If So, How? Frontiers of Population Forecasting, Supplement to Population and Development Review. D. A. Ahlburg. New York: 118-138.
Cohen, J. E. (2005). Human Population Grows Up. Scientific American. **293:** 48-55.
Collingwood, R. G. (1945). The Idea of Nature. Oxford UK, Clarendon Press.
Collins, A. and D. Gentner (1987). How People Construct Mental Models. Cultural Models in Thought and Language. D. Holland and N. Quinn. Cambridge MA, Cambridge University Press.
Commission for European Communities (2001). White Paper - Strategy for a Future Chemicals Policy. Brussels, Commission for the European Communities.
Commission on Risk Assessment and Risk Management (1997). Volume 1: Framework for Environmental Health Risk Management. Washington D.C., The Presidential/Congressional Commission on Risk Assessment and Risk Management.
Commoner, B. (1971). The Closing Circle. New York Bantam Books.
Cooperrider, A. Y. (1996). "Science as a Model for Ecosystem Management - Panacea or Problem." Ecological Applications **6**(3): 736-737.
Costanza, R. (1992). Towards an Operational Definition of Ecosystem Health. Ecosystem Health: New Goals for Environmental Management. R. Costanza, B. D. Haskell and B. G. Norton. Covelo California, Island Press: 239-256.
Costanza, R. (1993). "Developing Ecological Research that is Relevant for Achieving Sustainability." Ecological Applications **3**(4): 579-581.
Costanza, R. (1995). Ecological and Economic System Health and Social Decision Making. Evaluating and Monitoring the Health of Large Scale Ecosystems. D. J. Rapport, C. Gaudet and P. Calow. New York, Springer-Verlag. **NATO ASI Series Vol I - 28:** 103-125.
Costanza, R. (2000). "Visions of Alternative (Unpredictable) Futures and Their Use in Policy Analysis." Conservation Ecology **4**(1).
Costanza, R., et al. (1997). "The value of the world's ecosystem services and natural capital." Nature **387**(66630): 253-260.

Costanza, R., B. G. Norton, B.D. Haskell, Eds. (1992). Ecosystem Health: New Goals for Environmental Management. Washington D.C., Island Press.
Covich, A. P. et al. (1995). Ecological Integrity and Western Water Management: A Colorado Perpective. Fort Collins, Colorado Water Resources Research Institute.
CPCS (1990). RepGrid 2 Manual. Calgary, Center for Person-Computer Studies, University of Calgary.
CPHA (1986). Ottawa Charter for Health Promotion. Ottawa, Canadian Public Health Association.
CPHA (1992). Human and Ecosystem Health. Ottawa, Canadian Public Health Association.
Craik, K. (1943). The Nature of Explanation. Cambridge UK, Cambridge University Press.
Cronbach, L. (1951). "Coefficient Alpha and the Internal Structure of Tests." Psychometrika **16**(3): 297-333.
Dahms, C. W. and B. W. Geils (1997). An Assessment of Forest Ecosystem Health in the Southwest. Ft. Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimental Station.
Daily, G. C., et al. (1997). "Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems." Issues in Ecology **2**(Spring).
Daily, G. C. and P. R. Ehrlich (1992). "Population, Sustainability, and the Earth's Carrying Capacity: A framework for estimating population sizes and lifestyles that could be sustained without undermining future generations." Bioscience(November).
Daily, G. C. and P. R. Ehrlich (1996). "Socioeconomic equity, sustainability, and the Earth's carrying capacity." Ecological Applications **6**(4): 991-1001.
Dake, K. M. (1990). Technology on Trial: Orienting Dispositions Toward Environmental and Health Hazards. Unpublished Ph.D. Psychology. Berkeley, University of California.
Dake, K. M. (1991). "Orienting Dispositions in the Perception of Risk: An Analysis of Contemporary Worldviews and Cultural Biases." Journal of Cross-Cultural Psychology **22**(1): 61-82.
Dake, K.M. (1992). "Myths of Nature: Culture and the Social Construction of Risk." Journal of Social Issues **48**(4): 21-37.
Daly, H., Ed. (1973). Towards a Steady-State Economy. San Francisco, W.H. Freeman.
Daly, H. (1993). Sustainable Development: Towards an Operational Definition. Washington D.C., World Bank.
Daly, H. E. (1991). Steady State Economics 2nd ed. Washington D.C., Island Press.
Dannigkeit, W. (1999). Biotechnology from a global food security perspective. Agricultural biotechnology in developing countries: towards optimising the benefits for the poor ZEF, ISAAA, AgrEvo, DSE, Bonn, Germany.
Davies, K., D. Rapport, and K. Brady (1992). Ecosytem Health Indicators for Evaluating and Reporting Ecosystem Health: A Discussion Paper. Ottawa, Ecosystem Science and Evaluation Directorate, Environment Canada.
Davis, D. R., M. D. Epp, and H.D. Riordan. (2004). "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999." Journal of the American College of Nutrition **23**(6): 669-682.
de Kathen, A. (1999). Transgenic crops in developing countries: a report on field releases, biosafety regulations and environmental impact assessment. Berlin, Umweltbundesamt.
Deevey, E. S. (1960). "The Human Population." Scientfic American **203**(September): 195-204.
Denzau, A. T. and D. C. North (1983). Shared Mental Models: Ideologies and Institutions. Washington University of St. Loius Economics Working Paper Archive. St Louis Mo.
Diamond, J. (2004). Collapse: How Societies Choose to Succeed or Fail. New York, Penguin Books.
DiCastri, F. (2000). "Ecology in the Context of Economic Globalization." BioScience **50**(4): 321-332.

Dietz, T., P. Stern, and R.W. Rycroft. (1989). "Definitions of Conflict and the Legitimation of Resources: The Case of Environmental Risk." Sociological Forces **4**(1): 47-70.
Dietz, T., P. C. Stern, and G.A. Guagnano (1998). "Social structural and social psychological bases of environmental concern." Environment and Behaviour **30**(4): 450-471.
Dobkins, S. and T. Gleason (1997). "Comparing exemplar and prototype models of categorization." Canadian Journal of Experimental Psychology.
Domany, E., J. L. Hemmen, and K. Schulten Eds. (1991). Models of Neural Networks. Berlin, Springer.
Douglas, M. and A. Wildavsky (1982). Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers. Berkeley, University of California Press.
Duncan, O. D. (1961). "From a Social System to Ecosystem." Sociological Enquiry **31**: 140-149.
Dunlap, R. E. and K. D. V. Liere (1978). "The New Environmental Paradigm: A proposed measuring instrument and the preliminary results." Journal of Environmental Education **9**: 10-19.
Dunlap, R. E. and K. D. V. Liere (1984). "Commitment to the dominant social paradigm and concern for environmental quality." Social Science Quarterly **65**: 1013-1028.
Dunlap, R. et al. (2000). "Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale." Journal of Social Issues **56**(3): 425-442.
Dunn, W. N. and A. Ginsburg (1986). "A Socio-cognitive Network Approach to Organizational Analysis." Human Relations **40**(11): 955-976.
Dunn, W. N., T. J. Pavlak, and G.E. Roberts. (1987). "Cognitive performance appraisal -- Mapping managers' category structures using the grid technique." Personnel Review **16**(3): 16-19.
Eden, C. and S. Jones (1984). "Using Repertory Grids for Problem Construction." Journal of the Operational Research Society **35**(9): 779-790.
Ehrenfeld, D. (1992). Ecosystem health and ecological theories. Ecosystem Health. R. Costanza, B. G. Norton and B. D. Haskell. Washington D.C., Island Press.
Ehrlich, P. R. and G. C. Daily (1993). "Science and the Management of Natural Resources." Ecological Applications **3**(4): 558-560.
Ehrlich, P. R. and A. H. Ehrlich (1990). The Population Explosion. New York, Simon and Schuster.
Ehrlich, P. R. and A. H. Ehrlich (1992a). Extinction: The cause and consequences of the disappearance of species. New York, Random House.
Ehrlich, P. R. and A. H. Ehrlich (1992b). "The Value of Biodiversity." Ambio **21**(3): 219-226.
Ehrlich, P. R. and A. H. Ehrlich (2002). "Population, development, and human natures." Environment and Development Economics **7**: 158-170.
Ehrlich, P. R. and J. P. Holdren (1971). "The impact of population growth." Science **171**: 1212-1217.
Ehrlich, P. R. and B. H. Walker (1998). "Rivets and redundancy." BioScience **48**(5): 387.
Ehrlich, P. R. and E. O. Wilson (1991). "Biodiversity Studies: Science and Policy." Science **253**(5021): 758-762.
Eisenberg, A. (1992). "The Metaphor in the Language of Science." Scientific American(May): 144.
Elton, C. S. (1927). Animal Ecology. London, Sedgewick & Jackson.
Elton, C. S. (1958). Ecology of Invasions by Animals and Plants. London, Chapman and Hall.
Environment Canada (1994). The Ecosystem Approach: Getting Beyond the Rhetoric. Ottawa, Environment Canada, The Task Group on the Ecosystem Approach and Ecosystem Science.
Environment Canada (1995). Discussion Paper: CEPA and the Ecosystem Approach. Ottawa, Ontario, Canadian Environmental Protection Act Review Office.

Environment Canada (1996). Ecological Risk Assessments of Priority Substances Under the Canadian Environmental Protection Act. Ottawa, Environment Protection Service. Commercial Chemicals Evaluation Branch.
Environment Canada (2000). Learning from Nature: Canada - The Ecosystem Approach and Integrated Land Management. Ottawa, Environment Canada.
Epstein, P. R. (1995). "Emerging Disease and Ecosystem Instability: New Threats to Public Health." American Journal of Public Health **85**(2): 168-172.
Erwin, T. L. (1991). "An Evolutionary Basis for Conservation Strategies." Science **253**(5021): 750-752.
ESI (2002). 2002 Environmental Sustainability Index. New York, An Initiative of the Global Leaders of Tomorrow Environment Task Force, In collaboration with: Yale Center for Environmental Law and Policy, Yale University, and the Center for International Earth Science Information Network, Columbia University.
Evans, F. C. (1956). "Ecosystems as the basic unit in ecology." Science **123**: 1127-1128.
Evans, L. T. (1998). Feeding Ten Billion - Plants and Population Growth. Cambridge U.K., Cambridge University Press.
Eyles, J. (1990). "Objectifying the subjective." Social Indicators Research **22**(139-153).
Eyles, J., D. Cole, and B. Gibson (1996). Human Health in Ecosystem Health: Issues of Meaning and Measurement. Windsor Ontario, Great Lakes Science Advisory Board, International Joint Commission.
F&O (1998). Aquaculture Production Statistics. Ottawa.
F&O (2002). Historical Fish Landing Statistics. Ottawa.
FAO (1996). State of the World's Plant Gene Resources for Food and Agriculture. Rome, United Nations Food and Agricultural Organisation.
FAO (2000). The state of world fisheries and aquaculture. Rome, Food and Agriculture Organization.
FAO/UNFPA/IISA (1982). Potential population supporting capacities of land in the developing world. Rome,, United Nations Food and Agricultural Organisation.
Fehr, W. H. (1984). Genetic Contributions to Yield Gains of Five Major Crop Plants. Madison Wisconsin, Crop Science Society of America.
Fischhoff, B., A. Bostrom, and M. Quadrel (1993). "Risk Perception and Communication,." Annual Review of Public Health **14**: 183-203.
Fischoff, B., S. R. Watson, and C. Hope. (1984). "Defining risk." Public Policy **17**: 123-139.
Fitzimmons, A. K. (1999). Defending Illusions: Federal Protection of Ecosystems. Lanham Maryland, Rowman & Littlefield.
Forbes, S. A. (1925). "The lake as a microcosm." Illinois Natural History Survey Bulletin **15**.
Ford K. et al. (1993). "Knowledge Acquisition as a Constructive Modeling Activity." International Journal of Intelligent Systems **8**(1): 9-32.
Forest Health Network (1999). Forest Health in Canada: An Overview 1998. Ottawa, Canadian Forest Service, Natural Resources Canada.
Francis, G. (1994). Ecosystems. Social Sciences and the Environment, Ottawa, University of Ottawa Press 1995.
Fransella, F., R. Bell, and D. Bannister (2004). A Manual for Repertory Grid Technique. Chichester U.K., John Wiley & Sons.
Freemark, K. E., C. Boutin, and C.J Keddy. (2002). "Importance of Farmland Habitats for Conservation of Plant Species." Conservation Biology **16**(2): 399-412.

Friedlingston, P. and S. Soloman (2005). "Contributions of past and present human generations to committed warming caused by carbon dioxide." Proceedings of the National Academy of Sciences of the United States **102**(31): 10832-10836.

Funtowicz, S. O. and J. R. Ravetz (1992). "Risk Management as a Postnormal Science." Risk Analysis **12**(1): 95-97.

Gagnon, S. C.Thompson and M. Barton (1994). "Ecocentric and Anthropocentric Attitudes toward the Environment." Journal of Environmental Psychology **14**: 149-157.

Gaines, B. R. (1988). "Positive feedback processes underlying the formation of expertise." IEEE Transactions on Systems, Man and Cybernetics SMC-18 **6**(1).

Gaines, B. R. (1989a). An Ounce of Knowledge is Worth A Ton of Data: Quantitative Studies of the Trade-Off between Expertise and Data based on Statistically Well-Founded Empirical Induction. Proceedings of the Sixth International Workshop on Machine Learning, San Mateo California, Morgen Kaufmann.

Gaines, B. R. (1989b). "Social and cognitive processes in knowledge acquistion." Knowledge Acquistion **1**(1): 251-280.

Gaines, B. R. (1996). Transforming Rules and Trees into Comprehensive Knowledge Structures. Advances in Knowledge Discovery and Data Mining. U. M. Fayyad, G. Piatetsky-Shapiro, P. Smyth and R. Uthurusamy. Cambridge Massachusetts, MIT Press.

Gaines, B. R. and P. Compton (1995). "Induction of Ripple-Down Rules Applied to Modeling Large Databases." Journal for Intelligent information Systems **5**(3): 211-228.

Gaines, B. R. and M. L. G. Shaw (1980). "New directions in the analysis and interactive elicitation of personal construct systems." International Journal of Man-Machine Studies **13**: 81-116.

Gaines, B. R. and M. L. G. Shaw (1986). "Induction of inference rules for expert systems." Fuzzy Sets and Systems **8**(3): 315-328.

Gaines, B. R. and M. L. G. Shaw (1989). Comparing the conceptual systems of experts. Eleventh International Joint Conference on Artificial Intelligence, Detroit Michigan, Morgan Kaufmann.

Gaines, B. R. and M. L. G. Shaw (1993). "Basing Knowledge Acqusition Tools on Personal Constuct Psychology." Knowledge Engineering Review **8**(1): 49-85.

Galloway, J. N. and E. B. Cowling (2002). "Reactive Nitrogen and the World: 200 Years of Change." Ambio **31**(2): 64-71.

Gause, G. F. (1934). The Struggle for Existence. Boston, Williams and Wilkins.

Gentile, J. H. and M. A. Harwell (1998). "The Issue of Significance in Ecological Risk Assessments." Human and Ecological Risk Assessment **4**(4): 815-828.

Gentner, D. (1982). Are Scientific Analogies Metaphors? Metaphor: Problems and Perspectives. D. S. Miall. Sussex England, The Harvester Press: 106-132.

Gentner, D. (1983). "Structure-mapping: A theoretical framework for analogy." Cognitive Science **7**: 155-170.

Gentner, D. (2002). Psychology of Mental Models. International Encyclopaedia of the Social and Behavioural Sciences. N. J. Smelser and P. B. Bates. Amsterdam, Elsevier Science: 9683-9687.

Gentner, D. and B. Bowdle (2002). Psychology of Metaphor Processing. Encyclopaedia of Cognitive Science. London, Nature Publishing Group.

Gentner, D. et al. (2001). Metaphor is like analogy. The Analogical Mind: Perspectives from Cognitive Science. D. Gentner, K. J. Holyoak and B. N. Kokinov. Eds. Cambridge MA, MIT Press: 199-253.

Gentner, D. and D. Gentner (1983). Flowing Waters or Teeming Crowds: Mental Models of Electricity. Mental Models. D. Gentner and A. L. Stevens. Eds. Hillsdale, New Jersey, Lawrence Erlbaum Associates, Inc.: 99-127.

Gentner, D. and K. J. Holyoak (1997). "Reasoning and learning by analogy: Introduction." American Psychologist **52**: 32-34.

Gentner, D. and M. Jeziorski (1993). The shift from metaphor to analogy in western science. Metaphor and thought. A. Ortony. Cambridge U.K., Cambridge University Press: 447-480.

Gentner, D. and A. L. Stevens, eds. (1983). Mental Models. Hillsdale, New Jersey, Lawrence Erlbaum Associates, Inc.

Gentner, D. and E. W. Whitley (1997). Mental models of population growth: A preliminary investigation. Environmental Ethics and Behaviour: The psychology of environmental valuation and degradation. M. H. Bazernan and D. M. Messick. San Franciso, New Lexington Press/ Jossey-Bass Inc.

Gibbons, A. (1963). "Pleistocene Population Explosions." Science **262**(1 October): 195-204.

Gibson, R. (1994). "The end of the world as we know it." Alternatives **20**(3).

Gilbertson, M. (2000). "Living with Great Lakes Chemicals: Contemporary Strategies and Cross-Paradigm Reconciliation." Ecosystem Health **6**(1): 24-38.

Gleason, H. A. (1939). "The individualistic concept of the plant association (with discussion)." American Midland Naturalist **21**: 92-110.

Goldburg, R. and T. Triplett (1997). Murky Waters: Environmental Effects of Aquaculture in the US. Washington D.C., The Environmental Defence Fund.

Goldstein, P. Z. (1999). "Functional Ecosystems and Biodiversity Buzzwords." Conservation Biology **13**(2): 247-255.

Graham, J. D. and J. K. Hammitt (1996). Refining the CRA Framework. Comparing Environmental Risks: Tools for Setting Government Priorities. J. C. Davies. Washington D.C., Resources for the Future: 93-109.

Graham, J. D. and J. B. Wiener (1995). Confronting Risk Tradeoffs. Risk versus Risk: Tradeoffs in Protecting Health and the Environment. J. D. Graham and J. B. Wiener. Cambrdge Mass., Harvard University Press: 226-271.

Gregory, R. (1997). Identifying Environmental Values. Tools to Aid Environmental Decision Making. V. Dale and M. English. Eds. Knoxville, University of Tennessee Press.

Gregory, R., T. C. Brown, and J.L. Knetsch. (1996). "Valuing Risks to the Environment." The Annals of the American Academy of Political and Social Science **454**: 54-63.

Gregory, R. and R. Mendelsohn (1993). "Perceived Risk, Dread, and Benefits." Risk Analysis **13**(3): 259-264.

Gregory, R. and R. L. Keeney (1994). "Creating policy alternatives using stakeholder values." Management Science **40**(8): 1035-1048.

Groves, R. M. (1989). Survey Errors and Survey Costs. New York, John Wiley & Sons.

Grumbine, E. R. (1994). "What is Ecosystem Management?" Conservation Biology **8**(1): 27-38.

Grumbine, E. R. (1997). "Reflections on 'what is ecosystem management?'" Conservation Biology **11**: 41-47.

Haas, P. M. (1992). "Introduction: epistemic communities and international policy coordination." International Organisation **446**(1): 1-35.

Haas, P. M. (2002). "Constructing environmental conflicts from resource scarcity." Global environmental politics **2**(1): 1-11.

Hails, R. S. (2000). "Genetically modified plants - the debate continues." Trends in Ecology and Evolution **15**(1): 14-18.

Halcrow-Bristol (2001). Issues in the Early Stages of Construction Projects - CRISP Commission - 00/8. Bristol U.K., University of Bristol and the Halcrow Group.
Hardin, G. (1986). "Cultural carrying capacity: A biological approach to human problems." BioScience **36**(9): 599-606.
Harris, H. J. et al. (1990). "Ecotoxicology and Ecosystem Integrity: The Great Lakes Examined." Environmental Science and Technology **24**(5): 598-603.
Harris, E. (1999). "Project Risk Assessment: A European Field Study." British Accounting Review **31**: 347-371.
Hart, J. A. (1977). "Cognitive maps of three latin american policy makers." World Poliics **30**(1): 115-140.
Health Canada (1997). Health and Environment - Partners for Life. Ottawa, Health Canada.
Hector, A. et al (1999). "Plant diversity and productivity experiments in European grasslands." Science **286:**: 1123-1127.
Hedrick, P. W. (2001). "Invasion of transgenes from salmon or other genetically modified organisms into natural populations." Canadian Journal of Fisheries and Aquatic Science **58**: 841-844.
Herricks, E. E. (1992). "Optimizing Bioassay Use in Environmental Management Through Test Selection." Water Science Technology **92**(11): 479-489.
Hewitt, C. G. (1921). The Conservation of the Wildlife of Canada. New York, Charles Scribner's Sons.
Heywood, V. H., Ed. (1995). Global Biodiversity Assessment. Cambridge UK, Cambridge University Press.
Hicks, J. R. (1946). Value and Capital. London, Oxford University Press.
Hill, S. D. (2002). Mental Models for the Management of Environmental Risks by Organizations. Faculty of Environmental Design. Calgary, Alberta, University of Calgary.
Hinkle, D. N. (1965). The change of personal constructs from the viewpoint of a theory of construct implications. Columbus Ohio, Ohio State University.
Hoffman, R. et al. (1995). "Eliciting Knowledge from Experts: A Methodological Analysis." Organizational Behaviour and Human Decision Processes 62(2): 129-158.
Hofstetter, P. (1998). Perspectives in Life Cycle Impact Assessment: A structured approach to combine models of the technosphere, ecosphere, and valuesphere. Boston, Massachusetts, Kluwer Academic Publishers.
Holling, C. S. (1973). "Resilience and stability of ecological systems." Annual Review of Ecology and Systematics **4**: 1-23.
Holling, C. S., Ed. (1978). Adaptive Environmental Assessment and Management. New York N.Y., John Wiley & Sons.
Holling, C. S. (1986). The resilience of terrestrial ecosystems: local surprise and global change. Sustainable Development of the Biosphere. W. C. Clark and R. E. Munn. Laxenburg, Austria, Cambridge University Press: 292-315.
Holling, C. S. (1987). "Simplifying the complex: The paradigm of ecological function and structure." European Journal Operational Research **30**: 139-146.
Holling, C. S. (1996). "Surprise for Science, Resilience for Ecosystems, and Incentives for People." Ecological Applications **6**(3): 733-735.
Houghton, J. T. et al. (1996). Climate change 1995: The science of climate change. Cambridge U.K., Cambridge University Press.
Houghton, R. A. (1994). "The worldwide extent of land use change." BioScience **44**(5): 305-313.

Hunsaker, C. T. and D. E. Carpenter (1990). Environmental Monitoring and Assessment Program. Research Triangle Park N.C., Environmental Protection Agency.
Hunter, M. L. (2000). "Refining Normative Concepts in Conservation." Conservation Biology **14**(2): 573-574.
Hutchinson, G. E. (1948). "Circular Causal Systems in Ecology." Annals of the New York Academy of Science **40**: 221-246.
HWC (1992). A Vital Link: Health and the Environment in Canada. Ottawa, Health and Welfare Canada, Health Protection Branch, Environmental Health Directorate.
IJC (1978a). The Ecosystem Approach. Report of the Great Lakes Science Advisory Board to the International Joint Commission. Windsor Ont., International Joint Commission, Great Lakes Office.
IJC (1978b). The Ecosystem Approach: Scope and Implications of an Ecosystem Approach to Transboundary Problems in the Great Lakes Basin. Special Report to the International Joint Commission. Washington-Ottawa, International Joint Commission, Great Lakes Research Advisory Board,.
IJC (1991). A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region. Washington-Ottawa, Council of Great Lake Research Managers.
IJC (1994). The Ecosystem Approach: Theory and Ecosystem Integrity. Windsor, Ontario, International Joint Commission Great Lakes Science Advisory Board,.
IJC (1997). 1995-1997 Priorities and Progress Under the Great Lakes Water Quality Agreement. Ottawa-Washington D.C., International Joint Commission.
IUCN (2000). IUCN Red List of Threatened Species. Gland Switzerland, International Union for the Conservation of Nature.
Jackson, J. B. et al. (2001). "Historical Overfishing and the Recent Collapse of Coastal Ecosystems." Science **293**(27 July): 629-638.
James, C. (2001). ISAAA Briefs Global review of commercialised transgenic crops. Ithaca N. Y., International Service for the Acquistion of Agri-biotech Applications No. 24.
Jankowicz, D. (2004). The Easy Guide to Repertory Grids. Chichester U.K, John Wiley & Sons.
Jasanoff, S. (1998). "The political science of risk perception." Reliability Engineering and System Safety **59**: 91-99.
Johnson, A. R. (1988). "Diagnostic Variables as Predictors of Ecological Risk." Environmental Management **12**(4): 515-523.
Johnson, B. and A. Hope (2000). "GM crops and equivocal environmental benefits." Nature - Biotechnology **18**(3 March): 242.
Johnson, D. (2001). "Repairing Earths Ecosystems." The Futurist **35**(1): 12-13.
Johnson-Laird, P. N. (1983). Mental Models: Toward a cognitive science of language, inference and consciousness. Cambridge, MA, Harvard University Press.
Johnston, W. E. and J. R. Vallentyne (1971). "Rationale, Background, and Development of Experimental Lakes Studies in Northwestern Ontario." Journal of the Fisheries Research Board of Canada **28**: 123-128.
Jungermann, H., H. Schutz, and M. Thurling. (1988). "Mental Models in Risk Assessment: Informing People About Drugs." Risk Analysis **8**(1): 147-154.
Kahneman, D., P. Slovic, and A. Tversky Eds. (1982). Judgment Under Uncertainty: Heuristics and Biases. New York, Cambridge University Press.
Kahneman, D. and A. Tversky (1981). "The Framing of Decisions and the Psychology of Choice." Science **211**: 453-458.

Kahneman, D. and A. Tversky (1979). "Prospect Theory: An Analysis of Decision Under Risk." Econometrica **47**: 263-291.

Kahneman, D. and A. Tversky (1973). "On the Psychology of Prediction." Psychological Review **80**: 237-251.

Kalaitzandonakes., N. (1999). "A Farm Level Perspective on Agrobiotechnology: How much value and for whom?" AgBioForum **2**(1): 61-64.

Kapustka, L. A. and W. G. Landis (1998). "Ecology: The Science versus the Myth." Human and Ecological Risk Assessment **4**(4): 829-838.

Karr, J. R. (1981). "Assessment of Biotic Integrity Using Fish Communities." Fisheries **6**(6): 21-27.

Karr, J. R. (1990). "Biological Integrity and the goal of environmental legislation: Lessons for conservation biology." Conservation Biology **4**: 244-250.

Karr, J. R. (2000). Health, Integrity, and Biological Assessment: The Importance of Measuring Whole Things. Ecological Integrity: Integrating Environment Conservation, and Health. D. Pimentel, L. Westra and R. F. Noss. Washington D.C., Island Press.

Karr, J. R. (2003). Vignette 11.1 Biological Integrity and Ecological Health. Fundamentals of Toxicology. M. C. Newman and M. A. Unger. Boca Raton Florida, Lewis Publishers. **Second Edition:** 245-249.

Karr, J. R. and C. O. Yoder (2004). "Biological Assessment and Criteria Improve TMDL Decision Making." Journal of Environmental Engineering **in press**.

Kaufman, J. H., et al. (1998). "Critical Biodiversiy." Conservation Biology **3**: 521-552.

Kay, J. J. (1991). "A Nonequilibrium Thermodynamic Framework for Discussing Ecosystem Integrity." Environmental Management **15**(4): 483-495.

Kay, J. J. (2001). Ecosystems, Science and Sustainability. Advances in Energy Studies: Exploring Supplies, Constraints, and Strategies, Porto Venere, Italy.

Kay, J. J. and E. Schneider (1994). "Embracing Complexity: The Challenge of the Ecosystem Approach." Alternatives **20**(3): 32-39.

Keeney, R. L. (1992). Value Focused Thinking. Cambridge Mass., Harvard University Press.

Keeney, R. L. and T. L. McDaniels (1992). "Structuring objectives for strategic decisions at B.C. Hydro." Interfaces **22**(6): 94-109.

Kellert, S. R. (1986). Social and Perceptual Factors in the Preservation of Species. The Preservation of Species. B. G. Norton. Princeton N.J., Princeton New Jersey: 50-73.

Kelly, G. A. (1955). The Psychology of Personal Constructs. New York, Norton.

Kelly, G. A. (1970). A brief introduction to personal construct theory. Perspectives in Personal Construct Theory. D. Bannister. London, Academic Press: 1-29.

Kelly, J. R. and M. A. Harwell (1989). Indicators of Ecosystem Response and Recovery. Ecotoxicology: Problems and Approaches. S. A. Levin, M. A. Harwell, J. R. Kelly and K. Kimball. New York, Springer Verlag.

Kempton, W. (1987). Two Theories of Home Heat Control. Cultural Models in Language and Thought. D. Holland and N. Quinn. Cambridge U.K., Cambridge University Press: 222-242.

Kempton, W., J. S. Boster, and J. A. Hartley(1995). Environmental Values in American Culture. Cambridge Mass., MIT Press.

Krewski, D. et al. (1995). "Health Risk Perception in Canada II: Worldviews, Attitudes and Opinion." Human and Ecological Risk Assessment **1**(3): 231-248.

Keyfitz, N. (1982). "Can Knowledge Improve Forecasts?" Population and Development Review: 729-751.

Keyfitz, N. (1989). "The Growing Human Population." Scientific American **261**(3): 119-126.

Keystone Center (1993). National Ecosystem Management Forum. Keystone, Colorado, Keystone Science and Public Policy Program.
Kimmins, J. P. H. (1992). The Ecosystem Concept: The Essential Ecological Foundation for Sustainable Forest Management. Canadian Pulp and Paper Association Woodlands Section Annual Meeting.
Kimmins, J. P. H. (1993). Ecosystem Integrity: What it is, and Why Foresters should maintain it. Proccedings of the Northern Silvaculture Committee Workshop, Prince George, B.C.
Kimmins, J. P. H. (1997). "Biodiversity and its relationship to ecosystem health and integrity." The Forestry Chronicle **73**(2): 229-232.
Klir, G. J. (1985). Architecture of System Problem Solving. New York, Plenum Press.
Knetsch, J. L. (1990). "Environmental policy implications of disparities between willingness to pay and compensation demanded measures of value." J. Environmental and Economic Management **18**(227-237).
Kraus, N., T. Malmfors, and P. Slovic (1992). "Intuitive Toxicology: Expert and Lay Judgement s of Chemical Risks." Risk Analysis **12**(2): 215-232.
Kuhn, T. (1970). The Structure of Scientific Revolutions. Chicago, University of Chicago Press.
Kleindorfer, P. et al. (1993). Decision sciences: An integrative perspective. Cambridge U.K., Cambridge University Press.
Kunreuther, H. and P. Slovic (1996). "Science, Values and Risk." The Annals of the American Academy of Political and Social Science **454**: 116-125.
Lack, D. (1954). The Natural Regulation of Animal Numbers. London, Oxford University Press.
Lackey, R. T. (1995). "Ecosystem Health, Biological Diversity, and Sustainable Development: Research that Makes Difference." Renewable Resources Journal **13**(2): 8-13.
Lackey, R. T. (1997). "If ecological risk assessment is the answer, what is the question?" Health and Ecological Risk Assessment (draft February 18,1997).
Lackey, R. T. (2001). "Values, Policy, and Ecosystem Health." BioScience **51**(6): 437-443.
Lakoff, G. and M. Johnson (1980). Metaphors We Live By. Chicago, University of Chicago Press.
Lancaster, J. (2000). "The Ridiculous Notion of Assessing Ecological Health and the Identifying the Useful Concepts Underneath." Human and Ecological Risk Assessment **6**(2): 1-10.
Landres, P. B., P. Morgan, and F.J. Swanson (1999). "Overview of the use of natural variability concepts in managing ecological systems." Ecological Applications **9**: 1179-1188.
Lawton, J. H. and R. M. May, Eds. (1995). Extinction Rates. Oxford U.K., Oxford Univ ersity Press.
Lazo, J. K. et al. (1999). "Expert and lay mental models of ecosystems: inferences for risk communication." Risk: Health, Safety & Environment **10**(1): 45-64.
Lazo, J. K. et al. (2000). "Expert and Laypersons Perceptions of Ecosystem Risk." Risk Analysis **20**(2): 179-194.
Leisinger, K. M. (2002). The "Political Economy" of Agricultural Biotechnology for the Developing World. Novartis Foundation For Sustainable Development.
Lemons, J. (1995). The Conservation of Biodiversity: Scientific Uncertainty and the Burden of Proof. Scientific Uncertainty and Environmental Problem Solving. J. Lemons. Boston, Blackwell Science.
Leopold, A. (1933). Game Mangement. New York, Charles Scribner's Sons.
Leopold, A. (1941). "Wilderness as a land laboratory." Living Wilderness **6**(July): 3.
Leopold, A. (1949). A Sand County Almanac and Sketches Here and There. New York, Oxford University Press.
Leopold, L. B., Ed. (1953). Round River: From the Journals of Aldo Leopold. New York, Oxford University Press.

LeRoy, S. and B. Cooper (2000). Off Limits: How Radical Environmentalists are Shutting Down Canada's National Parks. Vancouver, Fraser Institute.
Likens, G. E. (1992). The Ecosystem Approach: Its use and abuse. Oldendorf/Luhe Germany, Ecology Institute.
Likens, G. E. and F. H. Borman (1974). "Acid Rain: A serious regional problem." Science **184**(4143): 1176-1179.
Likens, G. E., et al. (1977). Biogeochemistry of a Forested Ecosystem. New York, Springer Verlag.
Lindeman, R. (1942). "The trophic-dynamic aspect of ecology." Ecology **23**(4): 399-418.
Lister, N-M. and J. J. Kay (2000). Celebrating Diversity: Adaptive Planning and Biodiversity Conservation. Biodiversity in Canada: Ecology, Ideas, and Action. S. Bocking. Peterborough, Ontario, Broadview Press: 189-218.
Losey, J. E., L. S. Rayor, and M.E. Carter. (1999). "Transgenic pollen harms monarch larvae." Nature **399**: 214.
Lovins, A. (1977). Soft Energy Paths: Towards a Durable Peace. New York N.Y., Harper Colophon Books.
Lubchenco, J. (1994). The Scientific Basis of Ecosystem Management: Framing the Context, Language, and Goals. Ecosystem Management: Status and Potential - Summary of the Workshop Convened by the Congressional Research Service for the Committee on Environment and Public Works, United States Senate, 105 Congress 2nd Session, U.S. Government Printing Office.
Lubchenco, J. et al. (1991). "The Sustainable Biosphere Initiative: An Ecological Research Agenda." Ecology **72**(2): 371-412.
Ludwig, D., R. Hilborn, and C. Walters (1993). "Uncertainty, Resource Exploitation, and Conservation: Lessons from History." Science **260**: 17,36.
MacArthur, R. H. (1955). "Fluctuations of animal populations and a measure of community stability." Ecology **36**: 533-536.
MacElroy, B. (2000). "Measuring response rates in online surveys." Quirk's Marketing Research Review. No. 583
MacNeill, J. W. (1971). Environmental Management - Constitutional Study Prepared for the Government of Canada. Ottawa, Information Canada.
MacNeill, J. W. (1989). "Strategies for Sustainable Economic Development." Scientific American **261**(September): 154-165.
Mageau, M. T., R. Costanza, R. E Ulanowicz (1995). "The development and initial testing of a quantitative assessment of ecosystem health." Ecosystem Health **1**: 201-213.
Maltby, E. and A. W. Weir (1996). Principles of Ecosystem Management (Consultative Draft): The scientific basis of ecosystem management for the third millennium - The First Sibthorp Paper. Commission on Ecosystem Management Workshop at the IUCN World Conservation Congress, Montreal, Canada.
Mann, C. C. (1991). "Extinction: Are Ecologists Crying Wolf?" Science **253**(5021): 736-738.
Manfreda, K. L. and V. Vehovar (2002). Survey Design Features Influencing Response Rates in Web Surveys. The International Conference on Improving Surveys, University of Copenhagen, Denmark.
Margalef, R. A. (1963). "On certain unifying principles in ecology." American Naturalist **97**: 357-374.
Margolis, H. (1996). Dealing with Risk: Why the Public and the Experts Disagree on Environmental Issues. Chicago, University of Chicago Press.
Markman, A. B. and D. Gentner (2001). "Thinking." Annual Review of Psychology **52**: 223-247.

Marris, C., I. Langford, and T. O'Riordan. (1996). Integrating Sociological and Psychological Approaches to Public Perception of Environmental Risks: Detailed Results From a Questionnaire Survey. Norwich, University of East Anglia.
Marris, C., I. Langford, and T. O'Riordan. (1997). "A quantitative test of the cultural theory of risk perceptions: comparison with the psychometric paradigm." Risk Analysis **17**(3): 303-312.
Marris, C. et al. (1998). "Exploring the "psychometric paradigm": comparisons between aggregate and individual analyses." Risk Analysis **18**(5): 635-647.
May, R. M. (1973). Stability and Complexity in Model Ecosystems. Princeton N.J., Princeton University Press.
May, R. M. (1988). "How many species are there on earth?" Science **241**(4872): 1441-1449.
May, R. M. (1999). "Unanswered questions in ecology." Philosophical Transactions of the Royal Society of London **354**: 1951-1959.
Mayes, J. (2000). Enquire Within. Wellington N.Z., Enquire Within Developments.
McAllister, D. E. (1995). "Status of the World Ocean and its Biodiversity." Sea Wind **9**(4): 1-72.
McAllister, D. E. (1998). The Crises in Marine Knowledge. Pacem in Maribus XXVI, Halifax.
McAllister, D. E. (2000). Biodiversity in Canadian Fresh and Marine Waters. Biodiversity in Canada: Ecology, Ideas and Action. S. Bocking. Ed. Peterborough, Broadview Press: 81-105.
McCann, K. S. (2000). "The diversity-stability debate." Nature **405**: 228-233.
McDaniels, T., L. J. Axelrod, and P. Slovic (1995). "Characterizing Perception of Ecological Risk." Risk Analysis **15**(5): 575-588.
McDaniels, T. L. (2000). "Creating and using objectives for ecological risk assessment and management." Environmental Science and Policy **3**(6): 295-298.
McIsaac, G. F. et al. (2001). "Nitrate flux in the Mississippi river." Nature **414**: 166-167.
Mckone, T. E. and A. W. Deshpande (2005). "Can Fuzzy LOGIC Bring Complex Environmental Problems into Focus?" Environmental Science & Technology: 42a -47a.
McLaughlin, A. and P. Mineau (1995). "The impact of agricultural practices on biodiversity." Agriculture, Ecosystems and Environment **55**: 201-212.
McLaughlin, S. and K. Percy (1999). "Forest Health in North America: Some perspectives on the actual and potential roles of climate change and air pollution." Water, Air, and Soil Pollution **116**: 151-197.
McMichael, A. J. (1993). Planetary Overload: Global Environmental Change and the Health of the Human Species. Cambridge U.K., Cambridge University Press.
McNeely, J. A. et al. (1990). "Strategies for Conserving Biodiversity." Environment **32**: 16-40.
MEA (2005). The Millennium Ecosystem Assessment - Ecosystems and Human Well-being – in press.Washington (DC), Island Press.
Meadows, D. H., D. L. Meadows, and W.W. Behrens II (1972). The Limits to Growth. New York, Universe Books.
Menzie-Cura. (1996). "Special Report of the Massachusetts Weight-of-Evidence for Evaluating Ecological Risks." Human and Ecological Risk Assessment **2**(2): 277-304.
Merchant, C. (1992). Radical Ecology: The Search for a Liveable World. New York N.Y., Routledge.
Miller, G. A. (1956). "The Magic Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information." Psychological Review **63**: 81-97.
Miller, J. A. (1989). "Diseases for our future: Global ecology and emerging viruses." BioScience **39**: 509-517.
Minns, C. K. (1992). "Use of Models for the Integrated Assessment of Ecosystem Health." Journal of Aquatic Ecosystem Health **I**: 109-118.

Mooney, H. A. and E. E. Cleland (2001). "The evolutionary impact of invasive species." Proceedings of the National Academy of Sciences of the United States **98**(10): 5446-5451.

Morgan, M. G., B. Fischoff, A. Bostrum, and C. J. Altman. (2002). Risk Communication. Cambridge Mass., Cambridge University Press.

Mosquin, T. (2000). The Roles of Biodiversity in Creating and Maintaining the Ecosphere. Biodiversity in Canada: Ecology, Ideas and Action. S. Bocking. Peterborough, Broadview Press: 107-136.

Mosquin, T. et al. (1995). Canada's Biodiversity: The Variety of Life, Its Status, Economic Benefits, Conservation Costs and Unmet Needs. Ottawa, Canadian Museum of Nature, Canadian Centre for Biodiversity.

Muir, J. (1911). My first summer in the Sierra. Boston,, Houghton Mifflin Company.

Muir, W. M. and R. D. Howard (1999). "Possible ecological risks of transgenic organism release when transgenes affect mating success: Sexual selection and the trojan gene hypothesis." Proceedings of the National Academy of Science **96**(24): 13853-13856.

Munkittrick, K. R. (2004). Development of an effects-based approach to evaluating sustainability of aquatic freshwater systems. Saint John NB, Canadian Rivers Institute and Department of Biology, University of New Brunswick.

Munkittrick, K. R. and L. S. McCarty (1995). "An integrated approach to aquatic ecosystem health: top-down, bottom-up or middle-out." Journal of Aquatic Ecosystem Health **4**: 77-90.

Myers, N. (2002). "Environmental Refugees: A Growing Phenomenon of the 21st Century." Philosophical Transactions of the Royal Society of London Series B-Biological Sciences: 609-613.

Myers, N. and A. H. Knoll (2001). "The biotic crisis and the future of evolution." Proceedings of the National Academy of Sciences of the United States **98**(10): 5389-5392.

Myers, N. et al. (2000). "Biodiversity hotspots for conservation priorities." Nature **403**(February): 853-858.

Myers, R. A. and B. Worm (2003). "Rapid Worldwide Depletion of Predatory Fish Communities." Nature **423**(15 May): 280-283.

Naeem, S. (1999). "Power Behind Diversity's Throne." Nature **401**(14 October): 653-654.

Naeem, S. (2004). Biodiversity. SciDevNet Policy Briefs. Accessed at http://www.scidev.net/dossiers/index.cfm?fuseaction=policybrief&dossier=11&policy=48 February 15, 2004

Naeem, S. and S. Li (1997). "Biodiversity enhances ecosystem reliability." Nature **390**.

Nelson, J. G. (1991). " Beyond parks and protected areas: from public ownership to private stewardship to landscape planning and management,." Environment **21**: 23-24.

Nelson, J. G. and R. Serafin (1992). "Assessing Biodiversity: A Human Ecological Approach." Ambio **21**(212-218).

Nicholson, A. J. and V. A. Bailey (1935). "The balance of animal populations." Proceedings of the Zoological Society of London **105**: 551-598.

Norton, B. G. (1995a). "Ecological integrity and social values at what scale." Ecosystem Health **1**: 228-241.

Norton, B. G. (1995b). "Seeking common ground for environmental change." Forum for Applied Research and Public Policy **10**(Summer): 100-102.

Norton, B. G. and R. E. Ulanowicz (1992). "Scale and Biodiversity Policy: A Hierarchical Approach." Ambio **21**(3): 244-249.

Noss, R. F. and A. Y. Cooperrider (1994). Saving Natures Legacy: Protecting and Restoring Biodiversity. Washington D.C., Island Press.

Novack, J. D. and D. B. Gowan (1984). Learning How To Learn. Cambridge Mass., Cambridge University Press.
Odum, E.P. (1953). Fundamentals of Ecology. Philadelphia, W.B. Saunders.
Odum, E. P. (1969). "The Strategy of Ecosystem Development." Science **164**: 262-270.
Odum, E. P. (1985). "Trends Expressed in Stressed Ecosystems." BioSciences **35**(7).
OECD (1993). Group on the State of Environment Workshops on Indicators for Use in Environmental Performance Reviews - Draft Synthesis Report. Paris, Organisation For Economic Co-operation and Development, Environment Directorate, Environment Policy Committee.
Office of Population Research (2004). World Population Clock, Princeton University.
O'Neill, R. V. (1996). "Get Ready to Rewrite Your Lecture Notes." Ecology **77**(2): 660.
O'Neill, R. V. (2000). "Homo economus as a keystone species." BioScience **50**(4): 333-337.
O'Neill, R. V. (2001). "Is it time to bury the ecosystem concept? (With full military honors, of course!)." Ecology **82**: 3275-3284.
O'Neill, R. V. et al. (1986). A Hierarchical Concept of Ecosystems. Princeton, Princeton University Press.
O'Neill, R. V. et al. (1982). "Ecosystem Risk Analysis: A New Methodology." Environmental Toxicology and Chemistry **1**: 167-177.
Oreskes, N. (2004). "The Scientific Consensus on Climate Change." Science **306**: 1686.
Orians, G. H. (1990). "Ecological Sustainability." Environment **32**(9): 10-15, 34-39.
O'Riordan, T. (1995). "Framework for Choice: Core Beliefs and the Environment." Environment **37**(8): 4-29.
Otway, H. and D. von Winterfeldt (1992). "Expert Judgement in Risk Analysis and Management: Process, Context, and Pitfalls." Risk Analysis 12(1): 83-93.
Panel on the Ecological Integrity of Canada's National Parks (2000). "Unimpaired for Future Generations?" Conserving Ecological Integrity with Canada's National Parks. Ottawa, Parks Canada.
Parks Canada (1997). State of the Parks Report - 1997 Report. Ottawa, Canadian Heritage.
Pauly, D. (1995). "Anecdotes and the shifting baseline syndrome of fisheries." Trends in Ecology and Evolution **10**(10): 430.
Pauly, D. (2004). "Empty Nets." Alternatives **30**(2): 8-13.
Pauly, D. and V. Christensen (1995). "Primary Production Required to Sustain Global Fisheries." Nature **374**: 255-257.
Pauly, D. et al. (1998). "Fishing down marine food webs." Science **279**(5352): 860-863.
Pauly, D. et al. (2002). "Towards sustainability in world fisheries." Nature **418**(8 August): 689-695.
PCAST (1998). Teaming with Life: Investing in Science to Understand and Use America's Living Capital. Washing ton D.C., President's Committee of Advisors on Science and Technology, Panel on Biodiversity and Ecosystems.
Pearce, D. (1988). "Economics, Equity, and Sustainable Development." Futures(December): 598-605.
Pearce, D. and R. K. Turner (1987). Economics of Natural Resources and the Environment. London, Wheatsheaf.
Pepper, S. C. (1942). World Hypotheses. Los Angeles, University of California Press.
Peters, R. L., E. Frost, and F. Pacel. (1996). Managing for Forest Ecosystem Health: A Reassessment of the "Forest Health Crisis". Washington D.C., Defenders of Wildlife Magazine.
Pew Initiative on Food and Biotechnology (2004). "Issues in the Regulation of Genetically Engineered Plants and Animals."

Pimentel, D., Ed. (1993). World Soil Erosion and Conservation. Cambridge, U.K., Cambridge University Press.
Pimentel, D. et al. (2004). "Water Resources: Agricultural and Environmental Issues." Bioscience **54**: 909-918.
Pimentel, D.et al. (1997). "Economic and Environmental Benefits of Biodiversity." BioScience **47**(11,): 747-757.
Pimm, S. L. (1984). "The complexity and stability of ecosystems." Nature **307**(26): 321-326.
Pimm, S. L. (1997). Human Impact on the Global Rate of Extinction. Workshop on the Conservation of Biodiversity: Merging biological, ethical and economic theory, Vancouver B.C., University of British Columbia.
Pimm, S. L. (2001). The World According to Pimm: A Scientist Audits the Earth. New York, McGraw-Hill.
Pimm, S. L. and J. H. Lawton (1978). "On feeding on more than one trophic level." Nature **275**: 542-544.
Pimm, S. L.. et al. (1995). "The future of biodiversity." Science **269**: 347-350.
Pinchot, G. (1910). The Fight for Conservation. New York, Doubleday, Page & Company.
Pitcher, T. J. (2000). "Ecosystem goals can reinvigorate fisheries management, help dispute resolution and encourage public support." Fish and Fisheries **1**: 99-103.
Poiani, K. A., et al. (2000). "Biodiversity Conservation at Multiple Scales: Functional sites, Landscapes, and Networks." Bioscience **50**(2): 133-146.
Ponting, C. (1991). A Green History of the World : The Environment and the Collapse of Great Civilizations. New York, Penguin Books.
Pope, M. L. and M. L. G. Shaw (1981). Personal construct psychology in education and learning. Recent advances in personal construct technoloy. M. L. G. Shaw. London, Academic Press: 105-114.
Population Reference Bureau (2004). World Population Data Sheet. Washington D.C.
Postel, S. (1994). Carrying Capacity: Earths Bottom Line. State of the World 1994: A Worldwatch Institute Report on Progress Toward a Sustainable Society. W. Institute. New York, W.W. Norton: 3-21.
Postel, S. L. et al. (1996). "Human appropriation of renewable fresh water." Science **271**(5250): 785-788.
Preiss, K. J. (2000). "A two stage process for eliciting and prioritising critical knowledge." Journal of Knowledge Management **4**(4): 328-336.
Pulliam, H. R. and N. M. Haddad (1994). "Human Population Growth and the Carrying Capacity Concept." Bulletin of the Ecological Society of America **75**(3): 141-157.
Purvis, A. and A. Hector (2000). "Getting the measure of biodiversity." Nature **405**(11 May): 212-219.
Quinn, N. and D. Holland (1987). Culture and Cognition. Cultural Models in Language and Thought. D. Holland and N. Quinn. Cambridge U.K., Cambridge University Press: 3-40.
Raats, M. M., P. Sparks, and S. Grugeon. (1994). Risk Perception and the Psychometric Paradigm: In Search of New Methods. Society for Risk Analysis Annual Meeting.
Rachel (1989). Zero Discharge: The Right Goal. Rachels Environment and Health Weekly. **155.**
Ramade, F. (1995). Qualitative and Quantitative Criteria Defining a "Healthy" Ecosystem. Evaluating and Monitoring the Health of Large Scale Ecosystems. D. J. Rapport, C. Gaudet and P. Calow. New York, Springer-Verlag. **NATO ASI Series Vol I - 28:** 43-61.
Rapoport, A. (1993). "The Metaphor in the Language of Science." Semiotiche Berlichte **12/13**: 25-43.
Rapport, D. J. (1989). "What Constitutes Ecosystem Health?" Perspectives in Biology and Medicine **33**(1): 120-132.

Rapport, D. J. (1992a). Defining the Practice of Clinical Ecology. Ecosystem Health: New Goals for Environmental Management. R. Costanza, B. G. Norton and B. D. Haskell. Washington D.C., Island Press: 135-144.

Rapport, D. J. (1992b). "Evaluating ecosystem health?" Journal of Aquatic Ecosystem Health **1**(15-24).

Rapport, D. J. (1995a). Ecosystem Health: An Emerging Integrative Science. Evaluating and Monitoring the Health of Large Scale Ecosystems. D. J. Rapport, C. Gaudet and P. Calow. New York, Springer-Verlag. **NATO ASI Series Vol I - 28:** 5-31.

Rapport, D. J. (1995b). "Ecosystem health: more than a metaphor?" Environmental Values **4**(287-309).

Rapport, D. J. (1997). "What is Ecosystem Health?" EcoDecision **Winter**.

Rapport, D. J. (2002). "The Health of Ecology and the Ecology of Health." Human and Ecological Risk Assessment **8**(1): 205-213.

Rapport, D. J. et al. (1998). "Evaluating landscape health: integrating societal goals and biophysical process." Journal of Environmental Management **53**(1): 1-15.

Rapport, D. J. et al. Eds. (1998). Ecosystem Health. Malden MA, Blackwell Science.

Rapport, D. J., R. Costanza, and A.J. McMichael, (1998). "Assessing ecosystem health." TREE **13**(10): 397-402.

Rapport, D. J. et al. (2000). "Reply to Calow: Critics of Ecosystem Health Misrepresented." Ecosystem Health **6**(1): 5-6.

Rapport, D. J. and A. Friend (1979). Towards a comprehensive framework for environmental statistics: A stress-response approach. Ottawa, Statistics Canada.

Rapport, D. J., C. Gaudet, and P. Calow, Eds. (1995). Evaluating and Monitoring the Health of Large Scale Ecosystems. Global Environmental Change. New York, Springer-Verlag.

Rapport, D. J. and R. H. H. Moll (2000). III.1.2 Applications of Ecological Theory and Modelling to Assess Ecosystem Health. Handbook of Ecosystem Theories and Management. S. E. Jorgensen and F. Muller. Boca Raton, Lewis Publishers: 487-496.

Rapport, D. J., H. A. Regier, and T.C. Hutchinson (1985). "Ecosystem behaviour under stress." American Naturalist **125**: 617-640.

Rapport, D. J. and H. A. Regier (1995). Disturbance and stress effects on ecological systems. Complex Ecology: The Part-Whole Relation in Ecosystems. B. C. Patten and S. E. Jorgensen. Englewood Cliffs, Prentice Hall: 397-414.

Rayner, S. (1992). Cultural Theory and Risk Analysis. Social Theories of Risk. S. Krimsky and D. Golding. Westport, Connecticut, Praeger: 83-115.

Reed, D. J. (1998). Green Shareholder Value, Hype or Hit - Sustainable Enterprise Perspectives. Washington D.C., World Resources Institute.

Rees, W. E. (1992). "Ecological Footprints and Appropriated Carrying Capacity: What Urban Economics Out." Environment and Urbanization **4**(2): 121-130.

Rees, W. E. (1994a). "Review essay: Trying to run with laces tied Toward improved accounting for the environment. E. Lutz ed." Environment and Planning **26**(1317-1328).

Rees, W. E. (1994b). Sustainability, Growth and Employment - Toward an Ecologically Stable, Economically Secure, and Socially Satisfying Future. Winnipeg, Manitoba, Prepared for the IISD Employment and Sustainable Development Project, International Institute for Sustainable Development.

Rees, W. E. (1995). Reducing the Ecological Footprint of Consumption. The Workshop on Policy Measures for Changing Consumption Patterns, Seoul, Korea, Korea Environmental Technology Research Institute.

Rees, W. E. (1996). "Revisiting carrying capacity: area-based indicators of sustainability." Population and Environment **17**(3).
Rees, W. E. (2003). "A blot on the land." Nature **421**: 898.
Reger, R. K. (1990). The Repertory Grid Technique for Eliciting the Content & Structure of Cognitive Constructive Systems. Mapping Strategic Thought. A. S. Huff. Chichester U.K., John Wiley & Sons.
Reichman, O. J. and H. R. Pulliam (1996). "The Scientific Basis for Ecosystem Management." Ecological Applications **6**(3): 694-696.
Reid, W. V. (1999). Status of Ecological Knowledge Related to Policy Decision-making Needs in the Area of Biodiversity and Ecosystems in the United States. Washington, World Resources Institute.
Richards, L. (2000). Using NVivo in Qualitative Research. Melbourne, Australia, QSR International Pty.
Risser, P. G. (1995). " Biodiversity and Ecosystem Function." Conservation Biology **9**: 742-746.
Rissler, J. and M. Mellon (1996). The ecological risks of engineered crops. Cambridge, MA, MIT Press.
Roberts, K. A. and R. W. Wilson (2002). ICT and the Research Process: Issues Around the Compatibility of Technology with Qualitative Data Analysis, Forum Qualitative Sozialforschung / Forum: Qualitative Social Research [On-line Journal], *3*(2). Accessed December 9, 2004 at: http://www.qualitative-research.net/fqs/fqs-eng.htm ,.
Rodman, J. (1980). "Paradigm Change in Political Science." American Behavioral Scientist **241**(1): 49-78.
Romney, A. K., S. C. Weller, and W. H. Batchelder. (1986). "Culture as consensus: A Theory of Culture and Informant Accuracy." American Anthropologist, New Series **88**(2): 313-338.
Romney, A. K. et al. (2000). " Statistical methods for characterizing similarities and differences between semantic structures." Proceedings of the National Academy of Sciences of the United States **97**(1): 518-523.
Rosenberg, A. et al. (2005). "The history of ocean resources: modeling cod biomass using historical records." Frontiers in Ecology and the Environment **3**(2): 78-88.
Rosenbloom, P. S. and A. Newell (1986). The chunking of goal hierarchies: A generalized model of practice. Machine Learning - An Artificial Intelligence Approach. R. S. Michalski, J. G. Carbonell and T. M. Mitchell. San Mateo, California, Morgan Kaufmann. **2:** 247-288.
Ross, N. et al. (1997). "The Ecosystem Health Metaphor In Science and Policy." Canadian Geographer **41**(2): 114-127.
Roulet, R. G. (1998). Exemplary Mathematics Teachers: Subject Conceptions and Instructional Practices. Department of Curriculum, Teaching & Learning, Ontario Institute for Studies in Education. Toronto, University of Toronto.
Rouse, W. B. and N. M. Morris (1986). "On Looking into the black box: Prospects and limits in the search for mental models." Psychological Bulletin **100**(3): 349-362.
Rowe, J. S. (1997). "Defining the ecosystem." Ecological Society of America Bulletin **78**(1): 95-97.
Rowe, J. S. (1998). ""Earth" as the metaphor for "life"." BioScience **48**(6): 428-429.
Ruckelhaus, W. D. (1985). "Risk, Science and Democracy." Issues in Science and Technology **1**(3): 19-38.
Russow, L. (1995). "Ecosystem health: An objective evaluation?" Environmental Values **4**: 363-369.
Ryder, R. A. (1990). "Ecosystem health, a human perception: Definition and detection and the dichotomous key." J. Great Lakes Research **16**: 619-624.
Sachs, J. D. (2005). Can Extreme Poverty Be Eliminated? Scientific American. **293:** 56-65.

Sagoff, M. (1995). "Carrying Capacity and Ecological Economics." BioScience **45**(9): 610-619.
Sala, O. et al. (2000). "Global Biodiversity Scenarios for the Year 2100." Science **287**(5459): 1770-1774.
Salwasser, H. (1990). "Sustainability as a conservation paradigm." Conservation Biology **4**: 213-216.
Samper, C. (2003). "The Millennium Ecosystem Assessment: Science and Policy for Sustainable Development." BioScience . **53**(12): 1148-1149.
Sampson, P. (1972). "Can consumers create new products?" Journal of the Market Research Society **12**: 40-51.
Schaeffer, D. et al. (1988). "Ecosystem Health: I Measuring Ecosystem Health." Environmental Management **12**(4): 445-455.
Schillewaert, N., F. Langerak, and T. Duhamel. (1998). "Non probability sampling for WWW surveys: A comparison of methods." Journal of the Market Research Society **4**(40): 307-313.
Schindler, D. W. (1974). "Experimental studies for eutrophication and lake recovery: some implications for lake mangement." Science **184**: 897-899.
Schindler, D. W. (1987). "Detecting Ecosystem Response to Anthropogenic Stress." Canadian Journal of Fisheries and Aquatic Science **44**: 6-25.
Schindler, D. W. (1990). "Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function." Oikos **57**(25-41).
Schindler, D. W. and M. A. Turner (1982). "Biological, chemical and physical response of lakes to experimental acidification." Water Air Soil Pollution **18**: 259-271.
Schneider, E. D. and J. J. Kay (1994). "Complexity and Thermodynamics." Futures **26**(6): 626-647.
Schneider, S. H. (1989). "The Changing Climate." Scientific American **261**(3): 70-79.
Schonlau, M. J. R. D. Fricker, and M.N. Elliott (2002). Conducting Research Surveys via E-mail and the Web. Santa Monica, California, Rand Corporation.
Schrader-Frechette, K. S. and E. D. McCoy (1993). Method in Ecology. New York, Cambridge University Press.
Schrader-Frechette, K. S. (1996). "Evaluating the Expertise of Experts." Risk 6: 115.
Schulze, E. D. and H. A. Mooney, Eds. (1993). Biodiversity and Ecosystem Function. New York, Springer Verlag.
Senge, P. M. (1994). The Fifth Discipline: The Art and Practice of the Learning Organization. New York, Currency Doubleday.
Sevón, G. (1984). Cognitive Maps of Past and Future Economic Events. in Research Perspectives on Decision Making under Uncertainty. K. Borcherding, B. Brehmer, C. Vlek and W.A. Wagenaar. Amsterdam, North-Holland: 71-80.
Shaw, M. L. G. (1980). On Becoming A Personal Scientist. London, Academic Press.
Shaw, M. L. G., Ed. (1981). Recent Advances in Personal Construct Psychology. London U.K., Academic Press.
Shaw, M. L. G. (1994). "A methodology for sharing personal construct systems." Journal of Constructivist Psychology **7**(1): 35-52.
Shaw, M. L. G. and B. R. Gaines (1982). Eliciting Entailments. Progress in cybernetics and systems research. R. Trappl, L. Ricardi and G. Pask. Washington D.C., Hemisphere. **9**: 425-435.
Shaw, M. L. G. and B. R. Gaines (1983a). A computer aid to knowledge engineering. Proceedings of the British Computer Society Conference on Expert Systems, Cambridge, British Computer Society.
Shaw, M. L. G. and B. R. Gaines (1983b). Eliciting the real problem. International working conference on model realism. H. Wedde. Oxford, Pergamon Press: 100-111.

Shaw, M. L. G. and B. R. Gaines (1984). Deriving the constructs underlying a decision. Fuzzy sets and decision analysis. H. J. Zimmerman, B. R. Gaines and L. A. Zadeh. Amsterdam, North-Holland.
Shaw, M. L. G. and B. R. Gaines (1987). An interactive knowledge elicitation technique using personal construct technology. Knowledge Acquisition For Knowledge Elicitation for Expert Systems: A Practical Handbook. A. Kidd. New York, Plenum Press: 109-136.
Shaw, M. L. G. and B. R. Gaines (1989). "A methodology for recognizing conflict, correspondence, consensus and contrast in a knowledge acquisition system." Knowledge Acquisition **1**(4): 341-363.
Shaw, M. L. G. and B. R. Gaines (1992). "Kelly's "Geometry of Psychological Space" and its Significance for Cognitive Modeling." The New Psychologist (October): 23-31.
Shaw, M.L.G. and B. R. Gaines (1998). WebGrid II: Developing Hierarchical Knowledge Structures from Flat Grids. Proceedings of the Eleventh Knowledge Acquisition for Knowledge-based Systems Workshop S15-7, Banff, Alberta.
Shaw, M. L. G. and J. B. Woodward (1988). "Validation in a knowledge support system: construing and consistency with multiple experts." International Journal of Man-Machine Studies **29**(3): 329-350.
Shepherd, E. and J. P. Watson, Eds. (1982). Personal Meanings. London, Wiley.
Shepherd, R., L. J. Frewer, and C. Howard (1996). Trust and Risk Communication on Food Issues. Annual Meeting of the Society for Risk Analysis-Europe.
Simberloff, D. (1998). "Flagships, umbrellas, and keystones: Is single-species management passé in the landscape era?" Biological Conservation **83**: 247-257.
Simon, H. A. (1955). "A behavioural model of rational choice." Quarterly Journal of Economics **69**: 99-118.
Simon, H. A. (1974). "How big is a chunk?" Science **183**: 482-488.
Sjöberg, L. (1995). Explaining Risk Perception: An Empirical and Quantitative Evaluation of Cultural Theory. Stockholm, Sweden, Center for Risk Research, University of Stockholm.
Sjöberg, L. (1998). "World Views, Political Attitudes and Risk Perception." Risk: Health, Safety & Environment **137**(Spring): 9.
Sjöberg, L. (2002). "Are received risk perception models alive and well?" Risk Analysis **22**(4): 665-669.
Sjöberg, L., B-E. Moen, and T. Rudmo. (2004). Explaining risk perception. An evaluation of the psychometric paradigm in risk perception research. Trondheim, Norway, Norwegian University of Science and Technology, Department of Psychology.
Slater, P. (1964). The Principal Components of a Repertory Grid. London, Vincent Andrew.
Slater, P. (1969). "Theory and technique of the repertory grid." British Journal of Psychiatry **115**: 1287-1296.
Slovic, P. (1992). Perception of Risk: Reflections on the Psychometric Paradigm. Social Theories of Risk. S. Krimsky and D. Golding. Westport, Connecticut, Praeger: 117-152.
Slovic, P. (1997). "Trust, Emotion, Sex, Politics and Science: Surveying the Risk Assessment Battlefield." The University of Chicago Legal Forum: 59-98.
Slovic, P., B. Fischhoff, and S. Lichtenstein. (1978). " Accident probabilities and seat belt usage: A psychological perspective." Accident Analysis and Prevention **10**: 281-285.
Slovic, P., B. Fischhoff, and S. Lichtenstein. (1980). Facts and Fears: Understanding perceived risk. Societal risk assessment: How safe is safe enough? R. C. Schwing and W. A. Albers. New York, Plenum Press: 181-214.

Slovic, P. et al. (1995). "Intuitive Toxicology. II Expert and Lay Judgements of Chemical Risks in Canada." Risk Analysis **15**(6): 661-675.
Slovic, P. et al. (1997). "Evaluating Chemical Risks: Results of a Survey of the British Toxicology Society." Human and Experimental Toxicology **16**: 289-304.
Slovic, P. and E. Peters (1998). "The importance of worldviews in risk perception." Risk Decision and Policy **3**(2): 165-170.
Small, C. (2001). Global Analysis of Urban Population Distributions and the Physical Environment. Open Meeting of the Human Dimensions of Global Environmental Change Research, Rio de Janeiro.
Smil, V. (2000). Feeding the World - A Challenge for the 21st Century. Cambridge UK, Cambridge University Press.
Smithson, M. (1987). Fuzzy set analysis for behavioral and social sciences. New York, Springer-Verlag.
Solomon, D. J. (2001). "Conducting web-based surveys." Practical Assessment, Research & Evaluation **7**(19).
Soulé, M. E. (1980). Threshold for survival: maintaining fitness and evolutionary potential. Conservation Biology. M. E. Soulé and B. A. Wilcox. Sunderland MA, Sinauer: 151-169.
Soulé, M. E. (1991). "Conservation Tactics for a Constant Crisis." Science **253**(5021): 744-750.
Soulé, M. E. (1996). "Are ecosystem processes enough?" Wild Earth **6**(1): 59-60.
Sowa, J. F., Ed. (1991). Principles of Semantic Networks: Explorations in the Representation of Knowledge. San Mateo, California,, Morgan-Kaufman.
Stanley, T. R. (1995). "Ecosystem management and the arrogance of humanism." Conservation Biology **6**: 18-23.
Statistics Canada (1991). Human Activity and the Environment. Ottawa.
Statistics Canada (2000). Human Activity and the Environment. Ottawa..
Stebbing, A. R. D. (1981). "Stress, health and homeostasis." Marine Pollution Bulletin **12**: 326-329.
Stern, P. C. and T. Dietz (1994). "The Value Basis of Environmental Concern." Journal of Social Issues **50**(3): 65-84.
Stewart, V. (1998). Enquire Within: The Repertory Grid Interview. Mt. Victoria, Wellington New Zealand., Enquire Within Developments Ltd.
Stigliani, W. M., et al. (1991). "Chemical time bombs." Environment **33**(4): 4-30.
Sustainableworld.com (2004). Population Projections. (http://www.sustainableworld.com/data/population/pop_proj.htm)
Suter, G. W. (1990). "Endpoints for Regional Risk Assessments." Environmental Management **14**(1): 9-23.
Suter, G. W. (1993). "A critique of ecosystem health concepts and uses." Environmental Toxicology and Chemistry **112**: 1533-1539.
Suter, G. W. (2000). "Generic Assessment Endpoints Are Needed for Ecological Risk Assessment." Risk Analysis **20**(2): 173-178.
Suter, G. W. and L. Barnthouse (1993). Assessment Concepts. Ecological Risk Assessment. G. W. Suter. Boca Raton, Lewis Publishers: 21-47.
Suter, G. W. and S. Bartell (1993). Ecosystem Level Effects. Ecological Risk Assessment. G. W. Suter. Boca Raton, Lewis Publishers: 275-283.
Suter, G. W. et al. (2004). "The U.S. Environmental Protection Agency's Generic Ecological Assessment Endpoints." Human and Ecological Risk Assessment 10: 967-981.
Swetnam, T. W., C. D. Allen, and J.L. Betancourt (1999). "Applied historical ecology: Using the past to manage for the future." Ecological Applications **9**: 1189-1206.

Tan, F. B. (1999). Exploring Business - IT Alignment Using the Repertory Grid. Proceedings of the 10th Australasian Conference on Information Systems, Melbourne.
Tansley, A. G. (1935). "The Use and Abuse of Vegetational Concepts and Terms." Ecology **16**: 284-307.
Terborgh, J. (1988). "The big thing that run the world, a sequel to E.O. Wilson." Conservation Biology **2**(4): 402-403.
Thomas, J. W. (1996). "Forest Service Perspective on Ecosystem Management." Ecological Applications **6**(3): 703-705.
Thompson, M., R. Ellis, & A. Wildavsky (1990). Cultural Theory. Boulder, Westview Press.
Thompson, S. C. G. and M. A. Barton (1994). "Ecocentric and Anthropocentric Attitudes towards the Environment." Journal of Environmental Psychology **14**: 149-157.
Thüring, M. and H. Jungermann (1986). Constructing and Running Mental Models for Inferences about the Future. New Directions in Research on Decision Making. B. Brehmer, H. Jungermann, P. Lourens and G. Sevón. Amsterdam, North-Holland: 163-174.
Tilman, D. (2000). "Causes consequences and ethics of biodiversity." Nature **405**: 208-211.
Tilman, D. et al. (2001). "Forecasting Agriculturally Driven Global Environmental Change." Science **292**(13 April): 281-284.
Tilman, D. et al. (1997). "The Influence of Functional Diversity and Composition on Ecosystem Processes." Science **277**(5330): 1300-1302.
Tilman, D. et al. (2001). "Diversity and Productivity in a Long Term Grassland Experiment." Science **294**(26 October): 843-845.
Tomalty, R., R. B. Gibson, and D. H. M. Alexander (1995). Ecosystem Planning for Canadian Urban Regions. Toronto, Intergovernmental Committee on Urban and Regional Research.
Toulmin, S. (1958). The Uses of Argument. Cambridge, UK, Cambridge University Press.
Trewavas, A. (2002). "Malthus foiled again and again." Nature **418**: 667-670.
Tucker, G. M. and M. F. Heath (1994). Birds in Europe: their conservation status. Bird Life International. Cambridge, UK.
Tversky, A. (1977). "Features of Similarity." Psychological Review **84**: 327-352.
Tversky, A. and D. Kahneman (1973). "Availability: A Heuristic for Judging Frequency and Probability." Cognitive Psychology **4**: 207-232.
Tversky, A. and D. Kahneman (1974). "Judgment under Uncertainty: Heuristics and Biases." Science **185**: 1124-1131.
Tversky, A. and D. Kahneman (1981). "The Framing of Decisions and the Psychology of Choice." Science **211**(January): 453-458.
U.N (1999). World Population Prospects: The 1998 Revision vol. 1 Comprehensive Tables. New York, United Nations, Department of Economic and Social Affairs, Population Division.
U.N. (2002). World Population Prospects: The 2002 Revision Population Database. New York, United Nations Population Division, (http://esa.un.org/unpp/)
U.N.D.P. (2000). World Resources 2000-2001: People and Ecosystems, The Fraying Web of Life. The Hague, Elsevier Science.
U.N.F.P.A. (2001). The State of the Worlds Population. New York, United Nations Population Fund.
U.S.C RS (1994). Ecosystem Management: Status and Potential. Summary of the Workshop Convened by the Congressional Research Service for the Committee on Environment and Public Works, United States Senate, 105 Congress 2nd Session, Washington D.C., U.S. Government Printing Office.
U.S. Census Bureau (2004). International Data Base. (http://www.census.gov/ipc/www/idbnew.html)

U.S.EPA (1987). Unfinished Business: A Comparative Assessment of Environmental Problems. Washington D.C., Environmental Protection Agency.
U.S.EPA (1990). Reducing Risk: Setting Priorities and Strategies for Environmental Protection; and Appendix A: "The Report of the Ecology and Welfare Subcommittee"; and Appendix B: "The Report of the Human Health Subcommittee"; and Appendix C: "The Report of the Strategic Options Subcommittee". Washington D.C., Environmental Protection Agency, Science Advisory Board.
U.S.EPA (1992). Framework for Ecological Risk Assessment. Washington D.C., Environmental Protection Agency, Risk Assessment Forum.
U.S.EPA (1994). A Conceptual Framework to Support the Development and Use of Environmental Information in Decision Making. Washington D.C., United States Environmental Protection Agency, Environmental Information and Statistics Division.
U.S.EPA (1995). The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies: Vol. 1 Overview; Vol. 2 ; Implementation Issues; Vol. 3 Case Studies - Interagency Ecosystem Management Taskforce. Washington D.C., Environmental Protection Agency, Office of Science and Technology Policy.
U.S.EPA (1998). Guidelines for Ecological Risk Assessment. Washington D.C., Risk Assessment Forum, Office of Research and Development, United States Environmental Protection Agency.
U.S.NRC (1983). Risk Assessment in the Federal Government. Washington D.C., National Academy Press.
U.S.NRC (1993). A Biological Survey for the Nation. Washington D.C., National Academy Press.
UNEP (1991). Concepts and Methods of Environmental Statistics: Statistics of the Natural Environment. New York, United Nations Environment Programme, Department of International Economic and Social Affairs, Statistical Office.
Upton, H. F. (1992). "Biodiversity and Conservation of the Marine Environment." Fisheries **17**(3): 20-25.
Vandenburgh, J. G. et al. (2002). Animal Biotechnology: Identifying Science-Based Concerns, Committee on Defining Science-Based Concerns Associated with Products of Animal Biotechnology. Washington, National Academy of Sciences.
Van Dyne, G. M. (1966). Ecosystems, Systems Ecology, and Systems Ecologists, Oak Ridge National Laboratory. **ORNL 3957**.
Vaughan, E. and M. Seifert (1992). "Variability in the Framing of Risk Issues." Journal of Social Issues **48**(4): 119-135.
Vigerstad, T. J. and L. S. McCarty (2000). "The Ecosystem Paradigm and Environmental Risk Management." Human and Ecological Risk Assessment **6**(3): 369-381.
Vitousek, P. et al. (1986). "Human Appropriation of the Products of Photosynthesis." Bioscience **36**(6): 368-373.
Vitousek, P. et al. (1996). "Biological Invasions as Global Environmental Change." American Scientist **84**: 468-478.
Vitousek, P. et al. (1997). "Human domination of Earth's ecosystems." Science **277**(494-499).
Wackernagel, M., et al. (1997). Ecological Footprints of Nations, How Much Nature Do they Use? -- How Much Nature Do They Have?, The Earth Council, Costa Rica.
Wackernagel, M. and W. Rees (1996). Our Ecological Footprint: Reducing Human Impact on the Earth. Gabriola Island, New Society Publishers.
Walker, B. H. (1992). "Biodiversity and Ecological Redundancy." Conservation Biology **6**(1): 18-23.
Walker, B. H. (1995). "Conserving biological diversity through ecosystem resilience." Conservation Biology **9**(1): 1-7.

Walters, C. J. (1986). Adaptive management of renewable resources. New York :, Collier Macmillan.
Walters, C. J. and C. S. Holling (1990). "Large-Scale Management Experiments and Learning by Doing." Ecology **7**(6): 2060-2068.
Watkinson, A. R. et al. (2000). "Predictions of Biodiversity Response to Genetically Modified Herbicide-Tolerant Crops." Science **289**(5484): 1554-1557.
Watling, L. and E. A. Norse (1998). "Disturbance of the seabed by mobile fishing gear: a comparison to forest clear cutting." Conservation Biology **12**: 1180-1197.
Watson, et al., Eds. (2000). Land Use, Land-Use Change and Forestry. Special Report of the Intergovernmental Panel on Climate Change. Cambridge U.K., Cambridge University Press.
WCED (1987). Our Common Future - The Brundtland Report, Oxford University Press.
Welch, R. M. et al. (1997). "Feeding a Growing World Population - Toward a "Greener" Revolution." Issues in Science and Technology Online **Fall**.
Western, D. (2001). "Human modified ecosystems and future evolution." Proceedings of the National Academy of Sciences of the United States **98**(10): 5458-5465.
Westman, W. E. (1977). "How Much Are Natures Services Worth." Science **197**: 960-964.
White, P. (1997). "Naïve ecology: causal judgments about a simple ecosystem." British Journal of Psychology **88**(May): 219-33.
Whitford, W. G., D. J. Rapport, A. G. De Soyza (1999). "Using resistance and resilience measurements for 'fitness' tests in ecosystem health." Journal of Environmental Management **57**: 21-29.
WHO (1948). Constitution. Geneva, Switzerland, World Health Organization.
Wicklum, D. and R. W. Davies (1995). "Ecosystem health and integrity?" Canadian Journal of Botany **73**: 997-1000.
Wilcox, B. A. (2001). "Ecosystem health in practice: emerging areas of application in environment and human health." Ecosystem Health **7**(4): 317-325.
Wildavsky, A. and K. Dake (1990). "Theories of Risk Perception: Who Fears What And Why?" Proceedings of the American Academy of Arts and Sciences **119**(4): 41-60.
Williams, D. and M. E. Patterson (1996). "Environmental Meaning and Ecosystem Management: Perspectives from Environmental Psychology and Human Geography." Society and Natural Resources **9**(507-521).
Williams, G. C. (1966). Adaptation and Natural Selection. Princeton N.J., Princeton University Press.
Williams, R. (1980). Ideas of nature. Problems in Materialism and Culture. London, Veros: 67-85.
Williamson, M. (1996). Biological Invasions. London, Chapman and Hall.
Wilson, E. O. (1987). "The little things that run the world." Conservation Biology **1**(4): 344-346.
Wilson, E. O. (1989). "Threats to Biodiversity." Scientific American **261**(3): 108-116.
Wolfenbarger, L. L. and P. R. Phifer (2001). "The Ecological Risks and Benefits of Genetically Engineered Plants." Science **290**(5499): 2088-2093.
Woodley, S., J. J. Kay, and George Francis Eds. (1993). Ecological Integrity and the Management of Ecosystems. Delray Beach, Florida, St. Lucie Press.
Woodwell, G. M. and H. H. Smith, Eds. (1969). Diversity and Stability In Ecological Systems. Brookhaven CT, Brookhaven National Laboratories.
Worm, B., M. et al. (2005). "Global Patterns of Predator Diversity in the Open Oceans." Science Express.
Worster, D. (1990). "The ecology of order and chaos." Environmental History Review **14**: 1-18.
WRI (2000). A Guide to World Resources 2000-2001: People and Ecosystems: The Fraying Web of Life. Washington D.C., World Resources Institute.

Wright, R. (2005). A Short History of Progress. New York, Caroll & Graf Publishers.
WWF (2000). Global Biodiversity and Terrestrial Biodiversity Decline. Washington D.C., World Wildlife Fund.
Yafee, S. L. (1999). "Three Faces of Ecosystem Management." Conservation Biology **13**(4): 713-725.
Yodzis, P. (1981). "The stability of real ecosystems." Nature **289**: 674-676.

Appendix 1. INTERVIEW REQUEST LETTER

University of British Columbia
Resource Management and Environmental Studies
2206 East Mall
Vancouver, B.C. V6T 1Z3

Dear

We are writing to you because we understand that you are someone who is knowledgeable about ecosystems and the risks to which they are exposed. We would like to request an opportunity to interview you to learn more about your views about ecosystems, and to elicit the assessment goals and criteria that you think should be used to evaluate risks to ecosystems.

Interdisciplinary collaboration is becoming increasingly difficult because there is a lack of consensus about what is important and worthwhile about ecosystems, and what needs to be managed, conserved or protected. We are trying to build a common conceptual framework to facilitate risk communication and collaboration.

We are conducting a two-stage survey. During the first stage of the survey we would like to interview you to learn more about how you think about ecosystems so we can compare and contrast your point of view with other experts. After our analysis is completed we are going to contact you and ask to participate in the second stage of the survey. You will fill out a short web-based questionnaire, where everyone will evaluate the same assessment goals using a common set of criteria. This will help us determine the degree of conflict and consensus that exists between different groups of experts.

In the interview, we will ask you to identify important ecosystem components and attributes. Next we will complete a grid together, where we will ask you to suggest corresponding assessment criteria. Then we will ask you to use these criteria to distinguish between different assessment goals or concepts.

During the next phase of the interview we want know what you think are the main threats to ecosystems today and the extent to which you agree or disagree with some common beliefs about the environment.

To close we will ask for some basic background information about yourself so we can compare your responses to those of other persons we interview..

Appendix 1. INTERVIEW REQUEST LETTER

After we have analysed the survey results, we will post a grid with a common set of assessment goals and criteria on the Internet, and ask everyone to fill in this questionnaire.

The ethical guidelines of the University of British Columbia govern this research. We appreciate the value of your time and we will try to keep the duration of the interview to under an hour. You should be able to complete the web-based questionnaire in less than a half an hour

All completed interviews and audio recordings will be stored in a secure location. Only the investigators will have access to them. Responses to the web-based questionnaire will be stored offline in a password-controlled cache. Individual records will only be identified by means of a code. All records will be destroyed after a period of five years.

We will not divulge your identity without your consent. However, we would like to acknowledge your contribution in our research report by including your name in a list of experts that we consulted. If we attribute specific comments or ideas to you, we will ask your permission.

We would also be pleased to provide you with a summary of the research results once the study is completed.

We hope that you will be able to participate, and would appreciate the suggestion of other persons you think we should interview. We look forward to speaking with you, and welcome any questions you might have about this research.

Yours sincerely

W.G.B. (Bill) Smith　　　　Tim McDaniels PhD

Appendix 3 SCRIPTS - FAQ's
Survey of Experts' Mental Models of Ecosystem Risk

Personal Identity
• Hi my name is Bill Smith. I am a graduate student at UBC.
Purpose of Research Project
• I am conducting research for my doctoral dissertation • The purpose of my research is to elicit the assessment goals and criteria that different disciplines use to assess risk to ecosystems
How was I selected
• You were selected because you are someone who is knowledgeable about the risks to which ecosystems are exposed. • I wonder if you have received or had time to consider my request for an interview. It was sent to you by e-mail dated the ___ /___ /___
Survey Design
• I am conducting a two-stage survey of experts. • The first stage is an interview that should take about an hour. • After all the interviews have been analysed, you will be contacted and asked to complete a short Web-based questionnaire.
Nature of Questions
<u>Personal Interview</u>: - During the interview, I would like to ask you about: **Valued Ecosystem Components and Attributes** • First we would like to learn more about what you think about ecosystems. You will be asked to identify valued ecosystem components or attributes that you think are worthy of management, conservation or protection. **Assessment criteria for eco-risks?** • Second we will ask you to suggest assessment criteria. **Threats to ecosystems today, and beliefs about the environment?** • Third we will ask what you think are the most pressing threats to ecosystems today and the extent to which you agree or disagree with some common beliefs about society and the environment. **Your professional background, education and experience?** • Lastly we will ask you to provide some background information about yourself so we can compare your response to others. **<u>Web-Based Questionnaire</u>** • After we have completed our analysis, you will be asked to complete a web-based questionnaire, where you will be asked to rate a common set of assessment goals and criteria

Appendix 3 SCRIPTS – FAQ's
Survey of Experts' Mental Models of Ecosystem Risk

Guarantee of Anonymity and Confidentiality

- We will not divulge your identity without your consent.
- However, we would like to acknowledge your contribution to our research by including your name in a list of experts we consulted in our report.
- Your responses will be tabulated and reported in statistical form only.
- If we want to attribute specific ideas or comments to you we will first get your permission.

Right of Refusal to Answer any Question

- At any time or for any reason, you may decline to answer any question

Any Questions before Proceeding?

- Do you have any questions about the proposed research?

Willingness to Proceed?

- Are you willing to be interviewed?
- Do you mind if I record the interview?

Other Questions

The Time Required for the Interview?

- The interview should take about an hour of your time.
- It should take twenty minutes to half an hour to complete the web-based questionnaire.

How will my Identity or any Information I provide be protected?

- All completed interviews and audio recordings will be stored in a secure location. Only the investigators will have access to them.
- Responses to the Web-based questionnaires will be stored off-line in a password-controlled cache.
- Individual records will be identified by means of a code.
- All audio recordings and transcripts will be destroyed after five years

How can I verify the authenticity of the research project?

- You can contact my supervisor Dr Tim McDaniels at 604-822-9288 or the chairman of my department, Dr. Les Lavkulitch at 604-822-3487

Appendix 4 INTERVIEW GUIDE
Survey of Experts' Mental Models of Ecosystem Risk

WHAT ARE REPERTORY GRIDS?

- A Repertory grid is a way of representing how different people think about the same domain. The function of the grid is to provide a technique for building an individual's conceptual structure without direct elicitation of their conceptual framework. The underlying assumption of is that it may be easier for experts to provide examples from their experience and to state how they would distinguish between them in terms of the properties relevant to the purpose of eliciting the grid
- Repertory Grids are usually developed for domains where there is still no consensus about the relevant distinctions and terminology and the primary source of knowledge is still the conceptual distinctions made by individual experts.
- The Repertory Grid is a matrix of elements, constructs and values. This matrix represents the respondents' construct system for the domain of enquiry: the language they use to describe and classify the elements
    - Elements are the columns, constructs are the rows and the values are the entries in each cell.
    - Elements are concrete examples drawn from experience that are representative of the domain you wish to explore. Although elements are normally entities they also include activities, processes and events
    - Constructs are the attributes or terms we use to describe the way in which the elements are similar or different from one another. They are usually elicited as binary or bi-polar distinctions but may also be more-or-less-than continuums. There are two meanings of the term construct: A construct represents how people classify their past experience and it also represents how people perceive the future - the framework through which they interpret or construe future events.
    - The Values assigned to the constructs describe the range within which these distinctions apply. The bipolar attributes of repertory grids can be treated as a pair of predicates defining fuzzy sets and the rating of an entity on an attribute can be regarded as defining the degree of membership in each set

Appendix 4 INTERVIEW GUIDE
Survey of Experts' Mental Models of Ecosystem Risk

DEVELOPING AN ELEMENT SET
• The strategy used to create an element set describing an ecosystem is to o First ask the respondent to suggest examples, o Then to name an element class and ask the respondent to provide you with examples of that class without prompting o Finally to allow them to select from a prepared set of examples • The one unbreakable rule about an element set is that people cannot complete an interview session about elements for which they have no knowledge or experience. The more experience they have the more complex the resulting process. • Elements can be nouns or noun phrases, verb or verb phrases. • Elements should be as concrete as possible, and when they describe processes or situations they should be bounded in time and space. • Each element set should be homogeneous and not overlap with others. All elements should carry equal weight, and be equally representative of a set.

ELICITING CONSTRUCTS
• Constructs can be elicited by comparing two or three elements at a time:
Triads
• The most common form of eliciting constructs is the triad method. Elements are presented in groups of three, being the smallest number that will produce both a similarity and a difference. Subjects are asked in what way are two alike and different from the third. This will elicit the emergent pole of the construct. The implicit pole may be elicited by the difference method (the subject could be asked in what way is the singleton differ from the pair) or by the opposite method (what would be the opposite of the description of the pair.)
Pairs
• In dyadic elicitation respondents are asked to consider whether two elements are alike or different in some way. Once they have described the similarity or difference, they are asked to provide a contrasting word or phrase that is opposite to the phrase they initially provided.

Appendix 4 INTERVIEW GUIDE
Survey of Experts' Mental Models of Ecosystem Risk

Sample Elicitation

For example, (Stewart 1998) we can compare three different types of wines in terms of sweetness, colour, and effervescence. The poles of the constructs are dry/sweet, red/white, and still/sparkling.

Example:

WINE	Cotes du Rhone	Lambrusco	Liebfraumilch
Sweetness	Dry	Medium	Medium
Colour	Red	White	White
Effervescence	Still	Sparkling	Still

If we add the champagne wine Moet Chandon to the list, it can be described using the dyadic comparisons already elicited. It is a sweet, white, sparkling wine. If we want to extend the characterization of the elements, we can use triadic elicitation to pose questions such as are two of the wines, such as Liebfraumilch and Lambrusco, alike in a way that distinguishes them from the third Moet Chandon. Cost has not been mentioned before and the construct cheap/expensive could be added to the set to distinguish the cheaper wines from the more expensive champagne.

Laddering – Up

- Another process that may be introduced into the interview is laddering. 'Laddering-up' has the interviewer take a construct and ask which pole of the construct is preferred, in terms of the purpose of the interview, and why; next you can ask for the reasons underlying the preference, and then ask them to elaborate each of the reasons and so on. This process takes you deeper into the construct system and eventually leads to what are known as "core constructs" - deeply held values and beliefs which the person adheres to strongly.

Laddering – Down

- Laddering down' has the interviewer take a construct and ask for some details about how one pole of the construct differs from the other - asking for more observable and behavioral detail about the construct. These laddered-down constructs nearly always appear as clusters in the final grid

RATING THE ELEMENTS

- After a number of constructs have been created, the next stage is to rate each element in terms of all the constructs, thereby forming a matrix that can be analyzed by different statistical methods.

Appendix 4 INTERVIEW GUIDE
Survey of Experts' Mental Models of Ecosystem Risk

CONDUCTING AN INTERVIEW

INTERVIEWING RESPONDENTS
• Assume a neutral attitude. Do not indicate your reaction to the respondent's answers nor attempt to influence their responses. The Grid interview usually reveals the key issues and problems to the respondent without prompting,
• Hold the respondent's interest. A good technique is to start repeating what the respondent said while you are writing it down or to ask the next question. Do not let the respondent's attention lapse.
• Be casual or conversational. Use an informal manner of speaking which is natural to you. Do not put the respondents on the defensive or subject them to the third degree. Be friendly. Put the respondents at ease.
• Repeat and clarify questions, misunderstood by the respondents. Keep track of these changes. Use brackets to indicate your own comments. It is very important not to introduce bias by predisposing respondents to answer in a certain way. Several types of probes will stimulate discussion and help obtain a complete response: o A brief expression of interest o An expectant pause o Repeating the question or the respondent's reply o A neutral question or comment e.g. why is that important? o Rephrasing the question in more easily understood language. o Defining key concepts and terms
RECORDING AND EDITING THE INTERVIEW
• Record the respondents' answers during the interview. Usually the first answer is the most meaningful. Do not alter an answer, if you gone on to other questions. Do not record a "don't know" answer too quickly as it often serves as the preface to the respondents' actual views.
• For open-ended questions just write down the respondent's words in the space provided. Jot down key words and phrases. Do not summarise or paraphrase. Use the respondent's own words. For lengthy remarks do not hesitate to use more space, even the back of page if necessary.
• For structured questions, if answers do not clearly match one of the categories provided, write in the respondent's exact words at this point in the questionnaire. When straight yes or no questions are qualified by comments, take these down, whether or not space is provided for them.

Appendix 4 INTERVIEW GUIDE
Survey of Experts' Mental Models of Ecosystem Risk

STEPS IN ELICITING EXPERTS MENTAL MODELS

1. ELICITING ECOSYSTEM COMPONENTS

• The first step is to ask the respondent to identify the important entities, processes and events that define an ecosystem. They should provide specific concrete examples that would be familiar to most observers.
• When the respondents run out of examples, start by suggesting possible response categories that correspond to the various hierarchical levels of organisation of an ecosystem. For example, you could use
    o Landscapes/Abiotic components,
    o Biotic Communities or Guilds,
    o Populations, or
    o Individual species.
• When the respondent is unable to suggest any more examples, you can show them a prepared list of examples (CARD #1) and ask whether or not they consider any of these examples to be important. Respondents are free to accept or reject any of the examples or to provide new suggestions.

2. ELICITING ASSESSMENT CRITERIA
• Assessment criteria are constructs that could be used to evaluate the condition or functioning of the ecosystem. In this context, constructs can be elicited by comparing desired with unacceptable states of the environment or by contrasting different conditions of ecosystems. • You should elicit at least one assessment criterion for each ecosystem component. For example, if the respondents chose habitat as one of their valued ecosystem components, you could describe habitat as being either connected or fragmented, small patch or large patch. • When the respondents are unable to suggest more criteria show them CARD #2. They are free to accept or reject any of the proposed criteria.
3. ELCITING ECO-CONCEPTS
• The next step is to elicit respondents' eco-concepts (e.g. natural, integrity, sustainable or healthy), the constructs they use to compare or evaluate the risks to different types of ecosystems.
4. RATING ECO-CONCEPT USING THE ASSESSMENT CRITERIA
• The final step of the elicitation process is to establish the range of values, usually dichotomies or bipolar opposites, within which each construct applies. In addition to categorical values, ordered values (e.g. high, normal, low) and indexes (e.g. ratios) can also be used. • If it is not already clear, ask the respondents to state the reasons why they prefer one pole of the construct to another. This process is called laddering-up, and can be used to uncover their core constructs – the respondents deeply held values and beliefs about ecosystems and their importance. • Laddering-down provides more details about how one pole differs from the other. These constructs often appear as clusters in the final grid.

Appendix 5 INTERVIEW QUESTIONNAIRE

SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

ECOSYSTEMS

1. When you think of an ecosystem what comes to mind? Would you please describe an ecosystem in your own words?

....

....

....

....

2. Would you say that an ecosystem is a

	Yes	No
• Real place?	☐	☐
• Dynamic set of processes and functions?	☐	☐
• Physical - biological entity?	☐	☐
• Problem solving approach?	☐	☐
• Holistic understanding of the relationship between living things and their environment?	☐	☐
• Other (please explain)	☐	☐

....

....

3. Would you now identify what you think are the most important components of an ecosystem? These should be observable entities, processes or relationships that you consider in most cases to be worthy of management, conservation or protection.
(Show respondents examples in Card #1 if necessary.)

VALUED ECOSYSTEM COMPONENTS

SYSTEM
....
....
....
....

VALUED ECOSYSTEM COMPONENTS (cont.)

ENTITIES

....
....
....
....
....
....

PROCESSES

....
....
....
....
....
....

RELATIONSHIPS

....
....
....
....
....
....

SOCIAL

....
....
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....
....
....

SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

4. For each ecosystem component you identified, would you now suggest one or more assessment criteria that could be used to evaluate the condition or functioning of the ecosystem?

(Show respondent the examples on Card # 2, if necessary.)

LANDSCAPES/ABIOTIC

Component		Assessment Criteria
•................................	-	....
•................................	-	....
•................................	-	....
•................................	-	....

COMMUNITIES/GUILDS

Component		Assessment Criteria
•................................	-	....
•................................	-	....
•................................	-	....
•................................	-	....
•................................	-	....

POPULATIONS

Component		Assessment Criteria
•................................	-	....
•................................	-	....
•................................	-	....
•................................	-	....

ORGANISMS / INDIVIDUALS

Component		Assessment Criteria
•................................	-	....
•................................	-	....
•................................	-	....
•................................	-	....

EXPERTS MENTAL MODELS OF RISK

5. Experts have a variety of ways of comparing different ecosystems. Are you familiar with the meaning of the following eco-concepts?

ECO-CONCEPTS ☑	Yes	No
• Carrying Capacity	☐	☐
• Ecological-Footprints	☐	☐
• Biological or Ecological Integrity	☐	☐
• Ecosystem Health	☐	☐
• Resilience	☐	☐
• Sustainability	☐	☐

6. (If respondent is familiar with three or more terms.) Are there ways in which a pair of these terms is similar and yet different from a third? For example how would you distinguish Carrying Capacity and Ecosystem Health from Biological Integrity? (Carrying Capacity and Ecosystem Health focus on human impacts, while Biological Integrity is concerned with the survival of other species.)

- ....
- ....
- ....
- ....

7 (If the respondent is familiar with more than one term.) How does each of these assessment concepts differ from one another? (For example, each term may have a different focus of concern, such as pollution or loss of biodiversity or meeting human needs.)

- ....
- ....
- ....
- ....
- ....

8. These terms (e.g. carrying capacity, integrity, health, & sustainability) are normative concepts. Should values, moral or ethical concerns play a role in scientific assessment? If so why?

....

....

9. Select an eco-concept (from the list provided earlier) that describes how you would compare the risks to different ecosystems. If none of the terms we have discussed are suitable, please suggest alternative terminology.

....

....

....

....

....

....

10 Operationally define this eco-concept by using the assessment criteria you chose earlier. Use these criteria to distinguish preferred from undesired conditions of the ecosystem?

CRITERIA	Emergent	Implicit

11. From your own perspective, what do you think are main threats to regional ecosystems? Are these threats global, national or local in importance? (Show respondent Card #3 if necessary.)

	Globally?	Nationally?	Locally?
Population growth	☐	☐	☐
Lifestyles and Consumption	☐	☐	☐
Poverty & Hunger	☐	☐	☐
Human Settlement	☐	☐	☐
Land use Conversion	☐	☐	☐
Energy Use	☐	☐	☐
Climate Change	☐	☐	☐
Over harvesting e.g. Fish & Wildlife	☐	☐	☐
Deforestation e.g. Clear-cutting	☐	☐	☐
Species Extinction	☐	☐	☐
Biological Invasions - Exotic species	☐	☐	☐
Resource Depletion	☐	☐	☐
Pollution - Air - Water	☐	☐	☐
Solid Waste Disposal	☐	☐	☐
Natural events- e.g. Wildfires	☐	☐	☐
Global Trade	☐	☐	☐
Industrialisation	☐	☐	☐
Monocultures	☐	☐	☐
Overuse of fertilisers - animal wastes	☐	☐	☐
Other please specify..................	☐	☐	☐
•..	☐	☐	☐
•..	☐	☐	☐

Appendix 5 INTERVIEW QUESTIONNAIRE
SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

12 Finally would you express the extent to which you agree or disagree with the following set of statements?
(Show respondent Card #4)

Do you agree ( ) or disagree( ) that?	SA	MA	N	MD	SD
1. The Earth has plenty of natural resources, if we can just learn how to develop them.	1	2	3	4	5
2. If wealth and opportunity were more fairly distributed in this country we would have fewer environmental and social problems	1	2	3	4	5
3. We are approaching the limit of the number of people the earth can support	1	2	3	4	5
4. Nature may be resilient but it can only absorb so much damage	1	2	3	4	5
5. We should voluntarily adopt a simpler less materialistic way of life in order to save the environment.	1	2	3	4	5
6. We cannot rely on the functioning of markets or goodwill of individuals to protect our health or the environment.	1	2	3	4	5
7. We should leave the tough decisions about the environment to the experts	1	2	3	4	5
8. It is often less costly to prevent environmental problems than to fix them.	1	2	3	4	5
9. In a fair society, people who invest and take risks should be rewarded.	1	2	3	4	5
10. Continued economic growth, and technological innovation is the key to improving our standard of living.	1	2	3	4	5
11. Plants and animals have the same right as humans to exist.	1	2	3	4	5
12. Humans will eventually learn enough about how nature works to be able to control it.	1	2	3	4	5
13. Nature will recover in the long run from any harm caused by humans.	1	2	3	4	5
14. Companies won't protect the environment until the law forces them to do something.	1	2	3	4	5
15. Human ingenuity will insure that we do NOT make the Earth unliveable.	1	2	3	4	5

Appendix 5 INTERVIEW QUESTIONNAIRE
SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

Do you agree ( ) or disagree ( ) that?	SA	MA	N	MD	SD
16. The public should be prepared to accept some environmental risks if they want to have a more prosperous economy	1	2	3	4	5
17. We have to protect the environment for our children and grandchildren, even if it means reducing our standard of living today.	1	2	3	4	5
18. Governments should not restrict peoples' personal freedom or their lifestyle choices.	1	2	3	4	5
19. Communities know better than government or industry what needs to be done to protect the environment.	1	2	3	4	5
20. We should rely on our own common sense rather than the opinions of so-called experts when trying to solve environmental problems.	1	2	3	4	5
21. In this country we should return to more traditional values and way of life.	1	2	3	4	5
22. Modern technology poses serious risks to the environment	1	2	3	4	5
23. If humans do not have a use for a species they shouldn't worry about it becoming extinct.	1	2	3	4	5
24. It is unfortunate but acceptable if some people loose their jobs or have to change their line of work for the sake of the environment.	1	2	3	4	5
25. The balance of nature is very delicate and easily upset.	1	2	3	4	5
26. There is so much disagreement among experts that it is hard to know who to believe about the environment.	1	2	3	4	5
27. The so-called "environmental" crisis facing society has been greatly exaggerated.	1	2	3	4	5
28. As long as the same species exists somewhere else in the world, humans have a right to use plants and animals to meet their needs.	1	2	3	4	5
29. Environmental choices always involve trade-offs.	1	2	3	4	5
30. Private enterprise is more likely than government to find solutions to environmental problems	1	2	3	4	5

Appendix 5 INTERVIEW QUESTIONNAIRE

SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

PROFESSIONAL BACKGROUND:

Highest Level of Education

Diploma ☐ Bachelors ☐ Masters ☐ Doctorate ☐

Other (specify)...

Employment/Affiliation

Academic	☐	Government	☐
Industry/Consulting	☐	Public Interest/Advocacy	☐

Other (specify)...

Current Position (Mark all that apply)

Research/Assessment	☐	Managerial/Administration.	☐
Teaching	☐	Regulation/Enforcement	☐

Other (specify)...

Professional Specialization (if any)

Ecotoxicology	☐	Wildlife Biology	☐
Landscape Ecology	☐	Fisheries Management	☐
Forestry	☐	Aquatic	☐

Other (specify)...

Work Experience

Years of directly relevant work experience in ecological risk assessment and management..

Age		Gender	
18-24	☐	Male	☐
25-29	☐	Female	☐
30-44	☐		
45-54	☐		
55+	☐		

Appendix 6 RESPONSE CARDS
SURVEY OF EXPERT'S MENTAL MODELS OF ECOSYSTEM RISK

Card #1 Examples of Valued Ecosystem Components

ECOSYSTEM	Examples of COMPONENTS
Landscape – Abiotic	• Habitat • Nutrient Pools and Cycling • Disturbance Regimes • Sinks
Communities- Guilds	• Species • Food Webs
Population	• Minimum Viable Population Size • Range
Individuals	• Reproductive Success • Prevalence of Disease

CARD #2 Sample Assessment Criteria

Emergent	1	2	3	4	5	Implicit
LANDSCAPE - ABIOTIC						
LargeHabitat Patches	1	2	3	4	5	Small Habitat Patches
Nutrient Retention	1	2	3	4	5	Nutrient Leakage
Unpolluted	1	2	3	4	5	Polluted
COMMUNITY-GUILDS						
Native Species	1	2	3	4	5	Exotic Species
Robust Food Webs	1	2	3	4	5	Fragile Food Webs
POPULATIONS						
Viable Population	1	2	3	4	5	Population @Risk of Extirpation
Normal Range	1	2	3	4	5	Reduced or Displaced Range
INDIVIDUALS						
High Reproductive Success	1	2	3	4	5	Low Reproductive Success-
Low mortality rates	1	2	3	4	5	High Mortality Rates

Card #3

ECOSYSTEM THREATS

- Population growth
- Lifestyles and Consumption
- Poverty & Hunger
- Human Settlement
- Land use Conversion
- Energy Use
- Climate Change
- Over harvesting e.g. Fish & Wildlife
- Deforestation e.g. Clear-cutting
- Species Extinction
- Biological Invasions – Exotic species
- Resource Depletion
- Pollution – Air – Water
- Solid Waste Disposal
- Natural events- e.g. Wildfires
- Global Trade
- Industrialisation
- Monocultures
- Overuse of fertilisers – animal wastes
- Other?

Card #4 Scale

Strongly Agree	Moderately Agree	Neither Agree nor Disagree	Moderately Disagree	Strongly Disagree
1	2	3	4	5

Appendix 7 LIST OF INTERVIEW RESPONDENTS
SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

1) Ray Andrews, Manager of Operations Kananaskis Country, (Chairman Central Rockies Ecosystem Interagency Liaison Group)	2) Paul L. Angermeir PhD Cooperative Fish & Wildlife Research Unit, Virginia Polytechnic Institute Blacksburg Virginia
3) Karen Beazley PhD, School of Resource and Environmental Studies, Dalhousie University, Halifax N.S.	4) Stephen Bocking PhD Environmental & Resource Studies Program, Trent University, Ontario
5) Martin J. Bunch PhD Faculty of Environmental Studies, York University, Toronto, Ontario	6) Ian Campbell, PhD Senior Project Director, Policy Research Initiative, Ottawa ON
7) Villy Christensen PhD Senior Research Fellow, UBC Fisheries Centre, Vancouver B.C.	8) Steve Carpenter PhD Center for Limnology, University of Wisconsin
9) Shirley A.M. Conover, PhD (Retired) Bewdley, Ontario,	10) William E. Cooper, PhD Michigan State University.
11) Joe Foy Western Canada Wilderness Committee, Vancouver, British.Columbia	12) George Francis, Emeritus Professor, Department of Environment & Resource Studies, University of Waterloo, Ontario
13) Dr. Bill Freedman, PhD Department of Biology, Dalhousie University, Halifax N.S.	14) Terry Glavin, Journalist, Marine Conservation Advisor, Sierra Club of BC,
15) Geoff Granville, PhD Manager, Environmental Affairs, Shell Canada, Calgary, Alberta	16) Peter Hall, PhD Science Advisor, Forestry Service Natural Resources Canada, Ottawa, ON
17) Andy Hamilton, PhD Former Science Advisor, Commission for Environmental Co-operation and International Joint Commission	18) Mike Healey, PhD Oceanography University of British Columbia Vancouver, British Columbia
19) Larry Hildebrand Manager, Coastal Zone Management Environment Canada – Dartmouth N.S.	20) Harry Hirvonen, Research Co-ordinator, Forest Health & Biodiversity, Natural Resources Canada, Ottawa ON
21) Doug Hyde Habitat Stewardship Co-ordinator Canadian Wildlife Service, Ottawa, ON	22) Dean Jeffries, PhD Research Scientist Canada Centre for Inland Waters Burlington, Ontario
23) James R. Karr, PhD Aquatic Sciences and Biology University of Washington, Seattle	24) Robert T. Lackey, PhD U.S. Environmental Protection Agency Corvallis, Oregon
25) Jean Langlois, Executive Director Canadian Parks & Wilderness Society Ottawa Valley Chapter	26) Henry Lickers Environmental Division Mohawk Council of Akwesasne
27) Nina-Marie Lister, PhD School of Urban & Regional Planning Ryerson Polytechnic University, Toronto	28) Misty MacDufee Raincoast Conservation Society Victoria, British Columbia

Appendix 7 LIST OF INTERVIEW RESPONDENTS
SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

29) Don MacIver , Director of Planning Rideau Valley Conservation Authority, Manotick, Ontario	30) André L. Martel, PhD Canadian Museum of Nature Gatineau, Quebec
31) Grey Merriam, PhD Emeritus Professor Biology, Carleton University, Ottawa, Ontario	32) Ted Mosquin, PhD (Retired) Lanark, Ontario
33) Kelly .R. Munkittrick , PhD Canadian Rivers Institute, St. John, New Brunswick	34) Neil Munro Science Advisor (retired), Parks Canada, Halifax N.S.
35) Aviva Patel, PhD Forest and Wildlife Campaigner, Sierra Club, Eastern Canada Chapter	36) Daniel Pauly , PhD UBC Fisheries Centre, Vancouver, British Columbia
37) Kevin Percy, PhD Atlantic Canada Forestry Centre Fredericton, New Brunswick	38) Mike Quinn, PhD, Director Miistakis Institute for the Rockies University of Calgary, Alberta
39) Bill Rees, PhD School of Community & Regional Planning, Vancouver, British Columbia	40) Henry Regier, PhD Emeritus Professor, Zoology University of Toronto
41) Paul H. Rennick, Rennick & Associates Peterborough, Ontario	42) Patricia Roberts-Pichette PhD Former Executive Secretary Canada/MAB, Ottawa, Ontario
43) Scott Slocombe, PhD Geography & Environmental Studies Wilfrid Laurier University, Waterloo ON	44) Harvey Shear, PhD Regional Science Advisor, Environment Canada-Ontario Region
45) Ussif Rashid Sumaila PhD Fisheries Economic Research Unit, UBC Fisheries Centre, Vancouver B.C.	46) Phil Taylor, PhD Department of Biology Acadia University, Wolfville, NS
47) Tony Turner A.M. Turner & Associates Ottawa, Ontario	48) Hague Vaughan PhD, Director, Ecological Monitoring and Assessment Network, Burlington, Ontario
49) David Waltner-Toews, PhD, DVM Department of Population Medicine, University of Guelph, Ontario	50) Ed Wiken, Director Science & Policy WildLife Habitat Canada, Ottawa, Ontario

Appendix 8. WEBGRID SURVEY & USER GUIDE

SURVEY OF EXPERT'S MENTAL MODELS OF ECOSYSTEM RISK

E-Mail Request to Participants:

Thank you for agreeing to participate in my study. Since I last spoke to you I have interviewed over fifty persons from coast-to-coast. Like you, they are knowledgeable about ecosystem risks but some are from very different disciplines or line of work. During the interview I asked each of you to tell me what you thought was important about ecosystems. I have analysed the interview results and identified widely shared conceptual distinctions many of you use when you talk about ecosystems.

I am now asking you to complete the second and final stage of my study. It requires you to apply a common set of criteria to describe how several concepts or types of ecosystems differ from one another. It should take less than thirty minutes to complete the questionnaire.

My questionnaire has to be filled out online and interacts with the server of the University of Calgary. Professors Muriel Shaw and Brian Gaines developed the Web Grid software behind the questionnaire. This software helps me elicit everyone's views about a common domain of expertise.

Just activate the survey web page http://www.ecosmiths.ca/wg_intro/frame.htm using your browser. (Either Microsoft Explorer or Netscape Navigator should do). I would start by downloading and reviewing the short User Guide from the introductory page. (You will need the Acrobat Reader to read the User Guide). The User Guide will provide you with an overview of the various data entry screens and functions of Web Grid. As you complete the survey the ? buttons throughout the questionnaire will also provide you with context sensitive help.

All you have to do is rate each of eight eco-concepts using 36 assessment criteria. If you find it too tedious or it is not brain friendly to proceed criterion-by-criterion, the User Guide explains how to select individual eco-concepts using the Elicitation Screen and to apply all the assessment criteria to a concept-at-a-time. Check the second line of the Elicitation Screen to ensure there are no remaining unspecified values. When all the values for the variables have been specified, this line will disappear.

2. ***Monocultures***

Monocultures describe managed areas, such as plantation forests, fish farms (aquaculture) and grain farms (e.g. wheat and corn) whose productivity is maintained through human supplied inputs and technology

3. ***Ecosystem Health***

Ecosystem Health describes an envelope or range of possible ecosystem conditions that will sustain life. Ecosystems provide food, fibre, energy, and the other commodities that humans need for their survival, and maintain clean air, pure water, and other vital life support functions. The goal of the approach is to optimize the array of goods and services which ecosystems provide, while preserving or increasing their capacity to produce those things in the future. As well, the ecosystem approach tries to maintain future management options so that we can accommodate changes in societal values.

4. ***Sustainability***

Environmental sustainability at the most basic level is a function of the state of ecosystems, the stresses on those systems, human vulnerability to environmental change, and the capacity of human institutions to respond to these challenges and provide global stewardship of environmental resources. Human success in influencing these aspects of their environment in a lasting manner will affect their chances of survival and their quality of life a generation or two into the future.

5. ***Natural/Pristine***

Natural or pristine refers to wilderness areas, relatively undisturbed by humans, where natural processes and events are still the driving force of evolutionary change.

6. ***Resilience***

Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. Humans are part of the natural world. We depend on ecological systems for our survival and we continuously impact the ecosystems in which we live from the local to global scale. Resilience gives humans the opportunity to anticipate and plan for the future

7. ***Biological/Ecological Integrity***

Biological or Ecological Integrity refers to an ecosystem's capacity to sustain the native biological communities that have adapted to a region through natural evolutionary forces. In plain language, ecosystems have integrity when they have their native components (plants, animals or other organisms) and processes that generate future integrity intact.

8. ***Urban/industrial***

Urban or Industrial refers to highly disturbed areas dominated by human economic activities and settlement.

WebGrid SURVEYS

Rather than requiring you to respond to a fixed format, forced choice questionnaire, we decided to use the WebGrid software developed by Professors Muriel Shaw and Brian Gaines of the University of Calgary (CPCS 2003, Gaines & Shaw 1996) for our survey questionnaire. Because it is not feasible for us to gather all you in the same room to complete the second stage of our study, WebGrid provides the means for you to share your response with us online. WebGrid is also an online toolkit. It permits you to enter and edit your own response. If you are not satisfied with the form or content of the questionnaire, it will also allow you to ***Add***, ***Delete*** or ***Edit*** the concepts and criteria used. When you are done you can also use WebGrid's analytical tools to examine your response. For example, you can use ***CLUSTER*** to display your assessment as a tree diagram revealing the underlying dependencies in your use of the criteria. ***MAP*** will allow you to display the data in a minimum number of dimensions allowing you to examine underlying similarities and differences in your use of these eco-concepts.

Repertory Grid Scales

We are asking you to use what are called Repertory Grid scales to apply the assessment criteria to describe what each of these eco-concepts means to you. You may not be familiar with the conventions of Repertory Grid scales.

Repertory grid scales are not read like conventional scales. Conventional scales may ask you to say how much you agree with a particular statement, with responses ranging from totally disagree to strongly agree. Instead, a repertory grid scale contrasts two different conditions.

For example, when some people think about habitat, they may think that a certain amount of connectivity is necessary and that habitat fragmentation is something we should avoid. Connectivity is contrasted with fragmentation. In thinking about the eco-concept biological or ecological integrity you may think that a habitat with biological or ecological integrity is likely to be interconnected rather than fragmented. In thinking about urban or industrial area, you may think that habitat in such an area is more likely to be fragmented rather than interconnected.

Each assessment criterion is presented as a range of values between two contrasting conditions or states. Pick the value that most adequately describes how you see each eco-concept.

If you think that either of the contrasting conditions or states could prevail, mark the assessment criterion 3 on a scale of 1 to 5. If you do not think a criterion applies at all, leave it blank. In WebGrid unspecified values are displayed as a ?

Now you are ready to begin.

Appendix 8. WEB GRID SURVEY USER GUIDE

CHOOSING AN ELICITATION STRATEGY

There are two possible strategies for completing the task. The first strategy we call criterion-centred: you rate all of the eco-concepts using the first criterion, then all of the concepts using the next criterion, and so on. The second strategy we call concept centred: you can take the first eco-concept and rate it using all of the criteria in turn, then rate the second eco-concept using all of the criteria in turn, and so on.

The WebGrid software defaults to the first strategy. If you want to apply the second strategy press ***Cancel*** rather than ***Done*** when the first screen pops up (See fig.2 page 8), and you will be taken directly to the *Elicitation Page*. (See fig 3 on page 10 of the User Guide.) You will see all the eco-concepts and assessment criteria listed in two separate boxes. Highlight one of the eco-concepts such as *Sustainability* with your browser and press the ***Edit*** button below the box and you will be taken to a screen that will allow you to input values for all the assessment criteria. Then repeat the same step for each of the remaining concepts.

SAVING YOUR WORK

When you have finished inputting your response you will be taken back to the *Elicitation Page* (see fig. 3 page 10). Press the ***Save/Exchange*** button at the bottom of the page to save your work to the cache and when the status page comes up you will be advised to save the page as an HTML form to your own computer. If you did not have time to rate all the concepts, you will now be able to reload the form at any time with your browser and complete the exercise.

We have asked you to complete a complex task. Please do not hesitate to contact us at bill@ecosmiths.ca. if you need any additional help.

Appendix 8. WEB GRID SURVEY USER GUIDE

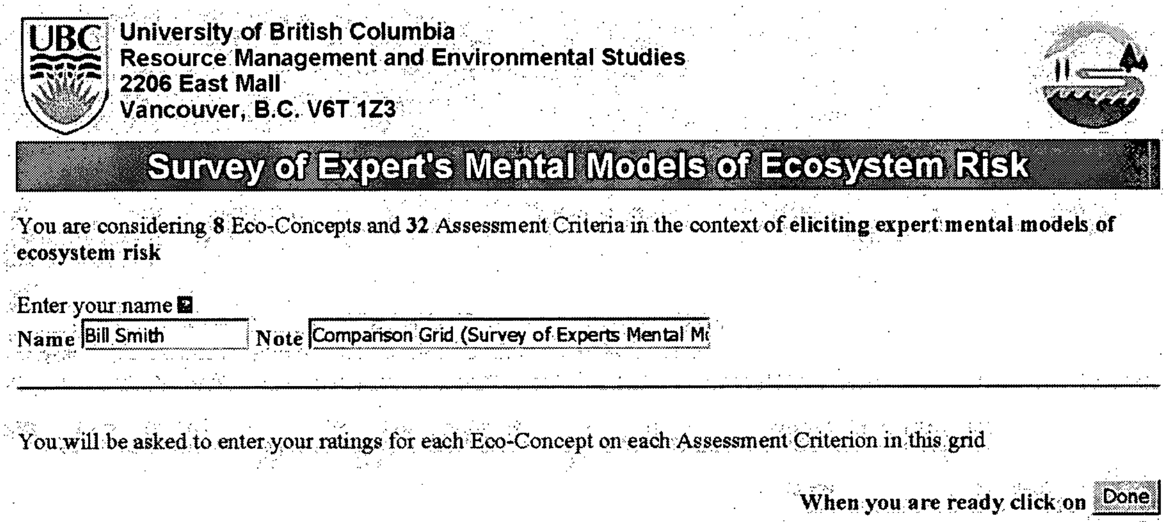

Figure 1: Exchange Grid

Enter your name in the space provided (fig. 1) and then press **Done** when you are ready to rate the eco-concepts.

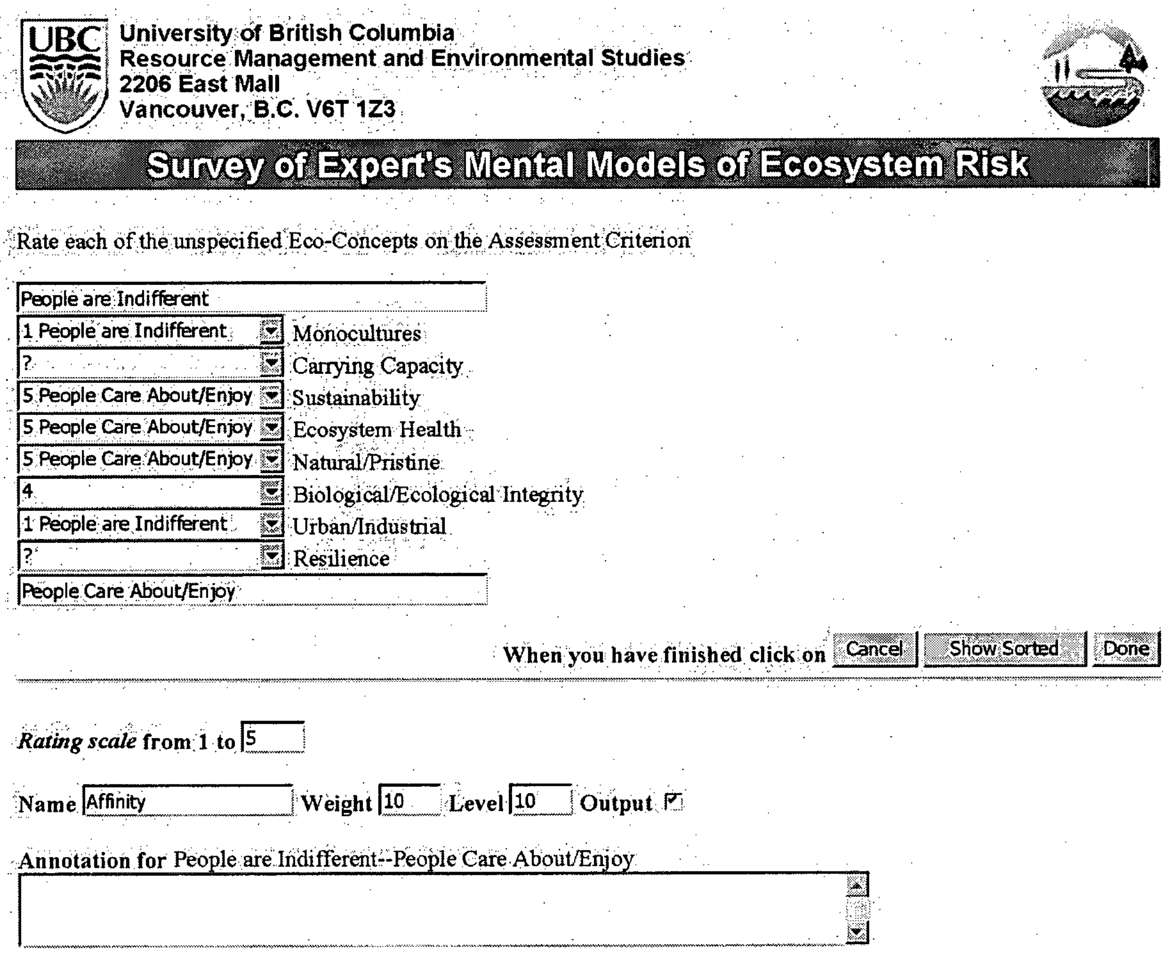

Figure 2 Rating Eco-Concepts

Appendix 8. WEB GRID SURVEY USER GUIDE

Next you will be asked to rate the eight eco-concepts using 36 assessment criteria (fig 2). The assessment criteria will allow you to distinguish between contrasting ecosystem conditions. You are asked to rate each criterion on a scale of 1-5. If you are unfamiliar with the criterion or feel it does not apply leave it blank. (Choose the?) If either of the contrasting conditions could apply then choose 3. You can also comment on the assessment criteria using the annotation textual box. Press ***Done*** when you have finished rating each of the eco-concepts.

When you have applied each of the assessment criteria, you will be taken to the *Elicitation Screen* (fig.3). You can then add, delete or edit eco-concepts or criteria.

If you would rather proceed concept-by-concept, press ***Cancel*** after you have applied one or more assessment criteria. You will be taken directly to the *Elicitation Screen* (fig.3). Highlight one of the eco-concepts using your cursor and then select ***Edit*** from the menu below the list of eco-concepts. You will be taken to an *Edit Screen* (fig 4) and you will be able to apply all the assessment criteria a concept-at-a-time.

Each time you finish inputting your data, press ***Done*** and you will be taken back to the *Elicitation Screen* (fig.3).

Until you have finished inputting values for all the assessment criteria the *Elicitation Screen* (fig.5) will show that there are values that remain unspecified. Press ***Specify*** to input the remaining values (fig.6)

Each time you input and save data you will be returned to the *Elicitation Screen*. When you are finished, press ***Save/Exchange*** button at the bottom of the page to save your work to the online cache.

When you exit the program to the *Status Screen* (fig.7) save your input as an HTML form to your own computer as a backup.

If you are unable to complete the survey in one sitting, you can reactivate the Web-Grid server by loading the saved HTML form (see fig 7) with Microsoft Explorer then press ***Continue*** and you will be taken to the *Elicitation Screen* and be able to finish inputting your response.

When you are finished, press ***Save/Exchange*** button at the bottom of the *Elicitation Screen* to save your work to the online cache. We would also like you to send us a copy of the HTML form as a backup

And you are done!

Appendix 8. WEB GRID SURVEY USER GUIDE

University of British Columbia
Resource Management and Environmental Studies
2206 East Mall
Vancouver, B.C. V6T 1Z3

Survey of Expert's Mental Models of Ecosystem Risk

You are considering **8** Eco-Concepts and **32** Assessment Criteria in the context of **eliciting expert mental models of ecosystem risk** [Continue] ?

The Assessment Criteria **Decreased Genetic Diversity--Increased Genetic Diversity** and **Many Species at Risk/Last of a Few--Most Species Survive & Thrive** are very similar - click here if you want to enter another Eco-Concept to distinguish them [Distinguish] ?

The Eco-Concepts **Carrying Capacity** and **Natural/Pristine** are very similar - click here if you want to enter another Assessment Criterion to distinguish them [Distinguish] ?

You can elicit another Assessment Criterion using a pair or triad of Eco-Concepts [Pair] [Triad] ?
If you want specific Eco-Concepts included, check this box ☐ and select them in the list below

You can delete, edit, sort, add and show matches among Eco-Concepts

- Monocultures
- Carrying Capacity
- Sustainability
- Ecosystem Health
- Natural/Pristine
- Biological/Ecological Integrity
- Urban/Industrial
- Resilience

[Delete] [Add] [Edit] [Edit note] [Sort] [Show matches] [Test case] ?

You can delete, edit, sort, add and show matches among Assessment Criteria

- Adequate Freshwater Supply--Fresh Water in Short Supply
- People are Indifferent--People Care About/Enjoy
- Low Mortality Rates--High Mortality Rates
- High Reproductive Success--Low Reproductive Success
- High Level of Contaminants--Low Level of Contaminants
- Population Growing or Declining--Population Size Stable & Viable
- Predominantly Native Species--Exotic & Invasive Species Present
- Complex Physical Structure--Simplified Physical Structure
- Unstable/Shifting Trophic Structure--Stable Trophic Structure
- Age Distribution Balanced--Age Distribution Skewed
- Bioaccumulation--Decomposition
- No Direct Human Use/Impacts--Substantial Human Harvesting/Use
- Smaller Shorter Lived Lifeforms--Larger Longer Lived Lifeforms
- Resilient - recover and repeat cycle--Vulnerable - shift to new state or cycle
- Nutrient Retention - absorb/import--Nutrient Leakage - release/export
- Habitat Fragmented or Lost--Habitat Interconnected
- Plentiful & Widely Dispersed--Rare or Endemic
- Decreased Genetic Diversity--Increased Genetic Diversity
- Complex Robust Food Webs--Simplified Fragile Food Webs
- Disease Spreads/Deformities Present--Disease/Deformities Absent or Rare
- Metabolic Processes Disrupted--Normal Metabolic Processes
- Small Habitat Patches--Large Habitat Patches
- Reduced Range or Displaced--Normal Range
- Biomass Decreasing--Biomass Constant/Increasing
- Regenerate to Same Species--Species Composition Changing
- Production--Respiration
- Minimum Climate Variability--Climate Warming or Cooling
- Human Population Constant/Declines--Human Population Grows
- Extensive or Severe Disturbance--Minor Variation in Disturbance Regime
- People Familiar - Grew up with--People Unfamiliar - Don't know
- Profound large-scale land use change--Minimal small scale land-use change
- Many Species at Risk/Last of a Few--Most Species Survive & Thrive

[Delete] [Add] [Edit] [Edit note] [Sort] [Show matches] ?

Analyses [Display] [Cluster] [Map] [Entail] [Compare] Selected ☐ Weights ☐ ?

[Send comment] [Edit status] [Save/Exchange] [? off] ?

Appendix 8. WEB GRID SURVEY USER GUIDE

Figure 3: Elicitation Screen

University of British Columbia
Resource Management and Environmental Studies
2206 East Mall
Vancouver, B.C. V6T 1Z3

Survey of Expert's Mental Models of Ecosystem Risk

You can edit the Eco-Concepts on the Assessment Criteria

Urban/Industrial

- 5 Fresh Water in Short Supply | Adequate Freshwater Supply--Fresh Water in Short Supply
- 1 People are Indifferent | People are Indifferent--People Care About/Enjoy
- 5 High Mortality Rates | Low Mortality Rates--High Mortality Rates
- 5 Low Reproductive Success | High Reproductive Success--Low Reproductive Success
- 1 High Level of Contaminants | High Level of Contaminants--Low Level of Contaminants
- 1 Population Growing or Declining | Population Growing or Declining--Population Size Stable & Viable
- 5 Exotic & Invasive Species Present | Predominantly Native Species--Exotic & Invasive Species Present
- 5 Simplified Physical Structure | Complex Physical Structure--Simplified Physical Structure
- 1 Unstable/Shifting Trophic Structure | Unstable/Shifting Trophic Structure--Stable Trophic Structure
- 5 Age Distribution Skewed | Age Distribution Balanced--Age Distribution Skewed
- 1 Bioaccumulation | Bioaccumulation--Decomposition
- 5 Substantial Human Harvesting/Use | No Direct Human Use/Impacts--Substantial Human Harvesting/Use
- 1 Smaller Shorter Lived Lifeforms | Smaller Shorter Lived Lifeforms--Larger Longer Lived Lifeforms
- 5 Vulnerable - shift to new state or cycle | Resilient - recover and repeat cycle--Vulnerable - shift to new state or cycle
- 5 Nutrient Leakage - release/export | Nutrient Retention - absorb/import--Nutrient Leakage - release/export
- 1 Habitat Fragmented or Lost | Habitat Fragmented or Lost--Habitat Interconnected
- 5 Rare or Endemic | Plentiful & Widely Dispersed--Rare or Endemic
- 1 Decreased Genetic Diversity | Decreased Genetic Diversity--Increased Genetic Diversity
- 5 Simplified Fragile Food Webs | Complex Robust Food Webs--Simplified Fragile Food Webs
- 1 Disease Spreads/Deformities Present | Disease Spreads/Deformities Present--Disease/Deformities Absent or Rare
- 1 Metabolic Processes Disrupted | Metabolic Processes Disrupted--Normal Metabolic Processes
- 1 Small Habitat Patches | Small Habitat Patches--Large Habitat Patches
- 1 Reduced Range or Displaced | Reduced Range or Displaced--Normal Range
- 1 Biomass Decreasing | Biomass Decreasing--Biomass Constant/Increasing
- 5 Species Composition Changing | Regenerate to Same Species--Species Composition Changing
- 5 Respiration | Production--Respiration
- 5 Climate Warming or Cooling | Minimum Climate Variability--Climate Warming or Cooling
- 5 Human Population Grows | Human Population Constant/Declines--Human Population Grows
- 1 Extensive or Severe Disturbance | Extensive or Severe Disturbance--Minor Variation in Disturbance Regime
- 1 People Familiar - Grew up with | People Familiar - Grew up with--People Unfamiliar - Don't know
- 1 Profound large-scale land use change | Profound large-scale land use change--Minimal small scale land-use change
- 1 Many Species at Risk/Last of a Few | Many Species at Risk/Last of a Few--Most Species Survive & Thrive

Annotation

Urban or Industrial refer to highly disturbed areas dominated by human economic activities and settlement.

When you have finished click on Cancel Done

Figure 4: Edit Eco-Concepts

Appendix 8. WEB GRID SURVEY USER GUIDE

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Survey of Expert's Mental Models of Ecosystem Risk

You are considering **8** Eco-Concepts and **32** Assessment Criteria in the context of **eliciting expert mental models of ecosystem risk** Continue ?

There are **16** unspecified values Specify ?

Figure 5: Elicitation Screen – Unspecified Values

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Rate each of the unspecified Eco-Concepts on the Assessment Criterion

Minimum Climate Variability	
?	Monocultures
?	Resilience
1 Minimum Climate Variability	Natural/Pristine
2	Carrying Capacity
2	Biological/Ecological Integrity
3	Sustainability
3	Ecosystem Health
5 Climate Warming or Cooling	Urban/Industrial
Climate Warming or Cooling	

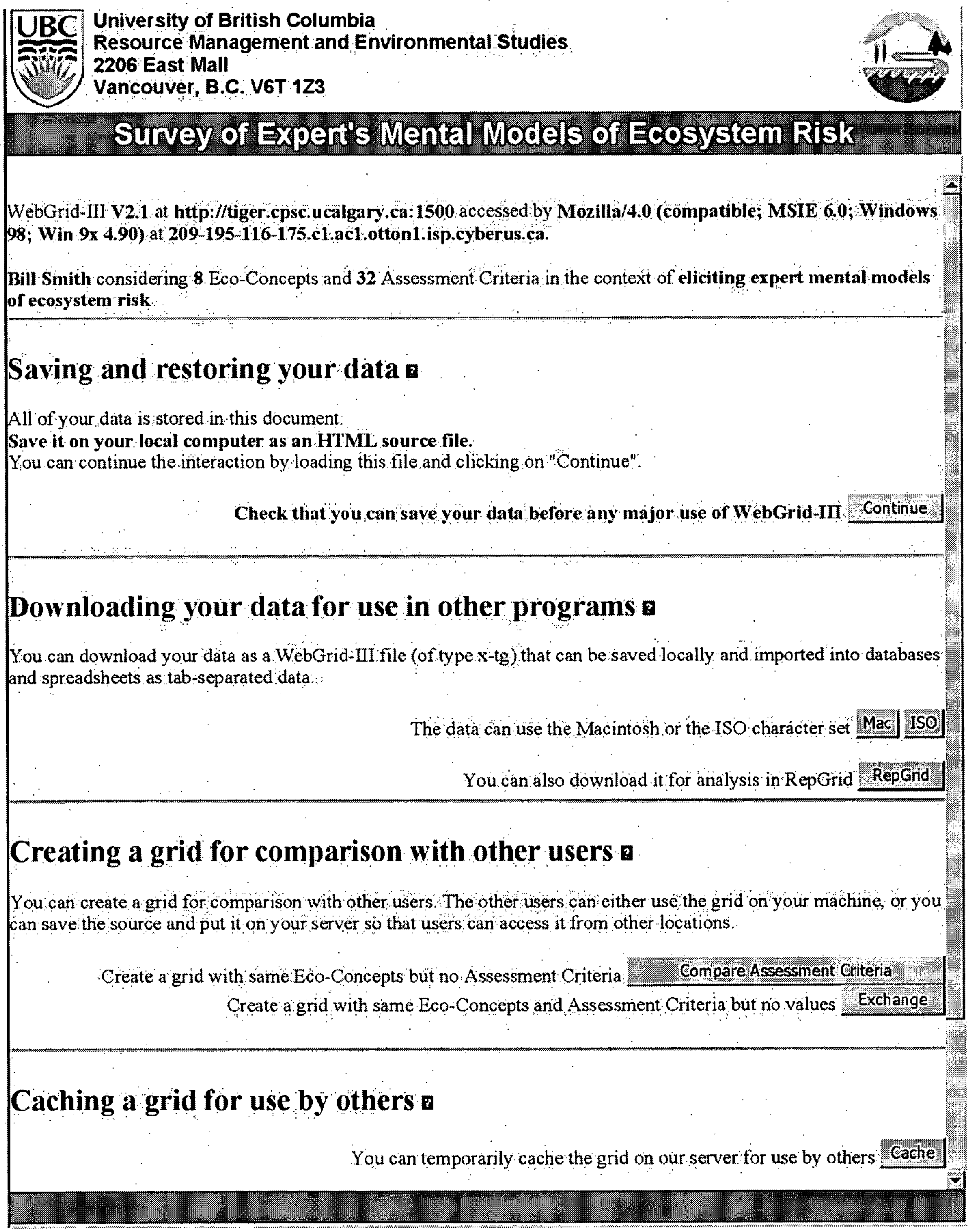
When you have finished click on Cancel Show Sorted Done

Rating scale **from 1 to** 5

Name Climate Change **Weight** 10 **Level** 10 **Output** ☑

Annotation for Minimum Climate Variability--Climate Warming or Cooling

Figure 6: Specify Missing Values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WebGrid-III **V2.1** at **http://tiger.cpsc.ucalgary.ca:1500** accessed by **Mozilla/4.0 (compatible; MSIE 6.0; Windows 98; Win 9x 4.90)** at **209-195-116-175.c1.ac1.otton1.isp.cyberus.ca.**

Bill Smith considering **8** Eco-Concepts and **32** Assessment Criteria in the context of **eliciting expert mental models of ecosystem risk**

Saving and restoring your data

All of your data is stored in this document.
Save it on your local computer as an HTML source file.
You can continue the interaction by loading this file and clicking on "Continue".

Check that you can save your data before any major use of WebGrid-III Continue

Downloading your data for use in other programs

You can download your data as a WebGrid-III file (of type x-tg) that can be saved locally and imported into databases and spreadsheets as tab-separated data.

The data can use the Macintosh or the ISO character set Mac ISO

You can also download it for analysis in RepGrid RepGrid

Creating a grid for comparison with other users

You can create a grid for comparison with other users. The other users can either use the grid on your machine, or you can save the source and put it on your server so that users can access it from other locations.

Create a grid with same Eco-Concepts but no Assessment Criteria Compare Assessment Criteria
Create a grid with same Eco-Concepts and Assessment Criteria but no values Exchange

Caching a grid for use by others

You can temporarily cache the grid on our server for use by others Cache

Figure 7: Status Screen

EDITING YOUR INPUT

The *Elicitation Screen* (fig. 3) provides the means of reviewing your response. For example, you can identify closely matched concepts (fig. 8) and edit your response eco-concept –by-eco-concept (fig 9).

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Survey of Expert's Mental Models of Ecosystem Risk

88.3%
Sustainability
Ecosystem Health
86.7%
Natural/Pristine
Biological/Ecological Integrity
85.9%
Monocultures
Urban/Industrial
81.2%
Carrying Capacity
Biological/Ecological Integrity
79.7%
Ecosystem Health
Resilience
77.3%
Carrying Capacity
Natural/Pristine
77.3%
Carrying Capacity
Resilience
77.3%
Biological/Ecological Integrity
Resilience
74.2%
Carrying Capacity
Ecosystem Health
74.2%
Sustainability
Resilience

Figure 8: Eco-Concept matches

You can revise any of the assessment criteria used to describe a particular eco-concept (fig. 9).

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Survey of Experts' Mental Models of Ecosystem Risk

You can edit the Eco-Concepts on the Assessment Criteria

Biological or **Ecological Integrity** refers to an ecosystems capacity to sustain the native biological communities that have adapted to a region through natural evolutionary forces. In plain language ecosystems have integrity when they have their native components (plants, animals or other organisms) and processes that generate future integrity intact.

Biological/Ecological Integrity

3 Low Morbity--High Morbidity
1 High Reproductive Success High Reproductive Success--Low Reproductive Success
4 Polluted--Unpolluted
3 Population Growth--Population Decline
1 Native Species Native Species--Exotic Species
1 Complex Physical Structure Complex Physical Structure--Simple Physical Structure
1 Stable Trophic Structure Stable Trophic Structure--Unstable/Shifting Trophic Structure
1 Age Classes Balanced Age Classes Balanced--Age Classes Skewed
1 Decomposition Decomposition--Bioaccumulation/Biomagnification
3 Subsidy--Stress
2 K-selected Lifeforms--R-selected Lifeforms
4 Pioneer--Climax
1 Nutrient Retention Nutrient Retention--Nutrient Leakage
1 Habitat Connectivity Habitat Connectivity--Habitat Loss - Fragmentation
2 Rare/Endemic--Common /Dispersed
5 High Species Diversity Low Species Diversity--High Species Diversity
5 Robust Food Webs Fragile Food Webs--Robust Food Webs
4 Tumours/Deformities Common--Tumours/Deformities Rare
1 Viable Population Viable Population--@Risk of Extirpation
5 Large Habitat Patches Small Habitat Patches--Large Habitat Patches
4 Reduced/Displaced Range--Normal Range
2 Biomass Stable/Increasing--Biomass Unstable/Decreasing
2 Larger-Longer Lived Lifeforms--Smaller-Shorter Lived Lifeforms
2 Production--Respiration

Annotation

Biological or Ecological Integrity refers to an ecosystems capacity to sustain the native biological communities that have adapted to a region through natural evolutionary forces. In

When you have finished click on Cancel Done

Figure 9: Edit Eco-Concepts

You can also identify closely matched assessment criteria (fig. 10), review and edit your use of these criteria (fig 11).

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Survey of Experts' Mental Models of Ecosystem Risk

Here are the matches between the selected Assessment Criteria

Low Species Diversity--High Species Diversity

91.7%
Unstable/Shifting Trophic Structure--Stable Trophic Structure
91.7%
Bioaccumulation/Biomagnification--Decomposition
91.7%
Fragile Food Webs--Robust Food Webs
91.7%
Small Habitat Patches--Large Habitat Patches
91.7%
Biomass Unstable/Decreasing--Biomass Stable/Increasing
87.5%
Exotic Species--Native Species
87.5%
Nutrient Leakage--Nutrient Retention
87.5%
@Risk of Extirpation--Viable Population
87.5%
Smaller-Shorter Lived Lifeforms--Larger-Longer Lived Lifeforms
83.3%
Simple Physical Structure--Complex Physical Structure
83.3%
Habitat Loss - Fragmentation--Habitat Connectivity
83.3%
Tumours/Deformities Common--Tumours/Deformities Rare
83.3%
Reduced/Displaced Range--Normal Range
79.2%
Low Reproductive Success--High Reproductive Success
79.2%
Age Classes Skewed--Age Classes Balanced
79.2%
Common /Dispersed--Rare/Endemic
75.0%
Polluted--Unpolluted
75.0%
R-selected Lifeforms--K-selected Lifeforms
75.0%
Pioneer--Climax
70.8%
High Morbidity--Low Mortality
70.8%
Population Decline--Population Growth
70.8%
Respiration--Production
66.7%
Stress--Subsidy

Done

Figure10 Assessment Criteria Matches

Appendix 8. WEB GRID SURVEY USER GUIDE

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Survey of Experts' Mental Models of Ecosystem Risk

You can edit any of the data for the Eco-Concepts or Assessment Criterion

Low Species Diversity

Urban or **Industrial** refer to highly disturbed areas dominated by human economic activities and settlement.

1 Low Species Diversity Urban/Industrial

Ecosystem Health describes an envelope or range of possible system conditions that will sustain life. Ecosystems provide food, fibre, energy, and the other commodities that humans need for their survival, and maintain clean air, pure water, and other vital life support functions. The goal of the Ecosystem Health approach is to optimise the array of goods and services ecosystems provide, while preserving or increasing their capacity to produce those things in the future. As well, the ecosystem approach tries to maintain future management options so that we can accommodate changes in societal values.

2 Ecosystem Health

Environmental Sustainability at the most basic level is a function of the state of ecosystems, the stresses on those systems, human vulnerability to environmental change, and the ability human institutions to respond to these challenges and the demands for global stewardship of environmental resources.

3 Sustainable

Carrying Capacity is the maximum population of a given species that a particular environment can support indefinitely without habitat damage. Human carrying capacity is heavily influenced by a society's level of technological development and pattern of organization.

4 Carrying Capacity

Natural or **Pristine** refers to wilderness areas, relatively undisturbed by humans, where natural processes and events are still the driving force of evolutionary change.

4 Natural/Pristine

Biological or **Ecological Integrity** refers to an ecosystems capacity to sustain the native biological communities that have adapted to a region through natural evolutionary forces. In plain language ecosystems have integrity when they have their native components (plants, animals or other organisms) and processes that generate future integrity intact.

5 High Species Diversity Biological/Ecological Integrity

High Species Diversity

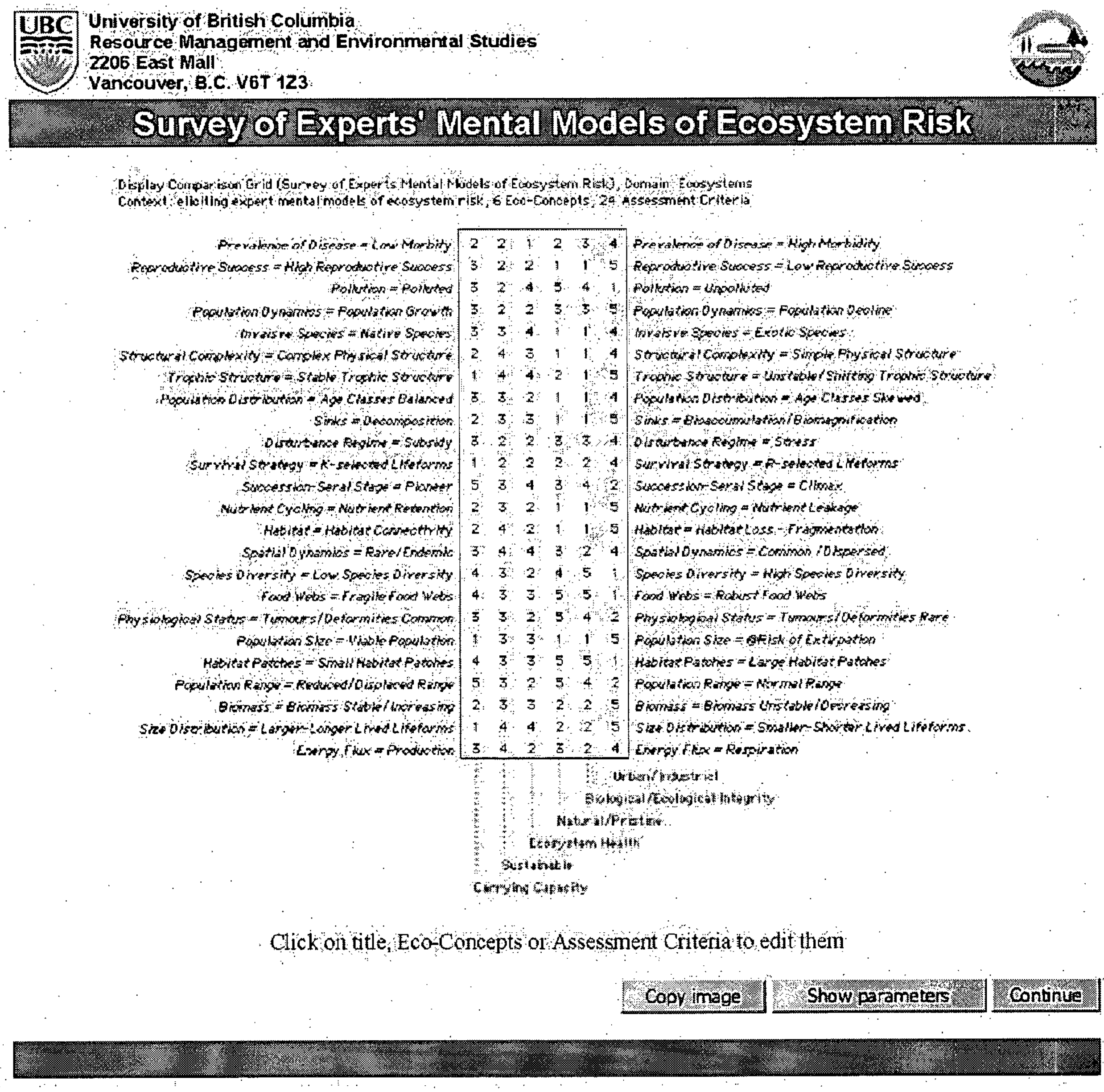
When you have finished click on Cancel Show Sorted Done

***Rating scale* from 1 to** 5

Figure11 Edit Assessment Criteria

ANALYSING THE OUTPUT

The Web Grid Software also provides analytical functions if you are interested that will allow you to examine and revise your input. It is not necessary to use these functions to complete the survey successfully.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Survey of Experts' Mental Models of Ecosystem Risk

Display Comparison Grid (Survey of Experts Mental Models of Ecosystem Risk), Domain: Ecosystems
Context: eliciting expert mental models of ecosystem risk, 6 Eco-Concepts, 24 Assessment Criteria

Prevalence of Disease = Low Morbity	2	2	1	2	3	4	Prevalence of Disease = High Morbidity
Reproductive Success = High Reproductive Success	3	2	2	1	1	5	Reproductive Success = Low Reproductive Success
Pollution = Polluted	3	2	4	5	4	1	Pollution = Unpolluted
Population Dynamics = Population Growth	3	2	2	3	3	5	Population Dynamics = Population Decline
Invasive Species = Native Species	3	3	4	1	1	4	Invasive Species = Exotic Species
Structural Complexity = Complex Physical Structure	2	4	3	1	1	4	Structural Complexity = Simple Physical Structure
Trophic Structure = Stable Trophic Structure	1	4	4	2	1	5	Trophic Structure = Unstable/Shifting Trophic Structure
Population Distribution = Age Classes Balanced	3	3	2	1	1	4	Population Distribution = Age Classes Skewed
Sinks = Decomposition	2	3	3	1	1	5	Sinks = Bioaccumulation/Biomagnification
Disturbance Regime = Subsidy	3	2	2	3	3	4	Disturbance Regime = Stress
Survival Strategy = K-selected Lifeforms	1	2	2	2	2	4	Survival Strategy = R-selected Lifeforms
Succession-Seral Stage = Pioneer	5	3	4	3	4	2	Succession-Seral Stage = Climax
Nutrient Cycling = Nutrient Retention	2	3	2	1	1	5	Nutrient Cycling = Nutrient Leakage
Habitat = Habitat Connectivity	2	4	2	1	1	5	Habitat = Habitat Loss - Fragmentation
Spatial Dynamics = Rare/Endemic	3	4	4	3	2	4	Spatial Dynamics = Common / Dispersed
Species Diversity = Low Species Diversity	4	3	2	4	5	1	Species Diversity = High Species Diversity
Food Webs = Fragile Food Webs	4	3	3	5	5	1	Food Webs = Robust Food Webs
Physiological Status = Tumours/Deformities Common	3	3	2	5	4	2	Physiological Status = Tumours/Deformities Rare
Population Size = Viable Population	1	3	3	1	1	5	Population Size = @Risk of Extirpation
Habitat Patches = Small Habitat Patches	4	3	3	5	5	1	Habitat Patches = Large Habitat Patches
Population Range = Reduced/Displaced Range	5	3	2	5	4	2	Population Range = Normal Range
Biomass = Biomass Stable/Increasing	2	3	3	2	2	5	Biomass = Biomass Unstable/Decreasing
Size Distribution = Larger-Longer Lived Lifeforms	1	4	4	2	2	5	Size Distribution = Smaller-Shorter Lived Lifeforms
Energy Flux = Production	3	4	2	3	2	4	Energy Flux = Respiration

Urban/Industrial
Biological/Ecological Integrity
Natural/Pristine
Ecosystem Health
Sustainable
Carrying Capacity

Click on title, Eco-Concepts or Assessment Criteria to edit them

Copy image | Show parameters | Continue

Figure 12 Display

Display (fig. 12) also allows you to review your input. You can click on any concept or criterion to edit them.

Appendix 8. WEB GRID SURVEY USER GUIDE

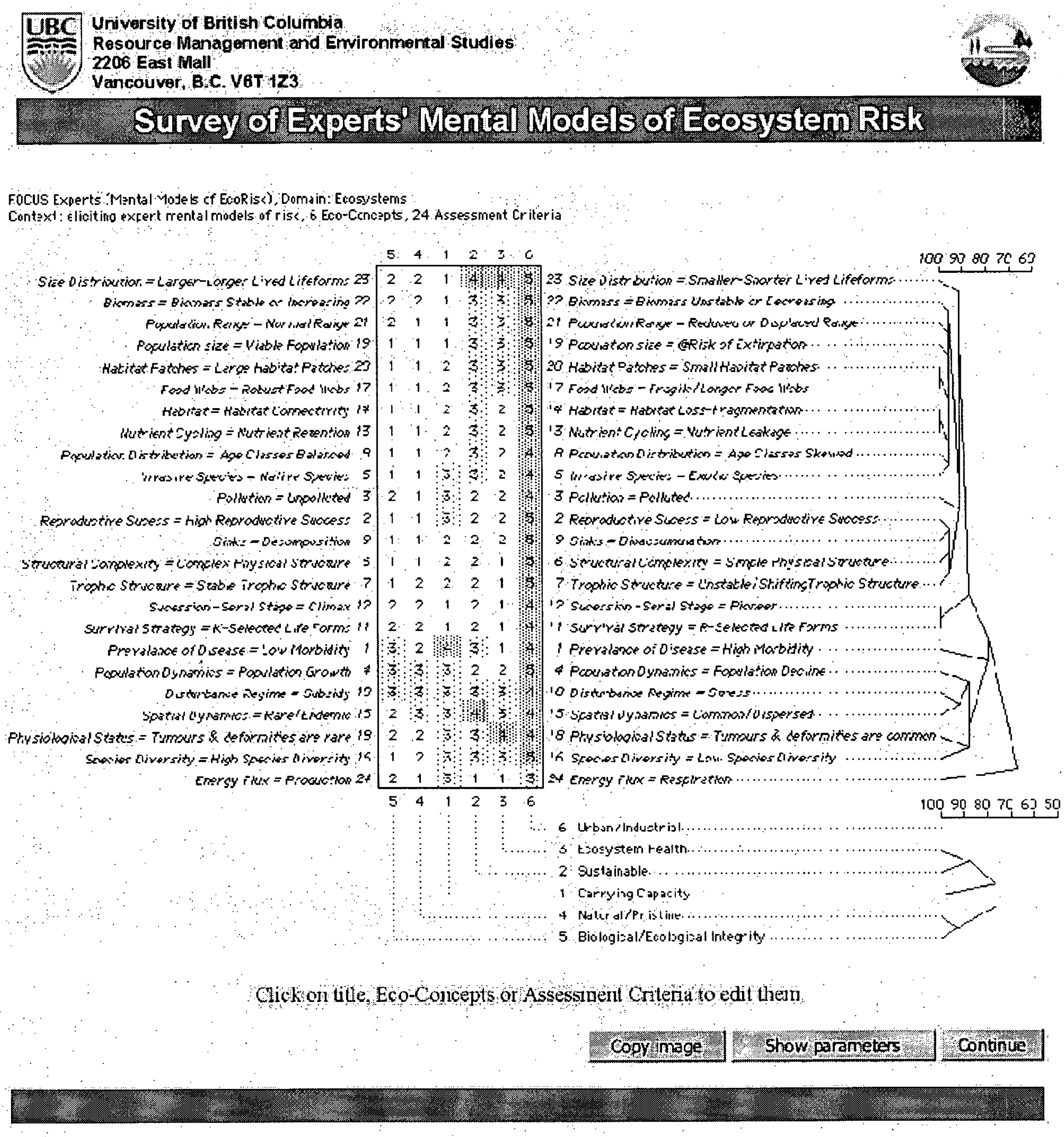

Figure 13 Cluster

$\boxed{\textit{Cluster}}$ (fig.13) uses the FOCUS algorithm to create a tree diagram showing the underlying dependencies among the concepts and criteria. You can click on any concept or criterion to edit them.

Appendix 8. WEB GRID SURVEY USER GUIDE

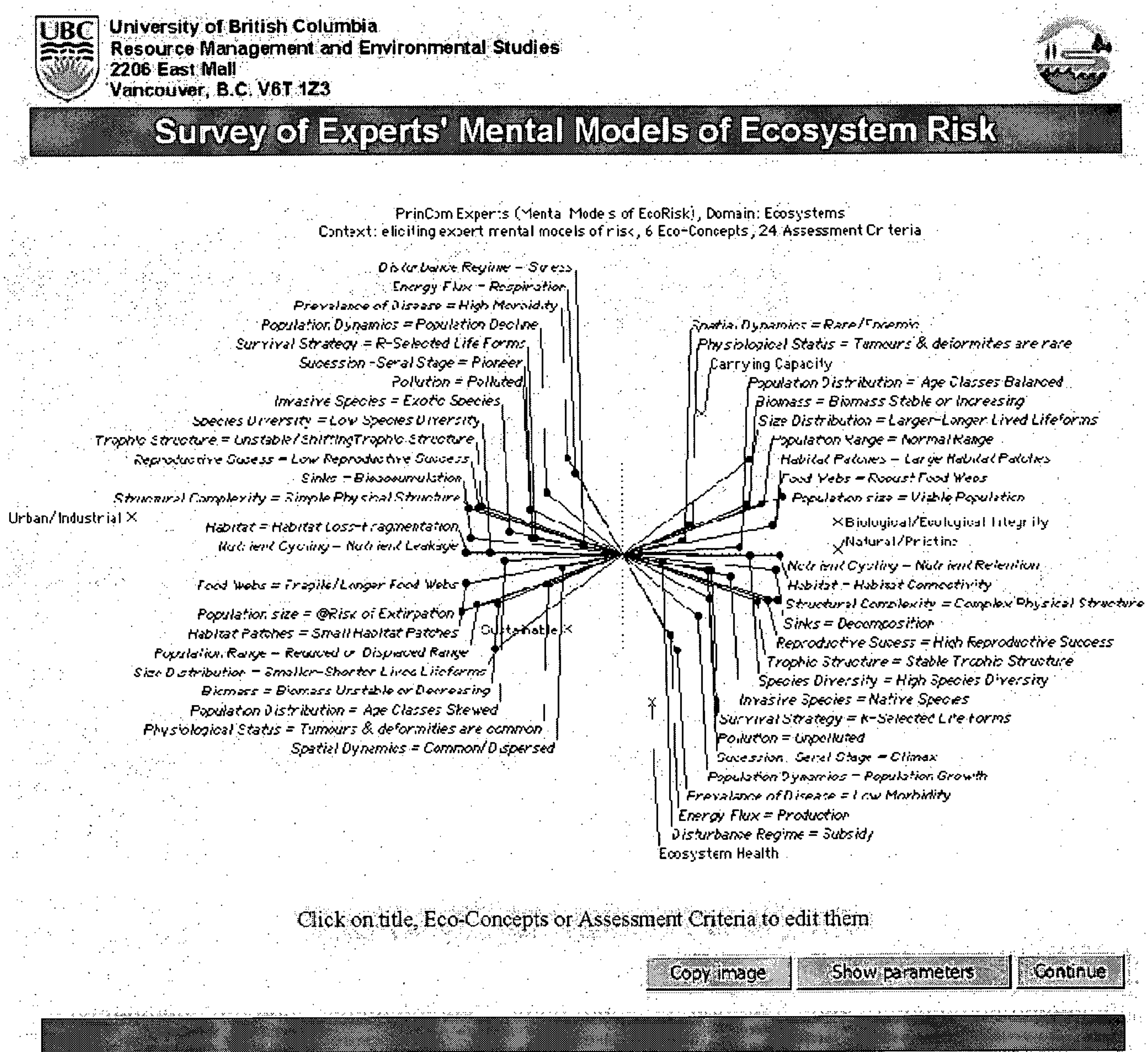

Figure 14 Map

Map (fig. 14) uses the PrinCom algorithm to represent the grid in a minimum number of dimensions. You can click on any concept or criterion to edit them.

Entail (fig. 15 over) uses the INDUCT algorithm to analyse the logical dependencies in the grid data and infers rules with exceptions that could be used to build a decision tree or influence diagram. You can click on any concept or criterion to edit them.

Appendix 8. WEB GRID SURVEY USER GUIDE

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Survey of Experts' Mental Models of Ecosystem Risk

Here are the entailments generated by Induct from your grid.

```
-> Food Webs = Robust Food Webs (3)
 +: Carrying Capacity, Natural/Pristine, Biological/Ecological Integrity
 |- Species Diversity = Low Species Diversity -> Food Webs = Fragile Food Webs (1)
 |   +: Urban/Industrial

Overall Evaluation
  Correct 4/4  100.00%

 -> Species Diversity = High Species Diversity (3)
  +: Carrying Capacity, Natural/Pristine, Biological/Ecological Integrity
 |- Size Distribution = Smaller-Shorter Lived Lifeforms -> Species Diversity = Low Species Divers:
 |   +: Ecosystem Health, Urban/Industrial

Overall Evaluation
  Correct 5/5  100.00%

 -> Physiological Status = Tumours/Deformities Common (2)
  +: Ecosystem Health, Urban/Industrial
 |- Species Diversity = High Species Diversity -> Physiological Status = Tumours/Deformities Rare
 |   +: Natural/Pristine, Biological/Ecological Integrity

Overall Evaluation
  Correct 4/4  100.00%

 -> Population Size = Viable Population (3)
  +: Carrying Capacity, Natural/Pristine, Biological/Ecological Integrity
 |- Food Webs = Fragile Food Webs -> Population Size = @Risk of Extirpation (1)
 |   +: Urban/Industrial

Overall Evaluation
  Correct 4/4  100.00%

 -> Habitat = Habitat Connectivity (4)
  +: Carrying Capacity, Ecosystem Health, Natural/Pristine, Biological/Ecological Integrity
 |- Energy Flux = Respiration & Size Distribution = Smaller-Shorter Lived Lifeforms -> Habitat = I
 |   +: Sustainable, Urban/Industrial

Overall Evaluation
  Correct 6/6  100.00%

 -> Spatial Dynamics = Common /Dispersed (3)
  +: Sustainable, Ecosystem Health, Urban/Industrial
 |- Size Distribution = Larger-Longer Lived Lifeforms -> Spatial Dynamics = Rare/Endemic (1)
 |   +: Biological/Ecological Integrity

Overall Evaluation
  Correct 4/4  100.00%

 -> Nutrient Cycling = Nutrient Retention (4)
  +: Carrying Capacity, Ecosystem Health, Natural/Pristine, Biological/Ecological Integrity
 |- Habitat = Habitat Loss - Fragmentation -> Nutrient Cycling = Nutrient Leakage (1)
 |   +: Urban/Industrial

Overall Evaluation
```

Figure 15 Entail

As others respondents complete the survey, we will be able to compare your responses using the **Compare** function (fig. 16 over).

Appendix 8. WEB GRID SURVEY USER GUIDE

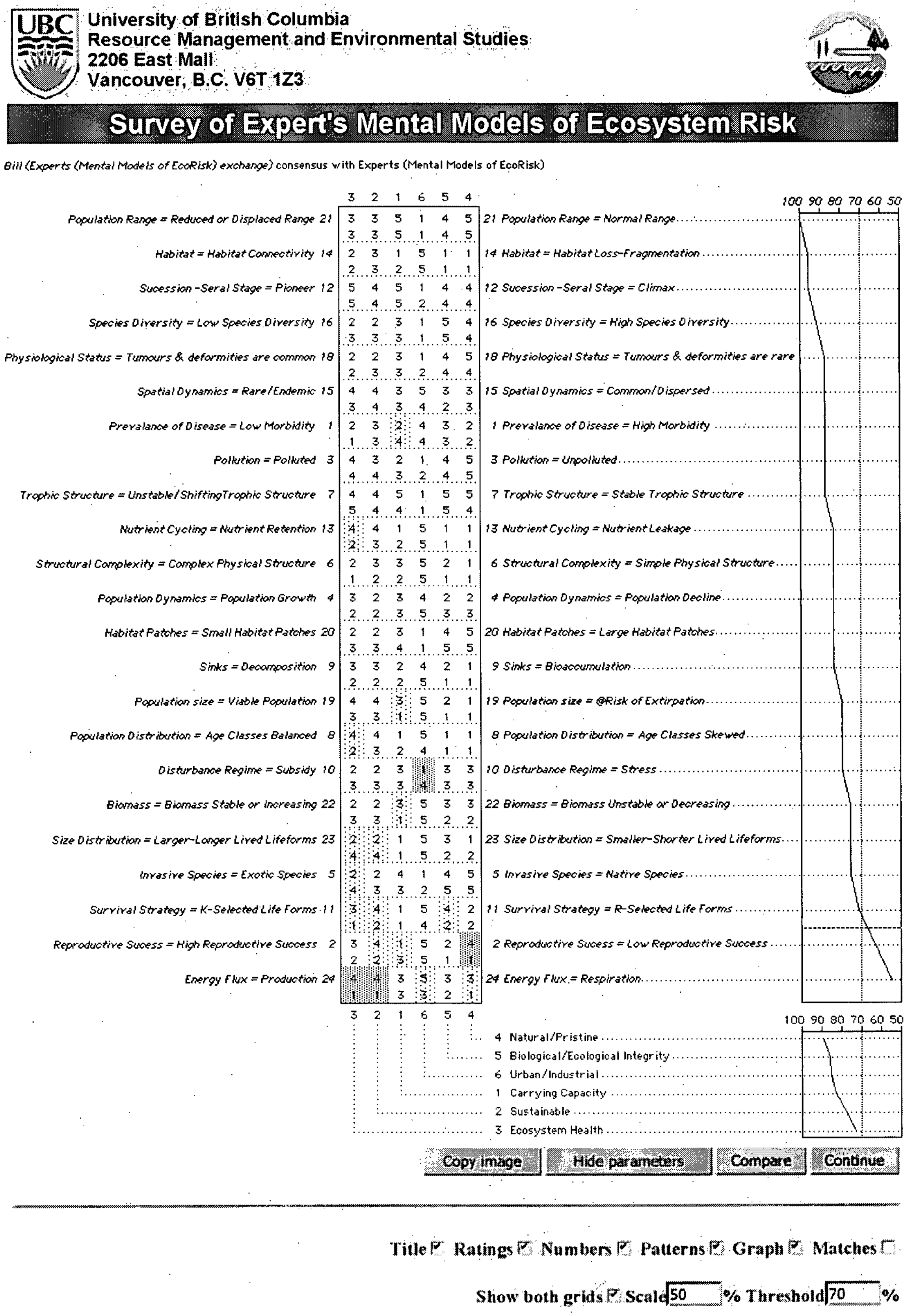

Figure 16: Comparison

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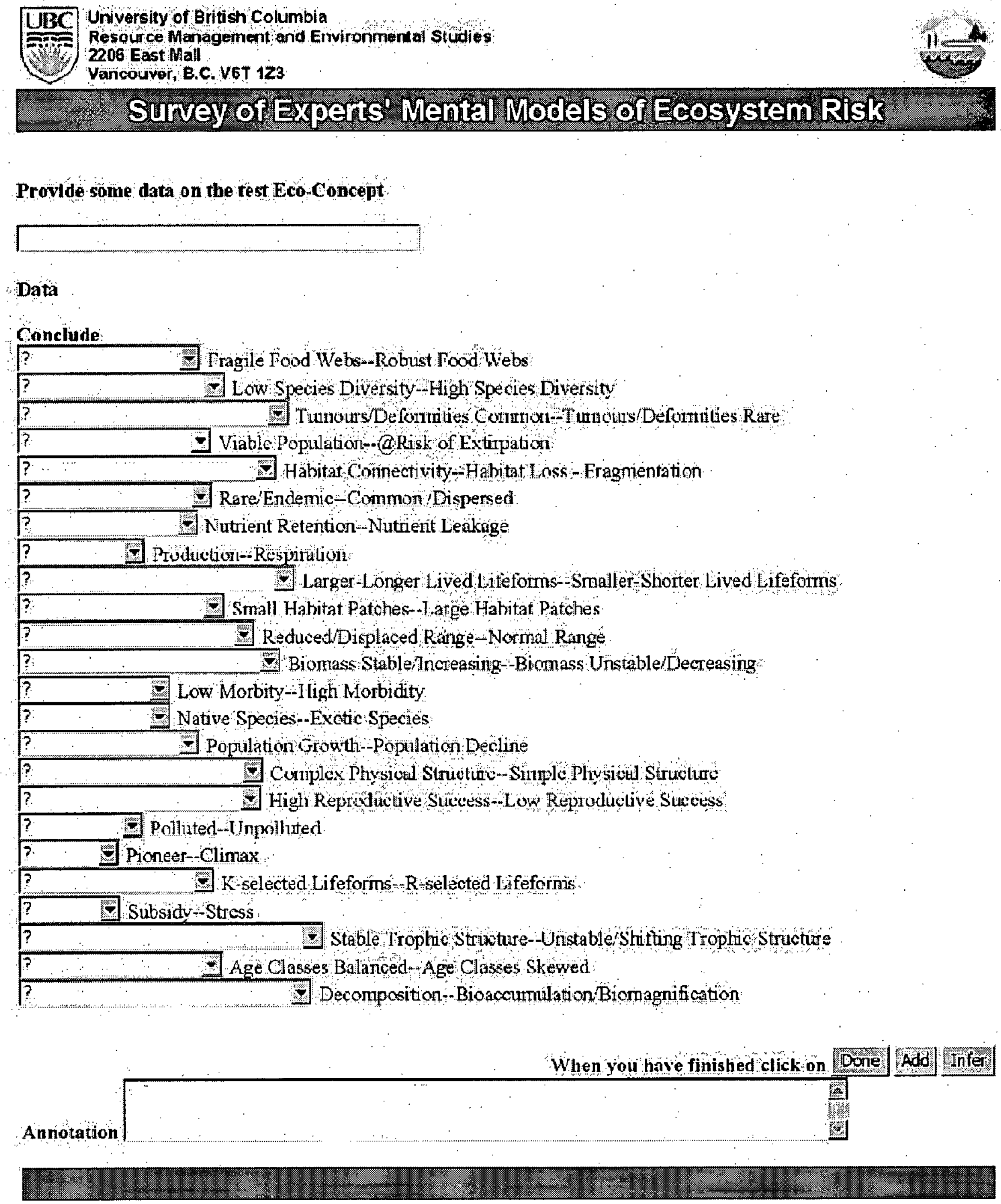
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Survey of Experts' Mental Models of Ecosystem Risk

Provide some data on the test Eco-Concept

Data

Conclude

? Fragile Food Webs--Robust Food Webs
? Low Species Diversity--High Species Diversity
? Tumours/Deformities Common--Tumours/Deformities Rare
? Viable Population--@Risk of Extirpation
? Habitat Connectivity--Habitat Loss - Fragmentation
? Rare/Endemic--Common /Dispersed
? Nutrient Retention--Nutrient Leakage
? Production--Respiration
? Larger-Longer Lived Lifeforms--Smaller-Shorter Lived Lifeforms
? Small Habitat Patches--Large Habitat Patches
? Reduced/Displaced Range--Normal Range
? Biomass Stable/Increasing--Biomass Unstable/Decreasing
? Low Morbity--High Morbidity
? Native Species--Exotic Species
? Population Growth--Population Decline
? Complex Physical Structure--Simple Physical Structure
? High Reproductive Success--Low Reproductive Success
? Polluted--Unpolluted
? Pioneer--Climax
? K-selected Lifeforms--R-selected Lifeforms
? Subsidy--Stress
? Stable Trophic Structure--Unstable/Shifting Trophic Structure
? Age Classes Balanced--Age Classes Skewed
? Decomposition--Bioaccumulation/Biomagnification

When you have finished click on Done Add Infer

Annotation

Figure 17: Test Case

If you are not satisfied with the selection concepts you are rating, you can generate new eco-concepts and add them to the grid using ***Test Case*** (fig. 17)

Each time you input data, you will be returned to the *Elicitation Screen* (fig.3). Don't forget to press the ***Save/Exchange*** button at the bottom of the page to save your work when you are finished.

REFERENCES

Web Grid III was developed by Professors Muriel Shaw and Brian Gaines, and is available from the University of Calgary: **http://tiger.cpsc.ucalgary.ca:1500/** . Additional information about the software they have developed is available from their website **http://www.repgrid.com/** .

CPCS (2003) WebGrid III. Cobble Hill B.C., Center for Person-Computer Studies.

CPCS (1993) RepGrid 2 Manual, Calgary Alberta, Center for Person Computer Studies.

Fransella, F., R. Bell, and Don Bannister (2004). A Manual for Repertory Grid Technique. Chichester U.K., John Wiley & Sons.

Gaines, B. R. and M. L. G. Shaw (1996). WebGrid: Knowledge Modeling and Inference through the World Wide Web. Proceedings of the Tenth Knowledge Acquisition for Knowledge-Based Systems Workshop, Banff, Alberta.

Gaines, B. R. and M. L. G. Shaw (1989). Comparing the conceptual systems of experts. Eleventh International Joint Conference on Artificial Intelligence, Detroit Michigan, Morgan Kaufmann.

Jankowicz, D. (2004). The Easy Guide to Repertory Grids. Chichester U.K, John Wiley & Sons.

Shaw, M. L. G. (1980). On Becoming a Personal Scientist. London, Academic Press.

Shaw, M. L. G. and B. R. Gaines (1989). "A methodology for recognizing conflict, correspondence, consensus and contrast in a knowledge acquisition system." Knowledge Acquisition 1(4): 341-363.

Gaines, B. R. (1989). An Ounce of Knowledge is Worth a Ton of Data: Quantitative Studies of the Trade-Off between Expertise and Data based on Statistically Well-Founded Empirical Induction. Proceedings of the Sixth International Workshop on Machine Learning, San Mateo California, Morgen Kaufmann.

Gaines, B. R. (1996). Transforming Rules and Trees into Comprehensive Knowledge Structures. Advances in Knowledge Discovery and Data Mining. U. M. Fayyad, G. Piatetsky-Shapiro, P. Smyth and R. Uthurusamy. Cambridge Massachusetts, MIT Press.

Appendix 9. WEB-BASED SURVEY
SURVEY OF EXPERTS MENTAL MODELS OF ECOSYSTEM RISK

REQUEST TO INTERNET DISCUSSION LISTS:

To Whom It May Concern:

I am requesting that you post this message on your discussion list. Would you please let me know if you are able to post this request for me? Thank you

- - - -Message - - -

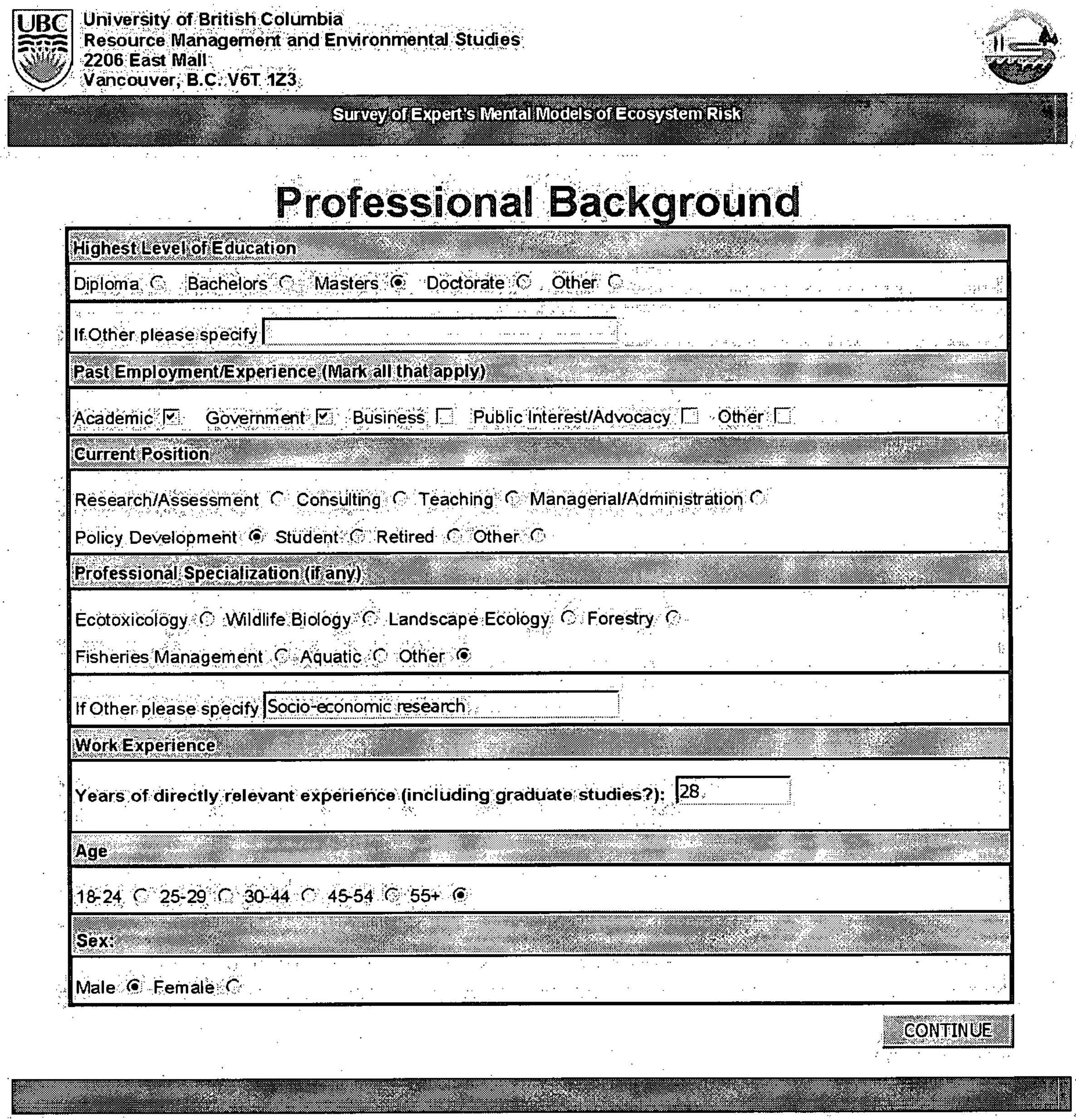
I am a Graduate Student at the University of British Columbia undertaking research for my doctoral dissertation. I am conducting a survey of professionals and other persons who are knowledgeable about ecosystems. Interdisciplinary collaboration is becoming increasingly difficult because there is a lack of consensus about what is important and worthwhile about ecosystems, and what needs to be managed, conserved or protected. I am trying to develop a conceptual framework through my research that would facilitate risk communication and collaboration. If you are someone knowledgeable about ecosystems, I would be interested in knowing your views.

My survey asks you to provide some basic background information about yourself. Next you will be asked about the assessment goals and criteria, that you think should be used to evaluate risk to ecosystems. Lastly the survey asks you to express the extent to which you agree or disagree with some common beliefs about society and the environment.

The introductory page to the survey provides additional explanation of the background of the study. You can access it from my website at http://www.ecosmiths.ca/ws/questionnaire.htm. I would very much appreciate it if you would take the time to complete the survey, and share your views about ecosystems. In all, it shouldn't take more than twenty or thirty minutes for you to complete the survey.

I have interviewed over fifty persons from coast to coast. Like you they are knowledgeable about ecosystem risks and are drawn from many different disciplines or lines of work. During the interview I asked them to tell me what they thought was important about ecosystems. I have analysed the interview results, and identified several widely-shared conceptual distinctions that many people use to talk about ecosystems.

Appendix 9. WEB-BASED SURVEY



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Professional Background

Highest Level of Education

Diploma ○ Bachelors ○ Masters ◉ Doctorate ○ Other ○

If Other please specify

Past Employment/Experience (Mark all that apply)

Academic ☑ Government ☑ Business ☐ Public Interest/Advocacy ☐ Other ☐

Current Position

Research/Assessment ○ Consulting ○ Teaching ○ Managerial/Administration ○

Policy Development ◉ Student ○ Retired ○ Other ○

Professional Specialization (if any)

Ecotoxicology ○ Wildlife Biology ○ Landscape Ecology ○ Forestry ○

Fisheries Management ○ Aquatic ○ Other ◉

If Other please specify Socio-economic research

Work Experience

Years of directly relevant experience (including graduate studies?): 28

Age

18-24 ○ 25-29 ○ 30-44 ○ 45-54 ○ 55+ ◉

Sex:

Male ◉ Female ○

CONTINUE

Figure 2 Professional Background

The respondent will be asked to provide information about their professional background (fig.2). As a control, the website tracks the origin of all visitors and the identity the computing devices used and the referring servers. The Elicitation instructions (fig. 3) simply ask the respondent to rate all concepts using the assessment criteria. Up to seven concepts and fifty assessment criteria can be included in the database. A sample layout for the elicitation process for each concept (fig 4) is provided on page 6. After all the eco-concepts have been rated on the assessment criteria, the respondent will be asked to indicate the extent to which they agree or disagree with a set of statements about society and the environment (fig 5).

Appendix 9. WEB-BASED SURVEY

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Survey of Expert's Mental Models of Ecosystem Risk

ELICITATION INSTRUCTIONS

Ecosystems consist of interrelated communities of organisms and the environment on which they depend. Ecosystems function as dynamic complex systems. Energy and matter is recycled within them. Their boundaries are never rigid and they open to external influences.

We would like you to apply a common set of assessment criteria to describe different ecosystems goals or concepts. You will be rating the eight eco-concepts described below.

1. **Carrying Capacity**

   Carrying Capacity is the maximum population of a given species that a particular environment can support indefinitely without habitat damage. Human carrying capacity is heavily influenced by a society's level of technological development and pattern of organization.

2. **Monocultures**

   Monocultures describe managed areas, such as plantation forests, fish farms (aquaculture) and grain farms (e.g. wheat and corn) whose productivity is maintained through human supplied inputs and technology.

3. **Ecosystem Health**

   Ecosystem Health describes envelope or range of possible ecosystem conditions that will sustain life. Ecosystems' provide food, fibre, energy, and the other commodities that humans need for their survival, and maintain clean air, pure water, and other vital life support functions. The goal of the approach is to optimise the array of goods and services ecosystems provide, while preserving or increasing their capacity to produce those things in the future. As well, the ecosystem approach tries to maintain future management options so that we can accommodate changes in societal values.

4. **Sustainability**

   Environmental sustainability at the most basic level is a function of the state of ecosystems, the stresses on those systems, human vulnerability to environmental change, and the capacity of human institutions to respond to these challenges and provide global stewardship of environmental resources. Human success in influencing these aspects of their environment in a lasting manner will affect their chances of survival and their quality of life a generation or two into the future.

5. **Natural/Pristine**

   Natural or Pristine refers to wilderness areas, relatively undisturbed by humans, where natural processes and events are still the driving force of evolutionary change.

6. **Resilience**

   Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. Humans are part of the natural world. We depend on ecological systems for our survival and we continuously impact the ecosystems in which we live from the local to global scale. Resilience gives humans the opportunity to anticipate and plan for the future.

7. **Biological/Ecological Integrity**

   Biological or Ecological Integrity refers to an ecosystems capacity to sustain the native biological communities that have adapted to a region through natural evolutionary forces. In plain language ecosystems have integrity when they have their native components (plants, animals or other organisms) and processes that generate future integrity intact.

8. **Urban/Industrial**

   Urban or Industrial refers to highly disturbed areas dominated by human economic activities and settlement.

The assessment criteria consist of a range of values between two contrasting conditions or states. Pick the value that most adequately describes each eco-concept.

Press CONTINUE **to start the elicitation process**

Figure 3 Elicitation Instructions

Appendix 9. WEB-BASED SURVEY

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Survey of Expert's Mental Models of Ecosystem Risk

ELICITATION PROCESS

ECO-CONCEPT: 1) Carrying Capacity						
Carrying Capacity is the maximum population of a given species that a particular environment can support indefinitely without habitat damage. Human carrying capacity is heavily influenced by a society's level of technological development and pattern of organization.						
ASSESSMENT CRITERIA			**PHYSICAL - ABIOTIC**			**ASSESSMENT CRITERIA**
Complex physical structure	1 ○	2 ◉	3 ○	4 ○	5 ○	Simplified physical structure
Minimum climate variability	1 ○	2 ◉	3 ○	4 ○	5 ○	Climate warming or cooling
Extensive or severe disruption	1 ○	2 ○	3 ○	4 ◉	5 ○	Minor variation in disturbance regime
Small habitat patches	1 ○	2 ○	3 ○	4 ○	5 ◉	Large habitat patches
Habitat fragmented or lost	1 ○	2 ○	3 ○	4 ○	5 ◉	Habitat interconnected
Nutrient retention – absorb/import	1 ○	2 ○	3 ◉	4 ○	5 ○	Nutrient leakage – release/export
Bioaccumulation	1 ○	2 ○	3 ◉	4 ○	5 ○	Decomposition
Resilient – recover & repeat cycle	1 ○	2 ◉	3 ○	4 ○	5 ○	Vulnerable – shift to new state/cycle
ASSESSMENT CRITERIA			**COMMUNITY-GUILDS**			**ASSESSMENT CRITERIA**
Biomass decreasing	1 ○	2 ○	3 ○	4 ◉	5 ○	Biomass constant /increasing
Production	1 ○	2 ○	3 ◉	4 ○	5 ○	Respiration
Unstable/shifting trophic structure	1 ○	2 ○	3 ○	4 ○	5 ◉	Stable trophic structure
Smaller shorter lived life forms	1 ○	2 ○	3 ◉	4 ○	5 ○	Larger longer lived life forms
Complex robust food web	1 ○	2 ○	3 ◉	4 ○	5 ○	Simplified fragile food web
Regenerate to same species	1 ○	2 ◉	3 ○	4 ○	5 ○	Species composition changing
Many species at risk/ last of a few	1 ○	2 ○	3 ○	4 ◉	5 ○	Most species survive & thrive
Predominantly native species	1 ○	2 ○	3 ◉	4 ○	5 ○	Exotic & invasive species present

Figure 4 Example of Elicitation

Appendix 9. WEB-BASED SURVEY

ASSESSMENT CRITERIA			POPULATIONS			ASSESSMENT CRITERIA
Population growing or declining	1	2	3	4	5	Population size stable & viable
Age distribution balanced	1	2	3	4	5	Age distribution skewed
Reduced range or displaced	1	2	3	4	5	Normal range
Plentiful & widely dispersed	1	2	3	4	5	Rare or endemic
ASSESSMENT CRITERIA			**INDIVIDUAL ORGANISMS**			**ASSESSMENT CRITERIA**
High reproductive success	1	2	3	4	5	Low reproductive success
Metabolic processes disrupted	1	2	3	4	5	Normal metabolic processes
Disease spreads/deformities present	1	2	3	4	5	Disease/deformities absent or rare
Low mortality rates	1	2	3	4	5	High mortality rates
Decreased genetic diversity	1	2	3	4	5	Increased genetic diversity
ASSESSMENT CRITERIA			**OTHER**			**ASSESSMENT CRITERIA**
Human population constant/declines	1	2	3	4	5	Human population grows
No direct human use or impacts	1	2	3	4	5	Substantial human harvesting/use
Profound large-scale land use change	1	2	3	4	5	Minimal small-scale land use change
Adequate fresh water supply	1	2	3	4	5	Fresh water in short supply
High level of contaminants	1	2	3	4	5	Low level of contaminants
People are indifferent	1	2	3	4	5	People care about / enjoy
People familiar – grew up with	1	2	3	4	5	People unfamiliar – don't know

Save my answers and go to next eco-concept

Figure 4 Example of Elicitation (continued)

Appendix 9. WEB-BASED SURVEY

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WORLD VIEWS

Finally would you express the extent to which you agree or disagree with the following statements about society and the environment. (SA= Strongly Agree, MA= Moderately Agree, N= Neither Agree nor Disagree, MD= Moderately Disagree, SD=Strongly Disagree)

Do you (●) agree or (●) disagree that?	SA	MA	N	MD	SD
1- The Earth has plenty of natural resources, if we can just learn how to develop them.	1 ○	2 ●	3 ○	4 ○	5 ○
2- If wealth and opportunity were more fairly distributed in this country we would have fewer environmental and social problems	1 ○	2 ●	3 ○	4 ○	5 ○
3- We are approaching or have exceeded the limit of the number of people the earth can support	1 ●	2 ○	3 ○	4 ○	5 ○
4- Nature may be resilient but it can only absorb so much damage	1 ○	2 ●	3 ○	4 ○	5 ○
5- We should voluntarily adopt a simpler less materialistic way of life in order to save the environment.	1 ●	2 ○	3 ○	4 ○	5 ○
6- We cannot rely on the functioning of markets or goodwill of individuals to protect our health or the environment.	1 ○	2 ○	3 ○	4 ●	5 ○
7- We should leave the tough decisions about the environment to the experts	1 ○	2 ○	3 ○	4 ●	5 ○
8- It is often less costly to prevent environmental problems than to fix them.	1 ●	2 ○	3 ○	4 ○	5 ○
9- In a fair society, people who invest and take risks should be rewarded.	1 ○	2 ○	3 ●	4 ○	5 ○
10- Continued economic growth, and technological innovation is the key to improving our standard of living.	1 ○	2 ●	3 ○	4 ○	5 ○
Do you (●) agree or (●) disagree that?	**SA**	**MA**	**N**	**MD**	**SD**
11- Plants and animals have the same right as humans to exist.	1 ○	2 ●	3 ○	4 ○	5 ○
12- Humans will eventually learn enough about how nature works to be able to control it.	1 ○	2 ○	3 ○	4 ○	5 ●
13- Nature will recover in the long run from any harm caused by humans.	1 ●	2 ○	3 ○	4 ○	5 ○
14- Companies won't protect the environment until the law forces them to do something.	1 ○	2 ●	3 ○	4 ○	5 ○

Figure 5 World View

Appendix 9. WEB-BASED SURVEY

15- Human ingenuity will insure that we do NOT make the Earth unliveable.	1 ○	2 ○	3 ○	4 ○	5 ◉
16- The public should be prepared to accept some environmental risks if they want to have a more prosperous economy	1 ○	2 ○	3 ○	4 ◉	5 ○
17- We have to protect the environment for our children and grandchildren, even if it means reducing our standard of living today.	1 ◉	2 ○	3 ○	4 ○	5 ○
18- Governments should not restrict peoples' personal freedom or their lifestyle choices.	1 ○	2 ○	3 ○	4 ◉	5 ○
19- Communities know better than government or industry what needs to be done to protect the environment.	1 ○	2 ◉	3 ○	4 ○	5 ○
20- We should rely on our own common sense rather than the opinions of so-called experts when trying to solve environmental problems.	1 ○	2 ○	3 ○	4 ◉	5 ○
Do you (◉) agree or (○) disagree that?	**SA**	**MA**	**N**	**MD**	**SD**
21- In this country we should return to more traditional values and way of life.	1 ○	2 ○	3 ○	4 ○	5 ◉
22- Modern technology poses serious risks to the environment	1 ○	2 ○	3 ○	4 ◉	5 ○
23- If humans do not have a particular use for a species they shouldn't worry about it becoming extinct.	1 ○	2 ○	3 ○	4 ○	5 ◉
24- It is unfortunate but acceptable if some people loose their jobs or have to change their line of work for the sake of the environment.	1 ○	2 ◉	3 ○	4 ○	5 ○
25- The balance of nature is very delicate and easily upset.	1 ○	2 ○	3 ○	4 ◉	5 ○
26- There is so much disagreement among experts that it is hard to know who to believe about the environment.	1 ○	2 ◉	3 ○	4 ○	5 ○
27- The so-called "environmental" crisis facing society has been greatly exaggerated.	1 ○	2 ○	3 ○	4 ○	5 ◉
28- As long as the same species exists somewhere else in the world, humans have a right to use plants and animals to meet their needs.	1 ○	2 ○	3 ○	4 ◉	5 ○
29- Environmental choices always involve trade-offs.	1 ◉	2 ○	3 ○	4 ○	5 ○
30- Private enterprise is more likely than government to find solutions to environmental problems	1 ○	2 ○	3 ○	4 ○	5 ◉

Press **SAVE** to submit your answers

Figure 5 World View (continued)

Appendix 10 INTERNET LIST SERVERS
SURVEY OF EXPERTS' MENTAL MODELS OF ECOSYSTEM RISK

Lists of Lists

Yahoo Groups: http://dir.yahoo.com/Science/Ecology

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Title Net E-mail List Directory: http://tile.net/search.php?table=&search_text=

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L-Soft http://www.lsoft.com/lists/list_q.html or

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CataList, the official catalog of LISTSERV® lists: http://www.lsoft.com/lists/listref.html

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Sustainable Development Gateway Mailing Lists: http://sdgateway.net/mailinglists/

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Long Term Ecological Research Directory: http://search.lternet.edu/dir.php

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CSEB - SCBE BioWeb LIST SERVERS for BIOLOGISTS
http://www.freenet.edmonton.ab.ca/cseb/b_listserve.html

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Center for International Earth Science Information Network (CIESIN)
http://www.ciesin.org/lists.html

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ENVIROLINK http://www.envirolink.org/

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National Academic Mailing List Service http://www.jisc.mail.ac.uk/lists/

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IAIA List Servers http://www.iaia.org/listserv.html

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www.science-search.org