RESOLVING EQUIVOCALITY IN ECOSYSTEM MANAGEMENT

by

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ABSTRACT

Equivocality creates major difficulties for decision making in ecosystem management. Equivocal situations are characterized as wicked, ill-defined, squishy, and messy. Information processing theory suggests that equivocality can overwhelm, confuse, and distort cognitive functions and lead to poor decisions. Equivocal information is vague or obscure, and leads to multiple interpretations. Past research on decision information has focused primarily on uncertainty, which is an insufficient amount of information. This research considered equivocality, which is an inadequate quality of information. It thus addressed a major gap in ecosystem management and information processing theory.

A qualitative, positivist, grounded theory-building research strategy was used to evaluate hypotheses concerning patterns of equivocality. Evidence of equivocality was examined for four stages of decision making, including problem formulation, information gathering, causal analysis, and action planning.

A case study approach compared information available for selecting protected areas for species-at-risk among two terrestrial and two marine ecosystems. These included the Vancouver Island marmot – subalpine ecosystem; the marbled murrelet – old growth forest ecosystem; the humpback whale – continental shelf pelagic ecosystem; and the giant Pacific octopus – continental shelf benthic ecosystem. Equivocality was found to be higher and to exhibit different patterns in marine environments. The unique biophysical and logistical characteristics of marine environments complicate cognitive information processing and lead to equivocality.

This study proposed two approaches for resolving equivocality. The first was a filtering method for recognizing patterns of equivocality in ecosystems. This approach would assist managers in defining research strategies and priorities, addressing polarized science-policy conflicts, and coping with equivocality in decision making.

The second approach is a set of tools and options for resolving equivocality in ecosystem management. These include structures, processes, and inputs to accomplish two tasks. First, vague and obscure information would be addressed by information-support systems that produce rich information and a clearer picture of the decision problem. Second, multiple interpretations would be resolved by structures and processes that facilitate communication, information sharing, and collaboration to promote shared interpretations of information.

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ACRONYMS

BC	British Columbia
BCCDC	B.C. Conservation Data Centre
CITES	*Convention on International Trade in Endangered Species of Wild Fauna and Flora*
CORE	Commission on Resources and Environment
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Department of Fisheries and Oceans
ERMS	Equivocality-resolving management system
FREMP	Fraser River Estuary Management Program
GIS	Geographic information systems
LME	Large marine ecosystem
LRMP	Land and Resource Management Planning
MPA	Marine protected area
MBARI	Monterey Bay Aquarium Research Institute
RENEW	Committee for the Recovery of Nationally Endangered Wildlife
ROV	Remotely operated vehicle
SOE	State-of-the-environment
TPA	Terrestrial protected area
TRIM	Terrain Resource Inventory Mapping
WESCAP	West Coast Offshore Exploration Environmental Assessment Panel

CHAPTER 1: INTRODUCTION

> "To me our knowledge of the way things work, in society or in nature, comes trailing clouds of vagueness" (Nobel Laureate Kenneth Arrow quoted in Bernstein 1996).

1.1 Overview

1.1.1 Equivocality in Ecosystem Management

At the turn of the twenty first century, resource scientists are embracing the concept of "ecosystem management" as the model for managing natural resources and ecosystems. Grumbine (1994, 1997) defined ecosystem management as a process that

> integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term.

Thus scientific knowledge is a major element in ecosystem management. Holling et al. (1978) suggested that the environmental policy making "implies knowledge – knowledge to develop alternative policies, and knowledge to evaluate their respective consequences." They indicated the purpose of knowledge was to "reduce uncertainty." Yet, they acknowledged that

> however intensively or extensively data are collected, however much we know of how the system functions, the domain of our knowledge of specific ecological and social systems is small when compared to that of our ignorance. Thus, one key issue for design and evaluation of policies is how to cope with the uncertain, the unexpected, and the unknown.

Lauck (1996) described the same situation:

> The major dilemma facing resource managers is the necessity to make correct policy choices while having insufficient, wrong or conflicting information. Errors in policy may compound, amplified by underlying dynamics. Even assuming perfect information, natural and imposed variation hampers the decision making process. Under ideal circumstances, most of the experts can still be wrong. Worse yet, chosen policies may lead to completely unpredictable human responses. Still, it is important to recognize that decisions often must be made under precisely these circumstances.

Mitchell (1995) reflected a similar outlook, stating that

> in most situations, there is imperfect knowledge or understanding in resource management. Nevertheless, decisions must be made. As a result, resource and environmental managers often make decisions without knowing the full consequences of their choices.

Holling et al. (1978), Lauck (1996), and Mitchell (1995) were clear that knowledge is an important ingredient to resource management, but that perfect knowledge will never be available. Ecosystem managers and theorists call the residual realm where knowledge is lacking “uncertainty.” The strategy for reducing this residual is to obtain more knowledge for management, and to manage resources adaptively to obtain more knowledge.

Understandably, given the importance of scientific knowledge, society invests enormous resources to reduce uncertainty by gathering information. Resource management agencies, resource users and industries, nongovernment organizations, and individuals participate in an every expanding enterprise of data collection, resource inventories and assessments, modeling and causal analyses, monitoring, and other information work. The emphasis has been on the collection of quantitative data to make predictions about the effects of human actions, such as resource harvesting or habitat alteration, on the future functioning of ecosystems.

This research examines the phenomenon of equivocality as a source of difficulty in decision making. Equivocality is defined in this research as a problem of *inadequate quality* of information for decision making (section 1.2.3). Equivocality means ambiguity; that is, a situation where vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse information can suggest two or more plausible meanings or interpretations for what a person is observing (Daft and MacIntosh 1981, 1978; Weick 1979; Daft and Weick 1984; Weick and Daft 1983). Equivocality is distinguished from uncertainty, which is defined as a problem of an *inadequate quantity* of information for decision making (Daft and Weick 1984; Daft, Lengel, and Trevino 1987; Tushman and Nadler 1978). Section 1.2.2 outlines a taxonomy of uncertainty.

Past research on decision making information has focused primarily on uncertainty. The distinction between equivocality and uncertainty, however, is important because the phenomenon of equivocality requires a different coping strategy than uncertainty. Uncertainty requires *more* information, whereas equivocality requires *richer* information and *more* discussion (section 1.5). If the information contingencies are misdiagnosed, information investments will be misdirected or wasted. This will affect the quality of decision making, and ultimately will affect the quality of outcomes of resource management, such as the protection of endangered species, the productivity of fisheries or forestry activities, or the quality of air and water.

Equivocality has considerable potential to skew or invalidate many otherwise sound resource management strategies or practices. Decision makers facing equivocality have divided opinions and must seek *consensus* in order to act (Ziman 1978). When there are two or more plausible interpretations of environmental data and no consensus, resource management decisions can become arbitrary or gambling. They may become arbitrary because the decision maker has no criterion for choosing among available interpretations except his or her own preferences. Decision makers may choose either “the syndromes of living dangerously (‘who cares how birds or bugs are affected – jobs and income are more important') or living safely ('nothing must be done until we know more')" (Holling et al. 1978 referring to uncertainty). Decisions may also become gambles in the sense that decisions are made without adequate prior knowledge of outcomes and are thus analogous to "flipping a coin" between equally plausible alternatives. Unfortunately, the alternatives may not have known probabilities of occurrence nor equal consequences after decisions are made.

Because of the importance of equivocality, this research endeavors to accomplish three goals. First, it investigates the extent and characteristics of equivocality in ecosystem management, with special reference to decision making in selecting marine and terrestrial protected areas. This extends elements of information processing theory from the organizational sciences into the natural scientific disciplines, and assesses the importance of equivocality as a phenomenon of concern for natural resource managers. At the same time, the research approaches used in this study are a novel extension of qualitative, grounded theory building methodologies into the study of environmental management.

Second, this research develops a method or filter for recognizing and evaluating the extent of equivocality in different ecosystems. At present, no such filtering methodologies exist for resource management. An essential first step in managing equivocality is to be able to sense its presence and character in a given decision context.

Finally, this research explores how existing and innovative resource management practices and technologies can be adapted to resolve equivocality in resource management.

The recognition and reduction goals address the *resolving* of equivocality. Resolving is a word with multiple meanings, including solving, clearing up, explaining, breaking into parts, changing, transforming, focusing, making certain, and deciding (Fowler 1965). It thus conveys both interpretation and decision – the major requirements for making decisions on equivocal issues.

1.1.2 Research Structure

This section provides a synopsis of the research design for this study (table 1.1). The research is based on information processing theory, which is a branch of organizational theory. The phenomenon of interest is equivocality. As discussed in section 1.1.1, it is assumed that the level of equivocality varies among different ecosystems. These differences would have implications

Table 1.1 Research Structure

Subject	**Relevant Sections**	**Statement**
Theoretical Orientation	Chapter 1	The *theoretical orientation* for exploring differences in information quality is the field of information processing of organizational theory.
Phenomenon of Interest	Chapter 1	The *phenomenon of interest* is the information quality characteristic referred to as *equivocality*, which is information that is insufficient, unrich, and ambiguous.
Underlying Assumption	Chapter 2	The *underlying assumption* of this study is that equivocality varies among different ecosystems.
Substantive Focus	Chapter 2	The *substantive focus* for this study is the identification, evaluation, and selection of protected areas for the conservation of ecosystems and habitats of species-at-risk in marine and terrestrial environments.
Subcases	Chapter 2 through 5	The *case studies* for exploring equivocality included two terrestrial and two marine ecosystems. The case studies are used to evaluate whether biophysical and logistical differences between marine and terrestrial environments lead to differences in the level of equivocality between these environments.
Methodology	Chapters 3	The *methodology* used for this research is a qualitative approach based on grounded theory building methods and case studies. This approach allows hypothesis testing and theory development.
Research Hypotheses	Chapter 2	The *research hypotheses* propose that equivocality affects decision making at various stages, including the definition of problems, gathering of information, analysis of causal information, and action planning.
Management Implications	Section 1.4 and 1.5; Chapter 6 and 7	The *management implications* of divergent patterns of equivocality between marine and terrestrial environments includes the need for methods for recognizing and evaluating equivocality and the design of equivocality-resolving management systems. These management systems are applicable to conservation of ecosystems and habitats of species-at-risk as well as other ecosystem management functions.

for information processing for decision making, and ultimately for how agencies would organize to cope with uncertainty.

A qualitative methodology is used to investigate differences in equivocality among ecosystems. The substantive focus for this research is a case study analyzing the quality of information considered in making decisions for the selection of protected areas. Subcases involved two terrestrial and two marine ecosystems. Research hypotheses were defined to evaluate the patterns of differences in equivocality in decision making within these ecosystems.

The research also sought to develop methods for recognizing and evaluating patterns of uncertainty in resource management. Finally, suggestions are made for remedying equivocality in decision making.

1.2 Information Quality and Equivocality

This section introduces information processing theory, outlines the information challenges complicating ecosystem management, and introduces the concept of equivocality.

1.2.1 Information Processing Theory

Information processing theory, a branch of organizational theory, views organizations as information processing systems (March 1994; Daft and Macintosh 1981; Knight and McDaniel 1979; Galbraith 1973, 1977; Huber, O'Connell, and Cummings 1975; Driver and Mock 1975; Driver and Streufert 1969; Walsh 1995; Pashler 1998). In this view, the configuration of processes and structures within organizations is strongly influenced by how organizations process information (March 1994; March and Simon 1958; Katz and Kahn 1978; Weick 1979, 1995; Galbraith 1973, 1974, 1977). The premise of this theory is that human cognitive capacities are limited (March 1978, 1994; Simon 1976; March and Simon 1958) so that when an organization faces greater uncertainty, there must be a change in the way the way information is gathered and processed in order for the organization to perform adequately and survive. This affects how organizations are designed (Galbraith 1973, 1974; 1977). According to Galbraith (1974)

> it is hypothesized that the observed variations in organizational forms are variations in the strategies of organizations 1) to increase their ability to preplan, 2) to increase their flexibility in order to adapt to their inability to preplan, or 3) to decrease the level of performance required for continued viability.

This research also builds on the theory and methodologies of Eisenhardt and others who have studied rapid decision making in high velocity environments characterized by extreme rates of technological change (Bourgeois and Eisenhardt 1987, 1988; Eisenhardt 1989a, 1989b, 1993; Eisenhardt and Bourgeois 1988, 1990; Eisenhardt and Tabrizi 1995). The Eisenhardt group considered decision situations that are driven by rapid change that leads to difficulties in interpreting information. The present research considered decision situations that are complicated by highly variable and dynamic physical and ecological characteristics of different types of ecosystems.

1.2.2 A Taxonomy of Information Quality

Considerable conceptual confusion surrounds the concepts of equivocality, uncertainty, and other forms of information quality. This section outlines some types of information quality in order to refine the definition of equivocality and distinguish it from other information quality constructs.

Table 1.2 Taxonomy of Information Quality Limitations

Information Quality Contingency	Defining Characteristics	Ecosystem Example
Certainty	The behavior of the system is deterministic and stable, and outcomes can be reliably predicted based on available data.	The magnitude and timing of ocean tides can be predicted with a high level of accuracy based on strong causal theories and reliable data.
Risk	The behavior of the system is known and the probability of various outcomes can be defined and quantified (Mitchell 1995). Predictions and forecasts may not be exact, but can be approximated within specified limits.	The risk of a specified magnitude of a flood can be estimated from long term river flow records (Mitchell 1995). Scientists are able to forecast the general rates of change in abundance of some species from their knowledge of weather conditions, nutrients, and predators.
Uncertainty about Quantities	Scientists may know key variables and parameters, but lack sufficient data to estimate the probability of a given outcome (Mitchell 1995). This is referred to as disagreement or uncertainty about quantities (Morgan and Henrion 1990).	Scientists know the key variables that are significant for estimating a flood, but have inadequate historical or environmental data for estimating probabilities with confidence (Mitchell 1995).
Noise Uncertainty	Because of high natural variability or "noise" in the data for a system, it is difficult to discern trends (Walters 1986; see also U.S. National Research Council 1986). This uncertainty may be due to inherent and irreducible randomness (Morgan and Henrion 1990).	A biologist may be unable to estimate a trend because the population data fluctuate wildly with no discernable pattern. Some marine fishes exhibit highly dynamic and unexplained variability over short periods.
Fuzziness	A phenomenon may be known, but the classification or definition of the phenomenon is vague or lacks crisp or clearcut boundaries. Boundaries between phenomena may be inexact, and transitions between various states may be gradual rather than abrupt. Thus it is difficult to define the state of the system. The antonym for fuzzy is crisp (McNeill and Freiberger 1993; Ells, Bulte, and van Kooten 1997; Meesters et al. 1998; Morgan and Henrion 1990).	A species may be at risk of extinction, but the classification of the species by degree of risk is fuzzy and hard to define though real. A species might be crisply classed as endangered when the number drops from 501 to 499 animals, but the actual endangerment has not changed significantly.
Structural Uncertainty	The structure of the underlying system is not known and scientists are unable to agree on the functional form of underlying causal models or the interpretation of data on causes and effects. There may be hidden or unknown variables operating (Walters 1986; Morgan and Henrion 1990; Holling et al. 1978). Unlike the indeterminacy case below, there is still hope of resolution.	A sudden change or regime shift occurs the ecology of in an ocean region that cannot be explained by present causal theories. A fish once thought extirpated from the region suddenly reappears in large numbers in a coastal area where it was formerly harvested.

Continued on next page

Table 1.2 continued…

Ignorance	The existence of problem situations escapes recognition, so that ecosystem managers are not aware of what they should know or what questions to ask (Mitchell 1995).	Scientists and society were unaware of the problems of acid precipitation in the 1960s (Mitchell 1995). Scientists and society were unaware of the problems of global climate change in the 1970s (Mitchell 1995).
Complexity	Modeling of the causal structure of a system is difficult due to the number of potential functional elements that must be estimated. The system may or may not produce predictable outcomes. A causal system may not be predictable because of modeling and computational limitations (Morgan and Henrion 1990; Bernstein 1996).	Weather forecasting is limited to short range forecasts due to extreme sensitivity to initial states, i.e., the "butterfly effect." The genome of a living organism tends to produce replicate organisms despite incredibly complex genetic codes.
Indeterminacy	Because of the complex and chaotic dynamics of the system, and the lack of understanding of the underlying causal mechanisms, the behavior of the system may never be predictable or understandable given existing scientific technology (Mitchell 1995; Morgan and Henrion 1990; U.S. National Research Council 1986; Smithson 1997; Traub and Wozniakowski 1994; Munro 1996).	Scientists may not be able to link changes in environmental factors to species abundance because the underlying relationships are inherently too complex and random to specify a model for the relationships.

Most discussions lump a variety of concepts under the general term *uncertainty*, which then also includes uncertainty as a subcategory. Morgan and Henrion (1990) referred to uncertainty as "a capacious term, used to encompass a multiplicity of concepts" (see also Lipschitz and Strauss 1997). They noted that there have been "several attempts to create taxonomies of different kinds of uncertainty." Table 1.2 provides a summary of various types of information quality limitations, including different varieties of uncertainty. Equivocality is addressed in section 1.2.3.

In table 1.2, *certainty* is based on predictability. If predictions are reliable, then our knowledge approaches certainty and decision makers can depend on this knowledge for decision making. For example, changes in marine tide levels have been predictable for centuries.

At the next level, *risk* involves knowledge of underlying causal systems so that outcomes can be predicted within probability ranges. For a well-monitored stream system, for example, hydrologists can estimate flood levels within certain ranges. Decision makers can use the estimates to guide their decisions, while recognizing some risk that actual flood levels may vary from estimates.

In the category of *uncertainty about quantities*, decision makers may understand the underlying causal mechanisms, such as what causes floods, but are uncertain about the quantification of important parameters. They may lack data on rainfall or snow packs needed to estimate the probability of a particular flood level, for example. In the related category of *noise uncertainty*, environmental data may exhibit such high variability and noise that no patterns or trends can be discerned.

In the *fuzziness* category, data categories may not crisp and distinct. The category of "endangered" when referring to a species is variable, with 100 animals presumably more endangered than 500 animals, with a gradient of endangerment in between. Such imprecise categories are addressed in fuzzy mathematics (McNeill and Freiberger 1993).

Structural uncertainty presents a higher level of difficulty for decision makers. Predictability is hindered by confusion about how the system operates. Surprises are possible when the structure of the system suddenly changes. The category of *ignorance* is related in the sense that decision makers do not understand the underlying system well enough to anticipate major changes.

Many environmental systems exhibit high levels of *complexity*. Complexity theory is a new field of science and mathematics. In mathematical terms, "the complexity of a problem is defined in terms of the number of mathematical operations needed to solve it" (Coveney and Highfield 1995). An example of a complex problem is the processes by which DNA produces a living being (Capra 1996). The process involves a myriad of operations that somehow operate to produce complex, functional replicate living organisms from genetic codes.

Finally, the category of *indeterminacy* is reserved for systems that may be permanently unpredictable, at least within existing scientific paradigms (Mitchell 1995). The unpredictability may result from lack of knowledge of causal systems or the inherently chaotic or random functioning of the system.

1.2.3 The Equivocality Problem

In most discussions of information quality, equivocality is not recognized as a distinct phenomenon. The focus has been on uncertainty, which is defined in terms of the level of predictability, as discussed in section 1.2.2. This section defines equivocality, and relates the problem of equivocality to other types of information quality.

Definition

Equivocality is a problem of *inadequate quality* of information for decision making (section 1.1.1). Equivocality means ambiguity; that is, a situation where vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse

Table 1.3 Terms Related to Equivocality

Vague	Unsettled; uncertain; undetermined; indefinite; proceeding from no known authority; as … *vague* mountains in the distance. Want of clearness; ambiguousness; haziness. Implies a lack of clear definition or formulation because of inadequate conception or consideration.
Obscure	Not easily understood; not obviously intelligible; abstruse. Not much known or observed; retired; remote from observation. Dark; destitute of light; dim; gloomy. Implies a hiding or veiling of meaning through some inadequacy of expression or withholding of full knowledge
Cloudy	Obscure; dark; indistinct; not understood. Having the appearance of gloom; indicating gloom, anxiety, sullenness, or ill-nature.
Unclear	Clouded; nontransparent; turbid; spotted; ambiguous; unintelligible; confused; indistinct to, of, senses or mind.
Murky	Dark; obscure; gloomy. Implies a heavy obscuring darkness such as that caused by smoke, fog, or dust in air or mud in water.
Blurred	A confused, ill-defined, or dim figure, outline, or representation. Dimmed vision of; darkened; rendered vague in outline, or indistinct.
Distorted	To twist out of usual shape. To misrepresent. Implies a wrenching from the natural, normal, or true shape, form, or direction (the odd camera angle distorts his face in the photograph).
Fuzzy	Not clear; blurred; indistinct.
Dark	Hidden; not easily understood. Implies an imperfect or clouded revelation often with ominous, mysterious, or sinister overtones.
Enigmatic	Something seemly having no explanation. An obscure question; a riddle. Stresses a puzzling, mystifying quality that is difficult to interpret.
Cryptic	Secret; occult; having hidden meaning. Implies a purposefully concealed meaning and often an intent to perplex or challenge
Mysterious	Containing, implying, or characterized by mystery. Cannot be fully understood by human reason; resists or defies explanation.
Meager	Poor; inadequate; not rich or fertile. Implies the absence of elements, qualities, or numbers necessary to a thing's richness, substance, or potency.
Sparse	Thinly spread or distributed; not dense; meager. Implies a thin scattering of units.

Uncertainty means lack of sureness about someone or something. Stresses lack of certitude that may range from a merely falling short of certainty to an almost complete lack of definite knowledge, especially about the outcome or result.

Sources: Merriam-Webster, Inc. 1992; Webster's 1965.

information can suggest two or more plausible meanings or interpretations for what a person is observing (Daft and MacIntosh 1981, 1978; Weick 1979; Daft and Weick 1984; Weick and Daft 1983). Table 1.3 identifies several terms related to equivocality. These terms also illustrate how vagueness and ambiguity are often associated. Equivocality is distinguished from uncertainty, which is defined as a problem of an *inadequate quantity* of information for decision making (Daft and Weick 1984; Daft, Lengel, and Trevino 1987; Tushman and Nadler 1978).

Equivocal situations "presume a messy, unclear field" with many "fuzzy and ill-defined" issues (Daft and Lengel 1986), and "wicked" (Allen and Gould 1986; Morgan and Henrion 1990) or "squishy" problems (Strauch 1975). High equivocality means confusion and lack of understanding (Daft and Lengel 1986; Daft, Lengel, and Trevino 1987). Under such conditions, people may be confused about causal relationships and what is happening in the environment. There is confusion not just about the answers, but also about whether or not the right questions are being addressed (Weick and Meader 1993). Equivocality leaves a decision maker without a clear understanding of the context for decisions, and thus a dilemma about which course of action to follow. These ideas are considered below.

Equivocal information is subject to multiple and often conflicting and contradictory interpretations (Daft and MacIntosh 1978; McCaskey 1982; Putnam and Sorenson 1982; Fahey and Narayanan 1989; Weick 1995; Lipschitz and Strauss 1997). Mitroff and Emshoff (1979) defined an ill-structured problem as "one for which various strategies for providing a possible solution rest on assumptions that are in sharp conflict with one another." As the mind attempts to settle on a particular conclusion, it may spontaneously shift and revert between interpretations (Stadler and Kruse 1995; Haken 1995). Analogous examples include puns (Weick 1995) and optical illusions (Haken 1995). Analysts may be able to read data and interpret their significance in several different, but equally plausible, ways. There may be multiple indicators and a rich assortment of variables that signal different and conflicting states-of-the-environment. The data may be clear but the underlying meaning may not be, because the data suggest two or more possible causes for a phenomenon. For example, a fire alarm from a district with a history of false alarms may mean an actual fire or just a false alarm. Environmental cues can thus trigger multiple interpretations. Unequivocal or unambiguous information, on the other hand, "conveys precise, clear information about relevant states of the world and generally is subject to only one interpretation" (Daft and MacIntosh 1978).

Characteristics of Equivocality

Equivocality can be defined by reference to its antonym, clarity. Clarity is high when information is rich and unambiguous. Equivocality may be high when information is unrich or ambiguous. The examples in table 1.4 illustrate the concepts of unrich ambiguous information.

Table 1.4 Examples of Equivocality and Clarity

	Equivocality	Clarity
Unrich Information	Equivocal type face: *Equivocality*	Clear type face: Clarity
	A myopic person, when not wearing glasses, may not identify a friend approaching at a distance.	The friend is instantly recognized with the rich information seen through corrective lenses.
	Large numbers such as "60,000 people" are hard to visualize.	The concept of a specific large number can be enriched by invoking a familiar image, such as a sellout crowd of 60,000 at a familiar stadium.
	Some species such as octopi or marbled murrelets exhibit cryptic coloring patterns that allow them to blend into their surroundings.	Close and detailed observation or inspection may allow cryptic colored animals to be seen.
	Raw data on an endangered species may indicate abundance and even trends, but biologists cannot decide on risk status because existing information does not clarify the underlying dynamics and assumptions affecting trends.	Biologists may have rich information on the endangered species that allow a clear understanding of future trends, including age and sex ratios, long term abundance patterns and cycles, subtleties of pairing behavior, natural history, or other factors.
Ambiguous Information	The myopic person wearing glasses may not be able to distinguish between approaching identical twins.	Identical twins might be identifiable if wearing distinguishing clothing.
	Acoustic fish surveys indicate the presence of large numbers of fish where such numbers have not been observed previously, but not in other areas where fish were expected. Biologists do not know what species they are observing, why they are present, or where they are traveling.	Fisheries vessels may conduct a net sample to identify species observed on acoustic surveys. Divers may confirm species of fish.
	The abundance of the endangered Vancouver Island marmot increased in the 1980s because it colonized clearcut areas. This was initially interpreted as a recovery of the species. However, the meaning of the increase later became more equivocal because of evidence that the new colonies were unsustainable.	The grey whale has increased in numbers from perhaps 1,000 animals to perhaps 25,000, leaving little doubt that the species has recovered.

Unrich Information

Equivocality is defined, in part, by a lack of *rich information*. Information is rich when it provides more cues that suggest what incoming data mean (Strauch 1975; Weick 1979a; Daft and MacIntosh 1981; Putnam and Sorenson 1982; Daft, Lengel, and Trevino 1987). Words that describe *rich information* are clear, focused, precise, vivid, deep, contextual, detailed, and abundant. While *comprehensive* information may improve richness, it is more important that information be *comprehensible.* Comprehensive implies full or all encompassing, whereas comprehensible means intelligible or understandable. Rich information is an antidote for vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse data for describing an environment. Rich information is illustrated by the expression, “a picture is worth a thousand words.”

Information Ambiguity

Equivocality is also defined by information that yields two or more possible meanings. Data may be clear, but still suggest multiple interpretations, all of which are plausible. Such data is not *consensible* (Ziman 1978), that is, does not facilitate consensus among its users. Much scientific effort is dedicated to removing ambiguity and gaining consensus on theory. Lack of consensibility thus thwarts scientific confidence.

Information for making resource management decisions is frequently ambiguous. Fisheries scientists, for example, may have limited information on the abundance of fish in the ocean or at various points in their life cycle. Confusion may result if fisheries scientists have sonar information that indicates an abundance of fish, but the species is unknown. Further confusion may result if some areas show many fish, and other areas do not. In such a situation, fisheries managers need more information, but also clearer information that allows managers to “see” what is happening below the surface. Similar situations apply to terrestrial ecosystems, such as biologists having difficulty tracking and counting mobile animals in dense forest environments. In forest environments, scientists can capture and use radiotelemetry to track only a limited number of individuals of important animal species.

Based on the above discussion, equivocality is thus defined and operationalized in terms of two variables: information richness and information ambiguity. These factors are outlined in table 1.5 below.

Table 1.5 Defining Characteristics of Equivocality

Characteristic	Clarity	Equivocality
Information Richness	Rich information provides a clear and detailed picture	Unrich information provides a cloudy or sparse picture
Information Ambiguity	Information suggests a single interpretation	Information suggests two or more interpretations

1.2.4 Relationship of Equivocality and Uncertainty

Equivocality is related to the concept of uncertainty. Daft and Weick (1984) characterized *uncertainty* as a *lack of a sufficient amount of information* for decision making (see also Daft, Lengel, and Trevino 1987; Tushman and Nadler 1978). Most of the information limitations documented in section 1.2.2 derive from a lack of information. Uncertainty, as defined in this research, may thus be addressed, at least in theory, by efforts to improve the amount of information and knowledge about a subject such as an ecosystem.

Equivocality, on the other hand, is primarily characterized as a problem of *inadequate quality* of information. Resolution of equivocality requires a different type of information processing (section 1.5). There is a strong requirement for increased richness of information and discussion to resolve multiple interpretations. Scientists and managers thus need a higher *quality* of information. Additional information may also be required to enrich the scientist's or manager's picture of the environment.

Various forms of uncertainty contribute to equivocality. Noise uncertainty may lead to *unclear* pictures of trends. Structural uncertainty may be due to *disagreement* about underlying causal models (table 1.1). As defined in this research, these problems are symptomatic of equivocality as well as uncertainty. In fact, equivocality may be a higher order phenomenon that encompasses various forms of uncertainty. One rich image of the relationship of equivocality and uncertainty may be that uncertainty is a small slice of pepperoni on a large equivocality pizza (G.A. Walter, personal communication).

1.3 Sources of Equivocality in Ecosystem Management

Various factors limit the ability of scientists and society to obtain unequivocal information concerning ecosystems. These factors include the characteristics of ecosystems, perceptual and cognitive illusions, and social issues and values. This section discusses these factors to further refine the concept of equivocality. For this research, the focus is on equivocality resulting from the characteristics of ecosystems (section 1.3.1), although illusions (section 1.3.2) and social factors (section 1.3.3) also contribute to equivocality in ecosystem management.

1.3.1 Characteristics of Ecosystems

Holling et al. (1978) discussed four properties that determine how ecosystems respond to change: organized connection between parts, spatial heterogeneity, stability and resilience, and dynamic variability.

Ecosystems are organized systems of connections among living organisms and their physical, chemical, and biological environments. The geology, climate, and physical factors determine the vegetation patterns, which in turn feed back to affect the physical factors. Vegetation and physical factors affect create habitats for animal species, and these species in turn alter habitat conditions. Grumbine (1994, 1997) discussed the hierarchical connections among ecosystem elements that require that scientists consider connections among different ecological layers, such as landscapes, ecosystems, populations, species and genes. Holling et al. (1978) argued that each component or species within the system has a limited number of connections to other species or components. "Everything is not strongly connected to everything else." Things are connected in "subassemblies" that are "tightly connected within themselves, but loosely connected to others." In the context of equivocality, ecosystems are complex, organized systems.

Ecosystems are also spatially heterogeneous. Holling et al. (1978) suggested that

> if we were to look in greater detail, we would see a mosaic of spatial elements – of patches – that differ in their biological and physical characteristics. The parts of this mosaic are not totally isolated from each other but linked by movement of material, energy, and some of the organisms; movement dictated by winds, by currents, or by active dispersal of organisms.

The implication is that the effects of a human activity or development may be transmitted through complex systems to different locations, and re-emerge in unexpected places and ways. Persistent organic pollutants including certain pesticides, for example, are volatilized in warm climates in tropical countries, travel through the atmosphere to colder climates, deposit in the fatty tissues of Arctic animals, and are consumed by Inuit who do not use pesticides.

Ecosystems vary in their patterns of stability and resilience. It cannot be assumed that an ecosystem, once disturbed, will return to its original condition. Responses to perturbations can take a number of different forms from relative stability to multi-equilibrium behavior (Holling et al. 1978). The connections among ecological systems are nonlinear, resulting in complex chains and loops in causation (Capra 1996). According to Holling et al. (1978), "a system can seem to be behaving according to one set of rules, until it suddenly flips into a radically different state."

For example, overexploitation of fisheries has resulted in restructuring of marine ecological communities, with noncommercial species replacing previously highly productive commercial species. Overharvesting prey species or nonharvesting of predators of commercial fish has also influenced the collapse of fisheries (Tsoa 1996).

Ecosystems are also dynamically variable. Holling et al. (1978) stated that

> ecological systems are not static but are in continual change – change in numbers, change in equilibrium conditions, change in species composition – and this dynamic change determines part of the structure, diversity, and variability of ecological systems.

The implication of dynamic variability is that change cannot be eliminated and is, in fact, beneficial for ecosystem functioning. Many forest ecosystems depend on forest fire disturbances to maintain diversity and productivity. Fire control programs have thus reduced the resilience and health of some forest ecosystems (Grumbine 1992).

Because of characteristics of ecosystems such as those outlined above, the study of ecosystems "may be the most intractable legitimate science every developed" (Slobodkin 1988). Consistent with complexity theory, a few variables can produce the enormous variety and richness of different ecosystems (Coveney and Highfield 1995; Capra 1996). For an understanding of equivocality, this means that the sheer complexity of ecosystems is a source of equivocality and a barrier to clarity. Equivocality is thus naturally endemic to ecosystem science.

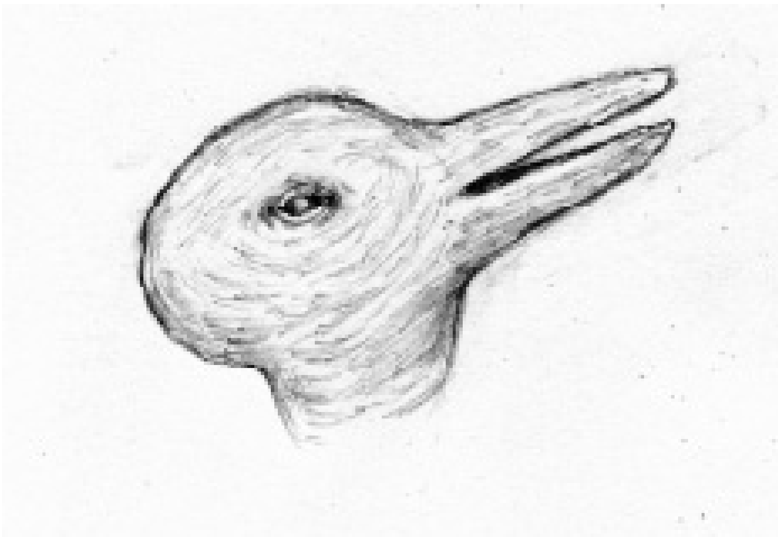
1.3.2 Perceptual and Cognitive Illusions

A second type of factor that limits the ability of scientists and society to obtain unequivocal information concerning ecosystems is the phenomena of perceptual and cognitive illusions. These illusions do not arise from ecosystems themselves so much as from the limitations of human perception and cognition.

Perceptual Illusions

Our minds use environmental cues to interpret what our eyes and other senses perceive. A perceptual illusion is a distortion of reality caused by a misinterpretation of environmental cues. Inconsistencies or vagueness in an image lead to conclusions that are inconclusive or contradictory. For example, humans can infer depth in a flat photograph from the spatial arrangement and relative sizes of objects in the picture. In some situations, however, perception can be wrong. For example, psychologists have altered the arrangement of objects into patterns that give a misperception of depth (Berstein et al. 1991). Some illusions are optical, such as the mirage of water shimmering on a desert horizon or the mislocation of objects in a swimming pool because of the bending of light. The human mind may perceive a smooth motion of events in a movie, whereas the reality is the projection of a series of static images each slightly different that the previous one. Significantly, illusions can also be ambiguous or equivocal, such as the rabbit-duck illustrated in Figure 1.1. In this example, introduced by psychologist Joseph Jastrow in 1900, the mind flips between the perception of a duck or a rabbit (Pinker 1997; Margolis 1996; Denneson 1999), aptly illustrating an equivocal perceptual illusion. Parenthetically, the rabbit-duck also illustrates conceptual ambiguity or equivocality. Thomas Kuhn (1962) used the rabbit-duck illusion as "a primary metaphor to illustrate his central concept of paradigm shifting" (Shearer and Gould 1999; Gould and Shearer 1999/2000).

Figure 1.1 Rabbit-Duck Illustration



Courtesy of Victoria Macfarlane.

The field of environmental psychology addresses the influence of the environment on human behavior, including the processes by which humans perceive the environment (Bell et al. 1990). For the present research, it should be recognized that human perceptions of the environment are complex and potentially illusory. Perceptual limitations and illusions can exacerbate equivocality in ecosystem management.

Cognitive Illusions and Failures

Cognitive illusions or failures are erroneous interpretations of information based on faulty intellectual biases or heuristics (Tversky and Kahneman 1974; Edwards and von Detlof 1986; Connolly et al. 2000; Morgan and Henrion 1990). Extensive research on cognitive illusions was stimulated by the work of Tversky and Kahneman (1974). Cognitive illusions result from the use of cognitive 'heuristics' or rules of thumb that people use to simplify decision making and are generally useful and effective for decisions. Berstein (1996) suggested that

> With rules of thumb, experience, instinct, and conventions – in other words, gut – we manage to stumble from the present into the future. . . . But without conventional wisdom, we could make no long-run decisions and would have trouble finding our way from day to day.

However, these same essential tools of thinking occasionally lead to major errors in decision making. According to Margolis (1996), "when confronted with situations that are novel, impoverished of familiar cues, blurred, or otherwise odd or unfamiliar or difficult, intuition (like perception) well be vulnerable to illusion." Intuition and perception are thus valid mechanisms, but "ordinarily effective functioning of habits of mind can yield illusory judgments" (Margolis 1996). Table 1.6 lists some of the common cognitive illusions.

The *availability heuristic* illustrates the importance of cognitive illusions. Humans tend to "assess the probability of an event by the ease with which instances or occurrences can be brought to mind" (Tversky and Kahneman 1974; Ross 2000). Regions experiencing a long history of abundant harvests will likely assess the probability of a large harvest to be higher than a region that has not experienced one for a long time. For centuries, the northern cod fishery was the most important on the Canadian Atlantic coast. This led to the perception, reinforced by scientific studies, that the fishery was robust and invulnerable. This perception was presumably based on recent and long term experience, that is, availability. The perception was incorrect, the fishery collapsed in the 1980s, and it has not recovered. The collapse of the east coast fishery has subsequently been referred to in discussions of the west coast salmon fisheries.

Another example of a cognitive bias is the focus on "charismatic megafauna" such as sea otters, owls, grizzly bears, or killer whales, which may distract attention from lesser-known and less popular species such as certain invertebrates (Franklin 1993). Because these species are "cute" or interesting, they tend to attract our attention. By focusing on them, however, society may lose opportunities for protecting a greater number of species due to inappropriate attention on a few

Table 1.6 Examples of Cognitive Illusions

Examples of common cognitive illusions and failures include:

- Simplification of issues due to an inability to tolerate ambiguous information referred to as "ambiguity aversion" (Weick 1979; Schwenk 1984; Thaler 1983; Bernstein 1996)
- Selective perception or narrowed field of vision (Hambrick 1981)
- Acceptance of a satisfactory solution rather than searching for the most optimal one, a process known as "satisficing" (March and Simon 1958; Howell and Cooke 1989)
- Anchoring to past conclusions or decisions which can lead to inadequate revisions of prediction in light of newly gathered information (Tversky and Kahneman 1974; Thomas 1988)
- Mindless or habitual enactment of existing scripts or "standard operating procedures" rather than thinking about alternatives and the implications of actions (Langer, Blank, and Chanowitz 1978; Weick 1979)
- Biased perception based on past successes or failures (Dutton and Duncan 1987) or on current conditions (Lawrence 1984)
- Interpretation of issues based on negative or positive issue labels (Thomas and McDaniel 1990; Milliken 1990)
- Restriction of perspective due to perceived threat (Staw, Sandelands, and Dutton 1981; Rousseau 1985) or potential catastrophe (Billings, Milburn, and Schaalman 1980).

(Kellert 1985). In addition, the focus on individual species may foreclose options for broader protection of threatened habitats and ecosystems (Franklin 1993).

Risk perception is another area where cognitive processes yield decisions that are not explainable by rational analysis. It is well documented that lay people perceive risks differently than experts. These cognitions are influenced by a variety of factors such as the dread of the consequences of a pollutant or the degree of knowledge people have of the hazard (Slovic 1987; Margolis 1996; Douglas and Wildavsky 1982; Ross 2000).

The issue of cognitive illusions is that such errors are common, pervasive, and potentially serious (Piattelli-Palmarini 1994; March 1994; Morgan and Henrion 1990; Tversky and Kahneman 1974; Kahneman, Slovic, and Tversky 1982). They also affect public policy making (Thaler 1983). Cognitive illusions also contribute to the potential for equivocality in environmental management by obscuring data and fomenting disparate interpretations of information.

1.3.3 Social Issues and Values

A third type of factor that limits the ability of scientists and society to obtain unequivocal information concerning ecosystems is the influence of social issues and values. Scientific data are influenced by the values and disciplinary paradigms of the scientists who collect and interpret them. Although values and social issues are not the focus of this study, the influence of values must be recognized. This influence is manifested in three ways.

First, the practice of science is subject to significant subjectivity and values contamination. In many environmental and other science-intensive problems, interest groups view environmental information through very different lenses, value orientations, and paradigms. Disputes can arise from the choice of research questions, the framing of hypotheses, the specification of assumptions, and the selection of data. Such choices vary considerably among researchers depending on the influence of institutional environments and disciplinary paradigms (Finlayson 1994; Holling 1996; Ozawa and Susskind 1985). Scientists may also disagree on the significance or implications of scientific evidence. Ambiguity and equivocality are thus inherent in the practice of science (Grinnell 1996). Indeed, the positivist or objectivist science perspective seeks to control for bias through rigorous scientific methods. Nonetheless, when evidence in inconclusive, “scientists are not deterred; they still draw conclusions in these gray areas” (Calne 1999). People feel uncomfortable when confronted with inconclusive problems, and their “desire for ‘explanations’ are readily satisfied by firm statements, especially if delivered in an authoritative tone, even if they don’t mean a thing” (Youngson 1998).

Second, the existence of equivocality within scientific data serves the purposes and positions of different stakeholders. In other words, scientific evidence can be used selectively to support the position of a client or employer (Mattson 1996; Rushefsky 1984; Youngson 1998; Bradshaw and Borchers 2000). For example, fisheries science data are used as a rationale for allocation decisions in fisheries management, such as for the setting of quotas and openings. Where these decisions are made based on uncertain or equivocal data, the credibility of scientific rationales is diminished, and fishers are able to challenge the decisions and seek larger quotas (Finlayson 1994; Scarce 2000; Harris 1995; Clark 1996). Data may also be organized in a distorted way that allows predetermined decisions to be made with confidence, whether or not the data provide reliable information (Scarce 2000; Gambling 1977). Scientists are also influenced to present unambiguous conclusions that ignore uncertainty and ambiguity in underlying models and data (Scarce 2000). Where equivocality is high, scientists can take positions on data that serve their clients positions. This can serve as a wedge between divergent interests, and complicate resolution of underlying equivocality in the data and resulting conflicts.

Third, society may accept that its natural environments are uncertain, and design their activities and programs to adapt to a greater range of uncertainty. Smit (1995) suggested that farm operations and programs could be redesigned to be more adaptive to a broader “coping range.” The coping range is the “range of conditions within which the activity can function reasonably, and beyond which it is vulnerable."

The dilemma for a government facing uncertainty is the need for certainty and deterministic decisions (Beanlands and Duinker 1983; Bradshaw and Borchers 2000). Because stakeholders may have genuinely divergent interests, political decisions or negotiation may be required to resolve equivocal issues. The reduction of scientific equivocality would improve the prospects for better decisions. Nonetheless, equivocality may be to some extent irreducible. A decision about whether or not to log a particular old growth forest in British Columbia will affect either jobs or the environment. The decision is equivocal – either the forest will be logged or it will not be logged. The situation actually produces attitude polarization (Maccoun 1998). Clear scientific information will not resolve this dilemma, though it may contribute to the discussions. Thus even with low equivocality, consensus may not be achieved on important decisions.

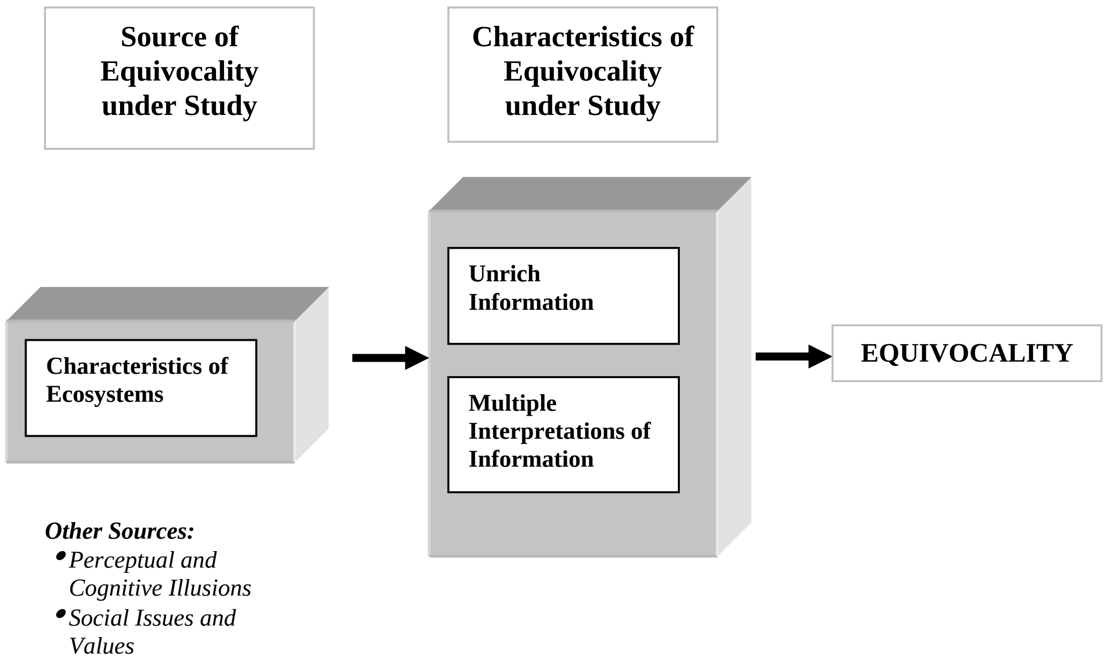
1.4 Diagnosing Equivocality

This section discusses the need for methods of diagnosing equivocality in a given management situation. Section 1.5 discusses the need for remedies for ameliorating equivocality.

Equivocality is a major challenge for resource management. As discussed in sections 1.2 and 1.3, it can overwhelm decision makers with confusion. If decision makers are perplexed over choices among two or more equally plausible alternatives, they may be left with the prospects of indecision or gambling on unknown outcomes.

Before a problem can be remedied, the decision maker should diagnose what is malfunctioning. For this purpose, it is essential to have a methodology for recognizing and evaluating the equivocality challenge. The diagnostic tool is discussed in chapter 5, which is based on the analysis of the case study. Section 1.2.3 and 1.3 provide the theoretical basis for analysis of the case study and the development of the diagnostic tool. This basis is illustrated in figure 1.2, which illustrates the relationships among the characteristics of equivocality (section 1.2.3) and sources of equivocality (section 1.3). This figure provides a framework for diagnosing the presence of equivocality. Each situation can be examined to determine if the sources of equivocality are present which produce information that is unrich, and ambiguous. If these characteristics apply, the decision situation is equivocal. However, the situation is less equivocal if information is rich or unambiguous.

Figure 1.2 Characteristics and Sources of Equivocality



Chapters 2 through 5 describe a case study that operationalizes a method for diagnosing equivocality. The case study focuses on the characteristics of ecosystems as a source of equivocality. The case study does not explicitly address perceptual and cognitive illusions or social issues and values. These sources of equivocality are recognized as important and considered as context for the focus on ecosystem factors. In the case study, the data will be queried to determine whether scientists have rich and unambiguous ecosystem information for making decisions. The case study will use a simple decision model to assess which aspects of a decision process are affected by equivocality.

1.5 Remedying Equivocality

In resource management practice, equivocality is often not recognized. Where it is noted, it is seen as a contextual or tangential factor that cannot be addressed. It does not become a focus of attention to be directly addressed, but may be assumed away. It may also be considered a short term evil to be resolved by more information. In management problem solving, issues are often not addressed because decision makers cannot see a feasible solution for them. This is consistent with problem sensing theory that suggests that decision makers often recognize problems only after they have found feasible remedies that would correct these problems (Dutton and Duncan

1987). One purpose of this research is to explore the prevalence of equivocality in ecosystem management with a goal of proposing both methods for diagnosis as well as potential remedies for addressing and resolving equivocality. Feasible solutions are thus necessary to recognize and deal with equivocality.

This section identifies two strategies for addressing equivocality: acquisition of rich information and engaging in discussion to construct shared meanings. These strategies are discussed below with reference to the two characteristics of equivocality identified in section 1.2.3, that is, information that is unrich and ambiguous.

1.5.1 Acquisition of Rich Information

When faced with equivocality, decision makers must have *rich information* about a problem. As noted in section 1.2.3, equivocal information is vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse. Equivocal information does not give clear mental pictures of the environment being observed. Rich information is sought as an antidote. Information "richness" is the ability of the information to improve understanding quickly by providing a greater number and variety of cues to suggest what new data mean (Daft and Lengel 1984a, 1986; Gerloff 1985; Ziman 1978). Rich information provides the details, nuances, and cues that frame a context for data with precision, and thereby reduces the number of plausible interpretations that data can suggest. Rich information is "highly informative and provides deeper, richer understanding to managers especially for ambiguous issues" (Daft 1992). Rich information provides "instant feedback" (Fulk 1993).

A researcher can look deeper into the data to discern patterns and meaning. "A great deal of excellent scientific knowledge depends on a widely shared human perceptual faculty – the mysterious skill that we call *pattern recognition*" (Ziman 1978). Ability to discriminate among objects and patterns is improved with technology that provides different types of information (Swets 1998). Rich information is also information that is sufficiently abundant to provide a rich picture. The quantity of information is thus related to the quality of information. In other words, decision makers may need both a greater quantity and quality of information to enhance information richness.

Rich information can be illustrated with an example. A simple depth sounder would provide one data point to discern the depth of water under a boat, whereas a multibeam sonar would provide a larger number of data points that create a sonic picture. This would provide richer data for discerning whether a shape on the ocean bottom was a ship or a large boulder. A sensor array with metal detection capabilities would add still further richness to the depth sounder images, but an unclear object could still be something metal other than a ship. If a diver visited a site, information would have very rich multiple cues that could be matched with his or her experience to positively identify the object. Perception is highly memory dependent, so that experienced observers with better search images are more able to perceive patterns in otherwise murky data. A diver would compare memories of ships with the information he or she sees or feels to make a judgment.

Rich information also requires immersion in the data or phenomenon of interest. According to Scarce (2000)

> John Muir once wrote that if he could just get people into the forest they would understand what he had experienced and would love Nature as he did. Muir saw that *experience* is the key to understanding human-environment interactions. One of the numbing features of the rationalized lives we lead is that we so seldom have the time, money, or energy to pause at the side of a pond and to stare into the weasel's eyes. Simultaneously – and not unconnected, I think – we claim that our lives have no meaning.

1.5.2 Discussion

A second characteristic of equivocal information is its tendency to convey two or more possible meanings (section 1.2.3). Data may be clear, but still suggest multiple interpretations, all of which are plausible. Multiple logical frameworks yield multiple, often conflicting, conclusions about what is happening.

The strategy for addressing multiple meanings is to facilitate communication, information sharing, and collaboration. Research on equivocality suggests that good communication is an important tool for transforming equivocal data into understandable information. Effective organizations facing equivocality spend a greater amount of time gathering and discussing information (Strauch 1975; Weick 1979a, 1995; Lyles and Mitroff 1980; Daft and MacIntosh 1981; Putnam and Sorenson 1982; Kreps 1980; Daft and Lengel 1986; Senge 1994; Bradshaw and Borchers 2000). Weick (1979, 1995) proposed that where equivocality increases, organizations must engage in two-way communication to reduce ambiguity. Kreps (1980) argued that, without such communication, "fatal mistakes are likely to occur because the organization is unable to process the equivocal inputs into understandable information." When faced with equivocal information, decision makers "must impose structure and clarity upon ambiguous events, and thereby provide direction, procedures, adequate coupling, clear data, and decision guidelines for participants" (Daft and Lengel 1984). Discussion is also inherent in science. Ziman (1978) suggested that

> scientific knowledge is the product of a collective human exercise to which scientist make individual contributions which are purified and extended by mutual criticism and intellectual cooperation. According to this theory, *the goal of science is a consensus of rational opinion over the widest possible field* [italics in original].

Decision makers cannot make decisions if the basis for these decisions is confused. According to Daft, Lengel, and Trevino (1987),

> equivocality leads to the exchange of subjective views among managers to define the problem and resolve disagreements. . . . The organization reduces equivocality by pooling opinions and overcoming disagreement. This leads to a shared understanding and social agreement about the correct response. The response to equivocality comes from within the management group in the form of defining what events mean and enacting a solution.

Thus the remedies for equivocality are acquisition of rich information and discussion to develop shared interpretations. These remedies are not novel. Since the time of Galileo, observation has been proffered as a basis for testing theory (Calne 1999). In acquiring rich information, we are simply enriching observations. At the same time, the basis for accepting theory is the court of peer review and "argumentation" among knowledgeable scientists (Calne 1999) – an analog to discussion. For equivocality, peer review is essential, but may be enhanced by richer forums for interaction and the use of rich information.

The remedies for equivocality can be translated into designs for management systems that resolve equivocality. Table 1.7 outlines the logic for design of management systems for resolving equivocality. The lack of information characteristic of equivocality can be addressed by selective information gathering that is guided by processes that scope or focus research efforts on key data required for decisions. The poor quality of information characteristic of equivocality can be addressed by gathering richer information, which can be supplied by information systems adapted to improve the richness of information. Finally, the multiple interpretation characteristic of equivocality is best addressed through discussion, which can be addressed through collaborative organizational structures and processes. These remedies provide the basis for designing equivocality-resolving management systems in chapter 7.

An important caveat is that these mitigation strategies are not panaceas. Rich information is not a replacement for quantitative information, nor should discussion be founded on self-interest

Table 1.7 Logic for Organizational Remedies for Addressing Equivocality

Equivocal data	Creates a need for:	Which can be partially satisfied by:
Data that are vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse.	Gathering of richer information to develop a clearer picture of a problem and its context.	Information support systems that produce appropriate amounts of rich information.
Data which leads to multiple interpretations	Discussion to construct a shared interpretation of information.	Organizational structures and processes that facilitate communication, information sharing, and collaboration.

and whim. Rich information is necessary because standard data sets often do not provide a sufficiently meaningful picture of the environment. Standard data sets are often too sparse. In the same vein, uninformed conversation is no replacement for focused discussions of available theories and standard and rich empirical data. Application of these mitigative strategies is only a beginning, and the search should be commenced for better methods of coping with equivocality.

1.6 Summary

Decision makers must process information in order to inform their decisions, and predict how various outcomes will be affected by their decisions. Information processing theory suggests that the configuration of processes and structures within organizations is strongly influenced by how organizations process information. Information used by decision makers varies greatly in quality. A variety of limitations on information quality was identified. These tend to be lumped under the term *uncertainty*. Equivocality, on the other hand, is an under-recognized phenomenon. Equivocality is a problem of information quality characterized by unrich and ambiguous information. Equivocality in ecosystem management arises from three sources: the characteristics of ecosystems, perceptual and cognitive illusions, and social issues and values. This research focuses on the first source: the characteristics of ecosystems and how these influence levels of equivocality.

The sources and character of equivocality must be diagnosed before decision makers can address the equivocality challenge. A method for diagnosing equivocality is developed through a case study in chapter 2 through 5.

Managers tend not to address problems until they perceive a feasible solution or remedy. An approach for addressing equivocality can be based on the characteristics of the phenomenon. Unrich information can be addressed by acquiring rich information, or enhancing information richness. Ambiguity in interpretation of information can be addressed by encouraging discussion to develop shared meanings. These strategies are discussed in chapter 7.

CHAPTER 2: CASE STUDY OF PROTECTED AREA SELECTION IN MARINE AND COASTAL ECOSYSTEMS

> "To witness the death of the last member of a parrot or orchid species is a near impossibility. With the exception of the showiest birds, mammals, or flowering plants, biologists are reluctant to say with finality when a species has finally come to an end. There is always a chance (and hope) that a few more individuals will turn up in some remote forest remnant or other. But the vast majority of species are not monitored at all. . . . they pass from earth without notice" (Wilson 1986).

This chapter provides an overview of the case study and specifies the primary research question and hypotheses investigated in this study. As background to the case study, it compares marine and terrestrial environments and institutional arrangements for protected area management in both environments. Because the case study considers decision making processes, it also discusses the potential effects of equivocality on various decision functions, and formulates hypotheses to test the level of equivocality for each of these functions.

2.1 Conceptual Framework for Case Study

The research explored how patterns of equivocality vary among different types of ecosystem. A comparison of marine and terrestrial environments was chosen as a case study. The comparison of marine and terrestrial ecosystems is relevant and appropriate because these types of ecosystem exhibit obvious biophysical and logistical differences. It was hypothesized that biophysical and logistical differences between marine and terrestrial environments lead to greater equivocality in marine environments (figure 2.1, column 1).

Equivocality becomes a challenge when decisions are required. The case study focused on one type of resource management function in particular, that is, the identification, evaluation, and selection of protected areas for conservation of species-at-risk. The decision whether a protected area should be established is a fundamental priority for ecosystem management. This case analysis uses a simple decision making model to evaluate the hypothesis (figure 2.1, column 2). The model consists of four decision functions: problem definition, information gathering, causal analysis, and action planning. It is expected that equivocality can affect each of these functions. To the extent that it does affect these functions, it will contribute to less effective resource management decisions. The analysis of the case focused on evidence for equivocality for each of the decision functions.

A set of seven hypotheses was developed to test whether equivocality differed among these ecosystems (figure 2.1, column 3). These hypotheses were used to examine evidence with respect

Figure 2.1 Conceptual Framework for Case Study

Column 1

FACTORS CAUSING EQUIVOCALITY
(Chapter 2)

Marine and terrestrial environments exhibit…

Column 2

DECISION MAKING IMPLICATIONS
(Chapter 2)

Equivocality affects…

Column 3

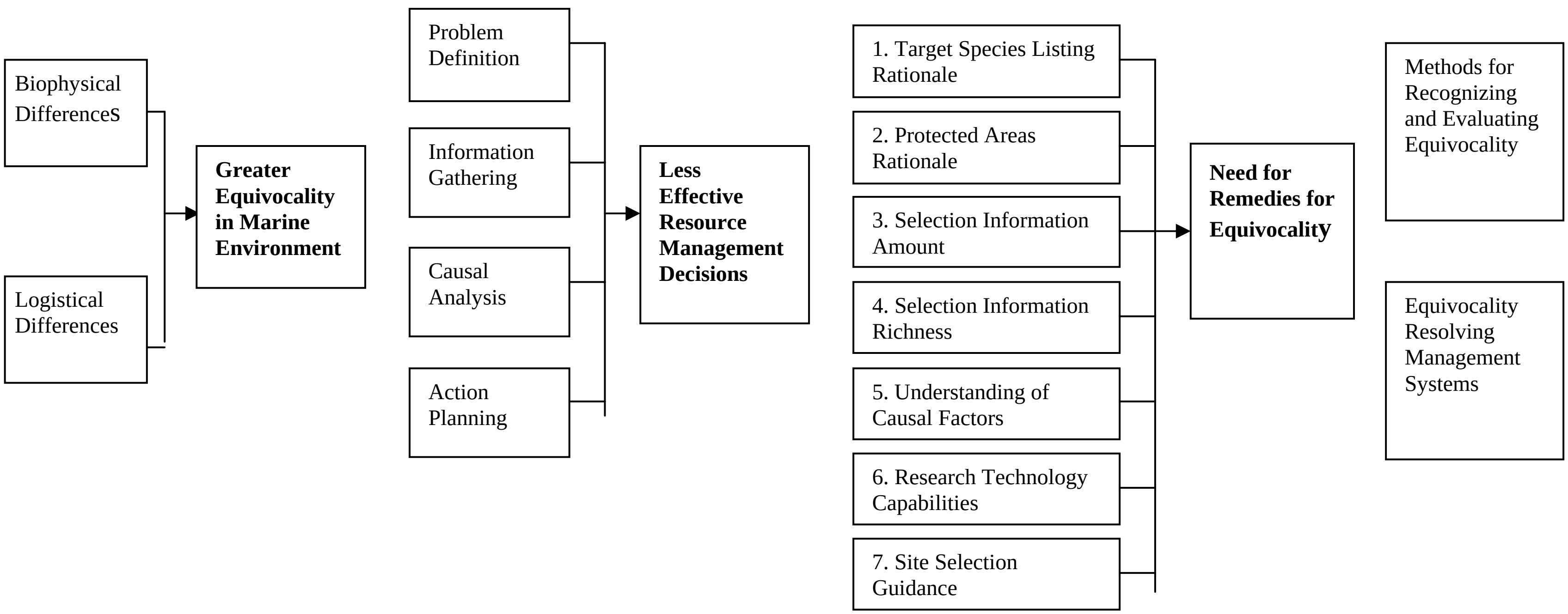
EVIDENCE FOR EQUIVOCALITY IN RESOURCE MANAGEMENT
(Chapter 2, 4, and 5)

Equivocality is evident with respect to…

Column 4

REMEDIES FOR EQUIVOCALITY
(Chapter 6 and 7)

Equivocality can be addressed by…



to seven information processing variables or factors, including target species listing rationale, protected areas rationale, selection information amount, selection information richness, understanding of causal factors, research technology capabilities, and site selection guidance. These variables operationalize the decision making functions.

Finally, the case study demonstrates the need for remedies for mitigating the effects of equivocality on resource management decision making (figure 2.1, column 4). Two types of remedy are required. First, methods are required for recognizing and evaluating equivocality (chapter 6). No solutions are possible without knowing the extent and patterns of equivocality. Second, equivocality-resolving management systems are required to address the effects of equivocality on resource management (chapter 7).

The methodology for the case analysis is described in chapter 3. The approach was based on a grounded theory building methodology with case studies. Research involved document and literature analysis, interviews, and participant observation. Cases were studied through detailed within-case and cross-case analyses. A set of 16 indicators was developed to ensure that the cases were comprehensively explored (chapter 4). The results of cross-case analysis of the four ecosystems are presented in chapter 4. Based on this analysis, the hypotheses were evaluated based on a qualitative rating system reported in chapter 5.

2.2 Primary Research Question and Hypothesis

This research evaluates the assumption that biophysical and logistical differences between marine and terrestrial environments create a more equivocal decision making environment for the management of marine protected areas than that for terrestrial protected areas (section 2.3). The management of marine protected areas may thus require unique and different ways for recognizing and coping with this equivocality.

The research employs a simple decision making model for assessing the effects of equivocality on decision making (sections 2.5 through 2.10). This model includes four stages or functions: problem definition, information gathering, causal analysis, and action planning. Past research has not clearly demonstrated how equivocality affects these different stages of decision making, or under which circumstances this equivocality manifests itself. There are indications that equivocality may occur at every stage of decision making. However, it is possible that some stages are more, or less, equivocal than others. Some marine environments could also exhibit more, less, or the same degree of equivocality as terrestrial environments at different decision stages.

This research therefore begins by exploring differences and similarities in equivocality between marine and terrestrial environments. It addresses the following research question:

> *What are the similarities and differences in the patterns of equivocality in information processing as they affect decision making for selection of protected areas for target species in different ecosystems?*

Target species are defined as endangered, threatened, or vulnerable species, or other species of management concern, along with their habitat and ecosystems (Noss, O'Connell, and Murphy 1997).

The *primary hypothesis* considers whether the selection information for marine protected areas exhibits *a different pattern of equivocality* than the selection information for terrestrial protected areas. For example, these patterns might differ in the case where one environment is higher in the problem definition stage and lower in the information gathering stage than the other environment. If the patterns of equivocality are different, then this has implications for the choice of management practices.

> *Primary Hypothesis: The patterns of equivocality in selection information differ between marine and terrestrial protected areas.*

The *null hypothesis* tests whether the patterns of equivocality are substantially similar in both marine and terrestrial selection information.

> *Null Hypothesis: The patterns of equivocality in selection information do not differ between marine and terrestrial protected areas.*

The implications of the null hypothesis are that differences in equivocality should not affect the choice of management practices.

2.3 Comparison of Marine and Terrestrial Environments

As governments and international organizations have focused management attention on the oceans, major efforts are being made to gather data and develop information and knowledge concerning marine environments. Although modern oceanography began in the last century, the field has expanded dramatically in the past few decades. In contrast, knowledge of terrestrial systems evolved over centuries as people have used resources such as forests, minerals, water, agricultural lands, wildlife, stream fisheries, and settlement lands.

Information processing contingencies differ between marine and terrestrial environments in two important ways: (1) the biophysical characteristics of the environments, and (2) the logistical constraints for information gathering.

2.3.1 Biophysical Differences

Table 2.1 summarizes how biophysical characteristics of marine environments differ from terrestrial environments. Because of these differences, scientific knowledge of terrestrial environments cannot be easily applied to marine environments (Roughgarden, Gaines, and Iwasa 1984; Ray 1988; Carr and Reed 1993). In addition, the long history of managing terrestrial resources provides a better level of scientific understanding and information base for supporting decision making concerning these resources. Ray (1988) argued that “we are almost infinitely less knowledgeable about the nature of marine systems than we are about terrestrial systems."

2.3.2 Logistical Differences

Logistical difficulties in gaining access to, and gathering information from, the marine environment compound problems arising from biophysical differences (table 2.2). Because information gathering is more complicated, difficult, and expensive in the marine environment, resource management organizations must make greater efforts to obtain information for problem solving and decision making. These efforts may involve greater demands on organizational resources. In addition, resource managers must often rely primarily on information from remote sensing and other indirect data gathering technologies such as sampling nets, and may have only occasional and transient access to the underwater environment for direct observation using diving equipment or submersibles (Edmunds 1996; Earle 1995). The characteristics of information obtained through such measures may be somewhat more "alien" to human observers than that obtained by direct observation of terrestrial systems.

At the same time, practical everyday understanding from personal and tangible experience working in the marine environment is also more limited. Youngson (1998) indicated that “none of us is capable of envisaging anything totally different from what we know: we are the prisoners of our experience.” Calne (1999) indicated that perception is “highly subjective” and “we see . . . what we are trained to see.” Margolis (1996) argued that researchers can become frozen in their paradigms based on experience (see also Ziman 1978).

> In contexts that are unfamiliar, or impoverished, or difficult in some other way, the very habits of mind that account for our fluent and effective performance in more normal circumstances can yield blunders of intuition that look confidently right to an otherwise highly intelligent and sophisticated person.

As land animals, people are less familiar with marine systems. They thus may not carry the repertoire of personal experience, habits of mind, and training necessary for understanding an unfamiliar environment such as the ocean.

Table 2.1 Illustrative Biophysical Differences between Marine and Terrestrial Environments

MARINE	TERRESTRIAL
Spatial Dimensions: Area, Depth, Continuity	
Oceans cover 70% of Earth's surface. Oceans are an average of 4 km deep, and their volume makes up 99.5 % of the living space of the planet. Marine systems are massive in scale. Oceans environments are vertically thicker, with life at all depths. The marine environment is more spatially continuous with fewer discontinuities than land. Although depth, salinity, distance, and other barriers contribute to biodiversity, physical boundaries between ecosystems are less pronounced and fixed than for terrestrial systems. Long-distance migrations, and vertical and horizontal intermingling of sea life, are thus possible for many species.	Land areas are not as extensive as marine. Life on land is concentrated on or near the surface, although a few microorganisms exist to depths of kilometers below the surface. Barriers in the terrestrial environment are more stationary and restrictive than in marine environments. These include mountains, rivers, and coastlines. The terrestrial environment is also more fragmented by human activities such as roads, cities, industrial plants, agriculture, and forest harvesting.
Aquatic vs. Terrestrial Environmental Factors	
The support systems necessary for marine life are primarily conditioned by water characteristics, including nutrients, temperature, buoyancy, pressure, and chemical reactions. Water movements mix and blend water characteristics over broad areas. The marine environment is fluid. Currents transport organisms, nutrients, and pollutants over vast distances. Where plants attach to the substrate, they depend less on seabed nutrients than land plants depend on soil nutrients. Marine reproductive cycles, such as larval and juvenile stages, are closely linked to water movements.	Terrestrial life depends on several media for life support, such as atmosphere, water, and soil. The terrestrial environment is solid. This affects the root systems, nutrient cycles, and vulnerability to pollution of ecosystems. Terrestrial ecosystems are tied to the land surface, which is fixed and stationary.
Variability	
Because the great mass of the oceans moderates temperature and certain other large-scale physical changes, some marine parameters exhibit greater overall stability. Because they are adapted to stable environments, the functional responses of marine species to fluctuations in physical parameters can be rapid, causing dramatic year-to-year variability in abundance and short-term shifts in distributions.	Terrestrial physical systems are more variable, with rapid and unpredictable fluctuations in temperature, moisture, and other environmental parameters. Most terrestrial species have evolved to adapt more effectively to interannual and decadal variability in the physical environment. Thus terrestrial species and communities show less short-term variability in abundance, distributions, and community structures than marine ecosystems.

Continued on next page

Table 2.1 – *Continued*

Large-scale events such as the El Niño phenomenon can cause rapid, cascading, large-scale, long-term, and unpredictable revolutions or switches in community structure. Many marine species have evolved life cycles involving diffusive dispersal of larvae and long range migration that allow adaptation to longer term environmental variations and that replenish populations in distant locations. Marine ecosystems may thus be more adaptable in the long-term and extinctions may be less likely, except where human overharvesting occurs. However, adaptations may tend toward ecosystems that have fewer human economic uses.	Terrestrial ecosystems, such as forest communities, are "rooted" in the soil and vegetation. They spread very slowly over long periods such as centuries or millennia. When faced with long-term changes such as regional climate change, some ecological communities that cannot adapt or migrate to locations that are more compatible may therefore disappear. Conversely, some species can propagate over wide areas through seed dispersal or migration. The slowness to adapt may cause terrestrial systems to be more subject to extinctions.
Ecological Differences	
Marine organisms, dominated by single-cell plankton, are often relatively simple compared to land species. Modes of reproduction influence distribution in ways that differ from terrestrial modes, such as the broadcast of large numbers of planktonic larvae that drift in the ocean currents to replenish other areas that may be depleted. The diversity, abundance, and life histories of most marine species are largely unknown. Marine species often serve different roles in an ecosystem as they develop through various life stages, such as fish feeding on plankton as larvae, benthic worms and prawns as juveniles, crabs, and mollusks as they grow larger, and finally on other fish as adults. Trophic systems differ in construction from terrestrial systems, with whales as the longest-lived species at the top of the food webs.	Land species concentrate in areas where adequate water and moisture exist, with complex adaptations of ecosystems to moisture regimes. Terrestrial species are often adapted to a wider range of environmental niches so that the number of land species is believed to be considerably larger than the number of marine species. The longest-lived land species are trees, some of which disperse at a slow pace of tens of kilometers per century. Land ecosystems support a larger number and diversity of species. On the other hand, higher taxonomic levels are more diverse in marine ecosystems, with at least 32 of the 33 animal phyla represented compared to 17 for both land and freshwater. The higher taxonomic diversity suggests greater variety of fundamentally different body plans and life histories in the ocean.

Sources: Berrill 1997; Malakoff 1997; Broad 1997; Christensen et al. 1996; Hilborn and Gunderson 1996; Parsons and McGuire 1996; Wilson, Acheson, and Kleban 1996; Busch 1996; Fredrickson and Onstott 1996; Norse 1995; Bisbal 1995; Kesteven 1995; Earle 1995; Fogarty 1995; Harris 1995; Gauthier 1995; Culotta 1995; Pimm et al. 1995; Sherman 1995, 1991; Agardy 1994; Caddy and Bakun 1994; J.R. Morgan 1994; Wilson et al. 1994; Baskin 1994; Ludwig, Hilborn and Walters 1993; Orians 1993; Carr and Reed 1993; Raven et al. 1992; Caron 1992; Harbison 1992; McIntyre 1992; Ray and Grassle 1991; Ehrlich and Wilson 1991; Perrin 1991; Ray 1991; 1988, 1986; Steele 1991a, 1991b, 1985, 1974; Thurman 1990; Juda and Burroughs 1990; Hilborn 1990; Brown 1985; Rice 1985; Mondor 1985; Shepherd 1984; Sissenwine 1984a, 1984b; Steele and Henderson 1984; Beddington 1984; Salm 1984; Roughgarden, Gaines, and Iwasa 1984; McCay 1978; Sumich 1976; Dickie 1975; Likens and Borman 1974; Odum 1959.

Table 2.2 Illustrative Logistical Differences Between Marine and Terrestrial Environments

	MARINE	TERRESTRIAL
Nautical Milieu and Transportation Technologies*	Most of the world's oceans are at great distances from land, and are essentially inaccessible to most investigations. Boats and other marine equipment are required to support human presence in marine areas, especially below the surface. Marine equipment is often more sophisticated and expensive, and less available, than land equipment, thus limiting fieldwork. Scientific observations of marine phenomena, therefore, tend to be short-term, narrower in spatial extent, and less intensive than terrestrial observations. Less than ten percent of the ocean has been sampled, and most has only been superficially mapped.	No special technology is required for access to many terrestrial areas, except for steep terrain. People can walk, climb, sit, and move relatively freely. Access technologies for land environments may include all-terrain vehicles, aircraft, or walking. Many ordinary citizens have access to terrestrial ecosystems to provide amateur monitoring and observations to support wildlife management.
Obscurity and Information Technologies	Most of the marine environment is covered by water. Special technology is required for observation. Most data gathering relies on remote sensing technologies. Remote observation technology may focus on single parameters and thereby produce information with limited richness. Marine species may become extinct before they are even known due to lack of familiarity with marine life.	People can directly and comparatively easily observe the land environment with normal senses or simple technology, such as binoculars and cameras. Direct observation of land ecosystems provides context-rich information with multiple cues about the environment. Ordinary citizens provide observations of environmental systems, such as wildlife presence, bird counts, and stream environments.
Everyday Experience	Although many persons work in marine industries or live in coastal communities, the 'habitat' of humans is land. Human presence and occupancy in marine environments is transient and limited to short voyages for shipping, fishing, mineral exploration, or recreation. Everyday knowledge of open ocean environments is thus very limited. Even our existing knowledge is based on what we can easily get to, and most of the open ocean is a mystery to science. Aboriginal, traditional, and local knowledge extends to coastal and even marine environments.	Everyday experience continuously informs humans about the terrestrial environments. Ecological knowledge and human familiarity with land systems is much greater than for marine environments. Aboriginal, traditional, and local knowledge incorporates the learning of people who have lived with and depended on the resource, sometimes for thousands of years. This learning is often ignored in resource management.

Sources: Edmunds 1996; Miller 1996; Norse 1995; Culotta 1995; Harris 1995; Earle 1995; King 1994; Ray and Grassle 1991; Ray 1988; Einhorn and Hogarth 1986; Rice 1985; Shepherd 1984; Beverton et al. 1984; Atema 1980; Ziman 1978; Steele 1974.

* Technology, as defined here, includes the types, procedures, and patterns of work; the equipment and materials used; and knowledge and experience applied in performing tasks (Gerloff 1985a, 1980b). Contrary to common perception, hardware and equipment may only be a small component of technology. In this research, technology includes approaches for gathering, processing, and interpreting information, including a range of tools such as remote sensing hardware, computer systems, scientific method, conceptual theories and models, and organizational deliberation processes.

2.3.3 Relevance of Case to Marine Conservation

The present case study has special relevance to the evolution of marine conservation. While forests have been managed, for better or worse, for hundreds of years, and agricultural lands for thousands of years, the initiation of programs for managing marine resources is relatively recent. Management has mostly been limited to the regulation of coastal fishing, ports, and shipping, and to management of coastal hazards.

The riches of the sea were once thought to be infinite. Oceans were treated as inexhaustible storehouses of fish and other resources. A maritime culture of "freedom of the seas" dominated resource management for centuries (Ray 1986; Juda and Burroughs 1990; Ray and Grassle 1991; Knecht 1994; McIntyre 1995; Harris 1995; Earle 1995; Broad 1997), which led to an attitude of "out of sight, out of mind" (Juda and Burroughs 1990). The idea that the seas might need surveillance and protection would have seemed bizarre (McIntyre 1995). If the oceans are limitless, then the effectiveness of resource management programs does not matter. Similar attitudes of optimism have prevailed for terrestrial environments as well. However, the problem has been exacerbated in marine environments by the immense scale of the oceans, the lack of awareness of limits of marine systems, and the lack of effective jurisdictions for management (Earle 1995; Broad 1997).

As human uses of the ocean have intensified in recent decades, international organizations, national governments, resource users, and the public have increasingly recognized the need for improved conservation of vulnerable resources. There has been a growing awareness of the finite and vulnerable nature of the living resources of the oceans, and signs of a growing acceptance of the need for ocean resource management (King 1994; Juda and Burroughs 1990; Sorensen and McCreary 1990). The United States government passed its *Coastal Zone Management Act* in 1972. Since the 1992 United Nations *Conference on Environment and Development* in Rio de Janeiro, the World Bank and other international agencies have adopted several programs to address the deteriorating state of the global oceans (Sherman 1995). In 1994, the United Nations *Law of the Sea Convention* that entered into force, a landmark agreement that strengthened international law (Birnie 1994; Anderson 1994; Murray 1994). The *convention* charges coastal states with several stewardship responsibilities, such as fisheries conservation, resource management, and preservation of the marine environment (Murray 1994). In 1996, Canada enacted its *Oceans Act* as an initiative to improve management of ocean resources.

The growing concern for marine environments has led to programs for establishing marine protected areas to conserve environmental features such as endangered species. Many of the new programs for protecting marine biodiversity have been modeled on terrestrial conservation practice and models. A well-developed science of conservation biology has developed from many decades of planning and management of terrestrial species in protected areas. Governments have typically applied this terrestrial experience to protected areas in marine environments (Thorne-Miller 1999). This application may not be appropriate. According to Thorne-Miller (1999),

> because of the differences in the two [marine and terrestrial] environments, the effectiveness of transferring particular terrestrial conservation techniques to marine environments is sometimes questionable. For example, individual threatened and endangered species are very often the focus of conservation efforts, but that approach is of limited value, particularly in the sea, where it is useful only for those few species we know to be in trouble and are able to monitor. Terrestrial species are more familiar and their distribution and status are more easily determined, whereas the status of most marine species is unknown.

2.4 Institutional Context

The conservation of marine and terrestrial ecosystem involves many resource management functions, such as integrated planning, user management, and impact assessment. This dissertation focuses on the function of identifying, evaluating, and selecting protected areas to conserve species-at-risk.

This section provides an overview of the institutional context for this research. It first considers the movement to establish protected areas, with special attention to the institutions in British Columbia (section 2.4.1). It then reviews the institutional structures and processes for listing species as species at risk (section 2.4.2). Because the institutional contexts for protected areas and species at risk are very complex, this review highlights only the institutions most relevant to this dissertation.

2.4.1 Establishment of Marine and Terrestrial Protected Areas

Societies have been establishing terrestrial protected areas for centuries. The modern movement to establish large areas for conservation began with the establishment of Yellowstone National Park in 1872 (Alder 1997).

On the marine side, the establishment of protected areas for conserving marine ecosystems and species has been one of the important components of new initiatives in the growing movement toward marine conservation (Alder 1997). Although the first major marine protected area, Glacier Bay National Monument, Alaska, was established in 1925, few new areas were established until the 1960s. The designation of marine protected areas expanded rapidly after 1975, but few management plans were prepared for these areas (Alder 1997).

In Canada, major planning for establishing marine protected areas began with the adoption of a National Marine Parks Policy in 1983, which was proposed for conserving representative ecosystems. Since that time, an organizational infrastructure has evolved, although few marine areas have actually been formally established.

Table 2.3 identifies some of the major agencies and legislation responsible for establishing protected areas in British Columbia, both for marine and terrestrial environments. The table illustrates the shared responsibility for protected areas among a group of agencies. The table also shows that substantial legal authority exists for establishing marine and terrestrial protected areas in British Columbia. In addition to government agencies listed on the table, local governments and nongovernmental organizations also have a role in establishing protected areas.

Table 2.3 Authority and Agencies for Establishing Protected Areas

Type of Protected Area	Type	Authority	Administering Agency
Marine Protected Areas	Marine	*Oceans Act*	Fisheries and Oceans Canada
Fisheries Closures	Marine	*Fisheries Act*	Fisheries and Oceans Canada
National Parks/National Park Reserve	Both	*Canada National Parks Act*	Parks Canada
National Marine Conservation Areas	Marine	*Marine Conservation Areas Act* (proposed)	Parks Canada
Gwaii Haanas Heritage Site	Both	*Haida First Nation in partnership with Parks Canada*	Archipelago Management Board, Gwaii Haanas National Park Reserve/Haida Heritage Site
National Wildlife Areas and Marine Wildlife Areas	Both	*Canada Wildlife Act*	Environment Canada (Canadian Wildlife Service)
Marine Bird Sanctuaries	Both	*Migratory Birds Convention Act*	Environment Canada
Provincial Parks, Recreation Areas, and Nature Conservancies	Both	*Park Act*	B.C. Ministry of Environment, Lands and Parks (BC Parks)
Ecological Reserves	Both	*Ecological Reserves Act*	B.C. Ministry of Environment, Lands and Parks (BC Parks)
Wildlife Management Areas	Both	*Wildlife Act*	B.C. Ministry of Environment, Lands and Parks (Wildlife Branch)
Wilderness Area	Terrestrial	*Forest Act*	B.C. Ministry of Forests
Protected Area	Both	*Environment and Land Use Act*	B.C. Ministry of Environment, Lands and Parks (BC Parks)

Sources: Morrison and Turner 1994; Department of Fisheries and Oceans Canada and B.C. Land Use Coordination Office 1998.

Protected areas are typically established to conserve various features, attributes, or resources of the natural environment, such as biologically productive areas, areas of high biological diversity, habitats of rare or endangered species, or representative samples of regional ecosystems. This research focuses on the conservation of the biodiversity of the ecosystems, including the habitats and ecosystems of rare, threatened, endangered, or vulnerable species, or other species of management concern. The biodiversity criterion is a high social priority, and hence is an important in nearly all lists of criteria for selecting protected areas.

In 1992, the government of British Columbia announced the *Protected Areas Strategy*. The strategy identified policies and strategies to increase the proportion of the provincial land base in protected status from 6 percent to 12 percent by the year 2000 (Land Use Coordination Office 1996; Province of British Columbia 1993; B.C. Parks and B.C. Forest Service 1992). By January 2001, the percentage had reached 12.4 percent of the terrestrial land base (Land Use Coordination Office 2001). These protected areas do not include wildlife reserves, migratory bird sanctuaries, and regional and local parks (B.C. Ministry of Environment, Lands and Parks 1999). The process of identifying, evaluating, and selecting these areas has occurred through a number of broad interagency, stakeholder, and public consultation and land use planning processes (Land Use Coordination Office 1996).

In 1994, an intergovernmental Marine Protected Areas Steering Committee and working group were established by the provincial and federal governments to develop a protected areas strategy for the B.C. coast. Member agencies included the Fisheries and Oceans Canada, Parks Canada, Canadian Wildlife Service, B.C. Land Use Coordination Office, B.C. Parks, and the B.C. Ministry of Agriculture, Fisheries and Food (Marine Protected Areas Steering Committee 1996). In addition to intergovernmental coordination, consultation processes have involved stakeholders and the public in the review of emerging marine protected areas strategies. Through these processes, the governments developed a coordinated process for identifying, assessing, and recommending protected area sites (Marine Protected Areas Steering Committee 1996). The cooperative processes on the Pacific coast are complemented by cooperative approaches among Fisheries and Oceans Canada, Environment Canada, and Parks Canada at a national level (Canada 1998).

2.4.2 Listing Species as Endangered or Threatened

This dissertation is based on case studies of the ecosystems of species that have been listed as species-at-risk or management concern. This section thus provides background on the organizational structures and processes for listing species.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is the primary national entity for assessing and designating the status of species at a national level as vulnerable, threatened, endangered, extirpated, or extinct (Munro 1993; Harcombe 1994; Scudder 1999). COSEWIC was established by intergovernmental agreement. Its membership consists of representatives of federal, provincial, and territorial agencies, and private conservation organizations. COSEWIC determines the status of species based on status reports prepared by member jurisdictions or individuals. The status reports consider species and ecosystem information that affects the abundance and risk of decline or extinction of a species. Status reports are reviewed by subcommittees that recommend assignment of status to COSEWIC (Harper et al. 1994). COSEWIC confers no direct protection on species-at-risk (Scudder 1999). According to Harper et al. 1994), COSEWIC

> is not mandated to take any action which would alter the fortunes of species beyond establishing their status and publishing the information upon which that status is based. There are no legal consequences or requirements following upon the declaration of status. The purpose of COSEWIC and of declaring status is to provide a national scientific consensus which may be used by jurisdictions in the exercise of their mandates.

Some level of coordinated effort for conserving species-at-risk continues at the national level. Harper et al. (1994) indicated that

> in 1988, the Council of Wildlife Ministers established a national strategy for the recovery of endangered species. Working from the COSEWIC lists, the Committee for the Recovery of Nationally Endangered Wildlife (RENEW) establishes recovery teams, approves recovery plans, encourages the cooperation and support of various government and nongovernment organizations, and publishes an annual report on national efforts to recover endangered and threatened terrestrial invertebrates. While RENEW can aid recovery efforts by establishing national priorities and standards, the participating government agencies remain responsible for implementing recovery plans that fall within their jurisdictions.

The Canadian government has attempted in the past to develop endangered species legislation, but has encountered opposition for a variety of reasons. Resource users believed that legislation would have economic effects, provinces were reluctant because of perceived intrusions on their jurisdiction, and environmentalists and scientists were opposed because proposed legislation was considered too soft (Scudder 1999; Duffy 1999; O'Neil 1999). On April 11, 2000, federal Environment Minister David Anderson introduced a proposed *Species at Risk Act* (SARA) to enhance protection of endangered species in Canada. The draft legislation was criticized for not providing automatic protection to species, for intruding on provincial jurisdictions, for protecting species rather than ecosystems, and for making listing decisions a political cabinet decision. The proposed act would legally recognize COSEWIC, but responsibility for formally listing species would be assigned with the federal cabinet. It would prohibit destruction of endangered or threatened species or their habitats. The strategy is to work through voluntary means, but provisions are included for emergency listings and actions to step in where other agencies do not act. The act would allow compensation to be paid for major costs or impacts on private parties. SARA would also complement the work of federal, provincial, and territorial governments who adopted an *Accord for the Protection of Species at Risk* in 1996 under which these governments committed to work together for protecting species at risk. The 2000 federal budget allocated $90 million for implementation of the act. The proposed SARA expired with the calling of a federal election in 2000, but was reintroduced by the Environment Minister in 2001 after the election.

Provincially, species can be listed under the *Wildlife Act of British Columbia* that is administered by the Wildlife Branch of the Ministry of Environment, Lands and Parks (Harper et al. 1994). Only a few species have been formally listed, all in 1980. One of these is a case species in this research, the Vancouver Island marmot. Since 1980, the B.C Wildlife Branch has used "red lists" and "blue lists" to more informally identify species as priorities for conservation. Red listed species are identified as endangered or threatened, or under consideration for that status. Blue listed species are vulnerable, but not yet endangered or threatened (Harper et al. 1994). Status reports are prepared for endangered or threatened species that are candidates for designation under the *Wildlife Act*. The assignment of status to a species is done by staff of the B.C. Conservation Data Centre based on available information (Harper et al. 1994) and "professional judgment" (Harcombe 1994). The centre was established in 1991 to assemble and track information on the status or occurrence of wildlife in British Columbia using methodologies standardized among conservation organizations around the world (Harcombe 1994).

This section outlined the major components of the organizational structures and processes for establishing protected areas and listing species-at-risk for marine and terrestrial environments of British Columbia.

2.5 Effects of Equivocality Attributes on Decision Making

The concept of equivocality was operationalized for this research using a simple decision making model. This model provided a structure for identifying hypotheses and gathering data. The model identifies four information processing functions involved in problem solving and decision making processes: problem definition, information gathering, causal analysis, and action planning. Equivocality can impact adversely on each of these information processing functions (table 2.4). The attributes of equivocality that affect each of these information processing functions have been summarized in tables 2.5, 2.8, 2.11, and 2.14, based in part on McCaskey (1982). This provided a basis for operationalizing equivocality in the context of environmental decision making. These attributes are: confusing questions, unclear information, poor causal understanding, and uncertain responses. These attributes jointly characterize the phenomenon of equivocality. The attributes provide different perspectives on the same concept and are not separate variables. There is considerable overlap and mutual influence among the attributes, and some attributes may be causes or symptoms of others (McCaskey 1982). It should also be noted that individuals differ in their tolerance for ambiguity and cognitive complexity (Downey, Hellriegel, and Slocum 1977; Downy and Slocum 1975; Sutcliffe 1994). The effects noted below vary among individuals and among organizations.

Table 2.4 Information Processing Functions and Equivocality Attributes

Information Processing Function	Attribute of Equivocality
1. Problem Definition	Confusing Questions
2. Information Gathering	Unclear Information
3. Causal Analysis	Poor Causal Understanding
4. Action Planning	Uncertain Responses

2.6 Problem Definition Function

2.6.1 Problem Definition: Confusing Questions

Several activities comprise the problem definition function (table 2.5). The existence of a problem must be sensed, perceived, or recognized. Once recognized, a decision must be made as to whether the problem is important enough to merit further attention. If it does merit attention, an organization must decide how to frame an inquiry that will get the answers it needs to inform its actions. Commonly, the framing of the inquiry assumes a certain set of actions that might be available to address a problem; the availability of a solution assists or clouds the definition of the problem. The framing process thus involves making assumptions consciously or unconsciously, and determining the scope of the effort to obtain answers. The problem definition process can be complicated when the questions are interconnected with other issues in unknown ways, or when the

Table 2.5 Problem Definition Function and Equivocality

PROBLEM DEFINITION

This function includes:
- sensing that certain problems need to solved in order to accomplish the purposes of the organization.
- choosing and priorizing the most appropriate questions to analyze these problems.
- framing these questions operationally to enable the organization to work on solutions.
- identifying assumptions, criteria, and scope of questions.

Examples of factors that affect this function include:
- the extent to which the structure of problems are nested or interconnected.
- the extent to which disparate values affect problem definition.

Equivocality Attribute: Confusing Questions
- Problem definitions are unclear and shifting.
- Managers are unable to frame meaningful questions.
- Conflicting assumptions, values, and perceptions confuse problem definitions.

Examples:
- Scientists and ecosystem managers cannot agree on definitions of what an endangered species is, or when it is endangered.
- Although there is agreement that we should protect ecosystems rather than species, scientists are unable to agree on the definition of an ecosystem, or systems of classifying ecosystems, as a preliminary step to extending protection to habitats, communities, and ecosystems.

Strauch 1977; Gambling 1977; Holling et al. 1978; Lyles and Mitroff 1980; Atema 1980a, 1980b; Daft and Macintosh 1981; Dorcey and Hall 1981; Okabe et al., 1986; Allen and Gould 1986; McCaskey 1982, 1988; Daft and Lengel 1984a, 1986; Putnam and Sorenson 1982; Gerloff 1985; Rice 1985;Weick 1985; Ozawa and Susskind 1985; Hilborn 1990; Laudon and Laudon 1991; Daft 1992; Huggett 1993; Weick and Meader 1993; Clark 1993; Ludwig et al. 1993; King 1994; Finlayson 1994; Cornett 1994; Senge 1994; Senge et al. 1994; Baskerville 1995; Kurtis 1997; Grumbine 1997.

questions involve subjective values that compete and are hard to resolve. In ecosystem management, as in other types of policy processes, decisions must be made, and the context for those decisions is often tense. Bernstein (1996) suggested “the most important decisions usually occur under complex, confusing, indistinct, or frightening conditions.”

Equivocality complicates decision making when definitions of the problem are unclear, shifting, vague, or competing. In other words, the nature of the problem is itself in question. Often any one problem is intertwined with other "messy problems" (McCaskey 1982). The problem may also be the symptom of higher problems that are not yet understood (Allen and Gould 1986). When facing equivocal situations, managers are confused not just about the answers, but also about whether they have the most appropriate questions (March and Olson 1976; Daft and Lengel 1986; Weick and Meader 1993).

Because problems are poorly defined, organizational members are not sure what questions to ask or which data or variables are important (Daft and Lengel 1986). They are not sure what criteria should be used to assess which decisions to make (Morgan and Henrion 1990). As McCaskey (1982) contended that "because the definition of the problem is in doubt, collecting and categorizing information becomes a problem. The information flow threatens either to become overwhelming or to be seriously deficient. Data may be incomplete and of dubious reliability." As a result, an increased amount of new information does not improve understanding but rather adds greater confusion. On the other hand, organizations may find that discussion helps to frame their situation and questions in a more meaningful way.

The ecological theory underlying the concept an "endangered species" can be used to illustrate the notion of a confusing question. Endangered species legislation does not provide clear criteria for officially listing a species as endangered, leaving agencies wide latitude in making decisions. There are no ecologically unequivocal criteria for defining when a species is endangered, though it is intended that decisions be defended on scientifically valid grounds (Grumbine 1992; Rohlf 1991). According to Easter-Pilcher (1996),

> given the amount of data missing from the final listings, it is clear that comparison and ranking of species by their degree of vulnerability is fraught with tremendous uncertainty. This level of uncertainty balloons with the inconsistent use of biological criteria within and across classes. Variables that are simply not mentioned are by far the most prevalent type of missing data. . . .
>
> The broad and vague definitions found within the ESA [Endangered Species Act] for terms such as endangered and threatened . . . mirror the vagueness within the entire selection process. . . .
>
> The potential use of data-hungry techniques such as population viability analysis fades in light of the reported high levels of missing data reported in this study.

Furthermore, because definitions are lacking, remedial actions tend to be delayed until populations are in serious trouble (Scott et al. 1987; Orians 1993).

There are also compelling questions about whether protecting species is even the correct target of policy. Case-by-case reviews of species status have led to unsystematic and inconsistent application of listing criteria and favoritism toward popular or charismatic species (Rohlf 1991). By focusing on species, ecosystems have been ignored. Scientists have argued that the species-by-species approach is leading to steady loss of species, and that in response, protection should be focused on habitats, communities, ecosystems, or simply biodiversity (Scott et al. 1987; Rohlf 1991; Orians 1993; Franklin 1993; Gauthier 1995; Clark 1996; Brunner and Clark 1996; Grumbine 1997; Noss, O'Connell, and Murphy 1997). However, no broadly accepted classification systems exist for these entities, and establishing protection for these systems will be difficult scientifically and politically (Orians 1993; Grumbine 1997). For the marine context, Ray (1988) argued that almost nothing is known about which marine species are endangered or even about the structure of marine ecosystems (see also National Research Council 1995). In fact, it is generally not possible to even define discrete habitats for fish within the marine environment

(Polacheck 1990).

<u>2.6.2 Hypotheses Concerning Problem Formulation</u>

Two types of questions must be answered before a protected areas site can be selected. First, the resource management agency must determine that the target species merits protection. Hypothesis 1 proposes that the ecological rationales for determining the merit of protecting a target species are less clear for marine than for terrestrial species (table 2.6).

The underlying issue for this hypothesis is whether the decision is important enough to merit action. It may thus be described as an *importance rationale* for the decision.

Table 2.6 Hypothesis 1: Target Species Listing Rationale

<u>Hypothesis 1a</u>: The ecological rationales for listing particular marine species as target species for protection are less clear than the ecological rationales for listing terrestrial species.

<u>Null Hypothesis 1b</u>: The ecological rationales for listing particular marine species as target species for protection are clearer than the rationales for listing terrestrial species.

<u>Null Hypothesis 1c</u>: The ecological rationales for listing particular marine species as target species for protection do not differ in clarity from the rationales for listing terrestrial species.

The second question that must be answered before a protected areas site can be selected is whether the designation of a protected area is the best means of conserving the target species, habitat, or ecosystem. Hypothesis 2 proposes that the ecological rationale for using protected areas for conserving target species is less clear in the marine case than for the terrestrial case (table 2.7).

Table 2.7 Hypothesis 2: Protected Areas Rationale

<u>Hypothesis 2a</u>: The ecological rationale for using a protected area approach to conserve case species is less clear for marine ecosystems than for terrestrial ecosystems.

<u>Null Hypothesis 2b</u>: The ecological rationale for using a protected area approach to conserve case species is more clear for marine than for terrestrial ecosystems.

<u>Null Hypothesis 2c</u>: The ecological rationale for using a protected area approach to conserve target species does not differ in clarity for marine and terrestrial ecosystems.

Whereas hypothesis 1 considered an importance rationale, hypothesis 2 addresses a *methods rationale*. It asks whether the rationale for using the protected area method for protecting a species is appropriate for the specific situation. The framing of a question is often influenced by the available actions that can be taken (Morgan and Henrion 1990), so that a protected area may be one solution but not the best solution for protecting a species. Where the rationale for choosing one option is not clear and unambiguous, equivocality will be higher.

The assumption of hypotheses 1 and 2 is that protected area decisions are more equivocal where the importance of the decision and method of acting are unclear or ambiguous.

2.7 Information Gathering Function

2.7.1 Information Gathering: Unclear Information

Another information processing function in decision making is the gathering of background information (table 2.8). In decision making and problem solving, it is important to have adequate rich information for describing the problem and its context (Einhorn and Hogarth 1986). For this information to be useful, it must be appropriately comprehensive, which means that it should describe the most important factors that affect a decision. It should also be sufficiently detailed to provide a clear picture. It should also provide an overview that shows the context for a decision.

For resource management, the important information may include a general description of environmental systems and their components, the state of the health of a system, or the abundance, distribution, and life cycles of important species. The quality of this information may vary depending on such factors as the number, distribution, resolution, timing, and duration of observations. For example, a species previously considered extinct may be reclassified as endangered because of new observations (Williams et al. 1989). Information quality is also related to the proportion of a system that is accessible for observation. Earle (1995), for example, estimated that "less than 10 percent of the ocean has been sampled, and much of it has not been more than superficially mapped."

Unrich information is a characteristic of equivocality that results from a lack of sufficient information comprehensiveness, representativeness, and richness. Unclear information may be perceived as vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse. Often, information-gathering technologies produce “noisy” images that require considerable interpretation to recognize environmental cues (Swets 1998). Incoming data lack "richness."

Table 2.8 Information Gathering Function and Equivocality

INFORMATION GATHERING

This function includes:

- obtaining information to describe a problem.
- developing information that provides an overview or rich picture of the context of a problem.

Examples of factors that affect this function include:

- the availability of descriptive information about a system and its components, such as the state of the health of the system; the species composition or driving factors of an ecosystem; or the abundance, distribution, life cycles, and range and distribution of key species.
- the rate of sampling of information, such as the number and timing of observations that can be made.
- the proportion of a system that is accessible for observation, such the proportion of the area of an ecosystem or phases in a species' life cycle.
- the level of information richness, qualitative detail, and multiple views presented by data gathering, analysis, and display technology.

Equivocality Attribute: Unclear Information

- Information is perceived as vague, obscure, cloudy, unclear, murky, blurred, distorted, fuzzy, dark, enigmatic, cryptic, mysterious, meager, or sparse.
- Environmental cues are hard to recognize.
- Information lacks richness.

Examples:

- Scientists and managers must rely on fragmentary and incomplete "pictures" of a resource. For example, they may not know the location or distribution of an important species at various points in its life cycle.
- Information technology gives one-dimensional perspectives on a resource. Sonar may indicate the presence of fish, but not allow identification of species, age, or reproductive status.
- Access technology may allow only transient presence of observers, such as in ocean depths or high mountainous areas.

References: see table 2.5.

2.7.2 Hypotheses Concerning Information Gathering

The information gathering function of decision making can be complicated by "unclear information." Two factors that affect the clarity of information for selecting protected areas are considered. First, there must be a sufficient amount of ecological information to provide a clear description of the ecology, status, and distribution of the target species. Hypothesis 3 proposes that there is a lesser amount of information for marine protected areas than for terrestrial protected areas (table 2.9).

Table 2.9 Hypothesis 3: Selection Information Amount

<u>Hypothesis 3a</u>: A lesser amount of descriptive ecological information is available for target marine species and ecosystems than for target terrestrial species and ecosystems.

<u>Null Hypothesis 3b</u>: A greater amount of descriptive ecological information is available for target marine species than for terrestrial target species.

<u>Null Hypothesis 3c</u>: The amount of descriptive ecological information available does not differ for target marine species versus terrestrial target species.

Second, the type of information available should provide description sufficiently rich in content and presentation to provide decision makers with a clear picture of the ecology, status, and distribution of the target species. Hypothesis 4 proposes that marine selection information is less rich than terrestrial selection information (table 2.10). If the information available for describing the species is lacking in amount or richness, then the information is unclear and is contributing to equivocality.

Table 2.10 Hypothesis 4: Selection Information Richness

<u>Hypothesis 4a</u>: Marine selection information exhibits less *information richness* than terrestrial selection information.

<u>Null Hypothesis 4b</u>: Marine selection information exhibits more information richness than terrestrial selected information.

<u>Null Hypothesis 4c</u>: Marine selection information does not exhibit different information richness than terrestrial selected information.

2.8 Causal Analysis Function

<u>2.8.1 Causal Analysis: Poor Causal Understanding</u>

Another information processing function is causal analysis, which involves the identification of key causal factors and the linkages among them (table 2.11). Causal analysis seeks to understand how a system responds to changes in the causal factors. For example, if fishing is a causal factor, how do population levels vary with higher or lower levels of fishing effort? Causal analysis depends on a scientific and practical understanding of the functional relationships among causal variables (Einhorn and Hogarth 1986). In ecosystems, such causal factors might include nutrients, temperatures, predators, and human impacts. The relationship among these causal factors is

Table 2.11 Causal Analysis Function and Equivocality

CAUSAL ANALYSIS

This function includes:

- identifying key causal factors and the linkages among causal factors.
- understanding how system responds to changes in causal factors.

Examples of factors that affect this function include:

- the state of scientific understanding concerning functional relationships among causal variables, such as nutrients, temperature, and predators.
- the availability and applicability of functional models of the causal system, such as models of population biology, minimum population viability, island biogeography, prey-predator dynamics, and interspecific competition.

Equivocality Attribute: Poor Causal Understanding

- Natural variation in the environment may obscure trends and allow multiple interpretations of what is occurring.
- Managers have poor understanding of cause-effect relations in the environment so they cannot determine "what causes what."
- Managers cannot classify incoming information into categories that fit within their causal map of the environment.
- Contradictions and paradoxes may occur.

Examples:

- Scientists do not have explanations for large variabilities in the populations of certain species, such as whether these variations are caused by natural or human influences.
- Some large-scale and long-term changes in marine community structures, such as the decline of Peruvian anchoveta, may be due to unknown causes or to little understood multidecadal cycles.

References: see table 2.5.

normally conceptualized through theoretical models, such as population biology, island biogeography, or predator-prey dynamics.

Causal understanding is represented in human thinking by mental models (Johnson-Laird 1982, 1983). A mental model is a cognitive representation of the world, a metaphor that organizes presumed causes and effects into an understandable conceptual map of reality (Norman 1983; Weick and Bougon 1986; Boland and Greenberg 1988; Haken 1995; Senge 1994). Interpretation of causality enables people to predict sequences of events and use this information to adapt to their environment (Geminiani, Carassa, and Bara 1996). People store their knowledge in conceptual models that are developed out of their experiences of living in the world (Kolodner 1997). They become defined as objective when more people come to share the same views of reality (Anderson, Howe, and Tolmie 1996).

Mental models are personal interpretations of reality that may or may not be accurate (White 1995). Bernstein (1996) reported that

> the evidence suggests that we reach decisions in accord with an underlying structure [model] that enables us to function predictably and, in most instances, systematically. The issue, rather, is the degree to which the reality in which we make our decisions deviates from the rational decision models . . .

McCaskey (1982) suggested that, in ambiguous situations, managers experience difficulty forming adequate conceptual maps explaining what is happening. They do not understand "what causes what" in the situation. Even when they know what they want to achieve, they do not understand how to do so. They are unable to develop coding structures or classification schemes for fitting incoming information into their hypothesized causal pictures of reality. Where causal maps are poor, organizations may experience contradictions and paradoxes in the data they collect about their environment (McCaskey 1988; Martin and Meyerson 1988; Fahey and Narayanan 1989; Waern 1990). Events occur that are not expected. Anxiety increases, and decision makers tend to rush to form their mental models (Kaplan and Kaplan 1983). Equivocality is exacerbated by difficulties in obtaining the functional knowledge necessary to understand marine ecosystems (Dorcey and Hall 1981). For example, marine biologists argued that the large-scale nature of the marine environment makes it much more difficult to perform controlled, replicated experiments (Ray 1988, Ludwig et al. 1993; Harris 1995). According to Ludwig et al. (1993), this leaves "ample scope for differing interpretations" concerning past events and prediction of future events. In fact, they asserted that "we shall never attain scientific consensus concerning the systems that are being exploited." Social theorists refer to the inability to interpret data unequivocally as "interpretative flexibility" (Finlayson 1994). Such flexibility in fisheries science is due to sparse and indeterminate data, indirect data gathering methods, and the ambiguities and assumptions of theoretical models (Finlayson 1994). Scientists frequently lack information on physical and biological oceanography, population dynamics and life histories of species including important commercial species, predator-prey relationships, interspecies interactions, or food webs (Harris 1995). Information on harvests, by-catch, and discarded catch are often sketchy (Harris 1995). Interpretive flexibility is also due to the nature of ecosystems, which are "dynamic, inherently uncertain, with potentially multiple futures" (Holling 1996).

2.8.2 Hypotheses Concerning Causal Analysis

The causal analysis function of decision making may be complicated by "poor causal understanding." Two factors are considered that may affect the level of causal understanding for selecting protected areas. First, causal understanding depends on the amount of information about causal factors and functional interrelationships that affect the ecology of target species. Hypothesis 5 proposes that there is more causal information for marine than for terrestrial environments (table 2.12).

Table 2.12 Hypothesis 5: Understanding of Causal Factors

Hypothesis 5a: There is a lesser amount of knowledge of causal factors and functional interrelationships affecting the ecology of marine species than for terrestrial species.

Null Hypothesis 5b: There is a greater amount of knowledge on causal factors and functional interrelationships affecting the ecology of marine species than for terrestrial species.

Null Hypothesis 5c: The amount of knowledge of causal factors and functional interrelationships affecting the ecology of marine species does not differ from terrestrial species.

Second, causal understanding depends on the capabilities of research technologies, such as data gathering and experimental technologies. Hypothesis 6 proposes that marine research technologies have lesser capability for obtaining causal information than terrestrial technologies (table 2.13). If the amount of ecological information available is insufficient for understanding causal factors and functional interrelationships, and the capability of research technology is underdeveloped, then causal understanding may be poor, thus contributing to equivocality.

Table 2.13 Hypothesis 6: Research Technology Capabilities

Hypothesis 6a: The capabilities of research technologies for establishing causal knowledge are less clearly developed for marine selection information than for terrestrial selection information.

Null Hypothesis 6b: The capabilities of research technologies for establishing causal knowledge are more clearly developed for marine selection information than for terrestrial selection information.

Null Hypothesis 6c: The capabilities of research technologies for establishing causal knowledge are not different in clarity of development for marine selection information than for terrestrial selection information.

2.9 Action Planning Function

2.9.1 Action Planning: Uncertain Response

The major purpose of information processing is to allow the organization to take informed actions to resolve issues and problems that have been identified (table 2.14). Action planning is affected by the clarity of the context for taking action, such as clear descriptive and causal information and agreed plausible interpretations of this information. It is also affected by knowledge of possible alternative strategies and courses of action that could be followed for purposes such as protection of a species.

Table 2.14 Action Planning Function and Equivocality

ACTION PLANNING

This function involves applying judgment to choose the best interpretation of what is happening in the system in order to develop action plans to solve problems. Action plans would include components such as goals, objectives, strategies, resource allocations, staff assignments, and measures of success.

Examples of factors that affect this function include:

- the level of clarity in the understanding of the context for action, including clear problem definition, descriptive and causal information, and agreed plausible interpretations of this information.
- the knowledge of alternative strategies or courses of action to accomplish purposes.
- the degree of confidence that strategies and actions will achieve the expected results.
- the influence of values that may affect the weighing of evidence.

Equivocality Attribute: Uncertain Response

- An organization has a difficult time in choosing a feasible plan of action. Multiple options present dilemmas.
- Lack of a plan of action complicates processing of incoming information and further questioning.

Examples:

- Data systems may be structured to justify decisions rather than inform decision makers.
- Scientists may debate the effectiveness and appropriateness of various conservation strategies, such as protected areas versus harvest restrictions.
- Debate over tactical issues undermines conservation strategies, such as conflicting opinions on the size, purpose, and distribution of protected areas.
- Agencies cannot provide scientifically defensible answers concerning the level of protection to enforce in protected areas to maintain ecosystem integrity, such as whether resource harvests should be banned.

References: see table 2.5.

The confidence of decision makers in their decisions and actions depends on their state of knowledge. In an ambiguous or equivocal world, it is hard to find one's direction. A vague picture of reality is complemented by vague and unclear goals. Absence of clear goals means that organization members will lack clear direction and measures of success (McCaskey 1982; Brunner and Clark 1997). Furthermore, decision makers lack a clear plan of action that would reduce the number of plausible interpretations of the environment (McCaskey 1982; Putnam and Sorenson 1982; Brunner and Clark 1997). People often have a clearer picture of their environment when they know what information they need to accomplish specific goals. A clear course of action would assist in categorizing which data are important and which causal sequences matter. Lacking such an action plan, people do not know what activities they are expected to perform or who is supposed to make decisions (McCaskey 1982). Ambiguity may also lead to a fluid group membership, with key decision-makers and influence-holders changing as they enter and leave the decision arena (McCaskey 1982).

Equivocality is an important issue in protected area management. Clark (1993) found a lack of consensus among scientists on what might be considered an "acceptable" policy or program for conserving biodiversity. Simberloff (1988) argued that rules for refuge design are untested, and that such rules could be adopted with maladaptive consequences. The answer as to whether the best approach is to create a single large refuge or several small sites is equivocal, for example, because there are plausible ecological arguments to support each approach. Even if the debate is resolved, the theory may not be applicable to oceanic refugia because marine ecological processes exhibit the types of differences discussed in section 2.3 (Carr and Reed 1993) such as replenishment of populations from distant stocks through transport of larvae by ocean currents.Another example of equivocality in protected area management is the question of what level of protection should be enforced. In other words, should an agency allow resource harvesting in a protected area, or should it declare a "no-take" zone? This resource allocation issue transcends science, and requires trade-offs between preservation and resource harvesting values. Allowing some harvest may improve the political acceptability for resource harvesters, but harvesting would also reduce the effectiveness of a protected area for preservation. The choice may thus be between fewer hectares of protected space or more space with less effective protection. More data will not provide a mutually accepted answer because there is more than one workable decision.

2.9.2 Hypothesis Concerning Action Planning

The action planning function of decision making may be complicated when the selection information leads to an "unclear response." The equivocality of selection information depends on whether this information provides clear or unclear guidance for defining protected areas. Hypothesis 7 tests the guidance given by selection information for defining protected area sites (table 2.15). If selection information does not provide clear guidance, then the lack of clarity contributes to equivocality.

Table 2.15 Hypothesis 7: Site Selection Guidance

Hypothesis 7a: The guidance given by selection information for defining protected area sites is less clear for MPAs than for TPAs.

Hypothesis 7b: The guidance given by selection information for defining protected area sites is less clear for MPAs than for TPAs.

Hypothesis 7c: The guidance given by selection information for defining protected area sites does not differ for MPAs and TPAs.

2.10 Summary of Equivocality Effects and Hypotheses

Table 2.16 provides a summary of the effects of equivocality on the four stages of decision making and seven hypotheses or information quality factors for assessing the patterns of equivocality in protected area decision making. The decision stages or information quality factors described should not be seen as independent elements, but should be considered an integrated set of attributes that are interacting and mutually reinforcing. In any given situation, not all aspects may be present in the same degree. Various equivocal situations may exhibit different patterns of equivocality in terms of the relative intensity of each attribute.

Because the different attributes affect different types of information processing functions, different remedies may be required for various patterns of equivocality. This research examines how the various attributes affect information equivocality in a range of ecosystems.

Table 2.16 Summary of Effects of Equivocality on Decision Making

1. PROBLEM DEFINITION: CONFUSING QUESTIONS

- Problem definitions are unclear and shifting.
- Managers are unable to frame meaningful questions.
- Conflicting assumptions, values, and perceptions confuse problem definitions.

Hypothesis 1: The ecological rationales for listing particular marine species as target species for protection are less clear than the ecological rationales for listing terrestrial species.

Hypothesis 2: The ecological rationale for using a protected area approach to conserve case species is less clear for marine ecosystems than for terrestrial ecosystems.

2. INFORMATION GATHERING: UNCLEAR INFORMATION

- Information is perceived as vague, abstract, fuzzy, clouded, or distorted.
- Environmental cues are hard to recognize.

Hypothesis 3: A lesser amount of descriptive ecological information is available for target marine species and ecosystems than for target terrestrial species and ecosystems.

Hypothesis 4: Marine selection information exhibits less information richness than terrestrial selection information.

3. CAUSAL ANALYSIS: POOR CAUSAL UNDERSTANDING

- Natural variation in the environment may obscure trends and allow multiple interpretations of what is occurring.
- Managers have poor understanding of cause-effect relations in the environment so they cannot determine "what causes what."
- Managers cannot classify incoming information into categories that fit within their causal map of the environment.
- Contradictions and paradoxes may occur.

Hypothesis 5: There is a lesser amount of knowledge of causal factors and functional interrelationships affecting the ecology of marine species than for terrestrial species.

Hypothesis 6: The capabilities of research technologies for establishing causal knowledge are less clearly developed for marine selection information than for terrestrial selection information.

4. ACTION PLANNING: UNCERTAIN RESPONSE

- An organization has a difficult time in choosing a feasible plan of action. Multiple options present dilemmas.
- Lack of a plan of action complicates processing of incoming information and further questioning.

Hypothesis 7: The guidance given by selection information for defining protected area sites is less clear for MPAs than for TPAs.

Source: This table is based on sections 2.5 through 2.15.

CHAPTER 3: METHOD

> "Theory developed from case study research is likely to have important strengths like novelty, testability, and empirical validity, which arise from the intimate linkage with empirical evidence. Second, given the strengths of this theory-building approach and its interdependence on prior literature and past empirical observation, it is particularly well-suited to new research areas for which existing theory seems inadequate" (Eisenhardt 1989).

This chapter discusses the methods used for this research. Section 3.1 discusses the overall research approaches, including the grounded theory building and case study approaches. Section 3.2 discusses the methods and procedures.

3.1 Research Approaches

3.1.1 Grounded Theory Building Approach

A grounded theory-building approach derives theory inductively from the study of a particular phenomenon. Theory-building approaches are useful for extending theoretical development into new areas that existing theory and previous research have not addressed (Strauss and Corbin 1990; Strauss 1987; Schatzman and Strauss 1973; Scarce 2000). In this research, a grounded theory-building approach was used to probe the variations in equivocality resulting from biophysical and logistical differences between natural environments. According to Strauss and Corbin (1990)

> grounded theory is a scientific method. Its procedures are designed so that, if carefully carried out, the method meets the criteria for doing 'good' science: significance, theory-observation compatibility, generalizability, reproducibility, precision, rigor, and verification.

The theory-building procedure adopted in this research most closely follows Eisenhardt's (1989a) studies of high-velocity environments (Bourgeois and Eisenhardt 1987, 1988; Eisenhardt 1989b, 1993; Eisenhardt and Bourgeois 1988, 1990; Eisenhardt and Tabrizi 1995), as described in section 1.3.1. Eisenhardt's approach modified and extended Glaser and Strauss' (1967) comparative grounded theory approach (see also Strauss and Corbin 1990), and combined it with Yin's (1981, 1994) multiple case study method. The approach involves induction of theory using case studies. This research process "adopts a positivist view of research. That is, the process is directed toward the development of testable hypotheses and theory which are generalizable across settings" (Eisenhardt 1989a). It is thus a combination of inductive research and hypothesis testing. The approach is designed for new topic areas where it produces novel, testable, and empirically valid theory (Eisenhardt 1989a; Kirk and Miller 1986). This approach, therefore, differs from a naturalistic inquiry mode where an investigator approaches research without prior propositions (Guba and Lincoln 1981; Lincoln and Guba 1984). This research assumes a premise that "there is a world that exists apart from our knowing it" (Scarce 2000). On the other hand, the goal of this study is theory-building which means that data from the research is allowed to influence the development of theory and meaning (Eisenhardt 1989a; Scarce 2000; Lincoln and Guba 1984; Gioia and Chittipeddi 1991; Glaser and Strauss 1967).

Grounded theory building involves four broad steps (Scarce 2000). "First is the gathering of 'rich'data – usually interviews and observations" (Scarce 2000). The researcher seeks "rich information" about the phenomenon of interest (section 1.5.1). "Second, the data are constantly analyzed" (Scarce 2000). This contrasts with approaches where data are first collected entirely, then analyzed. The analysis is allowed to influence the emerging specification of theory, so that theory is better grounded in the data. "Third, the data gathering and analysis steps are repeated several times. The insights from the immediately preceding round of data analysis are 'tested' by gathering and interpreting yet more data" (Scarce 2000). This retesting improves validity and reliability. "Finally, when the data yield no new 'theoretical' insights, no new ideas, the data-analysis portion of the research endeavor is completed" (Scarce 2000). At this point, the research has produced a theory grounded in the data.

3.1.2 Case Study Approach

The case study approach followed in this research was comparative. Cases were incrementally selected in order to enable the comparison and contrasting of evidence for and against the hypotheses and the theoretical concepts as they emerged (Glaser and Strauss 1967; Strauss and Corbin 1990). The purpose was to reveal both supporting and rival explanations for the equivocality phenomena under study. Yin (1994) also cautioned that researchers should be flexible, as necessary, in selecting cases different from those initially identified in order to explore fully the evidence related to the emerging theory.

Eisenhardt (1989a) argued that case studies are appropriate for building theory. Yin (1994) maintained that a case approach is suitable for studies that involve many causal variables and potential outcomes. Researchers are able to delve more deeply into sequences of events and the possible explanations for what has occurred or is occurring. This enables explanation of causal links in real life that are too complex for survey or experimental strategies. Case approaches also permit the use of a broad array of research methods such as interviews, observation, and documentary evidence. They focus on contemporary events and phenomena in situations where experimental control of contextual variables is not possible. Finally, they are suitable for research where the boundaries between phenomena and context are not clearly evident (Yin 1994). All of these conditions applied to the present research.

Yin (1994) distinguished the generalization from cases to theory as "analytical generalization" in contrast to "statistical generalization." In analytic generalization, "previously developed theory is used as a template with which to compare the empirical results of the case study" (Yin 1994). The case study approach is thus well suited to the present research that involves theory development.

Yin (1994) argued that a case study design is equivalent in generalizability to an experiment or a survey. Scientific facts are usually not based on single surveys or experiments, but are established as researchers replicate experiments under varying conditions. Similarly, case studies contribute to scientific theory through the accumulation of replicated cases. Surveys and other forms of research are also replicated under diverse contexts. Cases are not "samples" but comprehensive studies in their own right. Thus both case and experimental studies are generalizable to theoretical propositions rather than to populations or universes (see also Bryman 1989).

3.2 Methods and Procedures

3.2.1 Overview

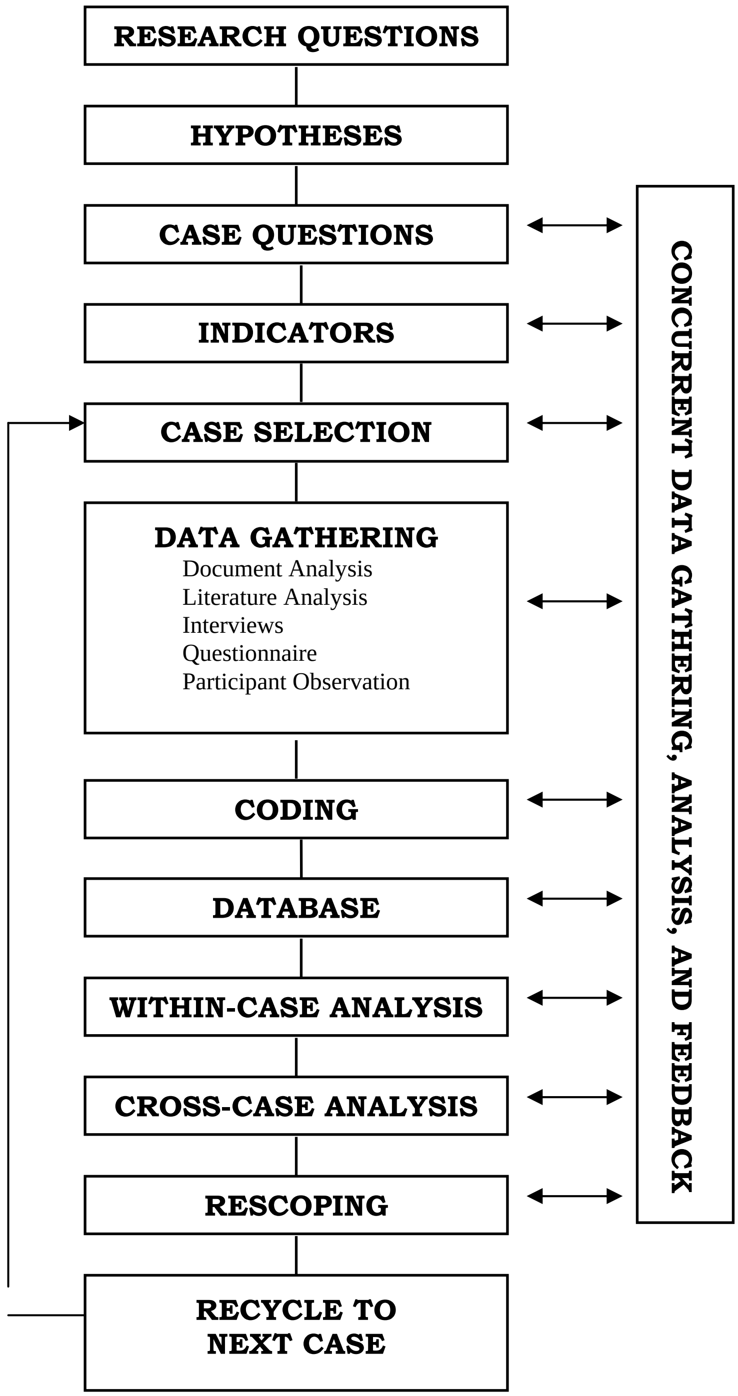
Figure 3.1 illustrates the research design for case studies conducted as part of this research. The overall focus was defined by the primary research questions, which ask how marine and terrestrial ecosystems differ in terms of equivocality (chapter 2). The specification of hypotheses provided further focus and operationalization of the research questions (chapter 2).

A set of case questions was formulated to identify information sets that were required to test the hypotheses (section 3.2.2 and appendix 1.

A set of indicators were defined to ensure that the sampling of ecosystem and species data was broad and representative of information and information processing functions for managing protected areas and ecosystems (chapter 4 and section 3.2.3).

Four species-ecosystem combinations were selected incrementally as the cases for this research (section 3.2.4). Two terrestrial and two marine cases were chosen.

Figure 3.1 Research Design for Case Studies



Multiple data gathering methods were used, including document analysis, detailed semistructured interviews, postinterview questionnaires, and participant observation (section 3.2.5).

The data were analyzed concurrently with collection (section 3.2.6). As the data were acquired, they were coded (section 3.2.7) and entered into the database (section 3.2.8). Using the database, a within-case analysis was conducted which resulted in the preparation of a case report (section 3.2.9). Case reports were analyzed and compared to produce a set of cross-case analysis tables, which are summarized in chapter 4 (section 3.2.10). At the end of each case, a reassessment of the completed cases was conducted to identify further questions that needed to be answered to complete the analysis (section 3.2.11). Once the case analyses were completed, the data were analyzed to evaluate the hypotheses (section 3.2.12).

These methodologies are described in detail in the following sections.

3.2.2 Case Questions

Section 2.0 identified a research question, primary hypothesis, and a set of seven hypotheses. These questions and hypotheses define the objectives of this research. The researcher developed case questions based on these hypotheses (appendix 1). Yin (1994) defined case questions as a set of substantive questions that reflect the information needed from a case. These questions are posed for the investigator's own use rather than to an interview or survey respondent. The case questions assist in identifying sources and content of information that are required for gathering data and analyzing a case. Case questions are similar to Mason's (1996) definition of research questions which, taken as a set of questions, "express the essence" of an inquiry. They are vehicles that move the researcher from broad research interests to a more specific research focus (Mason 1996; Marshall and Rossman 1995). The question format helps in the "design of a study which is focused rather than vague, but which can nevertheless be exploratory and fluid" (Mason 1996). The case questions controlled the content of the inquiry into the case studies, thus ensuring the research remained focused on the original research goals. The questions guided information collection from all sources and methods.

3.2.3 Indicators

A set of 16 indicators was devised to structure the gathering of data concerning the cases (table 3.1). Coding is a core technique in qualitative research (Dey 1993). The indicators provided a high-level coding framework for analysis. Qualitative research often develops hypotheses, or

Table 3.1 Summary of Indicators

1. **Target Species Population**
   The quality of information available about the target species' population abundance and trends in this abundance, and factors which affect abundance.
2. **Target Species Range and Distribution**
   The quality of information available on the present, past, and potential geographic extent of occurrence and distribution of the target species.
3. **Ecosystem Biogeography**
   The availability of clear and consistent information for defining the scale and boundaries of biogeographic areas and ecosystems within range of the target species.
4. **Ecosystem Biodiversity**
   The number and variety of species identified on taxon lists compared with the potential biodiversity or richness of the ecosystem.
5. **Key Species Roles**
   The quality of the information used for identifying the roles of key species for the ecosystem, such as primary producers, prey and predator species, keystone species, and indicator species.
6. **Ecosystem Driving Factors**
   The quality of information for the identification of major driving factors that affect the abundance, distribution, and status of key species in the ecosystem.
7. **Ecosystem Threats**
   The identification of key threats that affect the operation of the driving factors that affect abundance, distribution, and status of key species in the ecosystem.
8. **Access Constraints**
   The constraints imposed by the natural environment on the physical access of researchers to that environment for conducting field research work.
9. **Sampling Coverage**
   The spatial and temporal coverage of data gathering for descriptive information on the ecosystem.
10. **Visibility Constraints**
    The constraints imposed by the natural environment on the ability of researchers to observe the case species in that environment.
11. **Sensor Capability**
    The number and variety of observation technologies used for gathering important information on key species and driving forces for the ecosystem, and the variety and richness of data forms produced.
12. **Contextual Capability**
    The capability of the information to provide an overview of entire system, or large portion of it, rather than isolated detail.
13. **Field Research Technology**
    The technological capability to conduct experiments, monitor key environmental parameters, or undertake other studies 'in the field' to test hypotheses about ecological theories or models in order to develop causal knowledge about key driving factors and threats.
14. **Defining Listing Criteria**
    The level of consensus among ecosystem and species experts and wildlife managers on the logical relationship of the criteria to the driving factors and threats affecting the ecosystem and species, and the consequent suitability of the listing criteria for the particular species and ecosystem.
15. **Matching Mode to Threat**
    The suitability of using protected area option for the types of threat that might affect the target species or ecosystem.
16. **Making Spatial Decisions**
    The suitability of available descriptive and causal information for making spatial planning decisions.

propositions, during the process of research. Such an approach is premised on the presumption that the *a priori* specification of hypotheses will bias the researcher. The concern is that deductive hypotheses interfere with the inductive process of finding theory. This research, following Eisenhardt (1989a), was designed to test specific hypotheses. The indicators were thus devised as a tool to ensure that the data were sampled broadly to address the hypotheses. In other words, while the search of data was inductive, it was stratified or structured to focus on data that were relevant to the hypotheses. In addition, the indicators were also structured to provide representative “slices” of the substantive cases. Indicators sampled both species and nonspecies information. They were chosen provide broad yet selective coverage of types of ecosystem information that might be used in management. The use of indicators ensured that similar data were acquired from each of the cases to allow for comparison. Because comparison was an important means of testing hypotheses, the indicators were thus an essential tool for structuring data gathering and analysis.

The indicators were thus designed to address several objectives. First, as noted above, the indicators collectively provided a representative sample or slice of the most important evidence needed for comparison of the quality of information processing for marine and terrestrial ecosystems. This provided a broad examination of potential evidence within each case that would most contribute to understanding equivocality and testing the hypotheses. Four types of information were sampled, including the amount and quality of information on species and on ecosystems, the methods for gathering this information, and the application of information for management. The indicators thus provided different angles or perspectives for testing each of the hypotheses. This provided a crosscheck of the validity of different measures. This is consistent with the practice of using converging measures that are “alternative tests that pose the same questions but rely on different kinds of assumptions” (Pashler 1997).

Second, the indicators addressed information that is strategically important for making selection and management decisions for protected areas. Because this information is essential, its presence or absence was considered a reasonable measure of the adequacy and quality of information.

Third, the indicators addressed information sets that are typically acquired, reported, and used in conservation programs. This meant that many of the data for these indicators were readily available from status reports, biophysical inventories, computer databases, and other documented sources. Objective evidence was thus available in a tangible, documented form to complement interview data for triangulation of sources and methods (Jick 1979).

The indicators were initially developed from a review of the information needed for evaluation of the hypotheses. This review also included consideration of the types of data sets that are required for making selection decisions. The indicators were then refined following trial application to the first case. As the research proceeded, codes were developed within each indicator, as described in section 3.2.7.

3.2.4 Case Selection

The rationale and process for selecting cases in qualitative grounded theory research differs from quantitative approaches. In most *quantitative* research, the goal is to select samples that are "*representative* of the total empirical population that you wish to study" (Mason 1996; Miles and Huberman 1994). The population is identified and a randomized component is chosen for more in depth examination (Mason 1996). The purpose of being representative is to allow generalization from the sample to a larger population.

The representative approach is not commonly used in qualitative research because the approach does not "facilitate the detailed exploration of social processes" (Mason 1996; see also Miles and Huberman 1994, Yin 1994). As explained in section 3.1.2, qualitative cases are equivalent to surveys or experiments in their own right. In this research, the selection of cases was determined by "theoretical sampling" (Glaser and Strauss 1967; Eisenhardt 1989a; Strauss and Corbin 1990; Yin 1994; Cresswell 1997), which is also referred to as "purposive sampling" (Mason 1996; Miles and Huberman 1994). Cases were selected to make comparisons between cases and to test theoretical propositions. The cases were *selected incrementally* to highlight similarities and differences among cases with respect to the phenomenon of equivocality. According to Yin (1994)

> each case must be carefully selected so that it either (a) predicts similar results (a *literal replication*) or (b) produces contrasting results but for predictable reasons (a *theoretical replication*). The ability to conduct six or ten case studies, arranged effectively within a multiple-case design, is analogous to the ability to conduct six to ten experiments on related topics; a few cases (two or three) would be literal replications, whereas a few other cases (four to six) might be designed to pursue two different patterns of theoretical replications.

In this research, the cases are ecosystems. To facilitate the definition of what an ecosystem includes, each case was defined in terms of a case species. In other words, the ecosystem was thus defined as the “ecosystem occupied by the case species.”

In addition to defining the ecosystem, the case species itself provided a sampling slice or “window” into the ecosystem. An ecosystem is a very complex subject for research, often consisting of thousands of species and numerous environmental processes, all combined in networks of linkages that are barely known for even simple ecosystems. The focus on a case species within the ecosystem provided a tool for selecting a more limited and manageable set of data to collect within each case. For example, research focused on population data for the case species rather than for all species. Exploration of factors that affect collection of population data for the case species are suggestive of the factors that affect data collection for other species. Although this approach limited generalizability somewhat, it was necessary for manageability.

Table 3.2 identifies the criteria that were considered in selecting cases for this research. These criteria were applied to the Committee on the Status of Endangered Wildlife In Canada (COSEWIC) and the British Columbia Conservation Data Centre (B.C. Conservation Data Centre 1997) target lists to identify a "long list" of candidate species. This list was prioritized based on degree of risk or endangerment, the priorities given to recent research and recovery planning, and the amount of information available. In grounded theory research, theoretical sampling is designed not to represent typical phenomena, but to enable analysis of the characteristics and attributes of the phenomena. The final selection of cases thus favored cases that illustrate different levels of equivocality in the marine and terrestrial environments.

Table 3.2 Case Selection Criteria

Cases should be drawn from both marine and terrestrial contexts, but excluding cases involving predominantly coastal, river, and lake environments that are a mixture of marine and terrestrial.
Cases should be excluded in predominantly urban or agricultural locations. Species in these locations, such as the burrowing owl, are greatly influenced by human influences and human disturbances whereas this research is looking at the influences of the natural environment.
Cases should be located predominantly in British Columbia and Canada.
Cases involving species that are considered peripheral to larger populations in the United States will also be avoided because resource managers from that country would have a larger role in management than Canadians.
Priority should be given to cases that involve target species that are reasonably well studied to ensure comparability of research efforts. The best-studied species are mammals and birds.
From a practical perspective, cases should include situations where sources of information are readily available, including interviewees and documents.
Cases should consider recent or ongoing initiatives for conserving the species or ecosystem to provide the opportunity to explore processes that are at various stages of progress. Examining cases in progress reduces reconstructive interpretation of the experiences of the informants with the cases.
Cases should be excluded which involve species that are so rare that listing agencies cannot confirm whether they are extinct or extirpated. In these cases, little information would be available for analysis.
Cases should also involve species that are the protection of rare, threatened, endangered, or vulnerable species, or other species of management concern and their habitats and ecosystems. Cases meeting this criterion will be identified from the target species lists of official listing organizations.

Four cases were selected during the process of this research. The two terrestrial cases were the *T1 Vancouver Island Marmot – Subalpine Ecosystem* and the *T2 Marbled Murrelet – Old-Growth Forest Ecosystem*. The two marine cases were the *M1 Humpback Whale – Pelagic Ecosystem* and the *M2 Giant Pacific Octopus – Benthic Ecosystem*. In this dissertation, these ecosystems are sometimes referred to by their number such as "the T1 ecosystem," or by the species, for example the "marmot ecosystem."

The cases were considered incrementally. The cases were researched in the following order: the T1 marmot ecosystem, the M1 humpback ecosystem, the T2 murrelet ecosystem, and the M2 octopus ecosystem. Section 3.2.9 explains how the cases were considered and compared.

T1 Vancouver Island Marmot – Subalpine Ecosystem

The first terrestrial case was chosen to represent an example of low equivocality. The Vancouver Island marmot (*Marmota vancouverensis*) is a member of the squirrel family and lives in the interior mountains of southern Vancouver Island. It lives in a few small subalpine meadows. This case was expected to be low in equivocality because of the known habitat, limited range, and past efforts to understand the species. The ecosystem is also well defined, small in size, and limited in distribution.

Figure 3.2 Vancouver Island Marmot (*Marmota vancouverensis)*

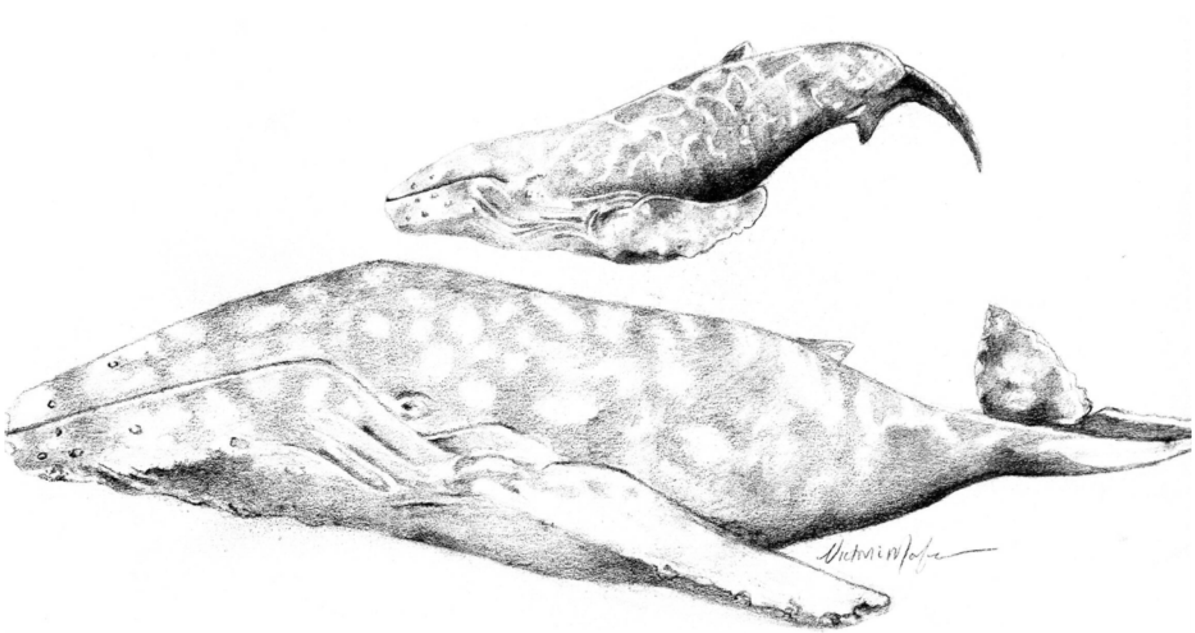
Courtesy of Victoria Macfarlane.

This marmot is listed as "endangered" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and "critically imperiled" by the British Columbia Conservation Data Centre (BCCDC), and is the world's rarest marmot. The species is declining with a total population of less than 100 animals, and it is in immediate danger of extinction.

M1 Humpback Whale – Pelagic Ecosystem

The second case considered and the first marine case was the pelagic marine ecosystems of the continental shelf of British Columbia that are occupied by the humpback whale (*Megaptera novaeangliae*). The *pelagic* marine environment refers to the open sea, particularly the top or middle layers of the ocean. It excludes the nearshore and sea bottom environments. This case was selected as a lower equivocality marine case. The humpback is a baleen whale, and comes to British Columbia waters in summer to feed. Today they are observed along the outer coast of North America. They migrate in winter to Hawaii, Mexico, or other southern locations to breed and calve. This case exemplified low equivocality because it often occurs in coastal areas, it is a large animal that must surface for breathing where it can be observed, it is one of the best studied whales, and it is comparatively easy to study relative to most other marine species (Chadwick

Figure 3.3 Humpback Whale (*Megaptera novaeangliae)*



Courtesy of Victoria Macfarlane.

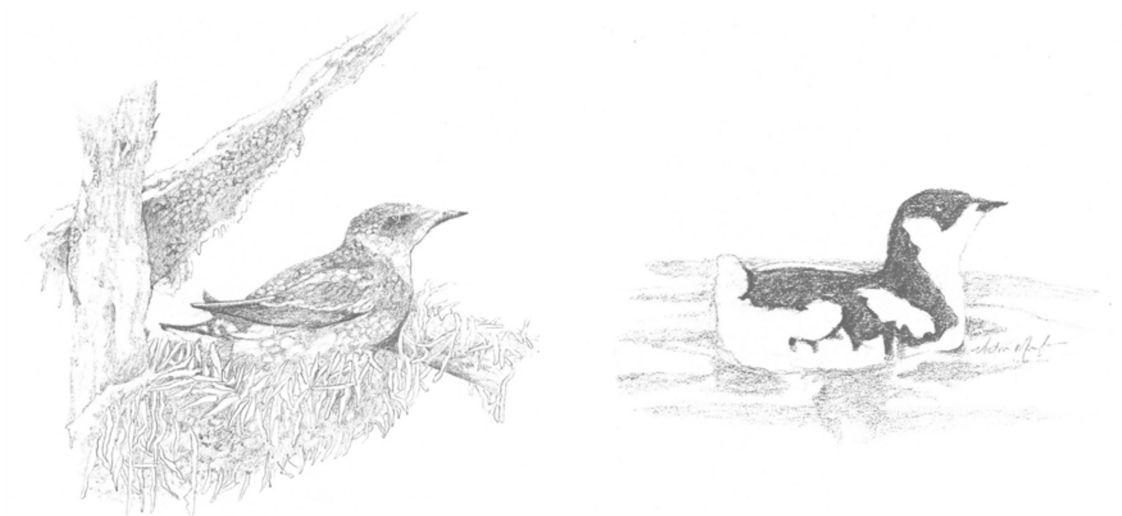
1999; Winn and Winn 1985). The assumption that this species is relatively well known was confirmed by interviews with Darling, Ellis, and Sloan.

The humpback is listed at "threatened" by COSEWIC and "critically imperiled" by British Columbia Conservation Data Centre. Although found in all oceans of the world, the humpback is considered "threatened" globally.

T2 Marbled Murrelet – Old-Growth Forest Ecosystem

The second terrestrial case was chosen as an example of high equivocality. It was chosen on the advice of several wildlife biologists that the marbled murrelet (*Brachyramphus marmoratus*) species was the most equivocal terrestrial species currently being studied in British Columbia (Michael Dunn, Canadian Wildlife Service, personal communication; Rick McKelvey, Canadian Wildlife Service, personal communication; Dr. Andrew Bryant, personal communication; and Doug Janz, B.C. Ministry of Environment, Lands and Parks, personal communication). The old-growth forest ecosystem is also the subject of considerable interest and research, and is an extensive and important ecosystem in British Columbia. This murrelet was considered equivocal because it moves between the sea and its nests at twilight and its nests are extremely difficult to locate. Bird watchers and biologists searched for decades before finding the first murrelet nest in British Columbia in 1991. Major studies are underway to understand its use of the forests.

Figure 3.4 Marbled Murrelet (*Brachyramphus marmoratus)*



Summer *Winter*

Courtesy of Victoria Macfarlane.

Although the murrelet nests in coastal old growth forests often many miles from the sea, it also forages in inland coastal waters. This research defined the case as the terrestrial component of the species' life history, and limited analysis to the old growth forest ecosystems.

The marbled murrelet is listed as "threatened" by COSEWIC. It is listed as "imperiled" by British Columbia Conservation Data Centre and is on the provincial "Red List" of endangered/threatened species.

M2 Giant Pacific Octopus – Benthic Ecosystem

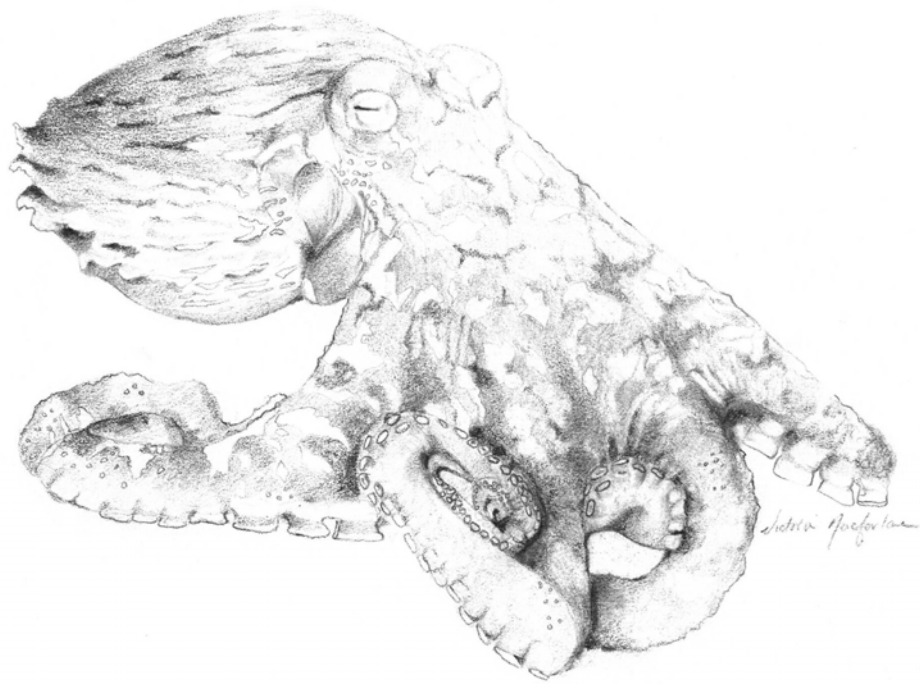
The final case considered was the benthic marine ecosystem of the continental shelf of British Columbia occupied by the giant Pacific octopus (*Octopus dofleini*). The *benthic* marine environment refers to the bottom of the sea. At early life stages, octopuses are also pelagic, but are benthic species as subadults and adults.

Several factors led to selecting this case. First, a benthic environment was chosen to provide contrast with the pelagic M1 case. It was expected that differences between pelagic and benthic environments would provide important insights. Benthic environments are important because over 98 percent of marine animals are benthic (Thurman 1990), and most of these are invertebrates (see section 4.4). Second, the octopus was the subject of a recent stock assessment by the Department of Fisheries and Oceans, which meant that it met the criteria of being reasonably well studied and the subject of current research interest, and having readily available information including interviewees and documents (table 3.4).

Based on the documentary information (Gillespie, Parker, and Morrison 1998), the M2 ecosystem was expected to be a *moderately equivocal* marine case. The species occupies benthic habitats, which are not well studied, and the octopus is a shy and cryptic species. The *O. dofleini* was chosen as the case species as a *proxy* for other species that were not chosen because information was lacking. The *O. dofleini*, for example, is the best known of nine octopuses identified in British Columbia waters. This species would be the least equivocal of the British Columbia octopuses, but it would be a researchable surrogate for species that are perhaps much more equivocal (Gillespie, Parker, and Morrison 1998).

The octopus is not rare, but recent stock review investigated the prospects for overharvest (Gillespie, Parker, and Morrison 1998). Very few marine species are listed as endangered, threatened, or extinct, and studies to evaluate marine species-at-risk have been rare (U.S. National Research Council 1995; Norse 1993; Carlton 1993; Peterson 1992b; Thorne-Miller and Catena

Figure 3.5 Giant Pacific Octopus (*Octopus dofleini*)



Courtesy of Victoria Macfarlane.

1991; Carlton et al. 1991; Burnett et al. 1989). Most listed marine species are pelagic marine mammals or birds. In addition, few noncommercial marine species have been studied.

An alternative species that was considered for the second marine case was the sixgill shark (*Hexanchus griseus*). This species was not chosen because more research was being done on the octopus, which made the octopus more feasible for study. The northern abalone (*Haliotis kamtschatkana*) was suggested as a case species (Dr. Norman Sloan, Parks Canada, personal communication), but much of the knowledge concerning this species applies to the intertidal areas that are more coastal than marine. The abalone was recently listed as threatened. The rockfish (family *Scorpaenidae*) was also suggested (Dr. John Nightingale, Vancouver Aquarium, personal communication). There are thirty-six species of rockfish in British Columbia (Department of Fisheries and Oceans, 1985), and the rockfish would have been a viable case for benthic ecosystems. The octopus was chosen, however, because it was more tractable for study as a single species.

The humpback whale and giant Pacific octopus were conservative selections as marine cases because many marine species would likely exhibit greater equivocality. However, very little research has been done on most of these species, so these alternatives were not chosen for this study. For example, the giant squid (genus *Architeuthis*) has a length of at least 18 meters and perhaps up to 45 meters, and weighs a ton. It has been reported being washed up on beaches for over 400 years, including shorelines close to British Columbia. Yet it has not been studied alive or in the wild. It is known only from studying stranded and dead specimens. Almost nothing is known of its ecology and life history (Roper and Boss 1982; Levin 1999). Such species would be difficult to consider in this research because there is very little published information, and no scientists available to interview as species experts. The conservative selection of marine cases is contrasted with the aggressive selection of the murrelet, which as noted earlier, was the consensus choice of biologists as the most equivocal terrestrial species. Thus any conclusions drawn from these cases would likely only be strengthened by the review of other species.

3.2.5 Data Gathering

Several methods were used to gather primary data for this research. The use of multiple methods enabled the researcher to view the emerging evidence from different perspectives. This is consistent with the practice of using multiple methods in qualitative research approaches to triangulate or view data from different angles. This approach improves the reliability and richness of data acquired for analysis (Yin 1994). The principal data gathering tools used were: literature review, document analysis, detailed semistructured interviews, postinterview questionnaires, and participant observation.

For grounded research, the choice of data sources is analogous to the selection of witnesses in a court case. This means that documents, informants, and other data sources were chosen based on what perspectives they could provide on the phenomenon of equivocality. The purpose is not to choose a representative sample, but rather to choose a balanced selection of knowledgeable sources. For example, if the nocturnal movements of the murrelet to hidden nesting sites on land was potential evidence of equivocality, then informants knowledgeable on these movements would be important. Similarly, persons observing marmots in the field were essential witnesses for establishing the technology for access to, and observation of, the marmot ecosystem.

In the grounded theory approach, the "stopping rule" for deciding when enough information has been gathered is partially subjective. The researcher stops gathering information not when a predetermined sample size is reached, but when *theoretical saturation* is reached (Strauss and Corbin 1990). This occurs when the researcher does not expect that consulting another source will produce new theoretical insights. Often this occurs when additional documents and interviews begin to repeat the same information, and the information in the database is perceived as sufficiently complete for reliable analysis.

Document and Literature Analysis

As a first step in gathering data, the researcher reviewed official government status reports and published scientific articles and books on the case species. This analysis provided an orientation to the case as well as many details on the species and its ecosystems. The documents included publications by interview participants where possible.

A review of published scientific literature was also conducted. This review included publications on certain specialized topics related to the ecosystems, such as information on biogeography, biodiversity, or environmental factors. It also included publications on information technologies, such as remote sensing, geographic information systems, and hydroacoustics.

Documents and scientific literature provided nonreactive data as a crosscheck on information provided from interviews and other sources. It also provided authoritative, peer-reviewed sources for information to compare with data emerging from other sources (Bryman 1989).

Detailed Semistructured Interviews

The researcher conducted 23 intensive interviews with key scientists, resource managers, and information specialists with special knowledge or major roles in studying or managing the target species or ecosystems (appendix 2). The number of interviews varied among the cases, with four for the T1 ecosystem, five for the M2 ecosystem, and seven each for the T2 and M1 ecosystems. Several interview participants contributed understanding for more than one ecosystem. For example, experts on biogeography and technical specialists on geographic information systems and remote sensing offered broad perspectives on ecosystem delineation for all ecosystems.

Selection of Interview Participants

The selection of interview participants was based on the review of official documents and publications that identified the primary researchers for the species or ecosystems. In addition, contacts were made with knowledgeable persons to identify who should be contacted. In most cases, interview participants were very well known for their work with the case species and ecosystems. The interview participants were *key informants* with major research or management roles related to the species or ecosystem (Bryman 1989; Scarce 2000).

An effort was made to balance the selection of interview candidates. For example, for each case, the following persons were interviewed:

- the most prominent biologist or biologists researching the case species in British

Columbia

- the principal resource manager responsible for management of the species, including the chair of the species recovery team where possible
- various specialists in the ecology and resource inventory practices for the ecosystem

A list of interview participants is provided in appendix 2.

The backgrounds of the interview participants differed widely. For example, the most prominent expert on a case species may not be an expert on the biodiversity or environmental systems affecting the overall ecosystem. Ecosystems are sufficiently complex that no individual scientist or manager could be an expert on all of the matters addressed in the research indicators. Therefore, interviews were tailored where possible to the specific backgrounds of the participants.

A manageable number of interviews were planned. As noted earlier, interviews ranged from four to seven for each case. This required very careful selection of interviewees for some cases such as the marbled murrelet, which has been the subject of study by a large number of scientists. In such situations, interview participants were chosen based on their reputation as senior researchers working on the case species. For the humpback whale, the interview participants working in British Columbia waters were chosen from the large number of researchers worldwide. On the other hand, few experts were available for the T1 marmot ecosystem, so only a few persons were interviewed.

Research Ethics Notice

The interview participants were experienced researchers and managers, and the research questions were of a scientific nature. Accordingly, the Simon Fraser University Ethics Review Committee determined that it was not necessary to maintain confidentiality and anonymity for interview subjects. Interview subjects were advised that their responses would not be confidential or anonymous, except where they requested that their comments be kept “off the record.” A written notice concerning research ethics was provided to interview participants advising them of their rights (appendix 3).

Interview Procedure

The interviews were detailed and semistructured (Bryman 1989; Scarce 2000). Eighteen of the 23 interviews were conducted by telephone and five in person. Questions were organized around the case questions and the research indicators. Interviewees were faxed brief explanation of the research and a copy of the list of indicators prior to the interview (appendix 4). A short resume was also attached to identify the researcher.

A loose protocol was designed to cue the researcher to ask important questions (appendix 5). Questions were a mix of open-ended and probing questions. The researcher adapted the focus of the interview, however, based on the background of the interview participant and the information that they would best be able to provide.

The interview process was informal and interview participants were encouraged to contribute whatever answers or insights they wished. In some cases, interviewees preferred to follow the list of indicators themselves, or to review their experience with fewer questions. The protocol was then used to review whether the important data were collected.

The semistructured interview approach created the ability to search for underlying explanations and probe for evidence that would test the research hypotheses. It also structured information gathering to ensure data were gathered, where possible, on each of the research indicators.

Interviews each lasted from 0.5 to 2.5 hours, with an average interview time of 1.4 hours (appendix 2). There were 11 interviews for terrestrial cases at an average length of 1.3 hours per interview for a total of 14.25 hours. There were 12 interviews for marine cases at an average length of 1.5 hours for a total 18.25 hours.

Of the 23 interviews, 22 were taped. One interview site tour was not taped because it involved a site visit and demonstration of technology (Dawson, interview). The tapes were previewed by the researcher to identify specialized terminology and then transcribed verbatim by a typist, Ms. Laura Minato. The researcher then carefully compared to the tapes to the transcripts for reliability and accuracy, and to identify words that were difficult to hear. A copy of the interview transcripts was then provided to each interviewee for his or her review, where possible. This included all but two interview candidates who could not be reached. Subjects were asked in a memorandum to review and scrutinize transcripts, request any changes to accurately record and reflect their opinions or information, and provide any additional information or insights (appendix 6). This process is referred to as a *member check* in qualitative research, and is done to improve reliability and credibility of interview data (Lincoln and Guba 1994). In a few cases, interviewees responded with minor corrections.

Postinterview Questionnaire

At the conclusion of each interview, where possible, the researcher asked the participant to complete a short questionnaire. Twenty questionnaires were faxed to the 23 interview participants. Three interview participants were not sent surveys because they were unable to complete them or because their expertise was too specialized for the more general content of the survey. Of the 20 forms distributed, 14 (70 percent) were completed and returned. There were three each for the T1 and T2 ecosystems, and four each for the M1 and M2 ecosystems.

The questionnaire provided an additional method for obtaining insights and observations from interview subjects. The use of the questionnaire allowed a more free-flowing process for the interviews. Asking the survey questions in the interview would have inhibited the creative thought processes of the interviewees.

The questionnaire used a mix of scaled and open-ended questions designed to elicit evaluative responses from participants (appendix 7). Because the sample size is very small, the data cannot be analyzed statistically. The raw data with simple means are provided in appendix 7, which provides an impression of the level of consensus and variance among experts. The responses are considered in the cross-case analyses (chapter 4).

Participant Observation

Professional and personal experience provides a basis for sensitivity to "what is going on with the phenomenon you are studying" (Strauss and Corbin 1990; Bryman 1989). Participant observation is the active participation of the researcher in the processes being studied (Yin 1994; Creswell 1997). Direct experience is a factor that could bias research, and should therefore be disclosed. On the other hand, this experience also provides an opportunity to obtain an "inside" or grounded perspective on a phenomenon.

In this research, the researcher had two types of involvement: professional and volunteer. The researcher has been involved professionally in the identification and planning of protected areas for over twenty-five years. This has involved the identification of conservation strategies for areas ranging from park sites to national protected area programs. In 1995, for example, the researcher assisted the Department of Fisheries and Oceans in the development of an approach for establishing marine protected areas (MPA) that is now the basis for Canada's MPA strategy. He has also participated in numerous coastal and terrestrial planning projects as a professional planner.

The researcher also volunteered to serve as a lead facilitator for a major workshop in April 1999 on Human-Marine Mammal Interactions, sponsored by the Department of Fisheries and Oceans and the University of Victoria. This activity provided an opportunity to meet many prominent marine scientists, whale researchers, and whale watching industry representatives. It also provided an overview of some of the major issues facing marine resource and whale species management. The author also served as a lead facilitator for an international workshop on marine protected areas at the Coastal Zone Canada 98 Conference in Victoria, BC in September 1998, a workshop attended by over 70 marine scientists and stakeholders from several countries. Finally, the author served as lead facilitator for the Marbled Murrelet Conservation Science Forum and Workshop on March 28-29, 2000 sponsored by the Marbled Murrelet Recovery Committee, which included 80 of the lead researchers on the murrelet in academia, government, nongovernment organizations, and industry.

3.2.6 Concurrent Analysis

In qualitative research, data gathering and analysis proceed concurrently (Dey 1993). The concurrent collection and analysis of data allows incoming data to influence the scope and approach to research. This especially applies to grounded theory research, which derives theory inductively from the analysis of data. Because analysis and theory-building are grounded in the data, the results tend to be relevant to the cases being studied.

In this research, an audit trail was maintained to provide a "chain of evidence" to enable reviewers to follow the acquisition of evidence from initial research to ultimate case study conclusions (Yin 1994). This is similar to a forensic investigation or accounting audit that uses an audit of procedures as a means of evaluating the reliability of the evidence gathering methods. An audit trail documents research activities and permits potential replication. These data controls improve the reliability and validity of data gathering procedures (Yin 1994).

Detailed tapes or notes were kept to allow external review of evidence. Notes were kept to document the evolution of the research process and record informal strategic thinking about conceptual and research issues. In some cases, informal "memos" were prepared outlining emerging theoretical concepts, insights, conclusions, and research leads as they arose in the research. Memos are "written records of analysis related to the formulation of theory" (Strauss and Corbin 1990).

Important evidence was recorded, summarized, or referenced in computer databases. The researcher archived electronic drafts of key research documents periodically, such as research databases, case reports, cross-case analyses, and other documents. A bibliographic database was maintained to provide a record of all documents and evidence collected.

3.2.7 Coding

Coding is a primary tool in qualitative research (Bryman 1989; Boyatzis 1997). The coding procedures for this research are described in Strauss and Corbin (1990). Strauss and Corbin describe a theory as a set of concepts that are linked by means of statements of relationships. Coding "represents the operations by which data are broken down, conceptualized, and put back together in new ways. It is the central process by which theories are built from data" (Strauss and

Corbin 1990).

In this research, the central phenomenon was equivocality. Theory building involved the examination of ecosystems to identify ideas, factors, incidents, events, or other instances of equivocality as a phenomenon. The first stage of coding required the development of a structure of codes referred to as *indicators* (section 3.2.3). Subsequent coding was conducted within these indicator categories.

The initial process of searching for instances and evidence of a phenomenon in data is referred to as "open coding," which is "the process of breaking down, examining, comparing, conceptualizing, and categorizing data" (Strauss and Corbin 1990). Open coding involves a set of procedures for categorizing, dimensionalizing, and splitting concepts into components. One of these procedures involves making comparisons; hence, grounded theory is often called "the constant comparative method." Comparisons were made in this research, for example, between the amounts of data available within each case ecosystem on the case species ranges.

Another coding method is the asking of questions. Questions were used to illuminate the potential categories, such as obstacles to visibility, and the characteristics of these categories, such as water cover, terrain, vegetation cover, or subterranean burrows. Each of these methods revealed nuances and categories that were then labeled with a coding label as instances of the equivocality phenomenon.

The second type of coding used in grounded theory research is referred to as "axial coding" (Strauss and Corbin 1990). Axial coding is a set of procedures for making connections between categories identified in open coding. According to Strauss and Corbin (1990), the focus is on

> specifying a category (*phenomenon*) in terms of conditions that give rise to it; the *context* (its specific set of properties) in which it is embedded; the action / interaction *strategies* by which it is handled, managed, carried out; and the *consequences* of those strategies. These specifying features of a category give it precision, thus we refer to them as *subcategories*.

In other words, axial coding refines and recombines categories and causal linkages among categories into theories. This is the process underlying theory-building research.

3.2.8 Database

The primary repository for coded data for this research was a set of computer-based databases, one for each case. Qualitative research is normally data intensive (Miles 1979), and databases are intended to provide a "thick description" of the phenomenon being investigated. In this research, the combined databases involved an equivalent of over 800 pages of text at 325 words per page. Each database included coded excerpts or notes from all document reviews, interviews, and many other data sources for that case. This evidence was condensed from more detailed original sources. The databases referenced sources for all included evidence. The databases provided a tool for storing, searching, comparing, analyzing, and summarizing information related to study variables.

The researcher also maintained a detailed bibliographic database that documented all documents and scientific publications that were identified, reviewed, or included in the analysis.

3.2.9 Within-Case Analysis

Each of the four cases in this research was reviewed separately before being compared with other cases. As part of the analysis, a report was prepared for each case. The purpose of case reports was to organize and interpret the evidence for each case in a systematic, thorough, and transparent fashion. The case reports also provided a descriptive information base for analysis, and background for outside reviewers.

The case reports provided a profile of key features of each case based on the indicators identified in section 3.2.3. This served to ensure consistent depth and span of analysis for all cases and comparability among case reports. These indicators were designed to provide a broad view of the ecosystem and species information.

3.2.10 Cross Case Analysis

A structured evaluation of the characteristics of the four cases was conducted to compare and contrast the evidence for equivocality in the four ecosystems. In summary, the cases were each analyzed first individually, in sequence, using the within-case approach described above. The sequence followed was as follows: T1, M1, T2, and M2. The evidence from each subsequent case, when completed, was compared and contrasted with previous cases using the "constant comparison" method (section 3.2.7; Strauss and Corbin 1990). This method involved comparison of cases to recognize and highlight patterns of similarities and differences among the cases (Miles and Huberman 1994). This pattern recognition reveals new relationships and builds theory. Pattern recognition is a basic cognitive process involved in scientific theory building (section 1.5.1; Ziman 1978; Barrow 1998). Scientists sift data for meaningful patterns. They then develop mental maps or models to describe these patterns, which then become the foundation for theory (Ziman 1978).

Thus, the evidence from the first case was analyzed, and an initial set of codes was identified to label emerging themes using the coding procedure described in section 3.2.7. A within-case analysis was then completed for the second case, following the same within-case procedure as for the first case.

Once both cases were completed, the coding and emerging themes from the two cases were compared to identify situations where evidence of equivocality converged or diverged. This included examination of contexts or environmental parameters that appear to lead to greater or lesser equivocality in each situation. The cases were also assessed to identify similarities and differences in the nature and coverage of the evidence. Where gaps were identified in the evidence for either case, evidence from the cases was reexamined. Following completion of the first and second cases, the third case was analyzed, and once the within-case analysis was completed, it was compared with the first two cases. The fourth case was analyzed in the same way.

The principal mechanism for comparing cases in this research was a set of "cross case comparison tables." These tables are summarized in chapter 4. The tables were developed to compare and contrast data from the cases based on the attributes of equivocality and the types of adaptive responses. A separate table was developed for each indicator. Miles and Huberman (1994) explained the rationale for this type of technique, which is commonly used in qualitative research for comparing cases. This approach provided multiple lenses for understanding what was occurring in the data, and for establishing scientific reliability and validity.

3.2.11 Rescoping

Qualitative analysis is grounded in the research data, so that data determine the theory and methods of analysis. As data are gathered and analyzed, emerging constructs such as equivocality may be redefined. This affects the case questions that are important and any propositions that are emerging. It also affects what type of cases may provide further enlightenment on the concepts.

At the conclusion of each case, the researcher assessed the contribution of the case to the research objectives and to emerging theory. The research questions and interview protocols were also reviewed and reshaped, as necessary, to ensure acquisition of the information necessary for analyzing subsequent cases. Final decisions were also made on the choice of the next case to probe for further clarification of the relations of equivocality and natural environments. Choice of the next case was based on theoretical sampling which selects the case that would be best able to provide a test of remaining theoretical propositions (Glaser and Strauss 1967; Eisenhardt 1989a).

3.2.12 Hypothesis Testing

Qualitative research is often limited to theory building, but not testing of hypotheses. Following Eisenhardt (1989a), this research was extended to test hypotheses. The results of this testing is reported in chapter 5.

The central technique for testing hypotheses in this research was a comparison of the four ecosystems based on criteria that arose from the coding process (section 3.2.7). Table 5.4 in chapter 5 provides an illustration. The table addresses a hypothesis that there is a greater amount of descriptive information for terrestrial than for marine ecosystems. One relevant parameter for the case species is the "proportion of the potential range of the case species in British Columbia that has been confirmed by census surveys." This category is relatively verifiable and quantitative, although there is no consensus on the precise estimates of the proportion for each ecosystem that has been surveyed. An arbitrary scaling of the categories was used to compare the ecosystems. A high rating for equivocality was defined as "more than two-thirds of the range is unknown or speculative" whereas low equivocality was defined as "more than two-thirds of species range has been surveyed and mapped." In between, medium equivocality was defined as "between one third and two thirds of the range has been surveyed, or projected from habitat requirements." This provided a clear basis for evaluating the cases. For one species (T1), almost all of the range had been surveyed very thoroughly. For another, about half of the range had been surveyed (T2). For the remaining two species (M1, M2), only a small fraction—perhaps less than 10 percent—had been surveyed.

As in this example, the rating categories were designed to provide relatively verifiable ratings. This was assisted by the use of "factual codes." Hesse-Biber and Dupuis (1995) defined factual codes as "codes that denote a certain fact." Facts are operationalizations of underlying conceptual categories and are easier to verify than theoretical concepts. Hesse-Biber and Dupuis proposed the use of factual codes for computer-aided qualitative data analysis to provide for greater objectivity in hypothesis testing. Their method was consistent with grounded theory. The rationale for the codes is included in chapter 5.

CHAPTER 4: CROSS-CASE ANALYSIS

> "We think that social phenomena exist not only in the mind but also in the objective world – and that some lawful and reasonably stable relationships are to be found among them. The lawfulness comes from the regularities and sequences that link together phenomena. From these patterns we can derive constructs that underlie individual and social life" (Miles and Huberman 1994).

This chapter compares information from each of the four case studies, based on detailed information summarized in case reports for each species. This chapter is organized around the indicators outlined in section 3.2.3. This chapter is a summary and discussion of the data gathered for this research, a summary of key data for each case, and a reference for the testing of hypotheses in chapter 5. The text highlights the major findings for the indicator, and the tables provide a summary of the data.

The indicators were chosen in part to sample different aspects of the case to provide multiple sources of evaluation for each hypothesis. Table 4.1 cross-references the hypotheses to the indicators that were most relevant to them. Unmarked cells do not necessarily indicate that the

Table 4.1 Comparison of Hypotheses with Indicators

	1. Target Species Population	2. Target Species Range	3. Ecosystem Biogeography	4. Ecosystem Biodiversity	5. Key Species Roles	6. Ecosystem Driving Factors	7. Ecosystem Threats	8. Access Capability	9. Sampling Coverage	10. Visibility Constraints	11. Sensor Capability	12. Contextual Capability	13. Field Research Technology	14. Defining Listing Criteria	15. Matching Mode to Threat	16. Making Spatial Decisions
H1: Listing Criteria		●	●	●	●	●	●	●	●	●	●	●	●	●		
H2: Protected Area Rationale		●	●	●	●	●	●		●			●	●		●	
H3: Amount of Descriptive Information	●	●	●	●	●	●		●	●	●		●	●			
H4: Information Richness	●	●	●	●	●	●	●	●	●	●	●					
H5: Amount of Causal Information			●	●	●	●	●	●	●	●						
H6: Research Technology Capability	●	●	●	●	●	●	●	●	●			●	●			
H7: Selection Guidance	●	●	●		●	●	●			●			●			●

Symbol: ● means this indicator provides major evidence for testing the hypothesis.

indicator provided no information, but rather that other cells were primary. Chapter 5 also references indicators that provide information for hypothesis testing.

4.1 Target Species Population Abundance and Trends

> The quality of information available about the target species' population abundance and trends in this abundance, and factors that affect abundance.

Introduction

Population data for a species are a 'window' for considering the quality of more general ecosystem information. According to Davis (1989), population dynamics of species

> offer relatively unambiguous insights to ecosystem structure and function. Organisms integrate the effects of a vast array of ecological factors, including predation, competition, and environmental conditions, that are expressed as changes in readily measured population parameters such as abundance, distribution, and growth and mortality rates.

Jamieson (interview) raised a concern that ecological measures such as biodiversity and driving factors might not be the best focus for evaluating information about ecosystems. He also favored population dynamics as a summary measure for ecosystems.At least two types of population data are required for managing any species. First, managers need information about the total population size or abundance of the species. Second, managers need information about trends in population abundance. Sharp declines in abundance, for example, may suggest underlying causal influences, and a potential for extinction. To forecast trends, managers need information on the characteristics of the reproductive potential and characteristics of species' population, such as age, sex ratio, fecundity, mortality, and family groups.

For population estimates, equivocality is resolved where reasonably reliable data are available on the population abundance, population trends, and population characteristics of the target species. Equivocality is increased where existing data do not provide sufficient reliable information for describing the population adequately. Deficits might include inability to define confidence limits for population estimates or trends, or major gaps in data for population characteristics.

Analysis

This indicator compares the amount and quality of information for estimating the population abundance and trends of the target species. This comparison is summarized in table 4.2.

Table 4.2 Comparison of Case Species Population Abundance and Trends

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Estimated Population: Range: 130 to 150. Minimum: less than 100. Maximum: 200.

Trends:

- A major population decline has occurred since mid-1980s (50 to 60 percent).
- High year-to-year fluctuations and some total colony die-outs have occurred in a single year.
- Researchers agreed that trends mean extinction without major intervention to save the species.

Demographic factors affecting trends:

- Juvenile recruitment is highly variable, with (a) serial randomness and no correlation in reproduction between years, and (b) low survival of young between years.
- Understanding of mortality factors is weak, including predation, disease, and lost dispersing marmots.

Census Procedures:

- A very strong data set exists for abundance based on work by biologists since 1972, with much more intensive work since late 1980s.

Other Factors*:*

- Range and habitat requirements are well known, so researchers know where to look (indicator 2).
- Census coverage covers most of the known marmot habitat (indicator 9).
- Vegetation obscures visibility in the marmot meadows, and marmots spend much time underground (indictor 10).
- Individual marmots are difficult to identify, making them harder to count (indicator 10).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Estimated Population: 45,000, plus or minus 20,000.

Trends:

- There are "no calculated estimates" for trends; "population trends cannot be defined with available data."
- There is strong qualitative evidence, such as anecdotal accounts, that B.C. populations are declining, including fewer or no sightings in certain areas.
- Limited survey and mark-recapture evidence suggests declines in certain areas.
- Tentative estimates of population declines are in the range of 3 – 6 percent.

Demographic factors affecting trends:

- The basic biology of the murrelet is relatively poorly understood, such as survival rates, longevity, and fecundity.
- Biologists are presently studying demographics, recruitment, and survivability.
- Nest studies have indicated that murrelets lay one egg, and that nest success is low; recruitment rates are thus known to be low.
- Nothing is known of pairing behavior, or interbreeding of populations.
- Biologists have speculated that breeding propensity may be related to food availability.

Census Procedures:

- Population abundance is "poorly known;" estimates are an "educated guess" and "still debatable, big time."
- Survey work has been focused and systematic, moving sequentially from area to area.

Continued on next page

Table 4.2 –*Continued*

- Biologists have used a variety of techniques, including audiovisual and radar surveys, radiotelemetry, and field work to find nests.

Other Factors*:*

- Murrelet nests are tens of kilometers inland and camouflaged in dense forests, making them extremely difficult to locate (indicator 2).
- Murrelets can be found in predictable locations at sea where they can be counted (indicator 2).
- Individual birds are difficult to identify; very few have been banded (indicator 10).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Estimated Population: At least 550; upper limit unknown.

Trends:

- There is strong qualitative evidence that B.C. populations are increasing, such as sightings that are more frequent, sightings of new individuals, and sightings in new areas.
- Studies of larger North Pacific populations suggested overall growth from 1,000 post whaling animals in the mid-1960s to 6,000 today.

Demographic factors affecting trends:

- Mark-recapture analyses cannot be applied to whale counts because dead whales cannot be removed from population databases. The death of whales cannot be confirmed because dead whales most often disappear at sea.

Census Procedures:

- Research in British Columbia has been nonsystematic and opportunistic because of insufficient funding.
- A large number of whale researchers in several countries and regions have collaborated to estimate the North Pacific population.

Other Factors*:*

- Free ranging mobility of species has made it difficult to assign a "BC" population. Humpbacks may be found where prey food exists (indicator 2).
- Humpback prey distributions are dynamic, patchy, and poorly understood (indicator 5).
- Humpback individuals can be identified by photo identification of tails (indicator 10).

MARINE CASE: M2 Benthic Octopus Ecosystem

Estimated Population: No estimate exists, although species is known to be "common."

Trends:

- No reliable information exists about past or present trends.
- Researchers do not believe the population is declining.
- Populations are believed to vary considerably within and between years. There is evidence of contagious recruitment events leading to large populations, and major population fluctuations. There is anecdotal evidence of superabundance and very large sizes under aboriginal conditions.

Demographic factors affecting trends:

- Researchers have studied life history and reproduction of octopuses in shallow water.
- Biologists have very little information on the biology of young octopuses; young octopuses are pelagic; growth rates are high; mortality is very high.

Continued on next page

Table 4.2 – *postinterview questionnaire continued*

Census Procedures:

- No survey estimates are being done at the present time.

- Data on populations are not being recorded in any quantitatively reliable fashion. Information is limited to inadequate harvest logs, a very few diver surveys in highly local areas, and anecdotal information from divers.

Other Factors:

- Adult octopuses possibly migrate twice annually to deep water, which forms a large portion of their range; researchers have no information about octopuses in deep water (indicator 2).
- Surveys have covered only a very small portion of octopus range (indicator 9).

POSTINTERVIEW QUESTIONNAIRE[1]

Q1. The information available on the population abundance of the target species.

- Amount: Rank from high to low is T1, T2, M1, M2
- Quality: Rank from high to low is T1, M1, T2, M2

Q2. The information available on the trends in target species abundance.

- Amount: Rank from high to low is T1, T2, M1, M2
- Quality: Rank from high to low is T1, M1, T2 and M2 tied

Q3. The information available on population characteristics

- Amount: Rank from high to low is T1, M2, T2, M1
- Quality: Rank from high to low is M2, T1, M1, T2

Q4. The information available for making and testing predictions on future abundance

- Amount: Rank from high to low is T1, T2, M2, M1
- Quality: Rank from high to low is T1 andT2 (tied), M2, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Bryant, Janz, Demarchi, and Klinka. COSEWIC 1998; Bryant 1996, 1997; Bryant and Janz 1996; Barash 1989; Armitage 1982; Greenwood 1996; Sutherland 1996; Call 1986; Davis 1982; Kirkland 1982; Kuchera 1982. For T2 Ecosystem: interviews with Kaiser, Manley, Chatwin, and Dunn. Davies 1999; Bahn 1998; US Fish and Wildlife Service 1997, 1996; Ralph et al. 1995; Rodway, Regehr, and Savard 1993; Jones 1993; Rodway 1990; Sealy 1975. For the M1 Ecosystem: interviews with Darling, Ellis, and Sloan. Pacific Whale Foundation 1998; Palsboll et al. 1997; Harper 1995; Ford et al. 1994; Baker, Straley, and Perry 1992; Whitehead 1987; Winn and Winn 1985; Hay 1982. For the M2 Ecosystem: interviews with Hartwick, Cosgrove, Gillespie, Marliave, and Jamieson. Keller 1999; Gillespie, Parker, and Morrison 1998; Hunt 1996; Jamieson and Francis 1986; Hartwick 1983; Petro-Canada 1983.

Abundance and trend estimates for the marmot are based on systematic surveys using well-developed and standardized methodologies (Bryant and Janz 1996; Bryant 1997). Marmot habitats are small in extent, and relatively well known. Marmot populations are highly variable from year to year, and understanding of reproduction and mortality factors is limited. There is unanimous agreement that the marmot is extremely rare and declining in numbers. Actual numbers were estimated at somewhere around 100 (Bryant, interview).

Estimates for the murrelet are based on qualitative evidence, as well as limited survey and mark-recapture data. Murrelets can be found in predictable locations at sea where censuses are usually conducted. Murrelet forest habitats are extremely difficult to survey (see section 4.2).

Biologists have limited information on reproduction and mortality on which to base trend estimates. Biologists consider present abundance and trend estimates as an "educated guess" based on limited data and extrapolations, and not based on scientific calculations (Dunn, interview; Kaiser, interview; Manley, interview; Rodway 1990). Major systematic surveys are presently underway to estimate the murrelets' abundance and distribution, which will improve the reliability of census numbers. At present, the best estimate would be 45,000 murrelets, plus or minus 20,000 (Kaiser, interview). Strong qualitative information suggests murrelet populations are in steady decline (Manley, interview; Chatwin, interview; Bahn, 1998).

North Pacific populations of humpbacks appear to be increasing strongly since whaling stopped in the 1960s. Surveys of the British Columbia population, on the other hand, have been nonsystematic and opportunistic. Humpbacks are free ranging mobile, and their distributions are dynamic and patchy. Estimates have not been done in a way that would allow statistical mark-recapture analyses and are thus only "a ballpark sort of guesstimate" (Darling interview). For example, dead whales are lost at sea, and cannot be removed from databases. However, increasing numbers of humpbacks have been identified in British Columbia waters that have not been identified before (Ellis, interview). Researchers believed that there are more than 550 humpbacks in British Columbia waters, but could not provide an upper estimate (Darling, interview; Ellis, interview).

Although the octopus is a common species in British Columbia, there is only anecdotal information on its abundance, or of past or present trends. Diver surveys have been limited to local areas and divable depths shallower than 20 meters. The depth range of the octopus ranges from intertidal depths to at least 300 meters. Below divable depths, information is limited to sketchy data from commercial fishing and limited trapping. Researchers have studied the life history and population dynamics of octopuses, but knowledge of early life stages is poor.

Discussion

In assessing these cases, the question is, how does the physical environment of the ecosystem affect the quality of information for estimating the abundance and trends of the target species? For the marmot, although local terrain, vegetation, and subterranean burrows often obscure the marmots, the small extent of well-defined habitat requirements assists researchers in finding marmots. On the other hand, dense, rugged forest habitats make surveys of murrelets very difficult, although they can be counted while feeding in nearshore habitats. Murrelet researchers have a very general estimate of population size and trends. The survey of humpbacks and octopuses is constrained by the sheer space of marine habitats as well as the cover of water. Like murrelets, humpback whales can be counted in nearshore waters where they congregate for feeding, though the resources for surveying whales are too limited to allow accurate counts. Information on octopus populations is very sparse.

A number of factors contribute to equivocality of population information, including variability in trend information, ability to discern trends, surprises in trends such as collapses, long-term records or history of trends, camouflage of animals or inability to find them, ability to identify individual animals for counting, and the ability to display data in a visually meaningful way. Population data quality is also affected by the level of funding for conducting surveys.

4.2 Target Species Range and Distribution

> The quality of information available on the present, past, and potential geographic extent of occurrence and distribution of the target species.

Introduction

Range and distribution address spatial occurrence of a species. This information is important for selecting protected areas for a species, and for identifying the habitat requirements, ecosystems, biogeographic areas (section 4.3), and driving factors (section 4.6) associated with the species.

Range means the geographic extent of locations where presence of one or more members of the species has been observed. Any area where a member of the species has been observed is part of the range. *Distribution* means the "quantifiable abundances of individuals within the range" (Ray and Hayden 1993). It is a measure of numbers of animals in different geographic locations at different times, and addresses major areas of concentration, seasonal distribution, and breeding and feeding habitats. Distribution is thus "a second order of analysis" (Ray and Hayden 1993).

Equivocality would be resolved where the scientific community has good information on the present and past range of the species. This would include knowledge of the temporal and spatial distribution of the species sufficient for predicting where to find concentrations of the species during all seasons. Equivocality would be increased where the range and distribution of the species is unclear, uncertain, or subject to conflicting opinion among the scientific community.

Analysis

This indicator compares the amount and quality of information for determining the range and distribution of the target species. The comparison is summarized in table 4.3.

Marmot colonies occur in small discrete subalpine meadow habitats found in only a few locations on Vancouver Island. The colonies collectively occupy a very small area, with marmots dispersing between colonies to provide for genetic exchange. The marmot is “rare primarily because of the small size and patchy distribution of natural subalpine meadows on Vancouver Island” (Bryant and Janz 1996). Demarchi (interview) stated “the marmot has evolved in the rarest habitat probably in Canada.” Colony sizes are limited by the amount of suitable habitat. Most of the existing colonies have been surveyed for the past two decades, and biologists do not expect to find more than a very few additional colonies (Janz, interview). Although marmots can disperse widely in search of habitat, the scarcity of natural habitat limits pioneering colonies. The exception is forest clear cuts, which may not be optimal habitat (Bryant, interview). Thus the marmot’s range and distribution are relatively well known.

Enormous efforts were required over many decades to locate the first murrelet nests in British Columbia. Murrelets nests are located almost exclusively high in large trees in large patches of dense, coastal temperate old-growth rainforest habitats where they are almost impossible to detect without radiotelemetry tracking and extensive tree climbing. Recently, biologists have developed strategies for finding the general locations of nests, but finding the actual nests is still extremely laborious and difficult. Detailed habitat evaluations have been done for nesting areas that have been identified in order to identify factors that can be used to locate additional sites. As a result of this work, murrelet nesting requirements are now “fairly well known” and “consistent” (Manley, interview). Systematic surveys are now underway to identify murrelet nesting areas along the British Columbia coast. Information on murrelet range and distribution is still incomplete, but is rapidly improving based on current survey efforts. Information about the locations of murrelet marine foraging areas is not “well advanced” (Dunn, interview).

Researchers indicated that they had “certainly a good idea of the ranges which are important” to humpbacks in British Columbia, such as foraging areas (Darling, interview). Information on the distribution of humpbacks within British Columbia waters, however, is very poor (Darling, interview; Ellis, interview; Sloan, interview). Perhaps less than 10 percent of their potential range has been surveyed (Darling, interview). According to Darling (interview), the effort to survey

Table 4.3 Comparison of Target Species Range

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Range:

- Marmots are found only on subalpine meadows of southern Vancouver Island, and in intervening matrices. Most marmots occur within a few extremely small subalpine meadows totaling 34.5 hectares within the $40km^2$ core area of present distribution.
- Strong agreement among biologists on present range, although there is a little doubt as to whether all colonies are known.
- Marmots occupy the same colonies from year to year.
- Marmot meadow habitats have changed due to long term climate changes, forest succession, and logging practices.
- Recovery plans propose reintroduction of marmots to suitable habitats formerly occupied by marmots, such as the Strathcona Provincial Park.

Dispersal or Migration:

- Marmots disperse between colonies; dispersals range from 5 to 30km.
- Precipitating causes for dispersing are not known. Dispersal is random and routes are not predictable. Dispersing marmots have been observed in several unexpected locations.
- Landscape used for dispersal between colonies is seriously disrupted by past logging.
- Marmots have failed to recolonize certain previously occupied colony sites.

Habitat Requirements:

- Marmot habitats have the following characteristics: rare subalpine meadows, on south facing slopes, at elevations from 1,100 to 1,400 meters, in the south-central mountains of Vancouver Island.
- Habitat requirements include: grasses and forbs to eat; appropriate terrain for burrows; and appropriate microclimate for forage production, thermoregulation, and hibernation.
- The marmots' very specialized habitat requirements limit the extent of search for colonies.
- Colonial habitats have enabled researchers to identify relatively fixed areas for observation.

Other Factors*:*

- Access to habitat is by four-wheel drive, hiking or skiing; the terrain is rugged and mountainous (indicator 8).
- The marmot's range is very small; most of likely areas for colonies have been surveyed for past two decades; many colonies have been surveyed annually (indicator 9).
- Visibility of marmot habitat is limited by weather conditions, terrain and vegetation; meadows can be observed from a few locations; marmots spend most of their time underground; individual marmots are difficult to identify (indicator 10).
- Marmots are observed with low technologies such as binoculars; mark-recapture tagging and radiotelemetry studies have been done (indicator 11).

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Table 4.3 – *T2 Ecosystem continued*

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Range:

- Murrelets are found from central California to the Aleutian Islands, with related species in Asia.
- Researchers strongly agreed that murrelets are limited, in nesting season, to areas of the coast that are near to suitable coastal temperate old-growth nesting habitats.
- Murrelets are no longer numerous in certain areas where they were formerly abundant, such eastern Vancouver Island.
- Considerable year-to-year variation in local distribution; observed shifts activity between watersheds may reflect prey distributions, response to predator risks, social behavior, or unknown factors.
- Distribution of foraging murrelets is relatively stable during nesting season. In foraging areas, murrelets exhibit wide but clumped or loose aggregations in predictable locations where forage is abundant.

Dispersal or Migration:

- Murrelets are year round residents on the British Columbia coast over most of their range.
- In winter, murrelets move from more exposed or outer coastal breeding season foraging locations to more sheltered, biologically productive areas within the general region.
- Murrelets occasionally visit nest sites even in nonbreeding season for unknown reasons.
- Although seasonal movements are known to occur, the patterns of movement, dispersal distances, and winter distributions are poorly known; movement to wintering areas may be by swimming.

Habitat Requirements:

- Murrelet nesting habitat are fairly well known and consistent:

  –Large patches of dense, coastal temperate old-growth rainforest with minimal fragmentation.

  –Inland location up to 70 to 85 km inland from foraging areas, and up to 1,100m in elevation.

  –Nesting patterns are low in density, and single nests are isolated.

  –Large old growth trees with large, moss covered limbs 20 to 40 m from the ground.

  –Nest platform must have a nearby gap in the forest cover and a suitable approach for landing.

  –A variety of old-growth tree species are used.

- Murrelets marine foraging habitats are predictable:

  –Shallow nearshore marine areas, usually less than 30 m deep, though occasionally deeper.

  –Widely distributed in channels, inlets, fjords, bays, and lagoons as well as outer coastlines.

  –Areas with an abundance of prey species including upwelling areas, strong tidal areas, shelf edges, underwater sills, mouths of bays, narrow passages, shallow banks, and kelp beds.

  –Site preference may be determined by food availability, proximity to nests, and environmental factors such as weather.

Other Factors*:*

- Access to murrelet nesting sites is extremely difficult (indicator 8).

Continued on next page

Table 4.3 – *continued*

- Cursory surveys have been done at least once for most of the coast; systematic surveys are being conducted throughout coast; murrelet surveys are generally one-time events, except in certain locations (indicator 9).
- Murrelets are extremely difficult to observe flying from forage to nest sites because of weather, flying behavior, and obscuring habitat; nest sites are difficult to detect in dense forests; murrelets are difficult to identify (indicator 10).
- Murrelets are observed by eyesight, binoculars, sound, and radar; murrelets have been captured, banded, and tracked using radiotelemetry (indicator 11).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Range:

- Humpbacks are found off almost every coastline in the world at some time of the year. North Pacific humpbacks occur in summer from California along the Pacific Rim to Japan; they breed and calve in Hawaii, Mexico, and the western Pacific; Hawaiian humpbacks summer primarily from Vancouver Island to Alaska.
- Half of the known winter population is not accounted for in summer feeding grounds; some of these may be in British Columbia.
- Information on the range of humpbacks in British Columbia is extremely limited.
- Free-ranging mobility of species has made it difficult to assign a "British Columbia" population.
- Former habitats, based on whaling records, indicate former range was not uniform, but humpbacks concentrated in certain areas; humpbacks formerly occurred in most of British Columbia waters, but are now infrequent in some areas such as Strait of Georgia.
- Distribution is "very, very dynamic" and changeable from week-to-week or year-to-year as they move to where prey are. Humpbacks can move large distances in short times during summer in search of prey. The distribution of key prey species is poorly known. Concentrations of humpbacks do occur repeatedly in some areas.
- Long term changes occur in humpback ranges for unknown reasons such as the arrival in Hawaii in the last century and the absence in the Georgia Strait since early in this century.

Dispersal or Migration:

- Humpbacks migrate each year between warmwater winter breeding-calving grounds in south to coldwater feeding grounds in the north.
- Migrations cover thousands of kilometers each way; migration routes are unknown, but may occur in relatively straight lines. Knowledge is based on extremely limited telemetry data and speed of transit. Activities of whales during migration, and direction finding methods, are not known.
- Migratory patterns are only partly known and the humpbacks appear to be free-ranging. Interchange between different breeding-calving areas and different feeding ranges is poorly known. Free-ranging among humpbacks makes it difficult to assign individuals to specific areas. British Columbia humpbacks have been found in all three wintering areas.
- Some humpbacks appear to remain resident rather than migrating, perhaps when not looking to breed or calve.

Habitat Requirements:

- Humpbacks feed on continental shelves, deep water sounds, channels, and offshore banks.
- Humpbacks seek areas with available prey food, such as euphausiids and small fish. Distributions of these prey are dynamic, patchy, and poorly understood.

Continued on next page

Table 4.3 – *continued*

Other Factors:

- Inshore access is easy by small boat; offshore access requires scarce ship time (indicator 8).
- Humpback surveys have been conducted in only a very few areas for brief periods. Less than 10 percent of British Columbia waters have been surveyed. A full survey of B.C. waters would be a huge undertaking (indicator 9).
- Visibility is complicated by extensive range and oceanic weather conditions, and the fact that humpbacks stay under water most of the time. Humpbacks can be identified from their markings (indicator 10).
- Humpbacks are observed with low technology eyesight, binoculars, and cameras. Photo-identification has been used for limited mark-recapture studies. Satellite tags have been used a few times (indicator 11).

MARINE CASE: M2 Benthic Octopus Ecosystem

Range:

- *Octopus dofleini* are found from California to Alaska, with related species in Japan.
- No specific information exists on octopus distributions within British Columbia.
- Researchers believe that distribution is fairly general wherever there is suitable habitat.
- Octopuses occupy different habitats during various stages of their life history:

  –Eggs hatch in dens below 20 meters (in British Columbia).

  –Hatchlings swim to surface and become planktonic.

  –Larger larvae settle to bottom.

  –Adults occupy shallow and deepwater habitats.
- Octopuses occupy the same types of habitats from year to year in shallow areas, but abundance varies considerably.
- Octopuses are solitary animals.

Dispersal or Migration:

- Octopuses might migrate bathymetrically between deep and shallow water twice a year; this hypothesis is based on sketchy information.
- There is evidence that larvae do not become enstreamed into current patterns as drifting plankton, but swim directionally, perhaps in schools, to find suitable habitats. Their direction finding is hard to document or understand.

Habitat Requirements:

- *Octopus dofleini*:

  –are found on most bottom types, especially where prey are available.

  –are commonly found where dens are available, such as rocky bottom areas.

  –avoid areas of low salinity or warm water.

  –occur at all depths from intertidal to at least 300 meters (which includes most of the British Columbia continental shelf).

Continued on next page

Table 4.3 – *continued*

–larvae are found at all depths in halibut trawls in the northeast Pacific Ocean.

- Below divable depths, "no one knows" about their movements, distribution, habitats, or activities.

Other Factors*:*

- Access to shallow water octopus habitat requires surface vessel and SCUBA equipment. Deepwater access requires submersibles or remotely operated vehicles, which are not available (indicator 8).
- Regular SCUBA diver surveys have been done in a very few locations and are limited to shallow water. Deepwater surveys are not possible (indicator 9).
- Visibility is impaired by murkiness of seawater and darkness. Octopuses are not being observed in deep water. Individual octopuses are difficult to identify (indicator 10).
- Octopuses are observed with eyesight and low technology underwater cameras. Some trapping, tagging and sonic tagging studies have been done (indicator 11).

POSTINTERVIEW QUESTIONNAIRE[1]

Q5. The information available on the geographic range and distribution of the target species in British Columbia:

- Amount: Rank from high to low is T1, M2, T2, M1
- Quality: Rank from high to low is T1, T2, M2, M1

Q6. The information available for making an testing predictions about the future distribution of the target species:

- Amount: Rank from high to low is T1 and T2 tied, M2, M1
- Quality: Rank from high to low is T1 and T2 tied, M2, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Bryant, Janz, Demarchi, Klinka; Cannings and Cannings 1998; Bryant 1997; Bryant and Janz 1996; Demarchi et al. 1996; Nagorsen, Keddie, and Luszcz 1996; Arnold 1990a; Barash 1989; Nagorsen 1987; Miller 1980; Munro 1978; Heard 1977. For T2 Ecosystem: interviews with Manley, Chatwin, Kaiser, and Dunn. Davies 1999; Bahn 1998; US Fish and Wildlife Service 1996; Resource Inventory Committee 1995; Savard and Lemon 1994; Rodway, Regehr, and Savard 1993; Jones 1993; Ewins, Carter, and Shibaev 1993; Rodway 1990; Sealey 1975. For the M1 Ecosystem: interviews with Darling, Ellis, and Sloan. Chadwick 1999; Palsboll et al. 1997; Calambokidis et al. 1996; Harper 1995; Ford et al. 1994; Whitehead 1987; Darling and McSweeney 1985; Winn and Winn 1985; Darling and Jurasz 1983; Hay 1982; Bryant et al. 1981. For the M2 Ecosystem: interviews with Hartwick, Cosgrove, and Gillespie. Gillespie, Parker, and Morrison 1998; Sheldon 1998; Jamieson and Francis 1986; Hartwick, Ambrose, and Robinson 1984a, 1984b.

humpbacks "hasn't occurred and it's all been second to other duties, people doing humpbacks for a few days and whenever they get a chance, very haphazard, so we have some idea of range, but the quality of information is not rigorous by any means." Ellis (interview) indicated that a survey of the whole coast would be "a fairly huge undertaking" and "a very expensive thing to do." Researchers around the Pacific Ocean are cooperating in efforts to identify long-range migration routes; movements of humpbacks within British Columbia waters are poorly known.

Information on the range of the octopus is very poor, and comes mainly from fishing log data. Biologists suggested that the octopus have broad distribution wherever there is suitable habitat (Gillespie, interview; Gillespie, Parker, and Morrison 1998), but have no scientifically collected data to define this distribution. Octopuses are "found on most bottom types" (Gillespie, interview). They occur in both shallow and deep water, in depths from intertidal to 100 meters. Their "distribution and population structure in deeper waters is unknown" (Gillespie, Parker, and Morrison 1998). Some researchers suggested that they might make migrations between shallow and deep-water zones twice yearly. However, tagging studies failed to provide evidence of this (Hartwick, interviews). When the tagged octopuses migrated below divable 20 meter depths, "nobody knows where they went" (Gillespie, interview). It is known that they grow rapidly in deeper waters, so feeding is obviously important (Gillespie, interview). In shallow waters, a few researchers have studied octopuses in a few small areas to learn of their habitat requirements, life histories, diets, and other factors.

Discussion

The range and distribution provide crucial data for decision making for conservation and protection of a species. The amount and quality of information differ considerably between these cases. The marmot's range and distribution are reasonably well identified. The murrelets nest primarily in old growth forests with certain characteristics, and efforts are under way to survey murrelets in these forests. Murrelet range information is improving, but this is due to an enormous effort. Information on humpbacks and octopuses, however, is very sketchy, and depends on opportunistic and unsystematic information. This information does not provide the basis for defining actual or potential range of these marine species on maps. The types of factors that increase equivocality include the cover provided by water or terrain, the camouflaging of the animals, the vast range of some animals, and the limited coverage of sampling.

4.3 Ecosystem Biogeography

> The availability of clear and consistent information for defining the scale and boundaries of biogeographic areas and ecosystems within range of the target species.

Introduction

The geographic definition of ecosystems is an important step in applying an ecosystem approach to the selection of protected areas (Wikramanayake et al. 1997). The mapping of ecosystems is based on the observed association of recurring assemblages of species with certain environmental conditions and geographic areas. Ecosystems are thus defined by placing boundaries around these biogeographic areas. These biogeographic areas become a major basis for deciding what components of an ecosystem should be included in protected areas. Biologists are mapping biogeographic areas for both terrestrial and marine areas for this purpose (Watson 1998; Zacharias, Howes, and Harper 1998; Ray and Hayden 1993). For biogeography to be useful for protected areas planning, however, it must provide a scientifically defensible method for establishing the scale and boundaries of ecosystems (Levings and Pringle 1998).

A broad set of physical and biological information is required to delineate biogeographic areas. Biophysical characteristics obviously differ between land and sea. For terrestrial areas, the variables include factors such as climate, landforms, soils, vegetation, and species assemblages. For marine areas, areas are defined based on depth, bottom topography, currents, chemistry, temperatures, plankton stocks, and trophic interactions. The 'ability to define biogeographic areas' is thus a surrogate measure for broader ecological information concerns.

Equivocality is resolved where there is high quality of information for defining and describing the biogeographic territory of the species and its ecosystems. If the information is clear and sufficient for the scientific community to arrive at uncontested definitions of the boundaries of ecosystems, this is evidence of a good information base and low equivocality. If key data sets are lacking or unclear, and the scientific community is unable to agree on these boundaries, this is evidence of a poor information base and high equivocality.

Analysis

This indicator compares the cases based on definition of biogeographic areas and ecosystems. Table 4.4 provides a comparison of the four ecosystems.

The T1 subalpine and T2 old-growth ecosystems are encompassed within relatively well defined biogeographic and biogeoclimatic classifications (Klinka, interview; Demarchi, interview). These systems have been in use for several years, and extensive resource inventories have provided data to define and characterize these zones. Marmot meadows are a small component of the coarse grained subalpine zones (Klinka, interview), but marmots use the forested portions of these zones for dispersal to other colonies. Murrelets nest in dense coastal temperate old-growth forests, which are well defined by the presence of very large and old trees. Terrestrial classification boundaries are based on topography, elevation, and vegetation patterns, which are readily identified.

Table 4.4 Comparison of Ecosystem Biogeography

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Biogeographic areas occupied by species:

- Marmots currently occur within Leeward Island Mountains Ecosection within the Vancouver Island Ecoregion. Their historic range also includes Windward Island Mountain Ecozone within the Western Vancouver Island Ecoregion.
- Marmot meadows lie between the Mountain Hemlock (MH) and Coastal Western Hemlock (CWH) biogeoclimatic zones.

Applicability of biogeographic classifications to species:

- Biogeographic mapping of subalpine zones is coarse grained, with heterogeneous mixtures of forest, meadows, and parklands.
- Historic range and marmot meadows straddle multiple biogeographic and biogeoclimatic zones.
- Actual marmot meadows are anomalous and rare habitats within the broader zones.
- Extensive logging and clearcuts have extensively altered surrounding habitats.

Information for classifying ecosystems:

- Boundaries of biogeographic and biogeoclimatic zones are well defined.
- Boundaries are readily identified based on topography, elevation, and vegetation.
- Very detailed mapping, airphotos, and other resource information is available for biogeographic areas.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Biogeographic areas occupied by species:

- Murrelets occur within coastal old-growth temperate rainforests, within the Coastal Western Hemlock (CWH) zones and especially the Wetter Marine CWH subzones; a few may occur in Mountain Hemlock (MH) zones.

Applicability of biogeographic classifications to species:

- Murrelets are strongly dependent on the CWH zones.
- Biologists have proposed the murrelet as an indicator or umbrella species that would represent the old-growth forest ecosystems.

Information for classifying ecosystems:

- Boundaries of biogeographic and biogeoclimatic zones are well defined. These boundaries based on topography, elevation, and vegetation that are readily identified.
- Very detailed mapping, airphotos, and other resource information are available for biogeographic areas.
- Extensive research is being done on old-growth forests due to forest harvesting pressures.

MARINE CASE: M1 Pelagic Humpback Ecosystem

Biogeographic areas occupied by species:

- Humpbacks occur within most marine biogeographic zones in British Columbia, except only occasionally in Georgia Strait. Historic ranges included all British Columbia waters before whaling.

Applicability of biogeographic classifications to species:

- Humpback whales range freely among most biogeographic areas.

Continued on next page

Table 4.4 – *continued*

- Humpbacks are most dependent on biogeographic areas important to prey species, such as upwelling areas.

Information for classifying ecosystems:

- Scientists consider larger classifications to be adequately defined, although they question some of the assignments of areas to levels.
- Hierarchical biogeographic classification systems have only recently been developed for marine areas, and are not fully tested.
- Boundaries are based on physical and chemical parameters that fluctuate; boundaries are thus fluid and dynamic representing fuzzy bandwidths rather than lines.
- Linkages between physical parameters and biological processes are not well understood. Limited research attempts have been made to define biogeographic boundaries based on species occurrence and ecological parameters.
- An alternative approach is to classify ecosystems based on life histories or ranges of species.
- Present classification systems do not distinguish between depths, such as pelagic, demersal, and benthic habitats.

MARINE CASE: M2 Benthic Octopus Ecosystem

See also M1 Ecosystem

Biogeographic areas occupied by species:

- The octopus possibly occurs in most marine biogeographic zones, but this cannot be confirmed without information on its range.
- Octopus occurs in subneritic and suboceanic provinces.
- Octopus dofleini is benthic in its adult phase, but pelagic in its planktonic larval stage.

Applicability of biogeographic classifications to species:

- Marine biogeographic classifications do not address benthic environments in British Columbia.
- Octopuses use different ecosystems at different life stages, thus present classifications do not encompass species.

Information for classifying ecosystems:

- Surficial substrate information is available in a general way.
- Classifications have not been applied to benthic areas.

POSTINTERVIEW QUESTIONNAIRE[1]

Q7. The information available for defining the ecological limits or geographic boundaries of the ecosystem:

- Amount: Rank from high to low is T1, T2, M1 and M2 tied
- Quality: Rank from high to low is T1, T2, M2, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Demarchi, Klinka, Bryant, and Janz. Levings, Pringle, and Aitkens 1998a, 1998b; Harding and McCullum 1994; Pojar and MacKinnon 1994; Campbell et al. 1990; Pojar, Klinka, and Meindinger 1987. For T2 Ecosystem: interviews with Manley, Chatwin, and Kaiser. Bahn 1998; Whitney 1997; Alaback and Pojar 1997; Pojar and MacKinnon 1994; Rodway, Regehr, and Savard 1993; Klinka, Nuszdorfer, and Skoda 1979. For the M1 Ecosystem: interviews with Harding, Harper, Sloan, and Darling. Harding 1998; Watson 1998; Levings, Pringle, and Aitkens 1998a, 1998b; Zacharias et al. 1998; Zacharias, Howes, and Harper 1998; Taylor and Roff 1997; Brodeur et al. 1996; Mercier and Mondor 1995; Harper et al. 1993; Ray and Hayden 1993; Sherman 1993; J.R. Morgan 1987. For the M2 Ecosystem: Watson 1998; Huggett 1998; Taylor and Roff 1997; Ray 1996; Thurman 1990.

Lack of information on the range and distribution of humpbacks and octopuses complicates assigning them to specific marine biogeographic zones. Both species have fairly general but patchy distributions throughout the continental shelf, and are located in areas of prey abundance. Biogeographic delineation of marine ecosystems has evolved over the past decade and a half (Harding, interview; Harper, interview; Watson 1998; Levings, Pringle, and Aitkens 1998; Zacharias et al. 1998; Zacharias, Howes, and Harper 1998). Marine classification boundaries are based on physical and chemical parameters, which tend to change location over time. Boundaries are thus fluid and dynamic, and represent broad "bandwidths" (Harding, interview) rather than discrete lines. In addition, some researchers were concerned that the linkage between physical and biological processes is not well understood, and proposed to base classification on biological parameters such as species distributions (Ray 1996; Ray and Hayden 1993). In addition, present classification systems assume "that the water column is vertically homogeneous" (Watson 1998), which may ignore differences between pelagic and benthic environments. For deep-sea environments, ecological processes of the water column are relatively independent of benthic environments. On the continental shelf, sea bottom environments influence conditions up to the surface (Angel 1997). Despite these concerns, biogeographers suggested that the present classification systems are adequate to define areas adequately for management purposes (Levings, Pringle, and Aitkens 1998b).

Discussion

The classification of biogeographic zones is affected by the amount and quality of information. In terrestrial areas, zones are defined by relatively fixed terrain and vegetation features, whereas marine zones are defined by shifting features such as ocean currents. Marine classification systems also do not reflect ecological differences among different water depths, nor is the link between physical and biological factors well understood. The information base for terrestrial biogeographic classification is thus more clear and consistent than for marine systems. Equivocality is increased by the fuzziness, fluidity, and openness of ecosystem boundaries, variability of environmental driving factors, and the availability of information on past environmental conditions.

4.4 Ecosystem Biodiversity

The number and variety of species identified on taxon lists compared with the potential biodiversity or richness of the ecosystem.

Introduction

Biological diversity refers to "the variety of organisms at all levels, from genetic variants belonging to the same species, to species diversity and including the variety of ecosystems" (Mackenzie, Ball and Virdee 1998). It also recognizes the relative abundance of species, and the variety of associations and interactions among species within an ecosystem. Knowledge of the biodiversity of an ecosystem is one of the most important indicators of the amount of information available for an ecosystem. Each species is unique and responds to a different set of environmental variables. Various species may respond differently to limiting factors such as geological or oceanographic processes, temperature, soil or water chemistry, or interactions with other species. Information on the diversity and ranges of species thus provides a first level indicator of the ecology, basic biophysical properties and processes, and boundaries of an ecosystem (Ray and Hayden 1993).

Biodiversity assessments are essential for managing ecosystems and selecting protected areas (Ray and McCormick-Ray 1994). Procedures for documenting the biodiversity of ecosystems are well-established and standardized. Field reports are provided by species and ecosystem experts. The physical context, procedures for gathering information, and level of effort obviously differ between ecosystems.

Biodiversity is documented through lists of taxa prepared and certified by taxonomic authorities, such as the B.C. Conservation Data Centre and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Equivocality is lower where lists of taxa are based on relatively comprehensive sampling coverage of the ecosystem, with a low rate of new discoveries of species or taxa from ongoing field sampling. In this case, taxa lists are well developed and confirmed based on systematic field observation or other means. However, where taxa lists are not available, or have been developed unsystematically or opportunistically trough spotty or unreliable sampling, information will more likely be fragmentary and unclear. This would also indicate higher equivocality.

Analysis

This indicator compares the status of information on biological diversity between the terrestrial and marine environments. The comparison is summarized in table 4.5.

On a global scale, a larger number of animal species are believed to occur in terrestrial ecosystems. However, there is a greater diversity in marine ecosystems at higher taxa levels such as phyla, classes, and families (Harding, interview; Thorne-Miller 1999; Lambert 1994; Angel 1997). A phylum is a higher order category above a class in taxonomic hierarchies. All phyla include marine animal species, but only half include terrestrial species. Among animals, 90 percent of classes are marine (Thorne-Miller 1999; Lambert 1994; Earle 1995). Approximately 75 percent of all animals are insects, which are terrestrial. If these are excluded, 65 percent of all animal species are marine. On the other hand, some estimates of deep-sea invertebrates range from 200,000 to as high as 1 to 10 million, which would make marine invertebrates comparable to insects in their number of species (Williamson 1997). These estimates, however, are based on extremely small samples of a very few areas (Gray 1997). From a taxonomic perspective, it is thus not clear which environment is most biodiverse.

Ecologists have documented most of the plants and vertebrates in subalpine and old-growth forest ecosystems (Klinka, interview; Demarchi, interview). Subalpine environments have a lower than average biodiversity compared to other terrestrial ecosystems (Luttmerding 1976; Bryant 1997; Bennett 1976; Cannings and Cannings 1998; Klinka, interview). Old-growth forests appear to have a higher relative amount of biodiversity, and many species appear to be dependent on these habitats for survival (MacKinnon 1998), though actual numbers are difficult to determine. British Columbia ecologists use standardized protocols to conduct inventories and vegetation plot analyses to analyze habitats and identify species compositions of various ecosystems (Demarchi, interview; Klinka, interview; Province of British Columbia 1998; Bullock 1996; Luttmerding et al. 1990; Pojar, Klinka, and Meidinger 1987). This has created a sizable database on biodiversity. However, the lack of knowledge about invertebrate species, including insects, is a major gap in terrestrial biodiversity knowledge (Bryant, interview).

Estimates of the number of marine species are controversial. Grassle and Maciolek (1992) extrapolated from small samples to conclude that there could be 100 million deep-sea invertebrate species, but proposed that 10 million was probably more correct (May 1993). May (1992) disputed this, estimating that there were about 500,000 species. Poore and Wilson (1993)

Table 4.5 Comparison of Ecosystem Biodiversity

TERRESTRIAL CASES: T1 Subalpine Marmot and T2 Old-Growth Forest Murrelet Ecosystems

Ecosystem Biodiversity:

- Species diversity is higher in terrestrial than marine areas.
- Species richness of British Columbia is high compared to the rest of Canada.
- Old-growth forests are highly productive, providing microhabitats for many organisms. A large number of species are *associated* with old-growth forests; it is difficult to determine how many are *dependent* on these ecosystems.
- Resource managers have prepared detailed maps and collected extensive resource inventories for terrestrial areas.

Plant Information:

- Plant diversity is low in subalpine areas due to microclimatic conditions, with a few rare species.
- Plant diversity of subalpine and old growth ecosystems has been intensively documented through fieldwork, including extensive vegetation plot surveys.
- Forest cover inventories have been done for old-growth forest areas, and tree species and age ranges are known.
- Vascular plants have been identified in vegetation plot studies.
- Many vascular plants are associated, but few dependent, on old-growth forests.
- Nonvascular plants, such as epiphytes that are important to murrelets, are abundant and diverse; these plants have not been well studied.

Vertebrate Information:

- Subalpine and old-growth vertebrate species are largely known, although life histories of many species are not well known or studied.

Invertebrate Information:

- Insects, which comprise an estimated 75 percent of all fauna, are poorly known.
- Almost no studies of invertebrate biodiversity in British Columbia.
- Very little information is available on forest invertebrates. Recent studies of insect diversity in forest crowns suggest very high levels of insect diversity. Some forest invertebrates and microorganisms are known to play key roles in the functioning of old-growth ecosystem.

MARINE CASE: M1 Pelagic Humpback and M2 Benthic Octopus Ecosystems

Ecosystem Biodiversity:

- Knowledge of large-scale patterns of deep-sea biodiversity is restricted to a few major taxa and based on very limited sampling and geographic coverage. Less than 1 percent of the marine environment has been explored.
- Diversity of higher marine taxa (phyla, classes, families) is higher in the ocean than on land. Of 34 animal phyla, 29 occur in marine habitats, and of these 14 are exclusively marine. Only 12 phyla occur in pelagic environments.
- If the 75 percent of animals that are insects are excluded, 65 percent of all animals are marine. Some estimates place the number of marine invertebrate as high as those for insects.

Continued on next page

Table 4.5 – Marine ecosystem cases continued

- Over 98 percent of marine animal species are benthic, and almost all of these occur on the continental shelves.

- Pelagic taxa tend to be species poor compared to benthic or terrestrial taxa. The low number of species is due to the ephemeral hydrodynamic factors such as currents, tides, and sea-level fluctuations that spread and mix gene pools. Pelagic environments thus do not allow for isolation and retention of species that are necessary for speciation.
- Genetic studies suggest the existence of many sibling species that appear to be the same species but are not.
- Species richness of British Columbia waters compares closely to world species richness based on area.
- Many major new discoveries of species, sibling species, phyla, and other elements of genetic diversity are being made in field studies in British Columbia and elsewhere. Recent discoveries have also been made of new types of organisms, including the very important prochlorophyte. Many newly discovered species are new to science and remain undescribed.
- Unique habitats have recently been discovered that are associated with debris, vents, seeps, and whale carcasses.
- A new octopus species greater than 15 kg was recently discovered in British Columbia; equivalent discoveries never occur on land.
- Minimal information exists on lower trophic species such as very small plant species or invertebrates.
- No formal biodiversity assessments have been done for British Columbia waters; biodiversity has been surveyed in a few locations in British Columbia; some British Columbia regions are better known, but others have not been explored.
- Biologists have good information on animals within divable depths in diving areas.
- The best known species are commercial or are caught by fishers as bycatch; remaining species are often poorly known or documented.
- Mid-depth species are delicate, and difficult to sample. Many of even the largest of these species have not been documented because mid-depths have not been explored extensively.
- Some marine species have recently been considered extinct, based on examination of museum specimens and the lack of recent observations of these species in nature.
- Because information from deeper waters comes from trawls, researchers have better information on muddy than rocky bottoms that would hang up nets. Net samples may also be biased because smaller animals may be missed in larger mesh size nets, some animals may avoid nets, some animals are eaten in nets before retrieval, and soft-bodied animals may be crushed or destroyed by the nets.
- Causes of marine biodiversity are poorly understood and variations in diversity at different depths suggest that extensive sampling will be necessary to accurately assess bathymetric patterns.
- Factors that influence biodiversity are different than for terrestrial environments, and include factors such as darkness, aquatic milieu, lower gravity, dilute food sources, higher pressure, and thermal stability. Ecologists have minimal knowledge of how these factors affect species or community ecology.
- Knowledge of adult macrofauna is good, but major gaps exist in identifying larvae stages of many species. The life histories and early stage distributions of many species are very poorly known or unknown.
- Although presence and absence is known on a regional scale, the relative abundance or mix of species is poorly known. This mix has likely changed considerably by human actions such as fishing.

<u>Plant Information</u>:

- Nearly all of larger marine plants are benthic.

Continued on next page

Table 4.5 – Marine ecosystem cases continued

- British Columbia marine flora among the most diverse in the world.

- Larger plants and algae species in British Columbia are mostly identified.
- Plants are not as relevant for octopuses, which are carnivorous and occur largely below the photic zone.

Vertebrate Information:

- Pelagic and benthic fish species are primarily known from commercial fishing data, and commercial species are better known.
- Marine mammal species are relatively well known, although little is known about some offshore species.

Invertebrate Information:

- British Columbia waters are rich in marine invertebrate species.
- Marine invertebrate species in British Columbia are poorly known; research is at a pioneering stage; only a small percentage of species are known.
- Many species such as invertebrates have wide ranges, small sizes, and cryptic behaviors.
- Nine octopuses have been identified in B.C. waters; three species occupy shallow water as well as deeper water; some octopuses occupy very deep water.

POSTINTERVIEW QUESTIONNAIRE[1]

Q8. The information available for describing the number and variety of species or taxa occurring in the ecosystem:

- Amount: Rank from high to low is T2, M1, M2, T1
- Quality: Rank from high to low is M1, T2, M2, T1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data.

Sources: For terrestrial ecosystems: interviews with Demarchi, Klinka, Bryant, and Janz. R. McKelvey, Canadian Wildlife Service, personal comm. Cannings and Cannings 1998; Province of British Columbia 1998; Bryant 1997; Bullock 1996; Pielou 1993; Luttmerding et al. 1990; Pojar, Klinka, and Meidinger 1987; Nagorsen 1987; Martell and Milko, 1986; Milko 1984; Belsky and Del Moral 1982; Heard 1977; Luttmerding 1976; Bennett 1976. For T2 Ecosystem: Bahn 1998; MacKinnon 1998; Alaback and Pojar 1997; Whitney 1997; Rodway, Regehr, and Savard 1993; Klinka, Nuszdorfer, and Skoda 1979. For the marine ecosystems: interviews with Harding, Sloan, Tanasichuk, Hartwick, Cosgrove, Gillespie, Jamieson, Marliave, and Ellis. Thorne-Miller 1999; Gillespie, Parker, and Morrison 1998; Trippel 1998; Williamson 1997; Gray 1997; Angel 1997; Pierrot-Bults 1997; Rex, Etter, and Stuart 1997; Koslow, Williams, and Paxton 1997; Carney 1997, 1996; Broad 1997; Hunt 1996; Earle 1995, 1991; US National Research Council 1995; Lambert 1994; Hawkes 1994; Tunnicliffe 1993; Poore and Wilson 1993; May 1993, 1992; Carlton 1993; Grassle and Maciolek 1992; Raven et al. 1992; Stoecker 1992; Pomeroy 1992; Peterson 1992; Angel 1992; Colwell and Hill 1992; Carlton et al. 1991; Grassle 1991; Thurman 1990; Nesis 1987; Jamieson and Francis 1986; Sumich 1976.

estimated 5 million. Other researchers have debated Grassle and Maciolek's methodologies, arguing that their extrapolation factors were too high (Koslow, Williams, and Paxton 1997). Carney (1997) suggested that "while proponents of various explanations for high [deep-sea] biological diversity can argue the merits of their ideas, proof for any particular hypothesis is lacking and supporting evidence is equivocal."

No formal biodiversity assessments have been done for British Columbia waters (Tunnicliffe

1993). Only a small percentage of marine species are known (Tunnicliffe 1993; Tanasichuk, interview). Pelagic species, which occupy the water column, are generally known from being caught in the nets of fishers and researchers (Jamieson, interview). The commercial species are known best.

Of the world's marine animal species, over 98 percent are benthic and most of these are invertebrates (Thurman 1990). Knowledge concerning these species is "still at the pioneering stage in BC" (Tunnicliffe 1993). Most of the research was done in previous decades, and "not much collection is happening today" (Jamieson, interview). Knowledge is better in divable depths less than 20 meters, but information for deeper waters is poor (Tunnicliffe, 1993; Harper, interview). Sloan (interview) suggested that biodiversity research for marine areas of British Columbia is "just beginning" and it is "likely to be in process for some decades yet."

The species mix of marine species is "quite different" in various areas (Jamieson, interview). Jamieson (interview) suggested that "we've got a rough idea what's there now but we don't know what the pristine condition would be like necessarily." He argued that the important variable is not species presence or absence, but the relative abundance.

Marliave (interview) indicated that while "we have I think excellent knowledge of the macrofaunal biodiversity but . . . we have very poor knowledge of early life history stages." He suggested that, when he began his career, over half of the species could not be identified in the larval stage and new species are still being discovered today.

Carlton (1993) and Carlton et al. (1991) argued that the common perception that marine species have not become extinct is fallacious. He documented four cases of marine snails that have disappeared and are probably extinct, and suggested that "hundreds of taxa" have not been reported since the eighteenth or nineteenth centuries, and may be extinct. This argues for the notion that many marine species may be endangered, but their peril is unknown to science because of the great difficulty of conducting marine research and the paucity of marine taxonomists.

There are nine octopus species in British Columbia waters. Scientists have some information on *Octopus dofleini*, the giant Pacific octopus, and *O. rubescens*, the red octopus. The remaining octopuses mostly occupy very deep waters. Hunt (1996) stated that few people have seen the deepwater octopuses alive, and "little is known about their eating habits and reproduction." The *O. dofleini* is thus the best-known example of octopuses in British Columbia, especially because of its abundance and part time shallow water occurrence.

Discussion

The question of whether biodiversity is higher on land or water is a good illustration of equivocality. If one assumes that species biodiversity is most important and the criterion is number of species, terrestrial environments exhibit the highest diversity. However, information on species biodiversity is unclear in both marine and terrestrial environments, though more unclear for benthic marine areas. Furthermore, biodiversity also varies within each type of environment, so that the benthic environment would have more species than the subalpine ecosystems. If one assumes that higher taxonomic biodiversity is important, marine higher taxa are more numerous than terrestrial ones. From a protected areas perspective, differences in the definition of biodiversity have equivocal implications for management. Ecosystem managers must decide what type of biodiversity to protect and how to protect it. Much of existing legislation and policy address the species level, but species are solely one element of biodiversity. This indicator contributes to equivocality due to the fuzziness and lack of consistent opinion on categories such as species and ecosystem, and the lack of more comprehensive biodiversity inventories.

4.5 Key Species Roles

> The quality of the information used for identifying the roles of key species for the ecosystem, such as primary producers, prey and predator species, keystone species, and indicator species.

Introduction

According to Ray and Hayden (1993), "a fundamental variable in a species' environment is other species within a higher level of organization called a community." Each species has a unique role with respect to other species. All species are part of food webs (Paine 1988). For example, primary producers fuel trophic systems, consisting of complex webs of prey and predators. Species referred to as *dominant species* are the most abundant species in an ecosystem and typically dominate energy flows or provide physical support and habitat for others (Power et al. 1996). *Keystone species*, despite lesser abundance, strongly influence ecological communities and ecosystem functions (Power et al. 1996; Mills, Soule, and Doak 1993). *Umbrella* or *indicator* species are species chosen by scientists as for targets for the health and status of the ecosystem. For research manageability, this research focuses on predators and prey of the case species as representatives of key species.

Role definitions are 'theories' about the functioning of ecosystems. These theories may be either well elaborated, or poorly developed. They may be well-tested, or very speculative. The validity of these theories depends on the quality of information used to model ecosystems and test hypotheses. Low equivocality information allows ecologists to reach consensus on the roles of key species in the ecosystem. Information thus provides a reasonable basis for identifying and describing these species, such as a well-researched trophic map or a list of reliable indicator species. Quality also relates to the depth of information, such as the existence of data on the abundance, range, distribution, population dynamics, and status of the key species. Equivocality is higher where the scientific community has insufficient information to evaluate the roles of key species, or has competing or no opinions concerning role definitions.

Analysis of Prey Species

This indicator compares information quality related to food webs through an examination of the forage species and predators that affect the target species. Predator-prey relationships are an important systems component of ecosystems. Table 4.6 provides a comparison of the cases for this indicator.

Marmots forage on a few well-defined plant species, with some seasonal variations. The suitability of forage species may be an important factor in habitat suitability.

Murrelets feed at sea, thus their foraging is not a terrestrial event for this terrestrial case. They feed on small fish.

Humpbacks are generalists in their diets (Darling, interview; Hay 1982) and feed opportunistically on the most available prey species (Darling, interview). A favorite food item is krill, also known as euphausiids, which are small crustaceans that are a food source for many species. The ecology of euphausiids is “poorly understood” (Bryant et al. 1981), including how oceans affect euphausiid productivity, and how that productivity affects fish abundance (Tanasichuk, interview). Humpbacks are also known to feed on herring and other small schooling fish (Darling, interview; Tanasichuk, interview; Ford et al. 1994). Marine food webs are dynamic. Biologists described the cycles of the Pacific sardine or “pilchard” as an example of shifts in food webs (Sloan, interview; Tanasichuk, interview; Ellis, interview). The pilchards disappeared in the 1930s, presumably because of overfishing, but have recently returned unexpectedly to British Columbia waters. There are no explanations for why they declined or why they have returned. Jamieson (interview) provided a further example of a hake fishery that was expected to result in an increase in euphausiid abundance, but rather led to a dogfish population increase.

Table 4.6 Comparison of Key Species Roles

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Foraging:

- Marmots are herbivores and feed on a few species of grasses and forbs.
- No apparent competitors for meadow food supplies.

Predation:

- Cougars, wolves, and raptors prey on marmots. Predation by eagles has been observed directly; cougars have been observed stalking marmot colonies.
- Although detailed information on predation frequency is not available, predators are a major factor in marmot survival.
- Marmot hair and implanted transmitters have been discovered in predator scat.
- Marmots are secondary prey species for their predators. Their predators feed primarily other more common species, such as deer.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Foraging:

- Murrelets depend on marine systems for food, thus foraging is not a terrestrial factor for this species.

Murrelet diet appears to vary with season, location, and prey availability. Murrelets feed on sandlance and herring, as well as other schooling fish. Their ability to substitute among prey species is unknown. Information on winter diets is poor, but they appear to focus on marine invertebrates as well as small schooling fish. Other bird and mammal species also prey on sandlance and herring, which are staple species.

Predation:

- Most murrelet nests are predated, principally by jays, crows, and ravens, and owls, falcons, northern goshawks, and possibly some rodents. Predation is rarely observed, though evidence of predation is commonly seen. Predation at sea is probably not extensive.
- Much of murrelet behavior is a response to predation risks. Murrelets flush easily when disturbed or predators appear. They exhibit camouflage coloring, and cryptic behavior in traveling to their nests.

MARINE CASE: M1 Pelagic Humpback Ecosystem

Foraging:

- Humpbacks are generalist feeders. They consume euphausiids (krill), herring, and other small fish. Little is known about how humpbacks locate their food, except that they find food quickly.
- Euphausiids are a key food species for fish that humpbacks eat, such as herring and other species.
- Structures of marine food webs are poorly known. Simplistically, phytoplankton are consumed by zooplankton which are consumed by euphausiids and small fish. Euphausiids, herring, and other humpback prey species are consumed by other fish, whales, and seabirds including marbled murrelets.
- Although euphausiids are a primary link between lower and upper trophic levels, little is known about the fish species that feed on euphausiids.

Continued on next page

Table 4.6 --*Continued*

- Ecology, population dynamics, distribution, driving factors, life histories, and roles of prey species, such as euphausiids, are complex and poorly known. Little is known about plankton distributions and variability in distributions. Minimal work has been done on how physical factors affect euphausiids.

- The structure of marine pelagic food webs are poorly understood, with various species fulfilling different niches in webs at different life stages.

Predation:

- Killer whales and some large sharks may prey on calves or infirm whales. Killer whale attacks observed elsewhere in the world. Sharks have been observed attacking other whale species.
- No information exists concerning possible predation events at sea, and detailed information on predation frequency is not available.

MARINE CASE: M2 Benthic Octopus Ecosystem

Foraging:

- Adult octopuses consume crabs, bivalves, gastropods, and small fish. Larvae feed on small food particles and very small animals; small octopuses grow very rapidly.
- Octopuses are opportunistic and varied in their prey selection. Octopuses may specialize so that diet varies from place to place. However, studies of prey selection have been limited and nonsystematic.
- The main source of information on diets is based on analysis of the midden heaps octopuses leave outside their dens. Midden heaps do not include soft-bodied prey which are consumed completely. Some prey is consumed away from dens and is not recorded in midden heaps. Analysis of stomach contents is not feasible because food in stomachs is not recognizable.
- A considerable amount of research has been done on crab species in certain areas of the British Columbia coast. Crabs are a major food source.
- Octopuses are effective predators and cannibals, and could exert a controlling effect on food webs, especially in their superabundance events.

Predation:

- Adult octopuses, depending on their size, are consumed by lingcod, halibut, seals, sea lions, sea otters, dogfish, and flatfish. Octopuses are also strongly cannibalistic. Octopuses have frequently been observed without one or more tentacles.
- Biologists do not know what feeds on small octopuses, but infer from their locations. Hatchlings are consumed by rockfish as they leave their natal dens. Larvae become part of surface planktonic; most are probably eaten by plankton feeders. Juveniles settle to the bottom where they may be eaten by small and medium sized fish.
- Octopuses have several defenses against predators, including changing skin color and texture, jetting away, leaving ink blobs, and retreating into their dens.
- Octopuses are probably not the primary prey of any species.

POSTINTERVIEW QUESTIONNAIRE[1]

Q9. The information available for identifying the roles of key species for the ecosystem:

- Amount: Rank from high to low is T1 and M2 tied, M1, T2
- Quality: Rank from high to low is M2, T1, T2, M1

Continued on next page

Table 4.6 --*Continued*

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Bryant, Demarchi, and Janz. COSEWIC 1998; Bryant 1997, 1996; Demarchi et al. 1996; Arnold 1990b; Martell and Milko 1986; Milko 1984; Heard 1977. For T2 Ecosystem: interviews with Kaiser, Manley, Chatwin, and Tanasichuk. Bahn 1998; Levings, Pringle, and Aitkens 1998b, US Fish and Wildlife Service 1996; Spies 1994; Rodway, Regehr, and Savard 1993; Mahon, Kaiser, and Burger 1992; Rodway 1990; Sealey 1975. For M1 Ecosystem: interviews with Tanasichuk, Sloan, Ellis, Darling, Harper, and Harding. Fred Sharpe, Simon Fraser University, personal communication. Pitman and Chivers 1999; Tanasichuk 1998a and 1998b; Pacific Whale Foundation 1998; Butman, Carlton, and Palumbi 1996, 1995; Jelmert and Oppen-Berntsen 1995; Ford et al. 1994; Tunnicliffe 1993; Smith 1992; Angel 1992; Whitehead 1987; Whitehead and Glass 1985; Winn and Winn 1985; Hay 1982; Beddington and May 1982; Bryant et al. 1981. For M2 Ecosystem: interviews with Cosgrove, Hartwick, Jamieson, Marliave, and Gillespie. Gillespie, Parker, and Morrison 1998; Sheldon 1998; Jamieson and Francis 1986; Petro-Canada Inc. 1983; Snively 1978; Ricketts and Calvin 1968.

The octopus is a high level, opportunistic predator that feeds on the most abundant suitable prey type in its home range (Cosgrove, interview; Gillespie, interview; Gillespie, Parker, and Morrison 1998; Jamieson and Francis 1986). Little is known about the prey selection of the octopus, which varies among individuals even in nearby areas (Gillespie, Parker, and Morrison 1998). Crabs are a primary food item, as well as a variety of gastropods and bivalves, including their own species (Hartwick, interview; Gillespie, Parker, and Morrison 1998; Jamieson and Francis 1986).

All of the target species are at least somewhat generalist in their feeding habits. The forage species are generally known. The difference among the cases is the level of knowledge concerning the ecology of the forage species. Subalpine meadow plants are well understood. The ecology of the marine forage species is not well understood.

Analysis of Predator Species

Predation is a major issue for marmots, murrelets, and octopuses. For these cases, there are three types of evidence (Bryant, interview; Janz, interview; Bryant 1996, 1997; Manley, interview; Kaiser, interview; Chatwin, interview; Bahn 1998; Rodway, Regehr, and Savard 1993; Rodway 1990; Hartwick, interview; Gillespie, interview; Cosgrove, interview; Jamieson and Francis 1986). Anecdotal evidence includes observation of predation events or stalking of the species by predators. Biologists have observed attacks of predators on marmots, murrelets, and octopuses. Circumstantial evidence includes marmot fur in predator scat, broken murrelet eggs, or octopuses with missing tentacles. Finally, there is suppositional evidence, such as the presumption that animals are vulnerable to predation and are disappearing, and the local dominant predators must be responsible. Direct evidence linking predators to specific predation events is often extremely limited (Bryant, interview; Kaiser, interview).

The large humpbacks are not immune to predation. There is sketchy anecdotal evidence that killer whales (Pitman and Chivers 1999) and large sharks may prey on vulnerable individuals. Calves of some whale species experience high mortality at sea, and the causes are not always known (Ellis, interview; Whitehead 1987; Winn and Winn 1985; Hay 1982).

For marmots, murrelets, and octopuses, cryptic behaviors and habitat choices are governed in part by avoidance of predators. In all cases, predation is rarely observed and is inferred from anecdotal, circumstantial, and presumed evidence. For humpbacks, predation is possibly not extensive, but evidence is sketchy.

Discussion

The diets of all four species are reasonably well known. The difference for equivocality among the species relates to ecosystem factors that affect the availability of food through their food webs. Marmot diets depend on a delicate balance of moisture and growing season. Whale diets depend on availability of small prey, which is determined by oceanographic conditions. In some cases, subpopulations of species such as murrelet diets may vary between different areas. In other cases, such as the humpback and octopus, diets may be largely opportunistic.

Predation is a somewhat equivocal issue for all of the species. Observations of predation events have occurred for the marmot, murrelet, and octopus, but predation is an elusive event that is difficult to sample meaningfully without extensive studies. Information tends to be anecdotal and circumstantial.

4.6 Ecosystem Driving Factors

> The quality of information for the identification of major driving factors that affect the abundance, distribution, and status of key species in the ecosystem.

Introduction

Identification of key driving factors is essential for ecosystem management, and especially for protected areas planning (Ray and McCormick-Ray 1994). Driving factors are the biotic or abiotic factors that influence the patterns of abundance, distribution, and status of key species in the ecosystem. For example, moisture influences the production of plant life on land, which in turn affects trophic systems. Marine life is affected by the pattern of currents that affect productivity, such as upwelling areas. Species status reports normally identify key driving factors for the species, such as certain types of prey or habitat characteristics. Ecosystem studies also normally identify major influences on ecosystem operation and health.

Equivocality is resolved where key driving factors have been identified, described, and modeled, with models tested through scientific study of causal linkages. Equivocality is higher where either that driving factors have not been identified or that models of driving factors have not been adequately scrutinized through scientific field studies. In such cases, conclusions about natural trends may be unclear or contradictory.

Analysis

This indicator compares ecosystems based on the amount and quality of information available on the driving factors that influence the ecosystem and target species. The comparison is summarized in table 4.7.

The physical and environmental factors that create the subalpine marmot meadows have been identified and agreed upon (Klinka, interview; Demarchi, interview; Bryant, interview; Janz, interview). It is not as clear how these factors interact to maintain marmot meadows. The marmot meadows are a "rare" and "abnormal" habitat (Demarchi, interview). It is maintained by a complex interaction of factors that affect the duration of winter conditions, snowpack dynamics, moisture, and growing season (Demarchi, interview; Klinka, interview; Bryant, interview; Janz, interview; Cannings and Cannings 1998; Bennett 1976; Luttmerding 1976). The factors that create the meadows are delicately balanced and vulnerable to change.

The coastal temperate rainforest habitats of the nesting murrelets are somewhat more robust and stable than the subalpine habitats. They were created by the interplay of rugged topography and strong marine climatic influences that create cool and moist conditions, frequent clouds and fog, heavy and persistent precipitation, and moderate temperatures and snow fall. Although affected by cyclical changes to climatic regimes, the old-growth forests are persistent, except when affected by humans.

The pelagic continental shelf ecosystem is dominated by atmospheric systems, ocean currents, and coastal topography. These systems are relatively complex in detail, although general patterns tend to persist. For example, upwelling events differ in strength and timing, but occur frequently. Overlaid on an environment of highly variable short term cycles and oscillations such as the El Niño events, there are major regime shifts that have considerably altered the physical, chemical, and biological environment (Salmon 1997; Harding, interview). The North Pacific is "one of the

Table 4.7 Comparison of Ecosystem Driving Factors

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Physical Geographic Factors:

- Important factors are elevation, sun aspect, rocky terrain, and suitable terrain for burrows.
- Excellent information exists on topography and geology. There is a lack of information on subterranean conditions.

Environmental Factors:

- Important environmental factors are:

  –Duration of winter conditions.

  –Dynamics of snowpacks, such as onset and persistence of snow, accumulation and melting, insulation provided for burrows.

  –Winter cold temperature levels.

  –Summer heat effects on snow melting, growing season, and marmot thermoregulation.

  –Effects of microclimate and moisture regimes on vegetation growth and marmot food forage species abundance.

Environmental Information:

- Weather stations monitor regional trends. Long-term data sets provide information on trends.
- Snowpack levels are monitored in British Columbia to forecast stream flows.
- Limited monitoring information exists for the specific mountain areas where marmot colonies occur.
- Limited understanding is available for the effects of climate change on marmot meadows.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Physical Geographic Factors:

- The most important physical factor is a location in dense forested mountains at an appropriate distance from the coast.
- Topography affects climate, including rains and temperature. Topography causes considerable diversity in local environments.
- Excellent information exists on topography and geology.

Environmental Factors:

- Important environmental factors:

  –The most important environmental factor is abundant rain. Marine weather systems coupled with mountainous topography bring heavy rains and damp climate, creating one of the wettest climates of the world.

  –Marine climates moderate temperatures, with cooler summers and more temperate winters than interior areas.

  –Pacific systems bring strong storms and winds, which cause forest disturbances.

- El Niño and La Niña phenomena cause short term changes in climate that may affect prey abundance; nesting habitat more stable, though differences in precipitation can be considerable

Continued on next page

Table 4.7 – continued

- On longer time scales, temperate rain forest conditions have persisted for centuries.

Environmental Information:

- Weather stations monitor regional trends. Long term data sets provide information on trends.
- Effects of long term climate conditions can be observed in biogeoclimatic zones. Paleoecological studies can identify past climatic trends and associated ecology

MARINE CASE: M1 Pelagic Humpback Ecosystem

Physical Geographic Factors:

- The important factor is the interaction of marine systems and coastal and continental topography.

Environmental Factors:

- Important environmental factors:

–The influence of North Pacific / Aleutian low pressure atmospheric systems and interactions with the topography of the North American continent. These factors create a very active and complex meteorological region with a procession of storms, and affect winds, currents, gyres, eddies, upwellings, precipitation, and other physical processes.

–Short and long term cycles, El Niño, La Niña, and regime shifts.

–Oceanographic processes and conditions such as temperature, water chemistry, salinity, nutrients, and sunlight that affect primary productivity.

Environmental Information:

- A very limited "measurement grid" exists for physical oceanography, based on satellites and a few stations. Only very general information exists on oceanographic patterns, such as currents, inshore circulation, effects of freshwater runoff. Sufficient information is available to begin modeling of oceanic systems.
- Causes of variability in oceanographic processes are unclear. Timing and intensities of upwellings are subject to tremendous annual variations. Climatic and oceanographic predictions are complicated by short and long term cycles, El Niño, La Niña, and regime shifts.
- Limited data are available on the patterns of climatic and oceanographic factors that affect primary productivity and drive the marine food web.

MARINE CASE: M2 Benthic Octopus Ecosystem

Physical Geographic Factors:

- An important factor is the configuration of seabed from intertidal zone to at least 300 meters. British Columbia seabed extremely complex and varied, and shaped by many processes; topography creates complex ocean dynamics.
- Octopuses require bottom conditions that provide lairs. Seabed topography and substrate known in only a general or regional way, with details limited to detailed surveys of a few areas only. Surficial sediments are locally very patchy.

Continued on next page

Table 4.7 – continued

- Sediment transport caused by mass wasting (slides) and currents; sediment texture determined by size and gravity sorting. Most sediments are relic ice age glacial deposits.

  –Deep sea temperatures tend to be cooler and less changing.

  –Deeper water continental shelf environments may be more complex where bathymetric and estuarine factors cause mixing of flows.

Environmental Factors:

- Important environmental factors:

  –Ecologists have minimal understanding of how environmental processes relate to species ecology for many benthic species.

  –Octopuses appear to be sensitive to temperature and salinity changes

Environmental Information: See Pelagic Humpback case

- Information on deep-sea conditions not monitored.

POSTINTERVIEW QUESTIONNAIRE[1]

Q10. The causal information available for identifying major environmental driving factors affecting the abundance of key species:

- Amount: Rank from high to low is M1, T1, T2, M2

- Quality: Rank from high to low is T1 and M1 and M2 all tied, T2

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Klinka, Demarchi, Bryant, and Janz. Cannings and Cannings 1998; Bryant 1997, 1996; Demarchi et al. 1996; Bryant and Janz 1996; Allainé et al. 1994; Arnold 1990b; Barash 1989; Nagorsen 1987; Milko 1984; Miller 1980; Anderson, Hoffmann, and Armitage 1979; Luttmerding 1976; Ryder 1976; Bennett 1976. For T2 Ecosystem: Bahn 1998; Montgomery 1997; Whitney 1997; Redmond and Taylor 1997. For the M1 Ecosystem: interviews with Harper, Tanasichuk, Sloan, and Harding. Salmon 1997; Mann and Lazier 1996; Harper 1995; J.R. Morgan 1993; Holliday 1993; Bottom et al. 1993; Thompson 1989; Petro-Canada Inc. 1983; Chevron Canada Resources Limited 1982. For the M2 Ecosystem: interviews with Gillespie, Hartwick, Cosgrove, Marliave, and Jamieson. Rex, Etter, and Stuart 1997; Gage 1997; Carney 1996; Ray 1996; Thurman 1990; LeBlond 1983; Petro-Canada Inc. 1983; Chevron Canada Resources Limited 1982; Sumich 1976.

most active meteorological regions on earth” (Salmon 1997). The ocean dynamics are “as diverse and fascinating as any oceanographic region on the globe” (Thompson 1989). Information on these oceanographic processes is limited due to a very limited “measurement grid” (Harper, interview), which provides only a very general picture of oceanographic patterns at a regional scale (Harper, interview; Harding, interview; Harper 1995; Thompson 1989). According to Harper (interview), “we know that there is variability in there but I don’t think we could say that we have captured or totally understand the causes of variability.” Bottom et al. (1993) stated that “extreme fluctuations in the physical environment and the lack of systematic inventory data limit understanding of the causes of natural variability" for the southern portions of the Gulf of Alaska Large Marine Ecosystem.

The benthic octopus ecosystem is influenced by the configuration and surficial materials of the seabed. Seabed characteristics are not well known. Mapping of bottom conditions has been done in a very general scale, but only a very few areas are mapped in detail (Harper, interview). Although the octopuses share the highly variable marine environment of the humpback, there is no direct evidence of the influences of oceanographic processes on octopuses (Gillespie, interview). Deep-water currents and tidal flows do occur (Jamieson, interview; LeBlond 1983). Octopuses are sensitive to temperature and salinity differences (Hartwick, interview; Cosgrove, interview), but they can change their distributions to occupy habitats that are more suitable if conditions become less favorable (Cosgrove, interview). Deepwater environments tend to be cooler and more thermally stable than surface areas (Rex, Etter, and Stuart 1997; Gage 1997; Harbison 1992), though environmental change may be higher in some complex oceanographic environments such as estuaries or lower in fjords with sills that block subsurface flow (LeBlond 1983; Harrison et al. 1983).

Discussion

Natural driving factors considerably influence all four species. The old growth ecosystem is reasonably stable and persistent, while the marmot meadows are delicately balanced and highly vulnerable to year-to-year stresses. Marine oceanographic processes are extremely dynamic and difficult to predict, and have major influences on marine ecosystems. Both the humpback and octopus can change distributions to habitats that are more suitable if conditions become unfavorable. Because protected areas are fixed in location, this creates difficulties for protected area site selection. Equivocality for this indicator is influenced by natural variability in driving factors as well as limited resolution of data sets. In general, marine variability is higher and marine data sets are sparser than for terrestrial systems.

4.7 Ecosystem Threats

> The identification of key threats that affect the operation of the driving factors that affect abundance, distribution, and status of key species in the ecosystem.

Introduction

The major purpose of a protected area is to guard against some form of threat. Threat analysis is thus an important form of causal analysis. Key human threats to species include factors such as habitat alteration, overharvesting, pollution, competition for food, climate change, alien species introduction, human harassment, or other disturbances. Humans cause interruptions or dislocation of vital environmental processes such as microclimates or current flows, changes to landscape or vegetation, losses of species, changes to community structure, and pollution.

Equivocality is resolved where ecologists are able to identify major threats to species and ecosystems. Equivocality is higher where ecological knowledge and data are not adequately available for ecologists to identify major threats to species or ecosystems.

Analysis

This indicator compares information available for each ecosystem on the types of threats that might affect natural ecosystem factors that influence the case ecosystems and species. The comparison is summarized in table 4.8.

The principal human threat to the subalpine marmot ecosystem is alteration of the landscape. Past clearcuts have disrupted the landscape through which marmots disperse from colony to colony thus undermining the metapopulation dynamics of this species. Clearcut areas also mimic marmot colonies, but are not sustainable as habitat and divert marmots from their natural habitats. Marmots are thus distracted to habitats that do not persist and which may expose them to higher predation (Byrant, interview; Janz, interview; Demarchi, interview). Climate change could also imperil marmot meadows by advancing the rate of forest succession (Klinka, interview; Demarchi, interview).

For the old-growth murrelet ecosystems, the principal threat is again habitat alteration caused by logging. Murrelets require very dense, unfragmented coastal temperate old-growth rainforests for nesting. Ongoing logging of these forests is a very clear and serious threat to murrelet survival (Kaiser, interview; Manley, interview; Chatwin, interview; Bahn, 1998; Morrison 1994; Rodway 1990). On the marine side, gill-net and other fisheries catch murrelets, and coastal developments threaten murrelet habitats (Kaiser, interview; Chatwin, interview; Bahn 1998; Rodway 1990).

The most serious potential threat to both the M1 and M2 marine ecosystems is depletion of the food web. Marine species face threats to their food supplies such as euphausiids, herring, sandlance, and other small prey (Darling, interview; Tanasichuk, interview; Sloan, interview; Thorne-Miller 1997; Harper 1995; Reimchen 1995; Whitehead 1987; Winn and Winn 1985). These prey species also partly support the murrelets, humpbacks, and octopuses. The depletion of the food web can result from overfishing. Another potential cause, still being investigated, is the

Table 4.8 Comparison of Ecosystem Threats

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Hunting:

- Marmots are not hunted, although they were a food species of aboriginal people in the past.

Food Threats:

- Marmots eat local grasses and forbs that are not being taken by humans.

Habitat Alteration:

- There is uncertainty concerning appropriateness of clearcut habitats as colony sites. Marmots colonize clearcut habitats that may be an unsuitable 'sink' for marmots because of diversion of marmots from their natural habitats. Clearcuts occur at a lower elevation and have different microclimates. They provide food species that may not be suitable, and cover for predators. As forests grow back, the meadow habitats disappear.
- Logging disrupts the landscape matrix through which marmots disperse to replenish depleted colonies, thus complicating the metapopulation dynamics of the marmots.
- Logging roads concentrate predators and marmots on the same pathways.
- Most timber in area has been logged, but high elevation logging may be possible.

Human Disturbance:

- The remote, rough terrain of marmot colonies discourages human disturbance.
- In rare incidences, vandals have shot marmots.

Climate Change:

- Climate change could influence marmot meadow succession and encourage tree invasion, although there is uncertainty whether trees are encroaching on marmot meadows. No higher elevations are available for marmots to retreat to if climate changes.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Hunting:

- Murrelets are not hunted.

Food Threats:

- Murrelets feed on fish that may be fished by humans, such as herring. Aquaria obtain sandlance for feed, but this is not yet extensive.

Habitat Alteration:

- Murrelets are strongly dependent on old growth forests, and the loss of these forests is the greatest threat to murrelets. Old-growth forests have high commercial value, and these forests are being logged systematically. Most of the remaining forests are scheduled to be logged in the next decade.
- Improved forest management could reduce effects of logging by leaving appropriate patches and avoiding clearcuts.
- Foreshore developments and activities degrade marine habitats.

Continued on next page

Table 4.8 –*Continued*

Human Disturbance:

- The remote, rough terrain of nesting areas discourages human disturbances in terrestrial habitats.
- A large number of murrelets are caught in gill-nets. Poor fishing practices create unnecessary mortality.
- Murrelets are disturbed by powerboats, sport fishing, troll-fishing, and other marine activities.
- Oil spills present a very serious risk to murrelets, which could decimate whole subpopulations.

Climate Change:

- Climate change could produce large-scale, wide-ranging changes in forest biomes. Tree growth would be reduced because of reduced precipitation. Forest biomes would eventually migrate to new locations and higher elevations. Climate change could create a more open forest structure. Fire disturbance frequency, which is presently very rare, could be increased.
- Climate change could alter marine systems and rearrange food webs.

MARINE CASE: M1 Pelagic Humpback Ecosystem

Hunting:

- Whaling was the most serious threat to whales. Resumption of aboriginal whaling is possible.

Food Threats:

- A reduction of food supply from fishing activities is perhaps the most serious threat to whales today. Fishing takes large volumes of potential whale food.

Habitat Alteration:

- The major alteration of marine habitats in general appears to be from pollution. Effects of pollution have not been identified as a current issue for humpback whales.

Human Disturbance:

- Humpbacks have become entangled in fishing nets on the east coast. Entanglement has not been considered an important risk in British Columbia.
- Evidence is equivocal concerning whether whale watching affects humpbacks.
- Evidence is equivocal concerning whether vessel traffic, hydrocarbon operations, and pollution currently have effects on humpbacks. Right whales and other species have been affected by collisions from ships.

Climate Change:

- Uncertainty exists concerning the effects of increased Ultraviolet B (UVB) radiation on marine productivity. However, UVB radiation could seriously deplete phytoplankton and hence primary productivity, with drastic effects down the food chain.
- The potential effects of global warming on humpbacks are not known. Oceanographic patterns might change and relocate currents, gyres, and upwelling processes, and alter ecosystem dynamics. This could have effects on the abundance or distributions of many species, such as introducing new predators into vulnerable ecosystems.

Continued on next page

Table 4.8 –*Continued*

MARINE CASE: M2 Benthic Octopus Ecosystem

Hunting:

- Octopuses are harvested, but in very small numbers compared to stocks. Local overharvesting would be possible, but this has not been observed.
- Overharvesting in marine systems has often occurred unnoticed until only a small portion of the population remains. Anecdotal evidence of fewer monster octopuses suggests that harvesting pressure could have affected population structures.
- Overharvesting of marine species could lead to irreversible succession in food webs, which may be more common than extinction in oceans.

Food Threats:

- Octopuses compete with fishers for crabs, but octopuses appear to have sufficient food supplies.

Habitat Alteration:

- Continental shelf areas are generally pristine.

Human Disturbance:

- The remote, deepwater terrain is very extensive and is only visited very locally and occasionally by divers.

Climate Change:

- Climate change could cause octopuses to move into deeper, cooler waters and perhaps to cooler latitudes. Deeper waters tend to be more stable thermally.

POSTINTERVIEW QUESTIONNAIRE[1]

Q11. The causal information available for identifying key human threats affecting the abundance of key species:

- Amount: Rank from high to low is T2, T1 and M2 (tied), M1
- Quality: Rank from high to low is T2, M2, T1, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data.

Sources: For T1 Ecosystem: interviews with Bryant, Klinka, Demarchi, and Janz. Bryant 1997, 1996; Nagorsen et al. 1996; Peters and Darling 1985; Dearden 1986; Dearden and Hall 1983; Franklin et al. 1971. For T2 Ecosystem: interviews with Manley, Kaiser, Chatwin, Tanasichuk, and Niziolomski. Bahn 1998; Hebda 1996; Morrison 1994; Pojar and MacKinnon 1994; Rodway 1990. For the M1 Ecosystem: interviews with Tanasichuk, Darling, Sloan, and Ellis. Thorne-Miller 1999; Harper 1995; Reimchen 1995; Omori, Norman, and Yamakawa 1992; Whitehead 1987; Winn and Winn 1985; Hay 1982. For the M2 Ecosystem: interviews with Cosgrove and Gillespie. Gillespie, Parker, and Morrison 1998; Jamieson and Francis 1986; Ricketts and Calvin 1968

depletion of atmospheric ozone, which results in higher ultraviolet radiation that can be toxic to phytoplankton, the base of the marine food web (Tanasichuk, interview; Thorne-Miller 1999; Bothwell, Sherbot, and Pollock 1994). Because little is known about the dynamics of marine food webs (indicators 5 and 6), these threats cannot be evaluated. Another potential threat to humpback whales is the very real potential for resumption of whaling (Darling, interview; Ellis, interview).

Discussion

The principal threat to case terrestrial ecosystems is the alteration of habitat, while depletion of food sources is the principal threat to the marine case ecosystems. Human-induced habitat alteration is predictable in the sense that forest harvesting is observable and regulated. The link between loss of habitat and loss of species is clear and unequivocal.

Depletion of marine food webs, however, is very difficult to assess. Overfishing has provided evidence that marine ecosystems restructure when one species is depleted, so that other species move in to fill the roles of the depleted species. However, it is not clear which species will be favored by this restructuring. Thus information on the principal threats to marine ecosystems is equivocal.

4.8 Access Constraints

> The constraints imposed by the natural environment on the physical access of researchers to that environment for conducting field research work.

Introduction

The ability to visit and conduct field research within an ecosystem is a prerequisite for ecological research. This research requires taking samples and making observations in order to describe the ecological components and their interactions. Decision makers tend to use information that is more accessible, so that inaccessibility results in less information gathering (Culnan 1983).

Natural environments differ in the extent to which they are accessible. A researcher can visit a prairie or old-field habitat easily using no technology except perhaps a car to get to the research site. On the other extreme, the deepest point in the oceans has been visited only once for a few minutes using technology that is extremely sophisticated and expensive. Humans have spent more time on the surface of the moon than on the deepest bottom of the ocean.

Equivocality is resolved where an environment is easily accessible by individuals operating alone with no special technology. Equivocality is higher where an environment is either not accessible in any practical sense, or accessible only at great effort and cost.

Analysis

This indicator compares the constraints posed by the natural environments on the ability to visit and inspect the case ecosystem in the field. The comparison is summarized in table 4.9.

Logistics are “the major deterrent” to marmot and subalpine research. Marmot meadows are “relatively inaccessible” (Janz, interview). Typically, meadows are approached by four-wheel drive vehicles, with additional hiking or skiing to reach the sites. Helicopters provide easier access, but are expensive (Demarchi, interview; Bryant, interview; Janz, interview). Helicopters may cost between $500 and $1,000 per hour to operate (Chatwin, interview). The marmot meadows are extremely steep, and can be treacherous. Accidental falls and minor injuries have occurred, caused by loss of footing on ice, loose ground, or wet plants (Klinka, interview; Bryant, interview; Janz, interview). Despite access constraints, habitat inventories have looked at approximately three-fourths of the marmots’ core habitat area, and extensive areas of habitat that were formerly occupied by marmots. This resulted in a “really good” inventory of the available habitat (Demarchi, interview).

Murrelet nesting habitats are located in high elevation areas up to 1100 meters where there are no roads or other convenient access (Manley, interview; Chatwin, interview). These areas are often unlogged because access for logging is restricted by “really steep cliffs or canyons.” Therefore, “it is the hardest places to get to that still have old-growth” (Manley, interview; also Chatwin, interview; Niziolomski, interview). This means an “extended wilderness trip to reach a lot of the areas” (Manley, interview). Because of access problems, “it is far more expensive to get to the high elevation spots” (Chatwin, interview). Helicopters are essential for fieldwork on murrelets. Nevertheless, helicopters were unable to land within walking distance of five of the 23 nests found in 1998 (Kaiser, interview). Because of access problems, sampling tends to be biased in favor or low elevation valley bottoms that are more suitable for access, and high elevation areas are sampled infrequently (Chatwin, interview; Bahn 1998). Once a potential nesting site is found, nest can only be found by climbing trees to look for nests. According to Manley (interview), “the only way that we can get estimates of murrelet nesting density in areas - is actually to climb a fixed area and find all the nest sites.” Tree climbing can be “very labor intensive,” which limits the use of this approach (Chatwin, interview). Researchers are also at risk from large predators such as grizzly bears and cougars (Manley, interview; Kaiser, interview).

Humpbacks can be observed with relative ease on the surface in nearshore areas (Darling, interview). Offshore observation, however, creates severe logistical difficulties, especially when

Table 4.9 Comparison of Access Constraints

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Access Modes:

- Researchers travel to marmot meadows using a four-wheel drive vehicle, hiking, or occasionally by helicopter.

Access Capability:

- Marmot meadows are in remote, high elevation, rugged terrain that complicates access. Access to marmot meadows may require some mountain skills.
- Helicopters are expensive to operate and cannot always land close to meadows.
- Large predators, such as cougars, can threaten researchers.
- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for work in this ecosystem "restricted access, rough terrain, narrow window (seasonally and daily)," and "remoteness, damp foggy weather, separation" (Appendix 7, section A7.6, question 21).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Access Modes:

- Researchers travel to murrelet nesting habitats by helicopter and hiking. Access is occasionally possible using wilderness roads and four-wheel drive vehicles.

Access Capability:

- Murrelets nest in remote forest sites usually far from roads or other convenient access. Field studies to find nest locations often require helicopter transport, extensive hiking through difficult terrain, tree climbing, and extended stays in the forest.
- Aircraft time is very expensive, and funding is often not available.
- Quality of information is affected by difficulty of access. Areas that are more accessible are more intensively sampled.
- Large predators such as grizzlies can threaten researchers; insects and devil's club can make work miserable.
- Boats are needed for marine surveys; larger boats are needed for visibility with transects.
- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for work in this ecosystem "easily overcome," difficult to access at times, very wet, thick bush, difficult and expensive bird to research," and "more expensive to work in remote areas" (Appendix 7, section A7.6, question 21).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Access Modes:

- Researchers travel to inshore areas by small to medium sized boats, and to offshore areas by ship.

Access Capability:

- Humpbacks can often be observed in inshore waters using a standard small craft and simple camera, or in some cases from shore vantages.

Continued on next page

Table 4.9 – continued

- Offshore observation of humpbacks is usually limited to "platforms of opportunity" and very short research periods and limited areas.

- Observation of offshore humpbacks requires a large vessel, but such vessels are:

  –few and declining in numbers.

  –generally difficult to schedule at appropriate times for ecological research.

  –extremely expensive to operate ($5,000 to $30,000 per day).

  –require cooperation of multiple unrelated research studies that must be compatibly designed.

  –limited in ability to operate in winter or bad weather.

  –limited in sampling capabilities for nighttimes and close to surface.

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for work in this ecosystem: "weather conditions can be extreme in north BC pelagic areas," "sea conditions, undefined boundaries of Vancouver Island ecosystem," and "lack of funding, limited field season" (Appendix 7, section A7.6, question 21).

MARINE CASE: M2 Benthic Octopus Ecosystem

Access Modes:

- Researchers travel to research sites using a range of vessels from small boat to ship. Researchers can use SCUBA, submersibles or Remotely Operated Vehicles (ROV) for underwater work.

Access Capability:

- Research diving work has occurred in only a few sites.
- Divers are only able to remain below water for a very short time. Observations must also be done at times that may be difficult for divers, such as at night.
- Most octopus research is done using SCUBA. SCUBA diving is limited by several factors, including depth, temperature, visibility, sea state, currents, and dangerous animals.
- Octopuses are known to occur to a depth of at least 300 meters. SCUBA is limited to waters up to 20 or 30 meters deep. Octopus habitat below 30 meters is not easily accessible by diving. Dives to deeper depths may require availability of decompression equipment.
- Visibility may be impaired by darkness from depth or nighttime, or from particulate or planktonic matter in the water column.
- The range of divers has been expanded by use of underwater sleds, diver controlled tugs, wet submersibles.
- Air bubbles from exhaled air causes noise and visual stimuli that may cause reactions in animals.
- Several types of remotely operated vehicle (ROV) are available in British Columbia. ROVs are expensive to operate, but less expensive than submersibles and declining in cost. ROVs can carry a large array of sensors. Some ROVs under development are autonomous of surface vessels and can remain on station for long periods. ROVs are not presently feasible for octopus research.
- No submersibles are stationed in British Columbia for research. Submersibles are extremely expensive to operate, costing tens of thousands of dollars per day to operate (up to $150,000 per day). Submersibles would not be feasible for octopus research.
- Depths below 100 meters are virtually unexplored.

Continued on next page

Table 4.9 – continued

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for work in this ecosystem: "seasonal variation in weather and sea conditions and visibility underwater, limited access to deeper water;" "open ocean weather, depth of water, limited visibility;" "octopus occur at low density over a large area, are cryptic, and occur in deep water – any work under these conditions is difficult and expensive;" and "bad weather and increasing depth, including currents and visibility" (Appendix 7, section A7.6, question 21).

Sources: For T1 Ecosystem: interviews with Janz, Demarchi, Bryant, Klinka. For T2 Ecosystem: interviews with Manley, Chatwin, Kaiser, Niziolomski. Mahon, Kaiser, and Burger 1992; Pretash, Burns, and Kaiser 1992. For the M1 Ecosystem: interviews with Darling, Ellis, Harper, Harding, Tanasichuk, and Sloan. Chadwick 1999; Levings, Pringle, and Aitkens 1998b, Angel 1992. For the M2 Ecosystem: interviews with Cosgrove, Hartwick, Gillespie, Marliave, and Jamieson. Perrow, Cote, and Evans 1996; Hunt 1996; Earle 1995; Lambert 1994; Wiebe, Davis, and Greene 1992; Harbison 1992; Wunsch 1992; Peterson 1992; Yoerger 1991; Gamble 1984.

weather is bad (Sloan, interview; Darling, interview; Ellis, interview). Offshore work requires ships that can cost $5,000 to $30,000 per day in operating expenses (Ellis, interview; Harper, interview; Judge 1998), and the amount and timing of sampling is a function of the ship time available (Harding, interview; Tanasichuk, interview). Ship time is scarce, and is mostly assigned to other work. Ships are also limited in nighttime and poor weather. Thus surveys for whales are largely limited to nearshore areas that can be accessed by smaller vessels. Whales are also not observed underwater, where they spend 95 percent of their time, because of poor visibility and a lack of underwater equipment such as submersibles. Whales also react to humans and equipment underwater.

Octopus surveys require underwater equipment. In British Columbia, surveys by direct observation have mostly been limited to SCUBA. SCUBA technology is limited to 30 meters, and divers are strictly limited to short stays underwater, especially in deeper water (Cosgrove, interview; Lambert 1994; Perrow, Cote, and Evans 1994). SCUBA requires a dive boat, but not necessarily a ship (Cosgrove, interview). For deeper waters, remotely operated vehicles (ROV) are expensive, and have not been available for octopus research in British Columbia (Cosgrove, interview). ROV technology is decreasing in cost and the technology is improving (Yoerger 1991). No submersibles are stationed in British Columbia for research, although this technology could technically be used for octopus research (Gillespie, interview; Hartwick, interview). Submersibles require a large ship and crew, and thus are expensive (Cosgrove, interview). At present, the technology for visiting deeper waters is prohibitively expensive for octopus research in British Columbia (Cosgrove, interview).

Discussion

The difficulties of access for all four ecosystems contribute to equivocality. Access difficulties limit the amount of rich information biologists can obtain by fieldwork. Marmot and murrelet access requires the use of a helicopter, and then difficult and often dangerous backcountry hiking. Humpback research inshore can be done using a small boat, but offshore access is not practical because of the need for ships. For the octopus, inshore work can be done by small boat and SCUBA, but offshore deeper water research is not presently feasible. Because deeper marine ecosystems often require more expensive access equipment, access constraints create more equivocality problems for these systems.

4.9 Sampling Coverage

> The spatial and temporal coverage of data gathering for descriptive information on the ecosystem.

Introduction

The sampling coverage indicator is a measure of the spatial and temporal coverage of data acquisition. Spatial coverage is the proportion of the total potential area of the ecosystem that has been sampled or studied. Temporal coverage is the frequency and timing of sampling over a given time period in each area.

Equivocality is resolved where sampling coverage on key species and the ecosystem is more frequent or continuous across broad areas of the ecosystem. Equivocality is increased where data are slowly or intermittently updated through occasional or rare sampling or sampling for a very small portion of the ecosystem. Sampling coverage is an important determinant of information richness. Information based on rare samples will be spotty and potentially distorted. Spatial coverage may also be patchy if, for example, satellites report continuously on sea surface temperature, but no samples are obtained of deeper thermal strata.

Analysis

This indicator compares the extent of spatial and temporal sampling coverage carried out within the case ecosystems. The comparison is summarized in table 4.10.

Although the first scientific report was prepared on the marmot in 1910, little was known about the distribution or ecology of the marmot until the 1970s. The first field research was conducted by Heard (1977). Between 1972 and 1995, varying amounts of fieldwork was completed, with at

Table 4.10 Comparison of Sampling Coverage

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Spatial Coverage:

- Most known areas where colonies could be found have been surveyed. The discovery of large new populations is not expected.
- The very small range of the marmot facilitates surveys.
- Coverage is described in questionnaires as “relatively good due to the limited extent of the subject ecosystem” (Appendix 7, section A7.6, question 15).

Temporal Coverage:

- Historical and archaeological studies have identified some past, now vacant, colony sites. Archival records and census records are also available, which provide considerable information.
- Extensive surveys have been conducted over the past two decades. Hundreds of field surveys have been conducted to provide for statistical analysis.
- Long term sampling coverage is described in questionnaires as “relatively poor because of poor logistics . . . and fewer resource conflicts,” for the ecosystem and “exhaustive – we know more about this species than any other in BC” for the species (Appendix 7, section A7.6, question 16).
- Coverage of short term or seasonal sampling is described in questionnaires as “relatively poor” for the ecosystem, but “exhaustive” for the marmot (Appendix 7, section A7.6, question 17).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Spatial Coverage:

- Murrelet surveys have been done for a large portion, perhaps more than half, of the British Columbia coast. Many locations have been surveyed one-time only.
- Biologists are conducting sequential surveys of murrelet habitats throughout the coast.
- Large range and sparse distribution has complicated censusing. Nest sites are scattered and may located some distance from the coast.
- Coverage is described in questionnaires as “discontinuous,” “inconsistent,” “very variable,” and “limited” (Appendix 7, section A7.6, question 15).

Temporal Coverage:

- Birdwatchers have surveyed and recorded murrelet presence for over a century. Murrelet surveys were done in some areas a few decades ago.
- There are no regular seabird surveys. Murrelet surveys have typically been one-time events with sometimes a few repeats per location.
- Murrelet distributions are highly variable for all periods from less than a day to year-to-year. Variability depends on times of the day, weather conditions, and other factors.
- US seabird protocols require multiyear surveys to confirm presence.
- Very few winter surveys have been done.
- Long term sampling coverage is described in questionnaires as “inadequate” and “good” for the late 1990s but “poor before that” (Appendix 7, section A7.6, question 16).
- Coverage of short term or seasonal sampling is described in questionnaires as “absent,” limited to May to July, and “much new information in past five years” (Appendix 7, section A7.6, question 17).

Continued on next page

Table 4.10 – continued

MARINE CASE: M1 Pelagic Humpback Ecosystem

Spatial Coverage:

- There are no regular humpback surveys. Observations of humpbacks in British Columbia are largely opportunistic.
- Humpbacks are presently surveyed in only a very few areas, with half of the observations occurring at one site. Data represent very small area samples.
- Large areas have not been surveyed where humpbacks are known to occur. A rough estimate is that 10 percent of B.C. waters have been surveyed.
- Extremely large range complicates censusing. Summer ranges are from northern British Columbia to the Aleutians; southern range from British Columbia to perhaps Washington or further south.
- A survey of all British Columbia waters to identify humpback whales would be a "fairly huge undertaking" because of the needs for ships for open ocean work.
- Coverage is described in questionnaires as "limited" and "very limited" (Appendix 7, section A7.6, question 15).

Temporal Coverage:

- Archival records are available, including whaling records, myth and folklore, and news reports. Whaling records provide information on locations of successful hunts, which may correlate with range.
- Whale surveys are done in the summer foraging season when whales return from their migrations. Winter surveys have not been done, although some individuals may remain in British Columbia waters.
- Humpback counts are "piggybacked" on other work being done, or reported by persons doing other work.
- Long term sampling coverage is described in questionnaires as "very inadequate," "unknown," "poor," "inadequate and ineffective" (Appendix 7, section A7.6, question 16).
- Coverage of short term or seasonal sampling is described in questionnaires as "inadequate," "scarce," "poor," and "inadequate" for most species except herring and some plankton (Appendix 7, section A7.6, question 17).

MARINE CASE: M2 Benthic Octopus Ecosystem

Spatial Coverage:

- Careful shallow water diver surveys have only been conducted in a few areas such as sites in Clayoquot and Barkley Sounds and Saanich Inlet.
- Octopus habitats reach at least a depth of 100 meters. Surveys of octopuses in deep water are limited to sporadic and unsystematic trawls and reports of fishers.
- Octopuses occupy different habitats at different life stages, such as surface layers as larvae and benthic areas as juveniles and adults. Minimal sampling has been done to confirm distributions.
- Coverage is described in questionnaires as "low to moderate," limited to certain sites, "very inadequate," and "almost nonexistent" for deep water sites (Appendix 7, section A7.6, question 15).

Temporal Coverage:

- Archival information is very limited. Aboriginal people remember intertidal areas where octopuses were formerly harvested.
- Most systematic research on octopus biology and ecology was carried out in the 1970s and 1980s. Current research is poorly funded, and occasional and incidental.

Continued on next page

Table 4.10 – continued

- No long term data sets exist for perceiving population dynamics or trends and their causes.
- Sampling is not done at biologically important times, but is piggybacked onto other programs. No improvement in the appropriateness of sampling times is expected in near future.
- Access limitations restrict sampling to periods when seas are not rough, which is when samples are most needed.
- Procedures for surveying octopus populations are poorly developed.
- Long term sampling coverage is described in questionnaires as "not very adequate," "has not been done," "not been a priority," and "increasingly inadequate" (Appendix 7, section A7.6, question 16).
- Coverage of short term or seasonal sampling is described in questionnaires as "limited to a few species and sites," "inadequate," "not a priority, hence has not been done," and "sporadic, patchy" (Appendix 7, section A7.6, question 17).

Sources: For T1 Ecosystem: interviews with Demarchi and Bryant. COSEWIC 1998; Bryant and Janz 1996; Nagorsen et al. 1996; Miller 1980; Heard 1977. For T2 Ecosystem: interviews with Chatwin, Kaiser, Manley, Niziolomski, Dawson. Bahn 1998; USDA and USDI 1998; Resource Inventory Committee 1995; Pretash, Burns, and Kaiser 1992, Rodway, Regehr, and Savage 1993. For the M1 Ecosystem: interviews with Darling, Ellis, Harding, and Tanasichuk. Thorne-Miller 1999; Levings, Pringle, and Aitkens 1998b; Pacific Whale Foundation 1998; Zacharias et al. 1998; Lambert 1994; Tunnicliffe 1993; Holliday 1993; Wiebe, Davis, and Greene 1992; Whitehead 1987; Winn and Winn 1985; Braham 1982. For the M2 Ecosystem: interviews with Cosgrove, Hartwick, Marliave, Jamieson, and Gillespie. Gillespie, Parker, and Morrison 1998; Ausden 1996.

least every known site visited at least once (Bryant and Janz 1996). Extensive fieldwork has been conducted since 1987 much of it by Dr. Andrew Bryant (Bryant, interview), with major site surveys conducted by government teams in 1993 and 1995 covering 75 percent of known sites (Demarchi, interview; Demarchi et al. 1996). According to Demarchi (interview), temporal coverage of this species has been "exhaustive" and "we probably know more about this species than any other in Canada." The marmot meadows have been observed over a long and continuous period.

Searches for murrelet nests have occurred for a century. Intensive work began in the early 1990s because of concern about the dependence of the murrelet on old-growth forests that were being logged intensively. Because of these surveys, there is now "adequate coverage for BC" for murrelet habitat in general terms (Kaiser, interview). Although finding actual nests is very difficult, researchers have identified nests, conducted detailed habitat surveys to determine habitat requirements, and are using this information to focus on areas of likely occurrence. Despite their efforts, "large areas of the coast . . . have not been surveyed" (Manley, interview; Kaiser, interview). In terms of timing, there are "no regular bird surveys," so surveys are typically one time events for many areas (Kaiser, interview). Areas where more detailed surveys were done were conducted to test the survey methodologies and determine seasonal and weather-related variability in the data (Manley, interview). Existing survey coverage provides reasonably good information on the types of area that murrelets nest in. This information has been used to develop

Geographic Information System (GIS) maps of potential murrelet habitat (Niziolomski, interview; Chatwin, interview).

Humpback whales have usually been observed close to coastlines. Surveys have largely been opportunistic, with observations made, for example, during killer whale counts or other marine studies (Darling, interview; Ellis, interview). Darling (interview) described surveys for humpbacks as "completely without rigor" and "almost ad hoc." Only a few areas have been covered, adding up to "probably less than ten percent" of the waters of British Columbia (Darling, interview). The majority of whale counts have been done at one site, Langara Island (Ellis, interview). Large populations could exist in areas such as offshore waters where surveys have not been conducted (Ellis, interview). A survey to cover the rest of the waters of British Columbia in search of whales "would be a fairly huge undertaking" because the animals are in open ocean and ships would be required (Ellis, interview). Virtually no observations have been conducted for whales underwater in British Columbia, where whales spend 95 percent of their time.

For research on the octopus, there has been "certain types of data collected tentatively for certain periods of time" (Hartwick, interview). According to Ausden (1996), because invertebrates "occupy different microhabitats during different stages of their life cycle, . . . it is frequently necessary to devise sampling strategies for invertebrates on a much finer scale than those used for many vertebrates. . . . It may also be necessary to sample a wide range of different habitats." For octopus, the procedures for surveying populations and determining their dynamics are poorly developed (Gillespie, Parker, and Morrison 1998). Research has focused in a few areas (Cosgrove, interview). Cosgrove (interview) indicated that "there are differences in various sites that we go to. Whether this reflects a difference in populations overall we do not have enough data to say. . . . So the big picture is really missing. We are still very much working with little tiny snapshots." Underwater data gathering for the octopus is sporadic and unsystematic. Sampling is limited to shallow, divable waters, and deeper waters are virtually unexplored for octopus. Where net samples are used in deeper waters, surveys are repeated in the same areas so that "there are areas that have never been explored" (Cosgrove, interview). Cosgrove (interview) indicated that "sampling and that kind of thing is very sporadic and there is no opportunity to follow these animals around and find out how they interact with each other and that kind of thing. It [the benthic environment] is probably one of the least, poorly explored areas of the planet."

Discussion

The density of sampling coverage affects the level of resolution of information for understanding an ecosystem. Where resolution is lower, information is less rich, and equivocality is higher. Sampling coverage differs considerably among these ecosystems. Most of the existing marmot ecosystems have been surveyed, and some sites have been monitored intensively for many years. Most of the range of the murrelet has been surveyed at least once, but much of this range has been surveyed only once. Perhaps less than 10 percent of the humpback range has been surveyed, and most surveys have occurred in a very few areas. For the octopus, sampling has been sporadic and limited to a few small sites, with virtually no direct exploration of its deeper range. The sparser sampling coverage for marine areas thus contributes to higher equivocality.

4.10 Visibility Constraints

The constraints imposed by the natural environment on the ability of researchers to observe the case species in that environment.

Introduction

The ability to make observations in an ecosystem varies among different physical environments. Equivocality is higher where the lack of visibility is a major obstacle for conducting research in an ecosystem. In lower equivocality cases, visibility is generally good. Visibility can be impaired by the ambient environment, such as fog, clouds, murky water, or darkness. Observation can be obscured by terrain, vegetation, or other natural features. Animals can also be camouflaged or exhibit cryptic behavior. Visibility can also be reduced or eliminated by the subsurface location of habitats, such as underground, underwater, or under the canopy of dense forests.

Analysis

This indicator compares the ecosystems in terms of the constraints on visibility for conducting field surveys of the case species. Table 4.11 summarizes the comparison.

Subalpine marmot meadows are often obscured by foggy, rainy, and “grungy” weather as well as snow cover (Bryant, interview; Janz, interview; Demarchi, interview). Marmots themselves are often obscured by vegetation, terrain, and boulders, and they can disappear into their burrows (Bryant, interview; Janz, interview; Demarchi, interview). Most of these constraints have been overcome by repeated surveys (Bryant, interview; Demarchi, interview).

Murrelets nests are hidden deep in ancient rainforests, resting on a mossy platform high in large trees. They can fly at speeds reaching 160 kilometers per hour, have cryptic coloring, and exhibit

Table 4.11 Comparison of Visibility Constraints

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Environmental Constraints:

- Poor weather and fog cause variability in count reliability during marmot surveys.

Habitat Constraints:

- Rugged terrain, boulders, and vegetation obscure the ability to observe marmots.
- Reliable counts of marmots have been obtained by repeated visits.

Space Constraints:

- Marmot meadows are small enough and sloped so that most of the habitats can often be observed completely from one or two vantage points.
- Marmots are found within a very limited range, which allows repeated surveys to address visibility constraints.
- Researchers have been unable to track marmots during their dispersals.

Subsurface Constraints:

- Marmots spend most of their time, perhaps 80 percent of their lives, underground where they cannot be observed. Researchers know almost nothing about their life below ground. However, the burrows are limited in extent to the area of the marmot colony. Marmots appear at somewhat predictable times in the mornings.
- Marmots hibernate for several months when observations are not done.

Identification of Individuals:

- The markings of individual marmots are not sufficiently differentiated to allow biologists to identify individuals.
- Ear-tagging has enabled very intensive mark-recapture analyses, calibration of visual counts, and an improved count strategy. Tagging studies that require capture of marmots must be conducted with extreme care and selectivity because of the extreme rarity and vulnerability of the marmot.

Questionnaire:

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for gathering information and making observations in this ecosystem: "remoteness, damp foggy weather, separation." (Appendix 7, section A7.6, question 22).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Environmental Constraints:

- Observations are often complicated by cloudy, raining, and/or foggy weather, which interferes with visual and radar observation and helicopter operations.
- Murrelets travel to their nests in twilight periods in poor light.
- Creek noise can obscure audio detections.

Habitat Constraints:

- Nest locations are deep in the forest, high on trees, and blended into surroundings.

Continued on next page

Table 4.11 – continued

- Murrelets disappear into dense forests to nest; nest locations are hidden deep in the forest, high on trees, and blended into surroundings. Nests are nearly invisible and very difficult to detect. Sightings are made against an open sky that can serve as a backdrop.

Space Constraints:

- Murrelet nests are scattered in remote, isolated, and rugged areas.

Subsurface Constraints:

- The deep forest locations of murrelet nests provide cover effectively equivalent to being underground or underwater.

Identification of Individuals:

- Murrelets do not have markings that allow identification of individual birds, or their gender or age. A few murrelets have been banded.

- Murrelets are difficult to observe because of their small size and camouflage coloring.

- Murrelets move from forage to nest sites singly or in pairs, flying at extremely fast speeds approaching 160 km/hr. They are shy, and behave secretively when visiting nests.

Questionnaire:

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for gathering information and making observations in this ecosystem: "nocturnal activity" of murrelet; "bird is secretive, difficult to see, cannot easily catch, variable activity patterns, easily disturbed" (Appendix 7, section A7.6, question 22).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Environmental Constraints:

- Marine surveys are complicated by weather conditions, which can include fog, high rain, and winds.

- Surveys are also complicated by rough sea conditions.

Habitat Constraints:

- The variable habitats of humpbacks include open sea, inlets, channels, and bays.

Space Constraints:

- Humpback ranges include an enormous expanse of offshore and inshore area. The size of this area makes repeated counts very difficult, except in a few areas.

- Humpbacks are extremely mobile and move quickly to new locations in search of food.

- Large numbers of humpbacks that occur on winter calving grounds have not been accounted for in summer. These humpbacks are probably spread out over an immense area of the Pacific coast of North America, including areas in British Columbia that have not been surveyed.

Subsurface Constraints:

- Humpbacks spend perhaps 95 percent of their time underwater, surfacing briefly to breathe. The underwater life whales makes it hard to observe some of their movements, and to ensure that the whales are identified and counted accurately, especially at a distance. Whales can move through some areas unseen.

Continued on next page

Table 4.11 – continued

- Whales can only be observed on the surface. SCUBA and underwater photography has not occurred in British Columbia because of poor visibility.

- Marine environments are “thick” compared to terrestrial, with several layers that are affected by very different environmental processes, such as microlayer, pelagic, demersal, and benthic ecosystem components.

<u>Identification of Individuals</u>:

- Humpbacks have distinctive markings on their flukes that allow researchers to identify individuals and compare information with researchers around the world.

- Recent genetic studies have improved the assignment of individuals to genetic groups.

<u>Questionnaire</u>:

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for gathering information and making observations in this ecosystem: “difficult to see what is happening in the marine environment;” “very restrictive;” “highly limiting;” “sea conditions – not insurmountable; ecosystem boundaries – crucial implications” (Appendix 7, section A7.6, question 22).

MARINE CASE: M2 Benthic Octopus Ecosystem

<u>Environmental Constraints</u>:

- Light penetrates to only a few meters, so that most of the underwater environment is in perpetual darkness. Octopuses are nocturnal animals that prefer dark habitats.

- The clarity of seawater depends on season. Visibility is affected by plankton blooms, silt, and other factors. Visibility is often limited to a few feet.

- Researchers can compensate for poor visibility conditions, in part, by checking habitats when visibility is good. They are then able to find the same octopus dens when visibility is poor.

- Divers can swim over habitats to gain an overview or hover over rugged underwater terrains such as cliff faces.

<u>Habitat Constraints</u>:

- Researchers are able to survey octopus habitats in shallow water less than 30 meters deep.

- Octopuses are believed to undertake bathymetric migrations between shallow and deepwater. Their distributions, movements, and activities in deepwater are not known.

<u>Space Constraints</u>:

- Octopuses occur throughout much of the British Columbia continental shelf.

<u>Subsurface Constraints</u>:

- Most of the octopus’ range is in deep water. Octopuses disappear completely during their twice annual bathymetric deepwater migrations.

- Observation of octopuses in their deepwater habitats is presently not feasible. SCUBA dive data are limited to top 20 or 30 meters; no direct observation occurs at waters below 30 meters. Deep water data are limited to occasional and irregular trawls or netting.

- Octopuses cannot be followed as the move around even in shallow water.

Continued on next page

Table 4.11 – continued

Identification of Individuals:

- Octopuses can change coloring and texture of skin to blend in with background
- Octopuses can flee by jetting away leaving a blob of ink, or disappearing into a den. Dens are relatively small and octopuses can be flushed out.
- Octopuses react to presence of observers.
- Individual octopuses are difficult to identify.
- Octopuses are solitary animals that return to specific dens, which allows identification of some individuals.
- Tagging studies, including sonic tags, have been used to track octopuses. Tagging studies can be extremely expensive.

Questionnaire:

- Questionnaires identified the following physical environmental conditions and factors as creating the most serious obstacles for gathering information and making observations in this ecosystem: "significant," "significant problem;" and "potentially prohibitive under current funding venues" (Appendix 7, section A7.6, question 22).

Sources: For T1 Ecosystem: interviews with Bryant, Janz, and Demarchi. Bryant 1997; Demarchi et al. 1996; Allainé et al. 1994; Arnold et al. 1991; Barash 1989. For T2 Ecosystem: interviews with Manley, Kaiser, and Chatwin. Davies 1999; Bahn 1998; Resource Inventory Committee 1995; Savard and Lemon 1994; Rodway, Regehr, and Savard 1993. For the M1 Ecosystem: interviews with Darling and Ellis. Chadwick 1999. For the M2 Ecosystem: interviews with Gillespie, Cosgrove, Marliave, Jamieson, and Hartwick. Sheldon 1998; Gillespie, Parker, and Morrison 1998; Hunt 1996; Harbison 1992; Gamble 1984; Snively 1978; Ricketts and Calvin 1968.

secretive behavior as they approach their nests. They travel in twilight, and are more active in inclement weather. Researchers and birdwatchers searched for decades to find the first nest in British Columbia. Researchers have addressed visibility constraints through extensive efforts to track murrelets by radar and radiotelemetry until nest locations were found. The study of habitats in these areas is improving the capability to find nests. Nevertheless, visibility is a major constraint for murrelet research.

Humpback whales are obscured by large volumes of water that cover and obscure marine processes and organisms and by great expanses of area. Whales spend 95 per cent of their time underwater; and range freely and rapidly through offshore areas as well as inlets and channels of the coast. The often-inclement weather and rough sea conditions complicate observation. Researchers have not been able to account for the summer location of half of the humpbacks that have been counted in southern wintering areas. The whereabouts of the remaining half of the population is not known, but many may be feeding in British Columbia waters.

Benthic octopus ecosystems are underwater, where water clarity is often poor and light levels low. Octopuses are able to change their color and skin texture to blend into their surroundings. At divable levels, researchers have been able to overcome visibility constraints by repeated visits. Divers also are neutrally buoyant, which means they can swim over the habitats to gain an overview and reach habitats that would be inaccessible in a terrestrial terrain, such as cliff faces (Gamble 1984). On the other hand, researchers have no access to waters below divable depths, so that the mass of water almost completely obscures observation of octopuses in deep water.

Discussion

Equivocal information is vague and obscure. Natural environments with low visibility are thus more equivocal than environments with higher visibility. Marmot habitats are relatively easy to observe, despite local constraints on visibility. For murrelets, visibility constraints have partly been overcome, but at the cost of an enormous effort by many researchers and others. Both humpbacks and the octopuses disappear for a large part of the year into areas that are not known. They are also hidden by their underwater existence.

4.11 Sensor Diversity

> The number and variety of observation technologies used for gathering important information on key species and driving forces for the ecosystem, and the variety and richness of data forms produced.

Introduction

Sensor diversity is a measure of the *number* and *variety* of sampling technologies used for gathering information on key species and ecosystems. Data from the environment come in many forms. Visual data, for example, provide cues for such environmental properties as forms and shapes, patterns, size, colors, depth, and movement. Audio data provide cues as to tone, pitch, loudness, timbre, distance, and motion. Olfactory (smell) and gustatory (taste) data provide indications of the presence of chemical and biotic agents. Tactile data provide cues as to temperature, texture, and weight. Beyond human senses, remote sensing provides evidence of various types of radiant waves, gravity, force, and other environmental properties.

The information content of data depends on the range of properties of the environment that can be detected. This depends on the number and variety of cues provided by different properties of data. Multiple perspectives on a data set provide more cues for interpretation. Data that provide a single data reading provide minimal context for interpretation (Einhorn and Hogarth 1986). The interest is in the range and variety of cues provided by the total array of ecosystem observation methods.

According to Bernstein et al. (1991), “stimuli from the world are often redundant, giving multiple cues to what is going on. If you lose or miss one stimulus in a pattern, others can fill in the gaps so that you can still recognize the total pattern.” They argued that depth perception, for example, is enhanced by contextual cues that reduce ambiguity. Three-dimensional depth illusions occur when cues are missing or out of context. Thus use of multiple and redundant methods and data forms enhance comprehension and reduces multiple interpretations. Sensor diversity thus depends on the ability to acquire a variety of data sets using different methods.

Equivocality is lower where a variety of observation technologies and data forms is used for gathering and confirming important data sets. For example, ecologists may gather population data through aerial reconnaissance as well as fieldwork using videotaping and direct observation. Equivocality is increased, on the other hand, where there is a limited variety of observation technologies and data forms are used for gathering and confirming important data sets. For example, scientists may use a sonar system that provides simple depth reading with no plotting capability or location data. Observer cannot visualize more that a column of water between the boat and a solid object or surface.

Analysis

This indicator compares the ecosystems in terms of the diversity of data forms and the richness of data that can be gathered for the ecosystems. Table 4.12 summarizes the comparison.

The simple technologies used for observing the subalpine marmot ecosystem provide an extremely rich picture of that ecosystem. The marmot habitats are small and generally open, and can be observed often from a single vantage by eyesight or binoculars. Tagging studies have provided extensive information on the life of the marmot. Habitat plots have been studied in minute detail, thus providing comprehensive and rich information on marmot habitats.

The technology and approaches used for studying old-growth murrelet ecosystems have been developed with somewhat more difficulty than those for the marmot ecosystem. Researchers abandoned mist netting and developed dip netting to catch murrelets for tagging. After years of at-sea surveys and audiovisual studies, researchers have found radar to be “the most promising new technology” (Manley, interview). In all cases, however, these detection technologies are hampered by an inability to gather a clear picture of the number of birds passing the survey point, either because individual birds cannot be discriminated, birds pass the point more than once, or birds use different routes that do not pass the point. The small camouflaged, fast-flying, cryptic birds are not clearly observed. After decades of attempts, researchers finally developed an effective approach for finding nest that involves radiotelemetry. Even when the location of a nest is known

Table 4.12 Comparison of Sensor Diversity

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Audiovisual Observation:

- Direct surface observation of marmots can be accomplished using "low technologies" such as binoculars and spotting scope, which reduce the costs of observation.

- Repeated counts have overcome most visibility constraints.

Trapping and Mark-Recapture Studies:

- Mark-recapture analyses using ear-tagging have allowed calibration and verification of census counts.

- Marmots extremely difficult to track when dispersing. Researchers have used surgically implanted radio transmitters that are tracked using hand held direction finders. Transmitters must be implanted by veterinarians. Rareness of marmots makes any capture risky to the species.

- Indirect evidence can be observed, such as existence of burrows, stains on rocks, or listening for marmot whistles.

Habitat Studies:

- Detailed information exists on topography, landforms, and geology for terrestrial areas.

- Extensive information is available from airphoto interpretation. Recent technological developments have improved the capability for very high-resolution three-dimensional images of natural landscapes.

- Aircraft and satellite based remote sensing can provide extensive data on elevations, terrain, vegetative cover, hydrology, and other features. Remote sensing data can be expensive.

- Ecologists have conducted extremely detailed habitat assessments for habitat areas using standardized ecosystem description protocols. Detailed on-the-ground physical surveys, vegetation sample plots, and habitat assessments have provided extremely rich information on habitats, including elevations, terrain, soils, hydrology, and other features.

Questionnaire:

- The capability of existing field observation technologies to provide rich information on key species and driving forces for this ecosystem was described in responses to the questionnaire as follows: "open habitats conducive to good observation of many system components, subject to vagaries of weather;" and "exhaustive for ground habitats, but we know almost nothing about their below ground habitats or life" (Appendix 7, section A7.6, question 18).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Audiovisual Observation:

- Visual detections are extremely difficult, with or without optical assistance such as binoculars.

- Audio and visual surveys produce ambiguous data concerning abundance, gender, and other factors. Visual and audio surveys can provide only a general indication of the presence of murrelets and do not provide indications of absolute abundance. Audio detections are more effective and less subjective at detecting murrelets than visual surveys.

- Radar has become the preferred approach for surveys. It provides good estimates of abundance and trends. It is not reliable in poor weather when audio detection works better. It is also subject to difficulties in discriminating individual birds and other biases. These biases can be addressed by repeating surveys.

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Table 4.12 – continued

Trapping and Mark-Recapture Studies:

- Biologists have developed a dip net method that is effective in capturing murrelets. Murrelet have sufficient numbers to allow capture without risk to their populations.
- 1,200 murrelets have been banded including 28 of which were young. Biologists used tags that are visible when bird on the water.
- Researchers have used radiotelemetry to find nest locations. Transmitters are located from helicopter-borne direction finders. Transmitters were tracked when murrelets were brooding and remain on the nest for long periods.

Habitat Studies:

- See habitat studies for subalpine marmot ecosystems.
- Biologists have discovered nest locations, and are evaluating the habitat requirements for these areas. This information is being used successfully to locate additional nesting locations.

Questionnaire:

- The capability of existing field observation technologies to provide rich information on key species and driving forces for this ecosystem was described in responses to the questionnaire as follows: "adequate (good for forests), data poor at this time;" and "technology is available, but no accessible to current budgets" (Appendix 7, section A7.6, question 18).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Audiovisual Observation:

- Direct observation of humpbacks can be accomplished using "low technologies" such as binoculars, cameras, and small boats, which reduce the costs of observation.
- Hydrophones are used to find whales and record their sounds.

Trapping and Mark-Recapture Studies:

- Photographic identification of unique markings on whale tails has proven extremely effective for whale research. Extensive cooperation among whale researchers worldwide has produced large photo-identification databases. Sometimes whales do not show their tails or photographs are of poor quality.
- Photo databases cannot provide controlled mark-recapture estimates of populations. Since dead whales are rarely seen, they cannot be removed from databases. In addition, humpback offspring leave their maternal group, making it difficult to determine their location.
- Researchers have conducted aerial and ship-borne line and strip transects.
- Whale migrations are extremely difficult to track. Researchers have used satellite tags, but satellite tags are extremely expensive and have only been used in a very few cases.

Habitat Studies:

- Water covers and obscures many marine features, processes, and organisms.
- Satellites can provide broad overviews of oceanographic systems, including circulation patterns, upwelling locations, altimetry or variations in sea surface elevation, chlorophyll levels, primary productivity, and other parameters. Cloud cover can obscure some satellite sensors. Radar interferometry sensors can penetrate clouds and darkness to detect changes in the earth's crust. Satellites cannot penetrate the sea surface to provide measurement of deeper distributions of phytoplankton, secondary production, and fisheries resources.
- Volunteer observing ships or ships of opportunity are the major source of measurements of the ocean's interior, which are limited in depth to 400 meters and limited in schedules and sampling density. Few oceanic regions have been rigorously sampled.

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Table 4.12 –continued

Questionnaire:

- The capability of existing field observation technologies to provide rich information on key species and driving forces for this ecosystem was described in responses to the questionnaire as follows: "limited for short term, but useful for long term studies;" "limited;" "adequate (technology in hand);" and "reasonably capable for determining [faunal] distribution etc. through hydroacoustics; physical parameters sampling very capable" (Appendix 7, section A7.6, question 18).

MARINE CASE: M2 Benthic Octopus Ecosystem

See also M1 Ecosystem

- Sonar bottom imaging acoustic systems can provide good images of bottom topography and substrate. There is a tradeoff for sonar acoustics between range and resolution. General information can be obtained and is available for wide areas. Detailed surveys are expensive, and have been developed for only a few areas. Advances are being made in multibeam sonar that provides clearer bottom images.

- Hydroacoustic survey equipment can locate fish and other organisms underwater in a cost efficient and reliable manner. This equipment must be properly calibrated and the measurements reliably interpreted.

- Unattended fixed and floating sensors, radar, and other sensors provide general information on physical oceanography.

- Nets and trawls have used for sampling marine species, including humpback food species. This sampling should be based on an understanding of the biology and behavior of the sampled species. Otherwise, sampling can be conducted at the wrong times, places, or depths. Specimens may avoid or be attracted to nets, or disappear through the meshing or be shredded by the nets. Nets cannot be deployed at night or rough weather.

<u>Audiovisual Observation</u>:

- Recall to memory of observations is poorer in diving than for terrestrial work, and writing is more difficult. Underwater voice tape recorders and video cameras are available.

- Direct observation of octopuses underwater can be accomplished by normal eyesight, still cameras, and video cameras. Researchers also use thermometers and depth meters. These are all low technology equipment.

- Divers can use similar ecological data gathering procedures to terrestrial environments for sessile ecosystems in shallow water, though time may limit the amount of detailed observation. Researchers have used point, quadrat, predetermined area, and transect surveys to search and assess octopus habitat. Point or predetermined area surveys allow animals to habituate to diver presence. Octopuses can be missed in underwater surveys if they are away from their dens or too small.

- Researchers suggested that underwater observation provides ecological insights and behavioral information, and is nondestructive and nondisturbing. Observations suggest that small changes in depth or location reveal major changes in species composition that would not be seen without direct observation.

- Video and still cameras are constrained by a narrower field and depth of vision. Octopuses can also change their color and texture to match their surroundings. Images are more difficult and time consuming to interpret.

- Canadian built ROVs deployed by the Monterey Bay Aquarium Research Institute have been equipped with broadcast quality video cameras, and extensive oceanographic instrumentation including temperature, salinity, depth, oxygen concentration, light transmission, scanning sonar, low-light cameras, still cameras, hydrophones, flow meters, and specimen samplers. This capability provides for high-resolution information.

- Submersibles are no longer available on the British Columbia coast.

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Table 4.12 –continued

Netting, Trapping, and Mark-Recapture Studies:

- Because information from deeper waters comes from trawls, researchers have better information on muddy than rocky bottoms that would hang up nets. Net samples may also be biased because smaller animals may be missed in larger mesh size nets, some animals may avoid nets, some animals are eaten in nets before retrieval, and soft bodied animals may be crushed or destroyed by the nets. Nets cannot be deployed in rough seas.

- Observation of octopus larvae has been rare in plankton tows, but octopuses have been found at all depths. Past a certain age, they appear to be able to detect the pressure wakes of the nets and evade the nets by swimming.

- Net systems now carry multiple nets with sensors to measure water properties, temperature, depth, conductivity and salinity, plant fluorescence and biomass, beam attenuation and total particulate matter.

- Nets and associated instruments are limited in temporal and spatial coverage because of the time required to deploy and retrieve nets and inspect specimens brought to the surface in the nets.

- Most information on the range of the octopus comes from commercial fishers who report catches and bycatch. This information is very general and nonsystematic.

- Trapping provides the best source of data for deep-water habitats. Trapping studies have covered only a few small areas. Unbaited habitat traps induce octopuses to take up residence in the trap, which is then retrieved. Trapping can provide data on life history traits, measurements, size, weight, sex, and maturity. Effectiveness of trapping studies depends on trap type, fishing location, time of year, age and gender of octopus. Trap studies can be biased by differences in the susceptibility of octopuses to enter the particular type of trap.

- Tag-recovery studies have been used to examine denning behavior, range, habitat requirements, prey food, relative population densities, and other variables. Tagging studies are costly even for small areas, and only a few studies have been done. Tagging studies have not provided data on deepsea octopus habitats because tagged octopuses have not been recovered.

- Sonic tagging technologies are being developed which could plot movements of octopuses. Sonic tags have limited range and affected by bottom terrain.

Habitat Studies: See M1 Pelagic Humpback Ecosystem

- For benthic ecosystems, divers can operate a variety of hand held suction and coring samplers.

- Octopus habitat requirements are varied and presently unpredictable.

Questionnaire:

- The capability of existing field observation technologies to provide rich information on key species and driving forces for this ecosystem was described in the questionnaire as follows: "significant;" "current technology is adequate but expensive and labor intensive;" "appropriate technologies exist, but all appropriate ones relative to octopus have not been utilized;" and "increasingly inadequate with depth" (Appendix 7, section A7.6, question 18).

Sources: For T1 Ecosystem: interviews with Demarchi, Klinka, Janz, and Bryant. Brown and Borstad 1999; COSEWIC 1998; Province of British Columbia 1998; Bryant 1997, 1996; Massonnet 1997; El-Baz 1997; Demarchi et al. 1996; Bryant and Janz 1996; Ecosystem Working Group 1995; Roughgarden, Running, and Matson 1991; Luttmerding et al. 1990; Demarchi et al. 1990; Martell and Milko 1986; Waring et al. 1986; Del Moral 1984; Belsky and Del Moral 1982; Franklin et al. 1971. For T2 Ecosystem: interviews with Kaiser, Chatwin, Manley, Niziolomski, Dunn, and Dawson. Bahn 1998; Schowengerdt 1997; Gibbons, Hill, and Sutherland 1996; Resource Inventory Committee 1995; Hoffer 1994; Sample 1994; Savard 1994; Spies 1994; Rodway, Regehr, and Savard 1993; Jones 1993; Pretash, Burns, and Kaiser 1992; Mahon, Kaiser, and Burger 1992; Rodway 1990; Sealey 1975. For the M1 Ecosystem: interviews with Darling, Ellis, Harper, Sloan, and Tanasichuk. Fred Sharpe, Doctoral candidate, Simon Fraser University, personal communication. Palsboll et al. 1997; Barratt-Lennard, Smith, and Ellis 1996;

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Table 4.12 –continued

Brodeur et al. 1996; Sutherland 1996; Nero and Huster 1996; Earle 1995; Holliday 1993; Wunsch 1992; Harbison 1992; Sarachik 1992; Richardson 1991; Baker 1991; Stewart 1991; Baker et al. 1990; Thompson 1989; Whitehead 1987; Svejkovsky 1987; Perry 1986; Darling and McSweeney 1985; Winn and Winn 1985; Bryant et al. 1981. For the M2 Ecosystem: interviews with Hartwick, Cosgrove, Marliave, Jamieson, and Gillespie. Gillespie, Parker, and Morrison 1998; Trippel 1998; Fox et al. 1998; Judge 1998; Perrow, Cote, and Evans 1996; Ausden 1996; Lambert 1994; Robison 1993; Ryan 1993; Wiebe, Davis, and Greene 1992; Wunsch 1992; Jamieson and Francis 1986; Hartwick, Ambrose, and Robinson 1984a, 1984b; Gamble 1984: Hartwick and Thorarinsson 1978.

generally, however, finding the actual nest involves considerable effort including tree climbing. Once nests are found, researchers are conducting detailed nest habitat assessments that are enabling them to define search criteria for finding additional nests. When combined with the extensive databases of resource inventory information that is available, researchers are able to develop Geographic Information System mapping of potential habitat areas that can be used in forest management.

For the pelagic humpback ecosystem, relatively simple technologies and approaches have been used in the past to study the humpbacks, including cameras and binoculars. Some experimental use has been made of satellite tags to track migration movements, but such tagging is extremely expensive. Humpbacks can be identified from their tail markings, so photo identification has provided considerable information on whale movements. Existing technology, if surveys were intensified, could provide better information on distributions and movements. Although simple technologies have provided information on the whale itself, knowledge of its ecosystem requires sophisticated technologies including satellite remote sensing, sonar, radar, and environmental instruments. These technologies are capable of providing rich information, and technology is rapidly improving (Judge 1998). However, detailed studies have only been done on a few areas. Researchers do not have rich information on the bottom conditions, water column, or species composition of large parts of the ecosystem.

Research within the benthic octopus ecosystem requires underwater equipment that can compensate for the poor visibility conditions often present in this environment. The richest information has been obtained by divers when visibility conditions are good. At these times, small areas of habitat can be observed for short periods. The same difficulty applies to other underwater technologies. Based on numerous dives in the submersible *Pisces*, Jamieson (interview) observed that "what I've really appreciated is just how variable it can be and how often small it is. You don't have to go through very much depth to get a change in species composition." Underwater cameras have been of limited utility (Marliave, interview). Tag-recapture studies have provided some information on habitat use. For deeper areas, data become decidedly unrich. Octopus presence can only be determined by trap or trawl, and octopuses may be able to avoid capture. For habitat assessments, bottom-typing sonar can provide a relief map of the sea bottom (Fox et al. 1998), but information is coarse grained and lacks detail on species composition and other factors. Bottom-typing technology is rapidly improving, however (Judge 1998). Researchers also use research trawls or nets to sample marine species. As Jamieson (interview) indicated, "we can't go down. We're looking at what comes up."

Discussion

Richer information (section 1.6.2) can be obtained by using an array of different sensors to observe an ecosystem. The richest information would be provided by direct observation that uses all senses. For example, a biologist standing in a meadow can see and hear marmots, see the surrounding context, feel the temperature, smell the vegetation, and so on. Similarly, observation technologies can extend the diversity of data that can be obtained from human senses.

For the subalpine marmot ecosystem, the simple environment favors simple technology for study. The more complex old-growth murrelet ecosystems have stimulated the development of new approaches at some considerable effort, including the use of radar and radiotelemetry. Data are still unrich, however, for murrelet research, though habitat information is generally available. The technology for observing humpback whales is relatively simple and effective, though sampling efforts have been limited. Almost no direct observations have been made below the water surface. For octopuses, researchers can obtain rich information only by diving, and diving is limited to certain small areas and shallow depths for short periods. Information on habitats of the pelagic and benthic ecosystems is patchy and unrich. Equivocality is thus affected by the capability and use of sensors for observing the case animals in their native habitat. Where sensor capability is restricted by environmental conditions, equivocality can be expected to be higher than this capability is less restricted.

4.12 Contextual Capability

> The capability of the information to provide an overview of an entire system, or large portion of it, rather than isolated detail.

Introduction

Contextual capability enables observers to "see the big picture" or obtain a "broad perspective" on the meaning of the data. The capability of information to provide an overview depends on how it is integrated and presented. Integrated data necessarily involve some preprocessing and interpretation. Some detail is lost in this process. Accuracy and reliability depend on the quality of data that are collected, the scales at which data are collected, and the averaging or scaling of data (Conroy and Noon 1996). Contextual capability also depends on format. A Geographic Information System (GIS) presents visual data in a manner that enhances contextual perspective.

Equivocality is resolved where data are integrated and presented in formats that provides 'the big picture' rather than isolated detail. It is increased where data are limited in focus to isolated detail, rather than providing an overview of the ecosystem.

Analysis

This indicator compares ecosystems in terms of the capability of existing technologies to provide an overview or "big picture" of the ecosystem. The comparison is summarized in table 4.13.

Existing information on the subalpine marmot ecosystem provides a rich overall picture of the marmot ecosystem. Airphoto, photography, and GIS images provide both synoptic overviews and finely grained detail (Bryant, interview; Dawson, interview). This is supplemented by large databases of resource inventory information, habitat analyses, and marmot population and distribution data (Demarchi, interview). The principal researcher has developed an intimate familiarity with the meadows through long term, intensive field research (Bryant, interview; Janz, interview).

Ecologists have extensive inventory information on the natural resources of the old growth forest ecosystems of the murrelet. Comprehensive air photograph information, enhanced by computer processing, provides rich synoptic pictures of forested areas (Dawson, interview). For selected nest locations, detailed field habitat analyses have been done (Chatwin, interview; Kaiser, interview). Nonetheless, much of the important ecological information for this ecosystem lies under dense tree cover. On-the-ground and tree climbing research work is needed to confirm nest locations and refine models for identifying murrelet habitats. Murrelet data have not been mapped to provide coastwide detail on their distribution, although some data do exist for mapping old growth forests. Foresters have also used GIS modeling to project forest future development, which is possible because forests are long-lived structures (Niziolomski, interview). For murrelets, photography has been of somewhat limited use because of the camouflage coloring, dense forests, and rapid flying speeds. A considerable amount of information has been published, but much of this information is rapidly becoming out-of-date because of recent research using radar technology.

Table 4.13 Comparison of Contextual Capability

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Data Reports, Publications, and Models:

- Dr. Andrew Bryant has developed matrix displays providing rich picture of census information by colony.
- Ecologists have completed detailed habitat inventories and field plot analyses to identify marmot habitat requirements and potential habitats.
- Although several journal articles, theses, status reports, and habitat reports have been published, extensive information remains unpublished. An award-winning website has been developed to distribute information and make contacts.

Spatial Information and Mapping:

- Extensive resource inventory mapping exists in the provincial resource inventories.
- Detailed Geographic Information System mapping provides rich picture of marmot habitats, and surrounding areas.
- Individual marmot meadow colony sites have been mapped at very detailed level.
- Advanced technology for electronic orthophotos is being developed to provide low-cost, high-resolution, three-dimensional versions of terrestrial air photos.

Imaging and Photography:

- Marmots are easy to photograph in their surface habitats. Marmot meadows can also be photographed.
- GIS and photography have been used to convey broad picture of marmot habitats and landscapes.

Personal Experience and Familiarity:

- The principal scientist for marmot, Dr. Andrew Bryant, has researched the same marmot colonies for over 12 years.
- The small range and size of the marmot colony sites allows researchers to develop an intense familiarity with the sites, which improves their ability to observe what is occurring.
- Habitat inventories have been done by multidisciplinary teams with diverse perspectives.

Questionnaire:

- The capability of existing information display and presentation technologies to provide an overview of the entire system, or large portion of it, rather than isolated detail is described in responses to the questionnaire as follows: "good overview capability by remote sensing, GIS, due to rather distinct characteristics (higher elevation, open habitats, snowfields, etc.);" and "comprehensive, we can show their habitats at three different spatial scales and show the interpretation of each" (Appendix 7, section A7.6, question 19).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Data Reports, Publications, and Models:

- Ecologists have completed detailed habitat inventories and field plot analyses to identify murrelet habitat requirements and potential habitats. These analyses have enabled researchers to identify potential nest locations.
- Extensive research has been carried out by government, industry, and university researchers from Alaska to California. A growing base of published literature exists. Much information remains to be published.

Continued on next page

Table 4.13 – continued

Spatial Information and Mapping:

- Extensive resource inventory mapping exists in the provincial resource inventories.
- Murrelets distributions have not been mapped comprehensively for the coast. Reliable mapping is limited to a few areas.
- Detailed Geographic Information System mapping provides information on murrelet habitats, and surrounding areas.
- GIS models are being used to identify potential nest locations and to project future murrelet habitat distributions based on management scenarios.
- Advancing technology for electronic orthophotos is being developed to provide low-cost, high-resolution, three-dimensional versions of air photos.

Imaging and Photography:

- Murrelets are difficult to photograph because of camouflage coloring, secretive behavior, and remote habitats
- Biologists fear that placing cameras to observe nests could disturb nesting behavior or attract predators.

Personal Experience and Familiarity:

- A number of teams of biologists have been studying murrelets using sometimes-different methods.
- Experienced observers have developed improved skills for detecting murrelets by audiovisual and radar methods.
- Interpretation of spatial information is dependent on the discipline and training of interpreter. Foresters perceive different information from air photos than wildlife biologists.

Questionnaire:

- The capability of existing information display and presentation technologies to provide an overview of the entire system, or large portion of it, rather than isolated detail is described in responses to the questionnaire as follows: "adequate, low power, misapplied, not applied;" "GIS information technology has been very useful for portraying habitat suitability, calculations;" and "promising, but needs integration over large areas (TFL and TSA have different coverage)" (Appendix 7, section A7.6, question 19).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Data Reports, Publications, and Models:

- The Department of Fisheries and Oceans (DFO) in Nanaimo and the U.S. National Fisheries Management Service in Seattle have developed and maintained extensive databases of whale photos.
- DFO has maintained catch records for commercially important fisheries for decades. Some of these fisheries involve humpback prey species, such as herring or pilchard. Commercial catch records are based on port of landing and inflexible statistical areas rather than point of capture.
- Some fisheries scientists have used statistical population modeling for decades, and ecosystem models are being developed.
- Numerous journal articles and status reports have been published for humpbacks worldwide. Very little has been published concerning British Columbia humpbacks, including important status information that is available.

Spatial Information and Mapping:

- Whale data are presently too fragmentary for display on maps or GIS.

Continued on next page

Table 4.13 – continued

- Some information on seabed geology has been mapped on "open files" and GIS.
- Satellite and other information have been processed to provide broad scale information on physical oceanography and primary productivity.
- Georeferencing is improving the accuracy and precision of marine resource information. Some catch data for commercial prey food fisheries are being georeferenced and recorded by onboard observers.
- Very high-speed computers have only recently become available to integrate spatial and temporal data from various sources into three-dimensional pictures.

<u>Imaging and Photography</u>:

- Photography provides excellent identification of whales.
- Advances in processing of remote sensing, bottom imaging, and acoustic information has been revolutionizing marine science. Satellite images can be complicated by cloud cover and inability to penetrate water.
- Satellite images and unattended sensor information can be transmitted to ground stations for processing in real time.
- Technologies for video exploration of undersea areas still not used heavily.
- Some researchers have used video simulations to illustrate complex phenomena such as humpback bubble net feeding.

<u>Personal Experience and Familiarity</u>:

- Humpbacks have been observed for thousands of hours from boats. Despite this extensive observation, there are many gaps in the understanding of whale behavior because this behavior is so dynamic.
- Extensive collaboration among humpback researchers around the world has been necessary, and has occurred.
- Although observation of whales underwater has been limited, this observation has greatly increased understanding of their behavior.
- Because ship based research usually requires that several research projects at the same time, the use of ships may enhance cooperation among scientists by bringing people together.

<u>Questionnaire</u>:

- The capability of existing information display and presentation technologies to provide an overview of the entire system, or large portion of it, rather than isolated detail is described in responses to the questionnaire as follows: "unknown;" "adequate;" "very capable;" and "deceptive, flashy presentation makes our level of understanding appear higher than it really is" (Appendix 7, section A7.6, question 19).

MARINE CASE: M2 Benthic Octopus Ecosystem

<u>Data Reports, Publications, and Models</u>:

- DFO has maintained catch records for commercially important fisheries for decades. This includes data on octopus catch and bycatch. Records are imprecise as to location of catch (see pelagic humpback case). Fisheries data have also been hampered by inadequate data processing, sampling, gear type biases, incidental bycatch, and market driven timing of fishing activity.
- Existing data on octopuses are unsystematic and anecdotal, and are inadequate for assessing octopus populations or for conducting ecological or population modeling.

Continued on next page

Table 4.13 – continued

- Only a few researchers are doing research on octopuses, and all of this research is occasional or part time. A few studies have been published in British Columbia on octopuses.

Spatial Information and Mapping:

- Octopus distributions and habitats have not been mapped.

- Position finding underwater can be difficult.

Imaging and Photography:

- Photographs and videos have provided vivid images to illustrate octopus habitats. These images may provide the only means for nondivers to see underwater information.

- Low light cameras are being developed which may improve imaging somewhat.

- ROVs equipped with advanced instrumentation such as dual beam acoustic systems and other sensors have been used to obtain more comprehensive images of patchiness of animal populations.

Personal Experience and Familiarity:

- Octopuses are often difficult to detect by divers without experience observing octopuses.

- Taxonomic identification of octopuses and other marine invertebrate species is difficult because of a lack of trained and experienced taxonomists.

- As a terrestrial animal, underwater environments are alien to human observers. Thus, the average person may have a better understanding of the terrestrial environment than research scientists have for the undersea.

Questionnaire:

- The capability of existing information display and presentation technologies to provide an overview of the entire system, or large portion of it, rather than isolated detail is described in responses to the questionnaire as follows: "good;" "broad data do not exist, technology could make use of data if it existed;" "inadequate scientific data on octopus to make these technologies potentially useful;" and "limited reliability, recently improving" (Appendix 7, section A7.6, question 18).

Sources: For T1 Ecosystem: interviews with Bryant, Klinka, Demarchi, and Janz. COSEWIC 1998; Bryant 1997; Demarchi et al. 1996; Bryant and Janz 1996; Miller 1980. For T2 Ecosystem: interviews with Niziolomski, Dawson, Kaiser, Chatwin, and Manley. Bahn 1998; Hoffer 1994; Huggett 1993; Rodway, Regehr, and Savard 1993. For the M1 Ecosystem: interviews with Darling, Ellis, Sloan, and Harper. Fred Sharpe, Simon Fraser University, personal communication. Levings, Pringle, and Aitkens 1998b; Earle 1995; Holliday 1993; Sombardier 1992; Sarachik 1992; Frye, Owens, and Valdes 1991; Richardson 1991; Stewart 1991; Winn and Winn 1985; Holling et al. 1978. For the M2 Ecosystem: interviews with Hartwick, Gillespie, Marliave, Jamieson, and Cosgrove. Gillespie, Parker, and Morrison 1998; Lambert 1994; Gamble 1984.

Whale researchers share whale identification photographs among researchers around the Pacific Ocean, which is slowly building up a picture of the population and distribution of humpback whales. Research in British Columbia, however, is minimal, and data are too fragmentary to be mapped to provide a synoptic picture of humpback distribution and habitats. Satellite remote sensing images can provide up-to-date synoptic images of marine weather and sea surface conditions (Sarachik 1992). This technology is less effective in cloudy weather and provides minimal information from below the sea surface. A variety of sonar and other technologies are slowly providing information on bottom conditions and water column properties.

Ocean conditions are highly variable both spatially and temporally, putting a premium on real time information. While technologies are improving, a detailed synoptic picture of this ecosystem does not exist.

The contextual perspective is even less available for the benthic octopus ecosystem. Researchers have only the vaguest idea about the distributions and habitats of octopuses. The seabed conditions are only known in general terms.

Discussion

A contextual perspective provides a "big picture" that provides an overview for interpreting information about an ecosystem (Einhorn and Hogarth 1986). This context and perspective resolves equivocality. The contextual perspective for the subalpine ecosystem is excellent. For the old-growth ecosystem, extensive information exists but the clarity of the overview is hindered to some extent by forest cover, although habitat characteristics are reasonably well known. For the pelagic and benthic ecosystems, serious constraints impede ability of researchers to gain an overview of either the case species or the ecosystems. Contextual capability for marine ecosystems below the surface is thus poor, and equivocality is thus raised.

4.13 Field Research Technology

> The technological capability to conduct experiments, monitor key environmental parameters, or undertake other studies 'in the field' to test hypotheses about ecological theories or models in order to develop causal knowledge about key driving factors and threats.

Introduction

The ability to test hypotheses is a fundamental requirement of causal research (Platt 1964; Romesburg 1981, 1989; Matter and Mannan 1989). To test hypotheses, ecologists conduct experiments (Carpenter et al. 1995), compare ecosystems (Glantz 1992), and monitor changes in critical parameters resulting from human or natural disturbances (Beanlands and Duinker 1983). Because ecosystems are complex and open systems, testing of ecological hypotheses is very difficult (Reichman and Pulliam 1996). It depends on the capability of research technology to assemble appropriate data in the field.

Equivocality is resolved where research technologies allow monitoring of key environmental parameters affecting the particular species and ecosystem, and allow field-testing of hypotheses regarding driving factors and threats, whether by experimentation, comparative analysis, monitoring, or other means. Technology includes both procedures and practices, and equipment. Equivocality is increased where research technologies do not allow field-testing of hypotheses and are not available for monitoring key parameters affecting the species or ecosystem.

Analysis

This indicator compares the ability to develop causal knowledge about the functioning of the case ecosystems. The comparison is summarized in table 4.14.

For the subalpine marmot ecosystem, the major causal research has focused on finding the causes for declines in marmot populations. Marmot numbers are dropping, and some colonies have disappeared. Marmots have also disappeared from former habitats in other areas. Dr. Andrew Bryant, the primary researcher, identified several possible causes, including disease, predators, weather patterns, and logging clearcuts. Bryant then developed a research program to "eliminate possibilities" (Bryant, interview). Bryant systematically evaluated evidence for each of these possibilities. Unfortunately, the marmot population is too small for statistical analysis of observations, leading to inadequate sample sizes, lack of experimental controls, and wide confidence intervals (Janz, interview; Bryant, interview). For example, transmitters were implanted in six marmots. Four died over the winter from disease. One was eaten by a predator. Site studies suggest the disease organisms are present in healthy colonies as well. Such results only prove that disease and predation are sometimes causes mortality. Bryant has also tested hypotheses by long-term careful observation of marmot colonies. Through 12 years of repeated surveys, he was able to determine that clearcut areas provide attractive habitat for marmots, perhaps distracting them from dispersing to natural colonies. The clearcut colonies, however, are not sustainable as regrowth occurs, and the marmots eventually disappear. Through a variety of approaches and strenuous efforts, causal knowledge has improved but the small population of the marmots makes standard scientific approaches difficult.

For the old-growth murrelet ecosystem, the causes of murrelet decline appear to be more certain, that is, loss of old growth habitat and gill net mortality at sea. The major issue for murrelet research has been to identify nesting locations. The approach has been to find nest locations through radiotelemetry studies, and then conduct detailed habitat analyses to identify habitat requirements (Manley, interview; Bahn 1998). These requirements have then been used successfully to guide the search for more nests (Manley, interview; Chatwin, interview). The requirements are a prediction about the locations in which nests will be found. They are also a hypothesis about what types of habitat characteristics are required to sustain murrelet populations (Bahn 1998). The next step will be to use comparative surveys of the relative density of nests in

Table 4.14 Comparison of Field Research Technology

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Controlled Studies and Experiments:

- Marmot researchers have conducted numerous experiments and controlled studies with marmot species other than the Vancouver Island marmot.

- Tagging and radiotelemetry studies have been done with the Vancouver Island marmot. The small and vulnerable marmot populations impede standard mark-recapture and other invasive studies. Small numbers and high variability also make standard statistical analyses of data difficult.

Natural and Quasi-Experiments and Comparative Studies:

- The primary marmot researcher, Dr. Andrew Bryant, has used a strong inference approach to evaluating hypotheses about the causes of declining marmot trends, such as disease, predation, environmental conditions, and logging.

- Studies have compared Vancouver Island subalpine habitats, marmot biology, and ecological factors with other regions.

- Past studies, air photos, and habitat inventories can be duplicated at a future date to assess changes. Similarly, dendrochronological and archaeological studies can be conducted to compare past and present conditions.

- Comparative studies of marmot habitats were conducted to identify habitat evaluation criteria.

Artifacts and Anecdotes:

- Early anecdotal evidence that marmot numbers were increasing in the mid-1980s led to underestimation of extinction risk to the marmot.

- Researchers and managers interpret qualitative information based on extensive experience, such as cougar tracks near marmot dens indicating marmot stalking.

- Because of the small marmot numbers, standard statistical procedures often cannot be used. Qualitative information must be used.

Questionnaire:

- The ability of researchers to undertake studies 'in the field' in order to test ecological hypotheses or models about key species and driving factors, using current technologies, is described in responses to the questionnaire as follows: "restricted to shorter growing season, restricted visibility due to low clouds/fog, harsh winter conditions, limited access;" and "limited, marmot colonies are both remote and separate, with few marmots in each one, difficult to gather simultaneous data from several colonies" (Appendix 7, section A7.6, question 18).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Controlled Studies and Experiments:

- Biologists are locating nests, conducting detailed habitat analyses, identifying habitat requirements, and then using GIS to predict nesting locations. Field studies are then being used to verify locations provides a test of nesting habitat models.

- GIS modeling is being used to identify forest characteristics. These predictions can be tested by on-the-ground surveys. Similarly, GIS simulations are being used to model forest development given various harvesting scenarios.

- The testing of models is hindered by lack of sufficient funding for fieldwork.

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Table 4.14 – continued

Natural and Quasi-Experiments and Comparative Studies:

- Ecologists are conducting nesting studies and comparing nesting sites with existing habitat requirements. These requirements are then being used to find additional nests.
- Extensive library of air photographs, resource inventory studies, and other information allow comparisons of present with past.
- Paleoecological and other retrospective methodologies can describe past conditions for comparison with present and projection to the future.

Artifacts and Anecdotes:

- Biologists have interpreted broken eggshells and other circumstantial evidence as indicators of predation.

Questionnaire:

- The ability of researchers to undertake studies 'in the field' in order to test ecological hypotheses or models about key species and driving factors, using current technologies, is described in responses to the questionnaire as follows: "well funded, poorly led, scientifically sound;" "moderate ability when funding is available through Forest Resources BC (1995-98);" and "not quite within reach, due to funding and high work loads, most have to deal with simpler questions" (Appendix 7, section A7.6, question 18).

MARINE CASE: M1 Pelagic Humpback Ecosystem

Controlled Studies and Experiments:

- Controlled studies to test hypothesis for whales are difficult because whales are large and mobile.
- Controlled studies for other ecosystem components are often complicated because a large portion of the the biomass associated with a particular marine ecosystem, such as Gwaii Haanas, migrates through the area or back and forth between the area and other areas.

Natural and Quasi-Experiments and Comparative Studies:

- The level of "natural noise" and high variability in marine systems complicates the ability to detect trends. Trends can only be detected from very long term monitoring studies, especially for ecosystems.
- Technologies for monitoring whales to test hypotheses are available, such as satellite images, satellite tags, ships, and photographic databases. These technologies cannot be deployed more broadly because of lack of funding for ships, technology, and especially people.
- Marine ecologists have conducted comparative studies of large marine ecosystems to test hypotheses about marine ecosystems. Such studies can be done on smaller scales.
- Comparative studies are frequently complicated by a lack of comprehensive information on the marine environment.

Artifacts and Anecdotes:

- Comprehensive information is rarely available for marine environments. Whales spend most of their time underwater or in unknown locations at sea. Researchers have brief glimpses of marine processes and events, which scientists feel may be misleading with "speculation presented as fact." On the other hand, one or two observations of killer whales preying on whales establishes that it can, and probably does happen.
- Photographic identification, although originally considered "grey" science, is now well accepted.

Continued on next page

Table 4.14 – continued

Questionnaire:

- The ability of researchers to undertake studies 'in the field' in order to test ecological hypotheses or models about key species and driving factors, using current technologies, is described in responses to the questionnaire as follows: "unknown;" "adequate;" "unsupported;" and "limited by imagination or lack thereof of researchers rather than technology" (Appendix 7, section A7.6, question 18).

MARINE CASE: M2 Benthic Octopus Ecosystem

Controlled Studies and Experiments:

- Controlled field studies and experiments involving octopuses in British Columbia are rare and cover very small areas.
- Experiments have been done in marine areas with sessile species, suggesting that marine experiments are possible, at least at divable depths. Examples include measurements of primary production, biomass, productivity, and respiration in response to environmental changes. Removal, exclusion, introduction, and translocation of species have been done to observe ecological relationships. Marine protected areas could provide control and treatment sites.
- Experiments are presently being conducted in British Columbia on a series of small islands to study the effects of different fishing practices on sea urchin environments. These methods could be extended to investigate further questions and hypotheses. For example, habitat alteration experiments, such as creating artificial lairs, would be possible.
- Adaptive management has been used to "learn from experience."
- Octopuses are studied in aquaria where experiments on feeding, breeding, and other factors have been done.
- Experimental research is limited by the lack of long-term data sets.

Natural and Quasi-Experiments and Comparative Studies:

- Researchers can compare octopus density in different habitats to identify habitat requirements.
- Octopus research is being done in other jurisdictions, such as Alaska and California. Such studies can be replicated in British Columbia. Comparisons with Alaskan studies have provided information on differences in distributions, habitat requirements, and other factors.

Artifacts and Anecdotes:

- Information on octopus abundance and trends is primarily anecdotal rather than from scientific surveys. This anecdotal and unsystematic information has been sufficient for fisheries researchers and managers to conclude, probably correctly, that octopuses are not endangered or threatened.
- Researchers in a submersible observed a deepsea octopus brooding at sea. This one anecdote establishes that some octopuses brood at sea.
- Fishers provide generally reliable anecdotal information on denning locations, distributions, and other information based on experience.

Questionnaire:

- The ability of researchers to undertake studies 'in the field' in order to test ecological hypotheses or models about key species and driving factors, using current technologies, is described in responses to the questionnaire as follows: "good;" " research done on octopuses is not a priority for funding agencies;" "logistically and financially constrained;" and "it depends on the specific hypotheses tested, too general a question" (Appendix 7, section A7.6, question 18).

Continued on next page

Table 4.14 – continued

Sources: For T1 Ecosystem: interviews with Bryant, Janz, Demarchi, and Klinka. COSEWIC 1998, Demarchi et al. 1996; Del Moral 1984; Franklin et al. 1971. For T2 Ecosystem: interviews with Manley, Chatwin, Niziolomski, Kaiser, Tanasichuk, and Dawson. Bahn 1998; Hebda 1996; Huggett 1993. For the M1 Ecosystem: interviews with Sloan, Darling, Harper, Tanasichuk, and Ellis. Harper 1995; Bakun 1993; Winn and Winn 1985. For the M2 Ecosystem: interviews with Gillespie, Cosgrove, Hartwick, and Marliave. Hunt 1996; Hairston 1989; Davis 1989; Adey 1987; Ballantine 1987; Gamble 1984.

various types of habitat to determine what the minimum habitat requirements are for sustaining murrelet populations, such as size of habitat, types of trees, and other characteristics. The efforts involved in this research have been very extensive.

Research on whales has primarily been limited to "descriptive studies" rather than hypothesis testing (Darling, interview). Whales are too large and mobile (Sloan, interview), and surface only briefly to breathe (Winn and Winn 1985). Whale researchers have mostly been limited to identifying migration patterns, describing behaviors, and identifying prey. For broader ecosystem questions, Harper (interview) suggested that "we have not got that capability and might not be possible" to detect changes in ecosystems. This is because "there is just too much natural noise in the system and we do not know where it comes from." He suggested that "you would have to go for quite a long time to say that something is changing." Harper (1995) also indicated that marine systems are often open systems, and a large portion of the biomass associated with a specific ecosystem migrates through or outside of the area. Bakun (1993) suggested that "the comparative method is the method of choice for situations not amenable to controlled experiments." He argued that the comparative method is therefore necessary for marine research, and applies this method to comparing several marine ecosystems to understand anchovy and sardine habitats.

Field research studies have been conducted for benthic octopus environments. Dr. E.B. Hartwick of Simon Fraser University coordinated underwater research on octopuses in the 1980s to study population dynamics. Jim Cosgrove, now with the Royal British Columbia Museum, has conducted fieldwork on octopuses for years, including tagging studies to explore habitat use. In principle, the methods used by Hartwick and Cosgrove could be extended to test further hypotheses in divable depths. Experiments have been successful in the past with sessile nearshore and intertidal organisms (Hairston 1989). The fixed nature of the substrate is a characteristic of the benthic environment that makes experimentation feasible, as well as the fact that some species remain in the habitat without wandering. The shallow water depths are also divable. Such experiments would be very difficult in deep water. Comparative analyses have also contributed to understanding of these ecosystems. Cosgrove (interview) noted that the depth distribution of octopuses differs between British Columbia and Alaska, and suggested that this is due to predation of octopuses by sea otters in Alaska.

Discussion

Causal research is difficult in all four case ecosystems. For marmots, small population size is critical. For murrelets, the deep forest environment and secretive nature of the species make causal research very expensive. Humpbacks are large and mobile, and invisible underwater. Octopus fieldwork is limited to shallow water, and is again very expensive. The humpback's pelagic environment is perhaps most difficult because this environment is the most "open" and indeterminate and because pelagic environments encompass volumes of water at all depths.

4.14 Defining Listing Criteria

> The level of consensus among ecosystem and species experts and wildlife managers on the logical relationship of the criteria to the driving factors and threats affecting the ecosystem and species, and the consequent suitability of the listing criteria for the particular species and ecosystem.

Introduction

Listing criteria are used to select species for inclusion on endangered species lists. These criteria define factors that suggest that the species is vulnerable to serious decline or extinction, including low population numbers, rapid declines, reduced range, growing threats, or other factors. Listing criteria, which were originally developed for land species, have been modified to apply to marine species (Watson 1998). An important concern is whether presently defined criteria are appropriate for the particular target species within the ecosystems being reviewed. For this research, the question is whether there is agreement among scientists concerning the appropriateness of the criteria, or dissention suggesting equivocality.

Equivocality is lower where there is general agreement among wildlife managers and scientists that the listing criteria provide a reliable basis for evaluating the status of the species, and that no additional criteria or qualifications are merited. Equivocality is higher where scientists and managers do not agree as to whether the listing criteria adequately reflect the level of risk to the species because of differences in ecological systems or complications in collecting data in the environment.

Analysis

This indicator compares the logic behind listing decisions for the four case species. The comparison is summarized in table 4.15.

Table 4.15 Comparison of Listing Criteria Definition

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Current Status:

- Listed as endangered by the Committee on the Status of Endangered Wildlife in Canada in 1979; it was confirmed as endangered in 1997 (COSEWIC).
- Protected and listed as endangered under the B.C. *Wildlife Act* in 1980.
- Listed as endangered under the U.S. *Endangered Species Act* in 1984.
- Listed as endangered by the International Union for the Conservation of Nature in 1994.

Criteria Applied in Listing Decisions:

COSEWIC Status Report Update (Bryant 1997)

- Small and fragmented natural habitat.
- Small population size.
- Serious declining trend with local extinction of several colonies over past decade.

Population Definition:

- Early debates about whether Vancouver Island marmot was a subspecies of another marmot delayed consideration.

Current Condition and Prospects:

- Unanimous agreement that marmot is very rare with a present population of 130-150. (The latest data indicate there may be less than 100.)
- Unanimous agreement that marmot population has declined drastically in the past decade.
- Unanimous agreement that marmot range is extremely small. Its range is concentrated in one small area on Vancouver Island.

Clarity of Ecosystem Threats:

- Active threats presently causing loss of marmot populations are predators, disease, and loss of habitat to logging.
- Potential threats that could cause future population losses include climate change and succession. These forces could suggest that the marmot is destined to extinction in its present habitat regardless of protection.

Present Opinion:

- Biologists are unanimous that marmot is endangered regardless of listing criteria applied.
- All listing agencies have given marmot maximum endangered rating.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Current Status:

- Listed as “threatened” by Committee on Status of Endangered Wildlife in Canada (COSEWIC) in 1990.
- Protected from direct exploitation by federal *Migratory Birds Convention Act*.

Continued on next page

Table 4.15 – T2 Ecosystem continued

- Listing upgraded from Blue to Red List by Government of British Columbia.

- Listed as “Identified Wildlife Species” under B.C. Forest Practices Code.
- Listed as “near threatened” by World Conservation Data Center.
- Listed as “endangered” by California, and “threatened” by Oregon and Washington; listed under U.S. *Endangered Species Act.*

Criteria Applied in Listing Decisions:

COSEWIC Status Report (Rodway 1990)

- Serious threats from the steady loss of essential old growth forest habitat.
- Threats in nearshore areas due to captures in gill nets, loss of nearshore habitats to human uses, and pollution.
- Predicted decline in population due to increasing realization of threats, especially loss of old growth nesting habitat.
- Lack of information on population levels, extent of suitable nesting habitats, seasonal movements, diet, and other factors.
- Low reproductive potential leads to slow recovery potentials from depressed population levels.

Population Definition:

- Biologists have raised a theory that British Columbia’s murrelet population may consist of a number of subpopulations. If so, the Georgia Strait subpopulation may be threatened, but northern populations less so.

Current Condition and Prospects:

- The murrelet population is roughly 45,000 birds, plus or minus 20,000.
- The murrelet population is probably declining as its old growth forest habitat is disappearing.
- The murrelet’s range is decreasing because of logging of old growth habitat.

Clarity of Ecosystem Threats:

- Old-growth forests are in fixed supply for the next centuries, and are being logged at a steady rate, which will reduce distribution extensively in next decade.
- Gill-netting and other marine disturbances reduce murrelet numbers at high rate.

Present Opinion:

- Biologists believe that the murrelet is threatened despite an apparently sizable British Columbia population and visibility. Listings are subject to debate and fluctuating support.
- Supporters of listing argued that listing is not based on abundance, but on growing threats to population, such as loss of old growth forest nesting habitat and mortality at sea, and life history suggesting slow recruitment.
- Murrelets have been proposed as umbrella or indicator species that represent old-growth forests due to their strong dependence on these ecosystems.

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Table 4.15 – ***Continued***

MARINE CASE: M1 Pelagic Humpback Ecosystem

Current Status:

- Protected by International Whaling Commission in 1965.
- Listed as threatened by Committee on Status of Endangered Wildlife in Canada (COSEWIC).
- Protected by U.S. *Marine Mammal Protection Act* and U.S. *Endangered Species Act*.
- Protected by *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES).

Criteria Applied in Listing Decisions:

COSEWIC Status Report Update (Whitehead 1987)

- Population depleted to a level of 2,000 animals in the North Pacific by whaling that ended in 1965.
- Threats of adverse reaction to ship traffic, overenthusiastic whale watching, fishing net entanglements, potential oil exploration, and pollution.
- Population trend was "unlikely" to be decreasing.

Population Definition:

- Biologists do not know if the North Pacific population is a single interbreeding stock or a set of substocks. If substocks exist, these substocks could be at risk, even though the overall population was growing.

Current Condition and Prospects:

- British Columbia's humpback population is probably greater than 550.
- Humpback populations appear to be growing in numbers. Humpback ranges appear to be expanding, and they appear to be re-entering former habitat abandoned because of whaling.
- The North Pacific population has increased from an original post-whaling population of 1,000 or 2,000 in 1965 to a present estimated 6,000.
- Humpback populations are broadly distributed and freely ranging around the North Pacific Ocean.

Clarity of Ecosystem Threats:

- An active threat that could cause slowed population growth is competition with fishers for prey food such as commercial fish.
- Potential threats that could cause future population losses include environmental change affecting prey food abundance, resumption of whaling, and disturbance by fishing and other human activities.

Present Opinion:

- Biologists concede that the humpback might not continue to merit listing as threatened under existing quantitative criteria. The dilemma is reaching a quantitative criteria may signify the population has reached a sustainable level, and could be downlisted.
- Downlisting could to small scale whaling by aboriginal hunters, which did occur with grey whales. This, in turn, could lead to large scale hunting by other nations.
- Some biologists suggested that listing criteria might not consider the value that the public puts on whales as a species, whether endangered or not.

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Table 4.15 – ***Continued***

MARINE CASE: M2 Benthic Octopus Ecosystem

Current Status:

- Department of Fisheries and Oceans (DFO) conducted a stock assessment to consider measures to manage harvests for conservation; harvest pressure is not a present concern (Gillespie, Parker, and Morrison 1998).

Criteria Applied in Listing Decisions:

DFO Stock Assessment Review (Gillespie, Parker, and Morrison 1990)

- *Octopus dofleini* is not endangered or threatened, but common.
- Management information is lacking. Detection of problems would occur from anecdotal information from divers or fishers.
- Management interest in octopus arises from fundamental shift in policy to a precautionary approach.

Population Definition:

- Biologists do not have enough information to identify subspecies.
- Octopuses in different areas often have different foraging strategies, prey species, habitat uses, and other characteristics.
- Planktonic distribution suggests that isolation and speciation are not likely.

Current Condition and Prospects:

- Present information on abundance is anecdotal and unsystematic.
- Overharvesting and population collapses are possible in local areas if large harvests occur in successive years. Stocks would likely rebuild if harvests were rotated among zones. Overharvesting is not considered likely to endanger the species.
- High variability of recruitment and contagious recruitment complicate estimates of endangerment.
- Octopuses have adaptive limitations that may limit endurance, range, and evolutionary survival in long term.
- Distributions of octopus may be changing with shallow intertidal areas less frequently used.

Clarity of Ecosystem Threats:

- Octopus threats are primarily local and do not appear to affect species abundance.

Present Opinion:

- Biologists do not believe that octopus is endangered, but recommend better information for harvest management.

POSTINTERVIEW QUESTIONNAIRE[1]

Q12. The extent to which the ranking criteria normally used by endangered species authorities to assess the risk status of the target species was appropriate for the ecosystem:

- Appropriateness: Rank from high to low is T1, M2, T2, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

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Table 4.15 – ***Continued***

Sources: For T1 Ecosystem: interviews with Demarchi, Janz, and Bryant. COSEWIC 1998; Bryant 1997; Janz et al. 1994. For T2 Ecosystem: interviews with Dunn, Kaiser, Manley, and Chatwin. Davies 1999; Bahn 1998; Sierra Legal Defence Fund 1997; US Fish and Wildlife Service 1996; Rodway 1990. For the M1 Ecosystem: interviews with Darling, Ellis, and Lochbaum. Whitehead 1987; Hay 1982. For the M2 Ecosystem: interviews with Cosgrove, Jamieson, Marliave, and Gillespie. Gillespie, Parker, and Morrison 1998; Jones and Kaly 1996.

The listing decision for the Vancouver Island marmot is unanimously supported by biologists. The marmot is endangered regardless of the ecological criteria applied. The marmot is extremely rare and its habitat severely restricted. Demarchi (interview), for example, stated that the "marmot has evolved in the rarest habitat probably in Canada." Janz (interview) suggested that the species is "naturally rare" because of its restricted habitat requirements. There is also agreement that the marmot has the potential for rapid extinction for ecological reasons. Demarchi (interview) stated that "some species become extinct for natural reasons." In other words, as ecological conditions change, extinction might be a normal or anticipated event, and such a normal event may be the unfortunate fate of the marmot. Natural forces such as climate change and forest succession, together with clearcut logging, could mean, for example, that the species will inevitably become extinct. Bryant (interview), however, argued that extinction is not inevitable, and expressed optimism that captive breeding and reintroduction could reverse declines. While scientists debate the probability of extinction, no one questions the risk. No one argued that the species should not be listed as endangered and given protection. From an ecosystem perspective, the key factor that justifies the listing of the marmot is its limited range and highly specialized habitat requirements. There is thus no lack of clarity in the rationale for listing the marmot as endangered. The rationale is consistent with the listing criteria.

The listing of the murrelet as threatened is more controversial, in part because the species nests in commercially valuable and practically irreplaceable old-growth habitats. Among scientists, there is "fairly good agreement" on the present listing (Manley, interview; Kaiser, interview). The controversy surrounds the apparently large population of 45,000, and their nearly ubiquitous visibility in many coastal areas (Manley, interview). On the other hand, biologists have suggested that the populations cannot avoid decline if their nesting areas continue to decline (Kaiser, interview; Manley, interview). As Manley (interview) indicated, passenger pigeons and buffalo were once not rare so "there is not really safety in numbers." Grumbine (1992) argued that population abundance, as a criterion, is insufficient because it does not incorporate natural ecosystem factors. Ralls, Demaster and Estes (1996) argued that minimum population criteria have to be modified to include the likelihood of major threats that could threaten populations. Otherwise, they contended, the risk to the populations would be understated. Other factors also influence the murrelet listing. Murrelets are also a long-lived bird that reproduces slowly, so recovery of the species would be slow. Subpopulations may also exist that would be considerably more endangered, such as the Georgia Strait populations.

The listing of the humpback whale as threatened is based on their depleted status following whaling. There is some evidence that numbers are recovering and that the species is no longer rare. Some biologists concede that the humpback whale might be downlisted from its present "threatened" status based on existing listing criteria. The North Pacific population size is reasonably large and probably increasing. The range is extensive and expanding. There are no immediate threats to the whales, although the major concern is competition with fishers for food species. Another threat is the prospect of renewed hunting if the species were no longer listed as threatened. Darling (interview) used the example of the recent downlisting of the grey wale in the United States. This led to the approval of a grey whale hunt by the Makah Indians in Washington State, which may have singled out an especially vulnerable subpopulation of resident whales in the area. Concerns about subpopulations could be addressed within the existing listing criteria by designating subpopulations as threatened. There are also fears that aboriginal hunting could lend support to renewed whaling by commercial whalers of other countries such as Japan. Another rationale is an opposition to whaling whether or not the whales are threatened or endangered – a nonecological rationale (Lochbaum, interview). The objection is that the criteria do not reflect the value that the public places on live, unharassed and unhunted whales. This thinking is supported by marine mammal protection regulations, which are not entirely based on ecological or endangerment criteria. In the United States, a higher standard applies under the *Marine Mammal Protection Act* than under the *Endangered Species Act*, suggesting a precedent for differential treatment of categories of animal.

The octopus is a commercially harvested species that is likely at no risk of extinction in the near future. It is a species of management concern, however, because of new changes in policy within the Department of Fisheries and Oceans. The department has adopted a "precautionary approach" to managing commercial species (Gillespie, interview). This means that the policy is to manage all commercial species carefully to avoid potential risks to their abundance. For the octopus, however, the lack of sufficient information on distribution and abundance makes management difficult (Gillespie, Parker, and Morrison 1998). The highly variable and contagious recruitment makes estimates of population abundance and risk difficult. The population dynamics of the octopus also mean, theoretically, that a fishery could take the entire adult population, causing a population collapse, at least locally. The *Octopus dofleini* has served as a proxy in this research for all octopus species. Some of the remaining octopus species are little known, and no status evaluations have been done to determine their level of endangerment.

Discussion

The equivocality of a listing decision depends on the logic of the criteria used to list a species and the relevance of existing information to that logic. The strong support for the marmot's listing is based on good information that the species is genuinely at grave risk. The information supporting the murrelet listing is strong, based on the direct link between the loss of nesting habitat and the decline of murrelet populations. The disputes arise over present abundance and visibility of the bird to the public – factors which may not correlate with future health. For the humpback, the present listing prevents renewed whaling. The management status of the octopus encourages better management, for which additional information is required.

Beyond the case species, listing decisions are fraught with equivocality. Listing decisions depend on someone sensing that a species might be at risk, and preparing a status report recommending that a species be listed. Grumbine (1992) suggested that listing decisions have favored animals over plants, and vertebrates over invertebrates. Terrestrial species have also been studied more than marine species. More generically, very few terrestrial or marine species have been evaluated for listing (Grumbine 1992). Listing decisions generally address vertebrates – a favoritism that ignores other valuable ecosystem components.

Listing decisions do not always confer protection. Listing a species under COSEWIC or provincial lists does not provide species with legal protection (Sierra Legal Defence Fund 1997). The federal Minister of Environment indicated that new endangered species legislation would be introduced to protect endangered species on all government and private lands. However, this legislation may be less stringent than its American counterpart (O'Neil 1999).

4.15 Matching Mode to Threat

The suitability of using protected area option for the types of threat that might affect the target species or ecosystem.

Introduction

The indicators for key driving factors and for threats identify the quality of information about the factors that should be considered in protected areas planning. This indicator compares these factors to the rationale for protected areas. It asks whether protected areas are necessary or appropriate for conservation of this species or ecosystem.

Equivocality is lower where there is agreement among resource managers and ecosystem and species scientists as to whether or not the designation of a protected area would enhance the health and survival prospects of the species and ecosystem. Equivocality is higher where there is no adequate information base for evaluating the value of protected areas for conserving a species or ecosystem.

Analysis

This indicator compares the suitability of a protected area approach for each of the ecosystems. This comparison is summarized in table 4.16.

Despite the acknowledged sensitivity of the marmot meadows to disturbance, not all researchers agreed that protected areas were appropriate. Demarchi (interview) argued that protected areas are necessary to stop roads, mining, tourists, logging, and other disturbances. Klinka (interview) suggested selective high elevation logging is still possible. Protected areas would thus protect the primary habitats of the marmot. On the other hand, Janz (interview) suggested that establishing protected areas would not harm the marmot, but that doubling or quadrupling the size of protected areas "is not going to solve the problem." Bryant (interview) suggested that, because most of the landscape matrix between the colonies has already been logged, the establishment of protected areas might be "thirty-five years too late." The difficulty arises because of the marmot's metapopulation ecology. The marmots disperse between colonies to replenish and intermix. Colonies are not large enough on their own to sustain reproduction, so the marmots must disperse to reproduce. Thus a protected area would need to cover not just the colony sites, but would need to ensure some protection for the landscape matrix in-between. This matrix would involve very large areas (Janz, interview) of mostly private, expensive land (Demarchi, interview; Bryant, interview). With the secondary habitats of the marmot degraded, programs to restore the marmot would be what Frazer (1992) called "a halfway technologies" in his study of sea turtles. A halfway technology "does not address the causes of or provide amelioration of the actual threats" the species faces.

The most serious threat to the murrelet is the continuing loss of its old-growth habitat. Much of the current research focus has been on finding nest location to discourage these locations from being logged. Biologists agreed that protected areas were necessary (Kaiser, interview; Chatwin,

Table 4.16 Comparison of Protection Mode

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Existing Protected Areas:

- Two marmot colony areas have been designated and are being expanded.
- Strathcona Park is already protected, possibly contains suitable habitat, and is planned as capture breeding reintroduction site.

Feasibility of Protecting Primary Habitats:

- Some disagreement exists among biologists over whether protected areas help marmots:

–Key threat of logging has already been done so protected area would not help: "35 years too late."

–High elevation logging, mining, and other activities could endanger colonies in the future.

Suitability of Protected Area Approach:

- Marmot habitats are on private land and therefore expensive.
- Marmot colonies could be included within protected areas, but landscape areas through which marmots disperse are much larger.

Practical Regulatory Alternatives to a Protected Area:

- Marmot habitats are on private land. Government land use control options are limited due to common law restrictions on denying "beneficial use" and limits on regulating private forest lands.

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Existing Protected Areas:

- Existing parks and other protected areas protect only six percent of murrelet habitat.
- Provincial protected areas strategy and recent federal park designations have added some protection.
- Some habitats may become part of aboriginal land claims settlements.
- Protection in the United States is much stronger, better funded, and more extensive due to endangered species legislation.

Feasibility of Protecting Primary Habitats:

- The principal threat to murrelets is the loss of old-growth forest habitat because murrelets are strongly dependent on old-growth habitats. Past losses of habitat may be responsible for population declines.

Suitability of Protected Area Approach:

- Large reserves or protected areas would be necessary to conserve murrelet nesting habitats because nests are widely dispersed and large blocks are required.
- Murrelets may be suitable umbrella or indicator species for a representative ecosystem designation.
- Forest Practices Code limits amount of protection that can be given to species if such protection limits forest harvesting. Existing legislation and Forest Practices Code limits the amount of habitat that can be protected to 10 to 12 percent of present habitat. Some biologists believe this would protect only a small fraction of the present population.

Continued on next page

Table 4.16 – continued

- Murrelets are too dispersed to use a marine protected area strategy, though some murrelets would be protected by areas designated for other conservation reasons.

Practical Regulatory Alternatives to a Protected Area:

- Some ecologists argued that improved forest management practices could conserve murrelet nesting habitats, although others dispute this.
- Some ecologists argued that second growth forests might become suitable habitat in time.
- Protection at sea could be improved by changes to fishing practices.

MARINE CASE: M1 Pelagic Humpback Ecosystem

Existing Protected Areas:

- A humpback whale sanctuary was established on Stellwagen Bank near New England to protect a feeding area.
- Other sanctuaries have been established for breeding areas, such as the Caribbean and Maui.

Feasibility of Protecting Primary Habitats:

- The principal modern threat to humpback whales would be loss of food prey species. Some whale researchers support protection of spawning and rearing areas for whale food species, such as euphausiids or herring. Fisheries interests are likely to be much opposed.

Suitability of Protected Area Approach:

- Humpbacks are free ranging and cosmopolitan, and dynamic in their movements. Primary habitats are thus rapidly changeable. Identification of primary habitats would thus be difficult.

Practical Regulatory Alternatives to a Protected Area:

- Maui whale sanctuary is controversial for biologists, whale watching industry, the state government, and others.

–Opponents argue that existing regulations offer sufficient protection without a protected area.

–Proponents cite educational value of protected area.

MARINE CASE: M2 Benthic Octopus Ecosystem

Existing Protected Areas:

- National Marine Conservation Areas, Marine Protected Areas, and other designated areas are expanding.

Feasibility of Protecting Primary Habitats:

- Octopus distribution is “pretty general.”
- Octopuses are not sedentary, but habitats are ephemeral because of their short life, life stages, and migrations.
- Biologists do not have information on special areas for reproduction.
- Researchers know very little about deepwater habitats that comprise most of the range.
- Brooding females stay in den, so are less likely to be harvested.

Suitability of Protected Area Approach:

- Ecosystem managers are attempting to follow an ecosystem management approach to designating protected areas.

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Table 4.16 – continued

- Octopus habitats could be included within areas that protect other higher priority species.

Practical Regulatory Alternatives to a Protected Area:

- Choice of management options, should they be necessary, is constrained by lack of knowledge and information.
- Large area closures or zones rotated to allow recovery are recommended as a potentially effective approach.

POSTINTERVIEW QUESTIONNAIRE[1]

Q13. The extent to which establishing a protected area would be appropriate for addressing the type of threat affecting the target species in the ecosystem:

- Appropriateness: Rank from high to low is T2, M2, T1 and M1 (tied)

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Bryant, Janz, Demarchi, and Klinka. COSEWIC 1998; Munro 1978. For T2 Ecosystem: interviews with Dunn, Chatwin, Kaiser, Manley, Niziolomski, and Bryant. Bahn 1998; Sierra Legal Defence Fund 1997; US Fish and Wildlife Service 1996; Hebda 1996; Kiester et al. 1996; Jones 1993; Rodway 1990. For the M1 Ecosystem: interviews with Darling, Ellis, Lochbaum, and Sloan. Harper 1995; Whitehead 1987; Winn and Winn 1985. For the M2 Ecosystem: interviews with Gillespie and Cosgrove. Gillespie, Parker, and Morrison 1998.

interview; Manley, interview). The difficulty is that murrelets are widely dispersed so that large areas would need to be reserved to protect the species (Kaiser, interview; Bryant, interview; Rodway 1990). This may be economically infeasible because of the high commercial value of old growth trees, and the potential for some of these areas to be allocated for aboriginal land claims (Kaiser, interview). On the other hand, some of the murrelet habitat is in areas that are "inoperable" or inaccessible for logging at present (Niziolomski, interview). An alternative to a protected area is some form of change to forest practices. The murrelet is an "identified wildlife species" under the Forest Practices Code, which means "general wildlife measures" are to be developed which, among other things, could restrict harvesting of habitats. Unfortunately, the code has not been implemented with much enthusiasm (Sierra Legal Defence Fund 1997), and is being weakened because of opposition of the forest industry. For example, limits have been placed on how much species protection restrictions can reduce timber supply or logging activity. Under current regulations, only 10 to 12 percent of the murrelet's habitat would be protected (Bahn 1998; Dunn, interview). Biologists indicated "it is really doubtful that you would have more than 10 to 12 percent of the murrelets with that much habitat" (Manley, interview). Large areas of protected nesting habitats are required for conserving this species from extinction (Sierra Legal Defence Fund 1993). Bahn (1998) stated "the marbled murrelet will likely go extinct under current silvicultural systems and cutting rates."

Biologists agreed that it would be difficult to protect humpback whales in protected areas because of their mobility and enormous range (Darling, interview; Ellis, interview; Sloan, interview). The principal threat to the humpback in British Columbia waters would be the loss of prey food to fishing activities. Biologists believed that, although "highly contentious," a fishing closure within existing marine conservation areas to fishing would be beneficial for restoring marine ecosystems (Harper 1995). Whales would also benefit.

Because the octopus is widely distributed, biologists do not consider a protected area as necessary (Cosgrove, interview; Gillespie, interview). Alternative regulatory measures exist, such as fisheries closures, rotating zone closures, seasonal closures, and size and gender restrictions (Gillespie, Parker, and Morrison 1998; Cosgrove, interview). The choice of the best options is constrained by the lack of information on what portions of the population is vulnerable, and the effects of various gear types on these populations (Gillespie, Parker, and Morrison 1998). Because of the lack of information on marine ecosystems and the mobile nature of many organisms, Ray (1996) argued that a "seascape" approach to conservation should be used that is similar to the "landscape" approach used for terrestrial systems.

Discussion

The decision to establish a protected area for a species can be equivocal. For the subalpine marmot ecosystem, the protection of the landscape matrix between colonies would be beneficial but is probably too late. Biologists are trying to protect the marmot from extinction until the forest matrix "regreens." At that point, protection may be required if the marmot is not extinct. For the murrelet, protected areas are required, but would subtract from commercially valuable old-growth forest harvests. Protection of humpback food species could reduce commercial food harvests. Protected areas appear not to be necessary for octopuses. In the marmot, murrelet, and humpback cases, protected areas would be beneficial, but the issue is commercial versus ecological value.

4.16 Making Spatial Decisions

The suitability of available descriptive and causal information for making spatial planning decisions.

Introduction

The decision to designate a protected area leads to a series of spatial decisions about type of area to protect, location, boundaries, size, zoning, buffers, and corridors, and associated management restrictions (Salm 1984; Salm and Clark 1989). This indicator can be assessed through interviews and document analysis. A key question is whether habitat managers have enough information to put lines on maps and scientifically justify these lines. For example, biologists may not know the full range of the animal. Ecologists may not know much about the driving factors affecting the ecosystem, or threats to the target species or ecosystem may not be well documented.

Equivocality is lower where available descriptive and causal information provides an adequate basis for making spatial decisions concerning specific protected areas. It is higher where protected areas planners lack descriptive information and causal understanding necessary for making these spatial decisions.

Analysis

This indicator compares the availability of information for making spatial planning decisions for a protected area, assuming one is to be designated. The comparison is summarized in table 4.17.

Marmot biologists have good information for determining the best location for marmot protected areas, should these be designated. The existing colonies are known and fixed in location. Furthermore, apparently suitable habitat exists in Strathcona Park where captive-breeding reintroductions are planned. The critical question for marmots is whether the landscape matrix between the colonies should be protected.

Although biologists know that old-growth forests with certain characteristics are important for murrelets, they are still conducting field studies to identify existing nesting areas. Biologists do not know how large protected areas should be, and current recommendations are based on legal rather than ecological criteria. Foresters suggested that forest harvests could be managed to optimize timber harvests and murrelet habitats (Niziolomski, interview). More information on murrelet habitat needs is required before such optimization can be completed. For areas surrounding murrelet habitats, minimization of fragmentation and roads would be important.

Protection of humpback food species (see indicator 15) could be accomplished by protecting upwelling areas, shallow banks, and other food rich areas. Little is known about the ecology of many of these species, except that populations are variable and habitats are patchy. Information is not sufficient to support spatial planning.

Protected areas for octopuses, if these became necessary, would require sufficient ecological

Table 4.17 Comparison of Spatial Decisions

TERRESTRIAL CASE: T1 Subalpine Marmot Ecosystem

Location Decisions:

- Biologists know the location of present colonies.
- Habitat evaluation criteria have been developed to enable identification of sites for captive-breeding reintroductions.
- Existing areas of Strathcona Park are potentially suitable for reintroductions, and are uncomplicated by ownership issues. However, biologists are concerned about why marmots originally disappeared from certain ostensibly suitable habitats such as Strathcona Park. This leads to uncertainty about spatial planning.

Size Decisions:

- Even with buffers, protected areas to protect marmot meadows would be small.
- Most of land in and around marmot meadows is owned by forest companies, and must be purchased.
- Protected areas would be very large if landscape matrix areas between colonies were protected.

Buffer, Corridor, and Supporting Area Decisions:

- Biologists agree that buffers are needed.
- Dispersal routes are not known, but dispersal is a requirement for replenishment of colonies. Protection of intervening landscape matrix areas between colonies to allow dispersal would be extremely difficult (see indicator 15).

TERRESTRIAL CASE: T2 Old-Growth Forest Murrelet Ecosystem

Location Decisions:

- Habitat models have been developed to identify potential nesting locations.
- Not enough information exists presently to define protected area locations:

  –Identification of protected area locations would be a result of landscape level planning.

  –Definition of protected area sites would be done through detailed habitat surveys.

Size Decisions:

- Biologists could not define what size would be necessary for an effective murrelet protected area. Current size recommendations are based on legal rather than ecological criteria.

Buffer, Corridor, and Supporting Area Decisions:

- Planning for corridors has not been discussed by biologists.
- GIS modeling could be used to define forest harvesting practices.

MARINE CASE: M1 Pelagic Humpback Ecosystem

Location Decisions:

- Biologists do not have sufficient information for identifying summering areas of the whales themselves. Whale behavior is too unpredictable and dynamic to identify specific protected areas for whales (see indicator 15).

Continued on next page

Table 4.17 –*Continued*

- Protected areas could be beneficial for protecting humpback prey species. Humpbacks can travel many kilometers in a day in search of the best feeding areas. Humpback prey are widely distributed, though patchy. Protection of representative ecosystems could encompass adequate food stocks.

Size Decisions:

- Designs of protected areas must consider the functioning of ecosystems. Ecosystem dynamics are not well known.
- The size of a protected area to conserve food stocks would depend on the location of prey, such as upwelling areas.

Buffer, Corridor, and Supporting Area Decisions:

- Biologists do not have sufficient information to protect important areas for whale feeding. The biology and distribution of whale food species is poorly known.

MARINE CASE: M2 Benthic Octopus Ecosystem

Location Decisions:

- Biologists do not know the locations of critical octopus habitats, such as reproductive areas.
- Information would be required to identify octopus home ranges and migratory patterns to ensure that important habitats are enclosed.
- Octopuses occupy different areas and habitats at different life stages.
- Sequential closures of zones would likely be sufficient for protecting octopus populations.
- Some protected areas could be designated to conserve species richness for dive tourism.

Size Decisions:

- Biologists suggested that a protected area would need to be large enough to encompass a range of habitats used at various life stages. This range of habitats is not known.
- Areas would need to be larger because information is lacking.

Buffer, Corridor, and Supporting Area Decisions:

- Harvesting and other activities would have to be controlled in areas outside protected areas to ensure harvesting activities do not affect populations within protected area.

POSTINTERVIEW QUESTIONNAIRE[1]

Q14. The extent to which available scientific information provides an adequate basis from making spatial planning decisions for protected areas in the ecosystem:

- Appropriateness: Rank from high to low is T1, T2, M2, M1

Notes: 1. Cases are ranked from high to low on each factor. Data should be evaluated with caution. Sample sizes are extremely small and variations exist within cases. Data are not statistically rigorous and are provided for qualitative impressions only. See appendix 7 to review original data and more analysis.

Sources: For T1 Ecosystem: interviews with Bryant, Janz, and Demarchi. COSEWIC 1998; Demarchi et al. 1996. For T2 Ecosystem: interviews with Dunn, Chatwin, Niziolomski; Manley, and Kaiser. Bahn 1998; US Fish and Wildlife Service 1997, 1996; Rodway, Regehr, and Savard 1993. For the M1 Ecosystem: interviews with Sloan, Ellis, Lochbaum, and Darling. For the M2 Ecosystem: interviews with Hartwick, Cosgrove, Marliave, Jamieson, and Gillespie. Gillespie, Parker, and Morrison 1998; Dugan and Davis 1993.

knowledge to identify the range of habitats used by the octopus. This information is not available, thus there is not sufficient information for spatial planning.

Discussion

Information for spatial planning is excellent for the subalpine marmot ecosystems, and information is rapidly developing for the old growth murrelet ecosystems. In both cases, habitat requirements are known, and there is reasonable information on the range and distribution of species. For humpbacks and octopuses, very little is known about the specific habitats they use in British Columbia waters. Marine researchers are not able to identify areas that need to be protected to conserve these species. Information is insufficient for spatial planning for pelagic and benthic ecosystems.

This chapter reviewed information on the sixteen indicators. This information provides the primary evidence for evaluation of the seven hypotheses reported in chapter 5.

CHAPTER 5: CONCLUSIONS CONCERNING HYPOTHESES

> "However intensively and extensively data are collected, however much we know of how the system functions, the domain of our knowledge of specific ecological functions is small when compared to that of our ignorance. Thus one issue for design and evaluation of policies is how to cope with the uncertain, the unexpected, and the unknown" (Holling et al. 1978).

This chapter discusses conclusions concerning the seven hypotheses. The analysis for this chapter is based on data from interviews, analysis of official documents, participant observation, and research literature, as summarized in chapter 4.

5.1 Hypotheses Concerning Problem Formulation

Equivocality in the problem formulation function was assessed through two hypotheses. The first deals with listing rationale, and addresses the importance of the decision. The other addresses the appropriateness of protected areas as a mode for protecting species in the case ecosystem, and addresses a methods rationale (section 2.6.2).

Hypothesis 1: Listing Rationale

> The ecological rationales for listing particular marine species as target species for protection are less clear than the ecological rationales for listing terrestrial species.

The first step in a species-at-risk program is to determine whether a species should be given special protection. This step determines whether it is important to take action. Listing decisions are typically made by a listing authority, such as the Committee on the Status of Wildlife in Canada (COSEWIC), the provincial government, or an agency responsible for the species (indicator 14; section 2.4).

Listing authorities rely on generally accepted evaluation criteria for judging the level of risk that a species will become extinct. These criteria include ecological factors such as rarity, population trends, range, and threats. Typically, scientists review what is known about a species, and apply the criteria to determine whether to list the species as endangered, threatened, or other category.

In order to evaluate this hypothesis, each case species and ecosystem was assessed to identify factors that would provide evidence for the presence or absence of equivocality. The ecological rationales for listing species were rated as exhibiting low, medium, or high equivocality. The focus of the rating process was the ecosystem rather than the case species. As noted in section 3.2.4, the case species provided a window into the listing process for the ecosystem.

For a low equivocality rating, the ecological rationales for listing the species within the ecosystem should be clear and appropriate for application within the ecosystem. Where low equivocality exists, scientists would be in general agreement with the rationales for listing species.

For a medium equivocality rating, the rationales for listing species within the ecosystem would be subject to variations. Variations might include the listing of a relatively common species as threatened because of very high population variability or rapid population declines.

For a high equivocality rating, species within the ecosystem would be difficult to evaluate for listing. Complications might arise from uncertainties or disagreements over whether listing criteria were applied appropriately in listing decisions, or over whether the listing criteria themselves were appropriate for application within the ecosystem. Use of the listing criteria might also be complicated by the lack of important information. In addition, there might be disagreements about the validity of listing criteria or the underlying rationales for the ecosystem.

The section includes subsections discussing the case species and the ecosystems. Table 5.1 presents evidence for lower and higher equivocality for terrestrial ecosystems, and table 5.2 for marine ecosystem. Table 5.3 summarizes the analysis for the hypothesis.

T1 Subalpine Marmot Ecosystem

The listing decision for the Vancouver Island marmot was uncontroversial (indicator 14). Researchers expressed no doubts that the present endangered status was merited, regardless of the criteria applied (Bryant, interview; Demarchi, interview; Janz, interview; Chatwin, interview). The rationale for the listing was low and declining populations (indicator 1), limited and shrinking range (indicator 2), and the need for urgent recovery measures to prevent imminent extinction (indicators 7 and 15). The only debate was whether recovery is possible (Demarchi, interview), though researchers and managers are agreed on the appropriateness of the criteria for this case (appendix 7). The marmot *species* listing rationale thus exhibits *low equivocality*.

The T1 subalpine *ecosystem* also exhibits *low equivocality* (Table 5.1). Considerable information exists on the terrain, vegetation, environmental systems, biodiversity, and food webs for this ecosystem. The ecosystem is in rugged terrain, but is small and generally open to observation, and is accessible without major equipment. At the same time, the ecosystem does exhibit some equivocality in the delicate balance, variability, and unpredictability of environmental systems that maintain marmot meadows. The strong information base and accessibility of this ecosystem to research provided strong support for the application of existing listing criteria for the

Table 5.1 Evidence concerning Equivocality in the Ecological Rationales for Listing Species within the Terrestrial Case Ecosystems

This table addresses the application of the listing criteria for the ecosystems primarily rather than the case species.

TERRESTRIAL CASES

T1 Subalpine Marmot Ecosystem

Overall Rating: Low

Evidence for Lower Equivocality

- The physical geographic and environmental systems have been studied and inventoried relatively well, and basic processes are understood (indicators 3 and 6).
- The biodiversity of this ecosystem is relatively well documented, except for invertebrates, and it is not expected that major new plant or vertebrate species will be discovered. Existing knowledge is sufficient for classification of endangered and threatened species (indicator 4).
- The functioning of major subalpine vertebrate food webs is relatively well understood (indicator 5).
- The human threats to this ecosystem are known (indicator 7).
- The ecosystem and its processes are relatively easy to access, observe, and study (indicators 8, 10, 11, 12, and 13).

Evidence for Higher Equivocality

- The marmot meadows are delicate balanced, variable, and unpredictable, and highly sensitive to changes in environmental systems.

T2 Old-Growth Murrelet Ecosystem

Overall Rating: Medium

Evidence for Lower Equivocality

- The physical geographic and environmental systems have been studied and inventoried relatively well, and basic processes are understood. Extensive research is continuing to document the dynamics forest ecosystems (indicators 3 and 6).
- The biodiversity of this ecosystem is relatively well documented, except for invertebrates, and it is not expected that major new plant or vertebrate species will be discovered. Existing knowledge is sufficient for classification of endangered and threatened species (indicator 4).
- The major vertebrate food webs are relatively well understood (indicator 5).
- The human threats to this ecosystem are known (indicator 7).
- Biologists are successfully carrying out a variety of causal research studies for this ecosystem (indicator 13).

Evidence for Higher Equivocality

- Old growth forest ecosystems are relatively complex. Although old-growth forests have been relatively stable for a long period, potentially little understood organisms, such as soil fungi, may have major effects on the functioning of this ecosystem (indicators 4, 5, and 6).
- Access to old growth forest ecosystems is difficult, often requiring helicopters and backcountry travel through rugged terrain (indicator 8).
- Observation and research within this ecosystem is difficult (indicator 10).

evaluation of species risk. The ecological rationale for listing species in this ecosystem is thus clear and equivocality is low.

T2 Old Growth Murrelet Ecosystem

The listing decision for the marbled murrelet was more controversial, due in part to the commercial value of old-growth forests (indicators 7 and 14). The interviewed biologists agreed generally that the marbled murrelet species was currently threatened or will be in time if old-growth forests continue to be harvested. The present apparently large population of 45,000 (indicator 1) and range covering much of the British Columbia coast (indicator 2) argued against listing. The assumed steady decline in population and slow population recruitment (indicator 1), the close association with old-growth forests for nesting (indicator 2), and the rapid logging of these old-growth forests (indicator 7) argued for the threatened listing. The threatened listing thus has strong merit, although some question the priority that should be given to protecting this species (indicator 7). The murrelet *species* listing criteria therefore can be classified as *medium equivocality*.

The T2 old-growth *ecosystem* also appears to exhibit *medium equivocality* (table 5.1). Considerable information is available on old-growth forest ecosystems because of inventory efforts, presence in the forest because of forest management and logging activities, and because some of the forests close to communities, where they can be studied. On the other hand, old-growth forest ecosystems are complex, and many parts of the forest are inaccessible. The strong information base for this ecosystem argued for low equivocality, but the complexity of this ecosystem and the difficulty obtaining access to it for research lead to higher equivocality. Despite the constraints of complexity and access, researchers are conducting extensive research on this ecosystem. A reasonable basis exists for the application of existing listing criteria for the evaluation of species risk. The ecological rationale for listing species in this ecosystem is thus moderately clear and equivocality is thus medium.

M1 Pelagic Humpback Ecosystem

The threatened listing for the humpback whale species is somewhat ambiguous (indicator 14). There is evidence that the humpback populations are increasing (indicator 1) and their range is expanding (indicator 2). There are concerns that downlisting could bring about renewed aboriginal hunting that could threaten subpopulations, or lead to a resumption of commercial whaling (indicator 7). There are also concerns that commercial fishing could overharvest the prey species of the whales, though this is not considered an urgent threat (indicator 7). The criteria for listing the humpback *species* as threatened thus appear to exhibit *medium equivocality*.

The M1 pelagic *ecosystem,* on the other hand, appears to exhibit *high equivocality* (table 5.2). Pelagic ecosystems are known in broad outlines, but details on ecosystem attributes and functioning are very limited. The very high fluidity and variability of these ecosystems makes these systems difficult to understand. Although biodiversity studies have identified major species, very little is known about the life histories of many species, particularly the early life stages. Access to this ecosystem requires expensive ships, which are only able to work in certain sea conditions. Because of the high variability and limited information on the functioning of this ecosystem, and the scarcity of data on biodiversity, determination of rareness, endangerment, and ranges occupied by many species is often not feasible. It is unlikely that such determinations will be possible for many years. These factors may explain the fact that very few marine species have been included on official lists as endangered or threatened. The ecological rationale for listing species in this ecosystem is thus poor, and equivocality is rated high in this research.

M2 Benthic Octopus Ecosystem

The octopus is not listed as threatened or endangered, but is a species of management concern because of its commercial value. The octopus is a commercially harvested species with minimal expected risk of extinction (indicators 7 and 14). The octopus has received recent attention because of recently adopted federal conservation policies that require commercial species to be managed cautiously. The species is common and widely distributed (indicator 2), and there is no evidence of overharvesting at present (indicator 7). However, information on population abundance, trends, range, and distribution are very sketchy (indicators 1 and 2). In addition, the species exhibits high variability and contagious recruitment, that is, unexplained population explosions and subsequent sharp declines (indicator 1; Marliave, interview). Biologists recommended further research to support management and avoid future risks of overharvesting. It is concluded that the criteria for evaluating the status of the *Octopus dofleini species* exhibits *medium equivocality*.

The M2 benthic *ecosystem,* however, appears to exhibit *high equivocality* (table 5.2). The sea bottom provides a fixed substrate for habitats, and benthic environmental systems tend to be more stable. On the other hand, little is known about benthic environments beyond very general and

Table 5.2 Evidence concerning Equivocality in the Ecological Rationales for Listing Species within the Marine Case Ecosystems

MARINE CASES

M1 Pelagic Humpback Ecosystem

Overall Rating: High

Evidence for Lower Equivocality

- Species in the water column have been caught by fishers or sampled by research trawls. Commercial species and most pelagic vertebrates have been identified (indicators 4 and 11).

- Pelagic ecosystems are believed to have fewer species than benthic or terrestrial ecosystems (indicator 4).

Evidence for Higher Equivocality

- Environmental systems are monitored by satellite and a limited grid of data gathering stations. Basic processes are understood in general, but prediction is complicated by high variability, multiple cycles, oscillations, and regime shifts (indicators 6 and 8).

- Food webs, biological productivity, and the distribution of food species are affected by the high variability of environmental systems. These processes are not well understood (indicator 5).

- Few biodiversity inventories have been conducted. The best information relates to commercial species, but minimal information exists on the ecology even of these species (indicator 4).

- Some whale species, other vertebrates, and large invertebrates have been observed, but are undocumented and their life histories and ecology are almost unknown. For example, the giant squid is known only from dead specimens washed up on beaches. Biodiversity is thus poorly known (indicator 4).

- Many invertebrate species are lost through the mesh of fishing and research nets, and some are able to avoid capture (indicator 11).

- Biodiversity studies are extremely difficult because of the vast extent of the ecosystems, the extreme variability of environmental factors, the different habitats occupied by various species in different life stages, the extreme mobility of many pelagic species, the difficulty in accessing many habitat areas, and the expense of conducting biodiversity studies. As a result, inventories can only be conducted in a few scattered locations, and the completion of broad surveys will require very long periods (indicator 2, 3, 8, 9, 10, 11, 13).

M2 Benthic Octopus Ecosystem

Overall Rating: High

Evidence for Lower Equivocality

- The sea bottom provides a fixed habitat so that many species remain in the same areas (indicator 6).

- Benthic environments tend to be more stable in terms of temperature, salinity, and other factors (indicator 6).

Evidence for Higher Equivocality

- The physical geography is known on a general level, but has not been studied in detail. Bottom terrains and habitats have not been mapped, except in a few locations (indicators 3 and 6).

Continued on next page

Table 5.2 –*Continued*

- Environmental systems of surface waters are monitored in general, but are highly variable and difficult to predict. Environmental systems operating in shallow water are understood in general, but only for a few areas. Benthic environments below divable depths are poorly understood (indicator 6).
- Very few biodiversity inventories have been conducted below divable depths. Benthic habitats are very species rich compared to pelagic environments. Many new and important species discoveries are being made. The best information relates to commercial species, but minimal information exists on the ecology even of these species. Although biologists have studied the giant Pacific octopus and have a general understanding of its shallow water ecology, nothing is known about it in deeper water. There are eight or nine species of octopus in British Columbia waters, most occurring in deep water. Most of these species are only vaguely known and are very poorly documented. Such information deficits are common (indicators 4 and 5).
- Biodiversity studies are extraordinarily difficult because of the vast extent of the ecosystems, the different habitats occupied by various species in different life stages, and the mobility of many benthic species. Access to divable depths is brief, and deeper habitats are not accessible because of the rare availability of submersible and remotely operated vehicles for research. The difficulty in accessing many habitat areas makes biodiversity studies extremely expensive and infrequent. As a result, inventories can only be conducted in a few scattered shallow locations, and the completion of broad surveys is not presently possible (indicator 2, 3, 8, 9, 10, 11, 13).

local information. Very few studies have been conducted below divable depths except for analysis of fishing catches and research trawls. Access is extraordinarily difficult, and at present is prohibitively expensive except for research of exceptional importance. Ecologists know little about the processes that might lead to extinction, and are unable to determine whether species are rare, endangered, or in many cases, extinct (Carleton 1992; 1993). The lack of information and inaccessibility of the M2 benthic ecosystem means this environment is very poorly understood. The ecological rationale for listing species in this ecosystem is thus poor, and equivocality is high.

Conclusions

Table 5.3 summarizes the findings discussed above. Hypothesis 1 proposed that the ecological rationale for listing particular marine species for protection are less clear for marine environments than for terrestrial environments. The first null hypothesis proposed that the ecological rationale for listing decisions would be clearer for marine than for terrestrial ecosystems. The second null hypothesis proposed that the ecological rationale for listing decisions would not differ in clarity for marine and terrestrial ecosystems.

In table 5.3, the T1 case species rated low in equivocality in row 1, and the other three cases were medium. The ecological rationale for listing the marmot as endangered is very clear, while there are qualifications on the listing of the other species in their respective categories.

Table 5.3 Listing Rationale

	Rating Criteria for Equivocality			Ratings		
	Low	**Medium**	**High**	**Low**	**Med**	**High**
1. The clarity of current ecological rationales for listing the case *species*	Ecological rationales are clear and appropriate	Ecological rationales are subject to variations	Ecological rationales are subject to uncertainties, disagreements, or serious information gaps	T1	T2 M1 M2	
2. The clarity of current ecological rationales for evaluating species within the *ecosystem*	Ecological rationales are clear and appropriate	Ecological rationales are subject to variations	Ecological rationales are subject to uncertainties, disagreements, or serious information gaps	T1	T2	M1 M2

On row 2, the T1 and T2 ecosystems rated low and medium in equivocality, while both marine ecosystems were high. Ecological rationales appeared to be less equivocal for listing species in the land environment because of existing inventories and ecological knowledge.

Based on the analysis, both null hypotheses are rejected. The ecosystem ratings (row 2) were weighted more heavily than the species ratings (row 1). Although the murrelet case matches the rating for the marine systems, the murrelet was chosen as a terrestrial case that would be very high in equivocality in a terrestrial species. Biologists were unanimous that this species was very difficult to study. On the other hand, the humpback was chosen as a low to moderate equivocality marine case, and more information certainly exists for this whale than most other whale or fish species. The giant Pacific octopus was chosen because information was available, and as a well-studied commercial species, it is clearly the best known of the several octopus species in British Columbia waters. All of the other octopus species would be less known and hence more equivocal. Thus, both the humpback and octopus species were very conservative cases for evaluating this hypothesis. For these reasons, the species ratings do not conflict with the ecosystem ratings. Hypothesis 1 is thus *not rejected*, and is supported by the data. Therefore, it is concluded that listing rationales are less clear for marine ecosystems that for terrestrial ones, which means the equivocality of listing rationales is greater for marine ecosystems than for terrestrial ecosystems.

Hypothesis 2: Protected Area Rationale

> The ecological rationale for selecting protected areas to conserve target species is less clear for marine protected areas than for terrestrial protected areas.

In order to test hypothesis 2, three concerns were evaluated: the characteristics of the species' habitats, the identification of habitats, and the efficacy of protected areas and alternative approaches for conserving habitats. Table 5.4 summarizes the comparison of ecosystems. This analysis is based on results summarized in chapter 4.

Habitat Characteristics

Habitat characteristics were considered in rows 1, 2, 3, and 4 of table 5.4. Row 1 assessed the degree to which the species uses the same habitat continuously. A low rating was applied to "stay at home" species that remain most of the time in certain areas, whereas a high rating was applied to more "footloose" species that wander among different habitats. In between were the more seasonal species. For this row, the T1 marmots tend to remain in their colonies where they can be observed, except for a few individuals that may disperse once in their lives. The T2 murrelet and M2 octopus migrate, but these species are observed in the same areas year after year. The M1 humpback migrates, and when in British Columbia waters, roams dynamically from place to place.

Row 2 measured the degree of continuity in the primary habitat. In general, a more continuous area of habitat would be more effective as a protected area. A low equivocality rating was applied if the primary habitats are continuous. A medium rating was given if the patterns were patchy and discontinuous. Both terrestrial cases occupy patchy habitats that are somewhat discontinuous. The high rating applied if the habitat distribution is broadly spread out and diffuse rather than focused either in one location or in patches. This distribution would complicate knowing where a protected area might be designated to be effective. Both marine species exhibited widely distributed and changeable habitat use.

Row 3 assessed the degree to which the case species are confined within specific biogeographic boundaries. A species that conforms to biogeographic boundaries might be protected by designating representative ecosystems as protected areas. A low rating applied to both terrestrial cases, which were confined to very specific types of biogeographic area. A medium rating was given to a species that occurs in a few known biogeographic areas. A high rating was assigned to the two marine cases, which involved species that were freely distributed unpredictably among different biogeographic areas.

Table 5.4 Protected Area Rationale

	Rating criteria for equivocality			Ratings		
	Low	**Medium**	**High**	**Low**	**Mid**	**High**
Habitat Characteristics						
1. Constancy of use of primary habitats by most of species individuals (2, 9, 12)	Primary habitat is used by individuals continuously for most of their lives, except for occasional dispersal	Primary habitat is used by individuals intermittently or seasonally but regularly by species between migrations	Species uses various primary habitats in a dynamically, ephemerally, or unpredictably	T1	T2 M2	M1
2. Continuousness of primary habitat patterns (2, 9, 12)	Pattern of primary habitats is continuous	Pattern of habitats is patchy and discontinuous	Pattern of primary habitats is widely distributed and dynamic		T1 T2	M1 M2
3. Fidelity to biogeographic zones (2, 3, 9, 12)	Species is confined mostly to one biogeographic area	Species is limited to a few known biogeographic areas	Species is distributed freely among different biogeographic areas	T1 T2		M1 M2
4. Pattern of dispersal or migration among primary habitats (2, 9, 12)	Patterns and routes of movement are relatively well known	General patterns of movement are conjectured based on limited information	Patterns of movement are not known or speculated		T1 T2 M1	M2
Habitat Identification						
5. Knowledge of case species habitat requirements (2, 9)	Habitat requirements are known based on detailed habitat evaluations	Habitat requirements are known from direct field observations of habitat use by species	Habitat requirements have not been evaluated or are poorly known	T1 T2	M2	M1
6. Identification and mapping of areas with suitable habitat[1] that is occupied[2] (2, 3, 4, 5, 6, 7, 9, 12)	Most suitable and occupied habitats have been mapped	Suitable and occupied habitats have not been mapped in detail, but likely areas are known from general habitat characteristics	Suitable habitats are not sufficiently known for mapping	T1	T2	M1 M2

Continued on next page

Table 5.4 continued

7. Knowledge of environmental and human factors that affect habitat conditions (2, 6)	Factors sufficiently stable and persistent to enable prediction of future conditions	Factors influencing future conditions have been identified, but predictions of future habitat conditions are uncertain	Factors are too dynamic or unstable to predict	T2 M2	T1	M1
Conservation Efficacy						
8. Knowledge base for determining whether or not a protected area option, if applied, would insulate primary habitats[3] of species from known threats (13, 7)	Existing knowledge provides firm basis for evaluating efficacy of protected area option	Existing knowledge provides a basis for evaluating the efficacy of protected area option, but the evaluation remains somewhat tentative or uncertain	No knowledge basis exists for evaluating efficacy of protected area	T1 T2	M1 M2	

1. Suitable habitat is habitat that meets habitat requirements for the species.

2. Occupied habitat is habitat that is used part time or full time by the species.

3. Primary habitat is defined here as the habitat area used most frequently or intensively by the species, such as the marmot meadows, murrelet nesting areas, or humpback feeding areas.

Row 4 assessed the degree to which the patterns of movements of the case species are known. A low rating was applied to situations where migration or dispersal rates are known. A medium rating would apply to cases where biologists have enough information to conjecture the general movements of the species, but not enough to know specific routes. A high rating would apply to situations where very little information exists on movements. For the T1 case, dispersal is known to occur among colonies, although the routing appears to be random and marmots are observed in unexpected locations. The T2 murrelets move from nesting to wintering areas in unknown but probably direct routes. The M1 humpbacks migrate apparently directly from wintering to summering areas, but then wander unpredictably within northeast Pacific coast waters and other regions. The T1, T2, and M1 cases were considered to exhibit medium equivocality. The M2 octopus migrations are believed to occur, but there is no information on routes or deep-water destinations. It was rated highly equivocal for habitat characteristics.

Habitat Identification

Rows 5, 6, and 7 addressed the ability of researchers to identify habitats that might be protected in a designated area.

Row 5 assessed whether the habitat requirements of the case species are known. Before a protected area could be considered, managers need a clear definition of what sorts of habitats need to be protected. A low equivocality rating applied where biologists have done systematic and detailed fieldwork to identify the types of habitat the species depends on. This has occurred with the T1 marmot and the T2 murrelet. A medium rating was applied where biologists have a general understanding of habitat requirements from direct field observation of the species using the habitat. This applied to the M2 octopus, where diver-biologists have observed octopus using their dens and foraging underwater. The high rating applied in the M1 humpback case where observations of habitat use have been sporadic and limited to the sea surface.

Row 6 addressed the degree to which suitable occupied habitats have been identified. Suitable habitats are ones that meet the habitat requirements of the species. Occupied habitats are habitats used full time or part time by the species. A low rating applied to the T1 marmot case where most suitable and occupied habitats have been mapped in some detail. A medium rating applied to the T2 murrelet case where habitats are not mapped in detail, but are known generally from habitat characteristics and observations of murrelets in inlets near old-growth forests. Biologists have used landscape mapping to focus on areas where likely habitat exists, and are in the process of confirming occupancy. The high rating applied to both marine cases where existing data are not sufficient to enable mapping of any major portion of their habitats.

Row 7 addressed knowledge of likely future changes to conditions of the habitats. Because protected area designations are generally long term or permanent, a protected area designation should give preference to habitats that are relatively durable and persistent. A low rating applied to stable and persistent habitats and a high rating applied to dynamic and unstable habitats. A medium rating applied where the key factors causing change are known, but the future conditions are uncertain because of variability in trends. The T2 murrelet habitats are very persistent naturally, but planned logging would remove most of the habitat. The M2 octopus habitats are also stable and are not likely to change too quickly except for changes to food webs caused by overfishing. The T2 and M2 habitats were rated as low for equivocality. The factors affecting T1 marmot habitats are known, but future conditions are likely changing in uncertain ways due to climate change and short-term variations can affect habitat suitability considerably. This ecosystem was rated medium. The M1 pelagic humpback ecosystem is highly dynamic, and subject to short and long term cycles, oscillations, and regime shifts. It was rated high.

Conservation Approach

Row 8 considered whether the establishment of protected areas is best approach for conserving the suitable habitats of the case species. It assessed whether sufficient information exists to determine whether a protected area would be effective in insulating primary habitats from known threats. Low equivocality means that existing knowledge provides a firm basis for evaluating efficacy, whereas a high rating indicates existing knowledge provided no basis for evaluation. A medium rating implies that existing knowledge provides some basis, but uncertainties remain. The equivocality of T1 and T2 ecosystems was rated low because biologists indicated that protected areas would be able to protect primary habitats from known threats. On the other hand, biologists had less confidence in the effectiveness of protected areas for the M1 and M2 species, largely because of the lack of information about their habitats and the species' mobility.

Conclusions

Hypothesis 2 proposed that the ecological rationale for using a protected area approach for conserving case species was less clear for marine ecosystems than for terrestrial ecosystems. The first null hypothesis proposed that the ecological rationale would be clearer for marine than for terrestrial ecosystems. The second null hypothesis proposed that the ecological rationale for using a protected area approach to conserve target species does not differ in clarity for marine and terrestrial ecosystems.

The habitat characteristics (rows 1 – 4) and habitat identification (rows 5 – 7) categories supported the notion that there is greater equivocality with respect to these factors for marine ecosystems than for terrestrial ecosystems. Thus, the null hypothesis that equivocality is higher for terrestrial ecosystems is rejected. The null hypothesis that there is no difference in equivocality is rejected because equivocality appears higher for the marine systems.

The conservation capability category (row 8) assessed the knowledge base for determining if a protected areas strategy would be effective, suggested marine systems are more equivocal. The conservation capability category suggests that there is greater equivocality associated with marine ecosystems than with terrestrial ones.

On balance, hypothesis 2 cannot be rejected, and is largely supported by the interview and documentary data. The conclusion of this analysis is that hypothesis 2 merits support. The ecological rationale for selecting protected areas to conserve target species is less clear for marine protected areas than for terrestrial protected areas. There is less clarity in terms of the environment of the marine species, including major threats, which makes a protected areas strategy both more problematic and less practical. If a protected areas strategy is ruled out on the grounds of impracticality due to the migration patterns of the species, then the question of relevance becomes: to what extent is the ecological rationale for choosing a particular conservation strategy, from among the alternatives available, more clear for terrestrial than marine species? This is a question for further research.

5.2 Hypotheses Concerning Information Gathering

Equivocality for the information gathering function is assessed through two hypotheses. Hypothesis 3 assessed the relative differences in the amount of descriptive information. Hypothesis 4 assessed the relative quality or "richness" of information.

Hypothesis 3: Selection Information Amount

> A lesser amount of descriptive ecological information is available for target marine species and ecosystems than for target terrestrial species and ecosystems.

In order to test this hypothesis, the state of descriptive information was assessed for each case species and ecosystem. The species analysis discussed in the following section was based primarily on indicators 1 and 2, as described in chapter 4. The ecosystem analysis is discussed in the next section.

Species Information

Table 5.5 summarizes the comparison of descriptive information available for the case species. Key data sets for case species include population and range estimates.

Population abundance and trends (indicator 1) were addressed in rows 1 and 2. The differences in ratings reflected the degree of precision and reliability in the estimates. For precision, a low equivocality rating indicates that the upper and lower bounds of the abundance or trend estimates are known. For reliability, the estimates would be provided by strong scientifically accepted procedures and data sets. For medium equivocality, biologists might know only the approximate population, base on limited data and informed expert opinion. For a high rating, researchers would not be able to give any estimate of trends or abundance, other than by speculation.

In both rows, the T1 case was rated as low and the T2 case was medium. The M1 case was rated as medium in both rows, and the M2 case was rated high in both rows. The consistency of these results between the two rows would be expected because population abundance and trends

Table 5.5 Amount of Descriptive Ecological Information for Case Species

	Rating criteria for equivocality			Ratings		
	Low	**Medium**	**High**	**Low**	**Mid**	**High**
Species Population						
1. Population abundance estimates for case species (1, 9, 10, 12, 13)[1]	Population estimates provide upper and lower bounds for abundance, based on accepted scientific techniques	Population estimates provide general information about the rarity or abundance of the species, based on limited censuses and expert opinion	Population estimates are unavailable or are based on expert speculation only	T1	M1 T2	M2
2. Population trend estimates for case species (1, 9, 10, 12, 13)	Trends have been estimated based on accepted scientific techniques and good quality time series data	Trends have been guesstimated based on cogent indirect evidence or expert opinion	Trends are not known or are based on expert speculation only	T1	M1 T2	M2
Species Range						
3. Proportion of the potential range of the case species' in British Columbia that has been confirmed by census surveys (1, 2, 8, 9, 10, 12)	More than two-thirds of species range has been surveyed and mapped	Between one third and two thirds of the range has been surveyed, or projected from habitat require-ments	More than two-thirds of the range is unknown or speculative	T1	T2	M1 M2
4. Identification of temporal changes in distribution and patterns of dispersal or migration movements of species within British Columbia (2, 8, 10, 12)	Origins, destin-ations, and routes of temporal movements are relatively stable and well known	Origins and destin-ations are generally known, but routes are conjectured and not verified	Patterns of move-ments are poorly known or speculative		T1 T2	M1 M2

Notes:

1. Sources of bias include factors such as the mobility of animals, recognition or marking of individuals, observability of animals, and other constraints on census reliability.

are estimated from the same procedures, so the estimates are only partially independent. The two rows provide a crosscheck on the same data point, the amount and quality of population information.

Species range and distribution (indicator 2) were addressed in rows 3 and 4. In row 3, ratings were based on the proportion of the range that has been surveyed, roughly divided in thirds.

Almost all of the marmot range has been surveyed, and at least half of the murrelet range. Very little of the humpback and octopus ranges, probably less than 10 percent, has been surveyed. Row 4 ratings were based on overall knowledge of species movements

Ecosystem Information

Table 5.6 summarizes descriptive information available for the case ecosystems. The key data sets were physical geography, environmental systems, biodiversity, and ecological systems. For all rows, the rating criteria for low equivocality signified that the data sets are relatively detailed. For high equivocality, the information would be sketchy or incomplete. The medium rating meant there would be information at an overview scale, but detailed site data are not available.

Row 1 addressed the amount of information on physical geography, including geology, terrain, and surficial conditions. Based on information from interviews and documents, the terrestrial ecosystems were rated as low for equivocality and the marine systems were rated, conservatively, as medium. Row 2 considered the amount of information on environmental systems. Information from interviews and documents suggested that very detailed information exists for terrestrial systems, whereas data are at an overview level for marine systems (chapter 4).

Rows 3, 4, and 5 addressed biodiversity. Knowledge of more common plant species is generally good for both terrestrial and marine ecosystems (row 3), and poor for all ecosystems for invertebrate diversity (row 5). Knowledge of vertebrate diversity is good for terrestrial systems, but is more limited for marine systems (row 4). Row 6 assessed the amount of information on predator-prey relationships. Information from interviews and documents suggested that information was detailed for T1 ecosystems, and that T2 food webs were understood in general for T2 ecosystems. Information for M1 and M2 ecosystems is sketchy.

Conclusions

Hypothesis 3 proposed that a lesser amount of descriptive ecological information is available for marine than for terrestrial species and ecosystems. The data from interviews, documents, and research literature provided a strong basis for evaluating this hypothesis. The hypothesis is *not* rejected, and is strongly supported by the data.

Table 5.6 Amount of Descriptive Ecological Information for Case Ecosystem

	Rating criteria for equivocality			Ratings		
	Low	Medium	High	Low	Mid	High
Physical Geography						
1. Amount of information on geology, terrain, and surficial conditions for the biogeographic area (3, 6, 9, 10, 12, 13)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete	T1 T2	M1 M2	
Environmental Systems						
2. Amount of information on atmospheric and oceanographic systems affecting ecosystem, including present states, trends, and patterns of change for the biogeographic area (3, 6, 9, 12, 13)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete	T1 T2	M1 M2	
Biodiversity						
3. Amount of information on plant species diversity for the biogeographic area (3, 4, 9, 10, 12)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete	T1 T2 M1 M2		
4. Amount of information on vertebrate species diversity for the biogeo-graphic area (3, 4, 9, 10, 12)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete	T1 T2	M1 M2	
5. Amount of information on invertebrate species diversity for the biogeo-graphic area (3, 4, 9, 10, 12)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete			T1 T2 M1 M2
Food Webs						
6. Amount of information on predator-prey relationships for the ecosystem, including current states, trends, and patterns of change (3, 4, 5, 6, 9, 10, 12, 13)	Information is very detailed	Information provides an overview only, with minimal site detail	Information is very sketchy or incomplete	T1	T2	M1 M2

Null hypothesis 3b proposed that descriptive information would be greater in marine than terrestrial ecosystems. This hypothesis is rejected. Null hypothesis 3c proposed that there would be no difference between the ecosystems in terms of the amount of descriptive information. This hypothesis is also rejected.

Based on the test of this hypothesis, it is concluded that more descriptive information exists for terrestrial than for marine environments. This means that equivocality is exacerbated in marine environments by the lack of information for understanding environmental systems.

Hypothesis 4. Information Richness

> Marine selection information exhibits less information richness than terrestrial selection information.

In order to test this hypothesis, the quality of species and ecosystem information was assessed for the four ecosystems. Richness was assessed in terms of access, spatial coverage, temporal coverage, and overview capability.

Access

Rows 1 and 2 of table 5.7 considered the capability of researchers to gain access to the ecosystem including the primary habitats of the case species.

Row 1 assessed the difficulty of access with ratings based on complexity and expense of access. The T1 ecosystem can be accessed by an individual using a vehicle, hiking, and skiing. Much of the T2 ecosystem requires helicopter plus extended backcountry hiking. Both T1 and T2 ecosystems require backcountry skills and avoidance of predators. The M1 ecosystem can be accessed by small boat in nearshore areas, but larger vessels are required for offshore observation. The M2 ecosystem can be accessed by small boat and SCUBA for shallow inshore areas, but a ship and submersible or remotely operated vehicle are needed for access to offshore and deep-water areas.

Row 2 addressed the ability to visit and observe the ecosystem at appropriate times and places of biological significance. The T1 ecosystem can be reached most times in summer when marmots are visible. Winter or early spring may require cross-country ski or helicopter access, but this is usually feasible. T2 ecosystems are often rugged and remote, and helicopters are often the most convenient access, although many areas can be reached by land vehicle and hiking. Poor weather

Table 5.7 Information Richness

Rating Criteria for Equivocality	Ratings

	Low	Medium	High	Low	Mid	High
Access						
1. Difficulty of access to the primary habitats of the case species and major features of the ecosystem (8)	Existing technology is relatively simple and inexpensive	Existing technology is moderately complex and expensive	Existing technology is highly complex and expensive	T1	T2[1] M1[2]	M2
2. Ability to visit and observe the primary habitats of the case species and ecosystem processes at appropriate times and places of biological significance (8, 9)	Researchers are almost always able to observe habitats at appropriate times and places	Researchers are usually or frequently able to observe habitats at appropriate times and places	Researchers are often not able to observe habitats at appropriate times and places	T1	T2 M1	M2
Sampling Coverage						
3. Spatial proportion of primary habitats of the case species that has been surveyed and inventoried to identify major ecological resources[3] (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	More than two-thirds	Between one-third and two-thirds	Less than one-third	T1 T2		M1 M2
4. Temporal coverage of observation and sampling of major ecological resources within the major habitats of the case species (2, 8)	Observations cover a series of several years at all appropriate times of the year	Observations cover years and times of the year adequately for perceiving general patterns	Observations are infrequent and intermittent	T1	T2	M1 M2
Visibility[4]						
5. Impairment of visibility of case species in the field due to natural surface conditions[5] (9)	Visibility is not extensively impaired	Visibility is partially impaired	Visibility is extensively impaired	T1	T2 M1	M2
6. Ability of existing technologies to track dispersal and migration movements and routes of key species including the case species (2, 9)	Existing technologies allow reliable tracking of dispersal and migration move-ments and routes	Existing technologies allow reliable tracking of origins and destinations only	Existing technologies do not allow reliable tracking of movements		T1 T2 M1	M2
Context						
7. Resolution: Ability of	Images provide	Images provide	Images provide	T1	T2	M2

Continued

Table 5.7 continued

existing observation technologies to provide high resolution, data rich pictures of features of the ecosystem[6]	fine detail for features at various ranges	fine detail for features at various ranges but from limited perspectives	fine detail for features only at very short, close up range of a few meters		M17	
8. Angle of View: Ability of existing spatial display technologies[7] to provide high resolution synoptic overviews or visual "big pictures" of the composition and arrangements of ecosystem resources[8]	Technologies provide high resolution displays with scales ranging from square meters to square kilometers	Technologies provide high resolution displays with scales ranging from hectares to square miles	Technologies provide high resolution displays limited to a few square meters	T1 T2	M1	M2

1. T2 old growth murrelet ecosystem is rated only for land component.

2. The offshore M1 pelagic humpback ecosystem would rate high whereas the inshore component would rate low or medium. Most of the ecosystem is offshore. The medium rating is conservative.

3. The term "ecological resources" refer to primary production, trophic systems, community composition, critical habitats, and endangered species of an area. This is a general measure of the amount of biological information.

4. Visibility is defined as the ability to discriminate among and recognize separate features of a mixed environment.

5. A row considered for the proportion of time the species spend below surface cover of vegetation, underground, or underwater where it is not visible. All case species spend a considerable time below surface, and thus all would be rated "high."

6. This row addresses the ability to provide high resolution, data rich images of ecosystem features. For example, a high-resolution image would be able to discriminate species of plants or trees in a forest. This row addresses the ability to obtain images rather than the existing stock of images. Low equivocality ratings apply where images can be captured from most distances. Medium ratings apply where images can be obtained only from certain perspectives. For example, for old growth forests, surface features may be obscured by forest cover. High equivocality applies where images are only high resolution at very short ranges.

7. Applies to surface features only.

8. Spatial display technologies include resource mapping, Geographic Information Systems, air photographs, and similar technologies.

9. This row addresses the ability to provide high resolution synoptic overviews or wide angle perspectives of ecosystem resources. Ecosystems differ in the extent to which detailed maps can be produced to illustrate ecosystem resources. Composition refers to the natural resources and features of the ecosystem, such as geology, terrain, hydrology, vegetation cover, and species habitats. Arrangement refers to the ability to map the patches and gradients between different intensities of resources present in various locations.

is a frequent occurrence in this ecosystem and can impede access or egress. Weather and sea conditions strongly constrain access to M1 ecosystems. Rough sea conditions are a frequent occurrence, and these conditions mean that ships are required to do research offshore. Ships are heavily scheduled and are often not available at times that are best for different types of research. The M1 ecosystem is rated conservatively as medium in this row. The M2 ecosystem is accessible only with SCUBA in shallow waters, and deeper portions of the M2 ecosystem are generally inaccessible.

Sampling Coverage

Rows 3 and 4 addressed sampling coverage. Row 3 considered the proportion of the primary habitats of the case species that were surveyed to identify ecological resources. The ratings were based on the proportion of the area that had been surveyed and inventoried to identify major ecological resources. The T1 and T2 ecosystems have been inventoried to identify a broad range of resources including elevations, major terrain features, forest cover, hydrology, and other features. The T1 ecosystems have also been sampled in very detailed ground surveys that cover most of the known habitats. The T2 ecosystems have been surveyed in regular government resource and forest cover inventories. Spatial coverage for the M1 ecosystem is variable. Oceanographers have good overall spatial information for surface areas from satellite remote sensing data. Humpback surveys, on the other hand, cover less than 10 percent of their range and do not cover subsurface activities (Darling, interview). The distributions of euphausiids are poorly surveyed (Tanasichuk, interview). Coverage for M2 ecosystems is also weak, with minimal direct observation of benthic habitats below divable depths. Bottom images are very coarse except for a few sites, and bottom habitats have not been mapped in any detail.

Row 4 considered temporal sampling coverage, and ecosystems were rated based on the length and frequency of observations. The T1 and T2 ecosystems have been surveyed regularly using aerial photography and ground truthing as part of forest management and other resource management programs. The T1 ecosystems have also been surveyed annually for the past two decades with visits to the key meadows for repeated counts of marmots. The T1 and T2 ecosystems were rated low and medium for equivocality respectively. The M1 ecosystems have been surveyed regularly using satellite imagery, fixed stations, and research cruises. M1 environmental systems have thus been covered. On the other hand, surveys cover surface zones only, and surveys for species distributions are limited to fisheries catch data and nonsystematic surveys. The M2 ecosystems are difficult to survey, and survey efforts have been infrequent except in a few sites. The M1 and M2 ecosystems were rated high for equivocality.

Visibility

Rows 5 and 6 addressed visibility. Row 5 considered how natural surface conditions affect visibility. The T1 ecosystems were rated low equivocality because the open structure of the meadows, in general, allows relatively reliable observation of the marmots and other ecological features. The forest cover of the T2 ecosystems and the water cover of the M1 ecosystems extensively obscure observation of these ecosystems. These ecosystems were rated medium. The M2 ecosystems were difficult to rate because they are essentially always underwater, yet a diver can observe the ecosystem. Viewed from the diver's perspective, observation of these ecosystems is limited by the short range of vision, filtering of color, and limitations on lighting. Below 20 meters depth, visibility becomes very difficult. The M2 ecosystem was thus rated high for equivocality.

Row 6 considered the ability of existing technologies to track dispersal and migration movements and routes of key species. Ratings were based on whether simply origins and destinations could be identified, or whether routes also could be tracked. The T1, T2, and M1 ecosystems have generally allowed identification of origins and destinations only, and were rated medium. Almost no information is available on the movements of M2 species such as the octopus, which was rated high. Tagging experiments on the octopus failed to provide information on deep water migrations (Hartwick, interview).

Context

Rows 7 and 8 addressed the overview or "picture quality" of ecosystem information. Row 7 considered the focus or resolution of the images. Resolution refers to the level of detail provided from observing the ecosystem in the field. It refers to how much an observer can see when in the field. The T1 ecosystem was rated high because very detailed resolution is possible at a variety of ranges. Marmot meadows can be observed from a distance, say at opposite slopes of a ridge. They can also be observed at very close range by personal inspection of meadows. The T2 ecosystem allows excellent resolution from above the canopy or below the canopy, but is limited by forest cover to certain perspectives. Fine detail of ground conditions cannot be obtained from air photographs, for instance. The underwater M1 and M2 ecosystems are severely constrained by light conditions, with visibility range being limited to only a few meters in most cases. On the other hand, for the M1 ecosystem surface and nearsurface conditions can be observed from boats, aircraft and satellites. A medium rating is conservative for this ecosystem. For the M2 ecosystem, resolution is very poor and a rating of high was given.

Row 8 considered the ability of technology to provide a broad, synoptic view of the ecosystem. Ratings were based on the scale of display of high-resolution information. For the T1 and T2 ecosystems, advanced air photography and GIS systems can provide very rich detail for large areas, providing excellent overviews. These ecosystems were rated low in equivocality. For the M1 and M2 ecosystems, high-resolution bottom-typing information displays can be developed at limited resolution for small areas such as a proposed marine protected area (Harper, interview; Jamieson, interview). For the M1 ecosystem, synoptic views of surface and near surface conditions can be provided by satellite images of a few ecosystem resources. Insufficient information exists for detailed, high-resolution displays of benthic environments. The M1 and M2 ecosystems were rated medium and high respectively.

Conclusions

Hypothesis 4 proposed that information for marine ecosystems would exhibit less information richness than for terrestrial ecosystems. This hypothesis is *not* rejected, and is strongly supported by the data.

Null hypothesis 4b proposed that ecological information for marine ecosystems would exhibit more information richness than terrestrial selected information. This hypothesis is *rejected*. Null hypotheses 4c proposed that there would be no difference between the ecosystems in terms of information richness. This hypothesis is also rejected.

It is concluded based on this analysis that information is richer for terrestrial than for marine ecosystems. Unrich information is associated with higher equivocality, thus this factor contributes to equivocality in the marine environment. Because marine information tends to be unrich, marine processes and resources tend to be blurred and conclusions concerning the state and trends of the environment are more equivocal.

5.3 Hypotheses Concerning Causal Analysis

Equivocality for the causal analysis function was assessed through two hypotheses. Hypothesis 5 assessed the relative differences in the amount of causal information. Hypothesis 6 assessed the relative differences in the field technology for conducting causal research.

Hypothesis 5: Causal Information Amount

> There is a lesser amount of knowledge of causal factors and functional interrelationships affecting the ecology of target species for marine than for terrestrial environments.

In order to test this hypothesis (table 5.8), the amount of causal information was assessed for food species and predation (indicator 5), environmental driving factors (indicator 6), and the effects of human threats on the ecosystem (indicator 7). These factors were considered a good measure of the amount of causal knowledge because of their central role in the functioning of all ecosystems.

The same rating criteria were applicable to all rows. A low equivocality rating was given where the scientific information addressed the most important data categories for understanding underlying processes and making predictions about future trends. A high equivocality rating was given where this information does not provide a basis for developing causal models or for making reasonable predictions of future conditions. A medium rating was given where scientists have sufficient information to conceptualize the main features of the underlying processes, but cannot make reasonable predictions about future conditions.

Key Species

Rows 1 and 2 (table 5.8) addressed the effects of key prey and predator species on the case species. Murrelets were not included in row 1 because they feed in nearshore waters. Row 1 indicated that the marmot food system is well known, whereas marine systems are poorly known. This row provides a weak test, however, because the marmot's ecosystem is extremely small and the marmot feeds on easily observed plants.

Row 2 considers predation. Both terrestrial ecosystems and the M2 marine case were rated as medium. Biologists have identified the major predators and have knowledge of the presence of predators in the case species' ecosystem. Predation events may be difficult to document in any ecosystem because these events often occur quickly and leave minimal evidence. For these three ecosystems, predation has been observed directly, although not often. Circumstantial evidence such as marmots in predator scat, broken murrelet eggs, and missing octopus tentacles indicate that predation is occurring. For the M1 case, the understanding of predation is based on very sketchy evidence of observation of predation by sharks and killer whales of other whale species.

Driving Factors

Rows 3 and 4 addressed driving factors that affect the case species. Row 3 considered the

Table 5.8 Causal Information Amount

	Rating Criteria for Equivocality			Ratings		
(Indicator number)	**Low**	**Medium**	**High**	**Low**	**Mid**	**High**
Food Species						
1. Amount of information on the environmental systems that influence the availability of food species to the case species[1] (3, 4, 5, 6, 8, 9, 10)	Scientists have good information	Scientists have partial or general information	Scientists have sketchy or no information	T1		M1 M2
Predation						
2. Amount of information on predators and the environmental factors that influence the level of predation on the case species (2, 4, 5, 6, 8, 9, 10, 11)	Scientists have good information	Scientists have partial or general information	Scientists have sketchy or no information		T1 T2[2] M2	M1
Driving Factors						
3. Amount of information for identifying the most important natural driving factors affecting the abundance and range of the species (6, 8)	Scientists have good information	Scientists have partial or general information	Scientists have little or no information	T1 T2	M1 M2	
4. Amount of information for forecasting trends for major driving factors with some consistency (6, 8)	Scientists have sufficient information	Scientists have partial or general information	Scientists have sketchy or no information	T2	M2	T1 M1
Threats						
5. Amount of information for predicting the impacts of human threats on case species with some consistency (7)	Scientists have sufficient information	Scientists have partial or general information	Scientists have sketchy or no information	T1 T2		M1 M2

Notes:

1. Murrelets feed in nearshore waters. Therefore, this row does not include the T2 ecosystem.
2. The T2 rating applies only to land-based predation.

amount of information for identification of the key factors that affect the species. For the T1 and T2 cases, scientists have identified the major forces that determine habitat conditions through habitat evaluations done in the field and ongoing research on terrestrial ecosystems. For the M1 and M2 ecosystems, scientists have identified some of the major causal mechanisms that drive the variability in these systems, including atmosphere, ocean currents, water mass, and the sea bottom bathymetry. While these factors are identified in general terms, not all causal factors are understood, such as factors causing major cycles and regime shifts. Because these cycles and shifts have large impacts on the variability of marine species distributions and abundances, this information deficit is important. The M1 and M2 ecosystems were thus rated medium.

Row 4 considered the ability to move beyond identification of key factors to the prediction of their future influence. In this analysis, predictability is poor in the T1 ecosystem because small changes to environmental systems tend to have large effects on marmot meadows and marmot survival. For example, marmots are very sensitive to changes in snowpack levels, which is driven by unpredictable atmospheric systems coming in from the Pacific Ocean. The M1 ecosystem is also highly dynamic and fluctuating, and as noted, marine cycles and regime shifts can dramatically affect prey abundance and distribution. The T1 and M1 ecosystems were thus rated high for equivocality. The T2 ecosystem, on the other hand, is a long-lived and persistent ecosystem that is not greatly affected by short-term fluctuations, and is thus reasonably predictable. It was rated low for equivocality. The benthic M2 ecosystem is much more stable than the pelagic M1 ecosystem, but is not predictable because of a basic lack of research and causal information. The M1 and M2 ecosystems are complex and dynamic. The "measurement grid" for these ecosystems is extremely limited. There is little information on how natural systems affect marine food webs. Benthic M2 environments are somewhat less variable and more predictable than the pelagic M1 case. The M2 ecosystem was rated conservatively at medium.

Human Threats

Row 5 assessed the availability of information for predicting the impacts of human activities. For the T1 and T2 ecosystems, the primary human threat is habitat alteration. The effect of habitat alteration is the clearly predictable decline of the case species. The major threat for the M1 and M2 ecosystems is the depletion of food sources. Depletion of marine food sources is also a secondary threat to murrelets. The linkages between the environmental systems and food webs themselves are dynamic and unpredictable. Overfishing has occurred in many fisheries either because of the inability to predict or to manage the impact of various harvest levels. The overharvesting of fisheries has often led to complex community changes. Thus, the predictability of human activities on marine systems is poor.

Conclusions

Hypothesis 5 proposed that that there is a lesser amount of knowledge of causal factors and functional interrelationships affecting the ecology of marine species than for terrestrial species. This hypothesis is *not rejected,* and is strongly supported by the data.

Null hypothesis 5b proposed that less ecological information would be available for terrestrial ecosystems than for marine systems. Null hypothesis 5c proposed that there would be no difference in ecological information between the marine and terrestrial ecosystems. Both of these hypotheses are rejected.

Based on this analysis, it is concluded that less causal information exists for marine environments than for terrestrial environments. Because less causal information exists, resource managers have weaker mental models of ecological systems. They are unable to choose among possible scenarios for explaining environmental trends in marine ecosystems. This factor thus suggests that marine ecosystems are more equivocal than terrestrial ones.

Hypothesis 6: Research Technology Capabilities

> The capabilities of research technologies for establishing causal knowledge are less clearly developed for marine selection information than for terrestrial selection information.

Causal knowledge is developed through various means. In this research, three approaches for developing causal information were considered: the use of controlled studies, comparative studies, and experiential data (table 5.9). First, controlled scientific studies and experiments can be conducted to test hypotheses. Second, natural systems perturbed by natural events or by human actions can be monitored and compared with unperturbed systems. Finally, though not considered properly scientific, human experience and anecdotal information can provide evidence of causal factors.

Controlled Scientific Studies

The preferred method for acquiring causal ecological information is the conduct of controlled scientific studies. The application of the scientific method provides for the control of bias, the scientific testing of hypotheses, and the rejection of erroneous theories. Because of its strengths,

Table 5.9 Research Technology Capabilities

(Indicator number)	Rating Criteria for Equivocality: Low	Medium	High	Ratings: Low	Mid	High
Controlled Studies						
1. Technology available for researchers to conduct controlled experiments to study the response of the species to natural factors and human threats (6, 7, 13)	Existing technology provides strong capability for conducting experiments	Existing technology provides partial capability for conducting experiments	Existing technology provides little or no capability for conducting experiments	T1[1] T2	M2	M1
Comparative Research						
2. Feasibility of using comparative studies to interpret the response of the species to natural factors and human threats[2] (6, 7, 13)	Researchers have a strong capability	Researchers have a partial capability	Researchers have minimal capability	T1 T2	M2	M1
Experiential Knowledge						
3. Ability to apply professional experience and anecdotal information (9, 12, 13)	Key researchers have developed an intense familiarity with most of the important habitats of the ecosystem	Key researchers have developed an intense familiarity with a portion of the habitats of the ecosystem	Key researchers have limited familiarity with a few habitats of the ecosystem	T1	T2	M1 M2

1. Although ecosystem experiments are possible, marmot experiments are difficult because of the small numbers and the risk of losing a marmot. Some experiments have been done, such as implanting transmitters or transplanting animals. However, small numbers, again, mean that results cannot be statistically analyzed.

2. As noted in the text, ratings for this row are parallel to those for controlled studies, and are thus not independent.

this method is thus considered more important in this evaluation. On the other hand, the conduct of controlled studies in ecosystems is often very difficult, and managers must rely on more readily available sources of information.

In order to meet scientific standards, controlled scientific studies of ecosystems must meet several prerequisites (Beanlands and Duinker 1983). For this hypothesis, the following requirements were considered:

- existence of suitable inventories of baseline conditions
- ability to establish time and space boundaries for studies

- ability to establish scientific controls, and to implement or observe differential perturbations or treatments to different areas
- ability to measure change in ecological attributes
- ability to replicate the research for confirmation of findings

Table 5.10 assesses the capability of research technologies to implement these requirements within each ecosystem.

Controlled studies are feasible within the T1 ecosystems (table 5.10), thus for this parameter the T1 ecosystem was rated low in equivocality (table 5.9). An extensive amount of detailed baseline information exists for this ecosystem. The marmot habitats are well defined and spatially fixed, which means that time and space boundaries can be established for ecosystem studies, and control and replicate areas can be identified. Environmental conditions, such as snow pack and temperatures, can be measured. Complications for marmot research include the rarity of the marmot that makes invasive procedures such as capture and tagging risky, and the sensitivity of the marmot meadows to natural environmental variability that limits the ability to identify trends. Nonetheless, researchers have a strong capability for conducting controlled ecosystem studies in this ecosystem.

Forest researchers have conducted numerous experiments with T2 ecosystems. There is a considerable amount of baseline information on old growth forests such as data on topography, forest cover, and species, although information on murrelet distribution is weak. The relatively fixed location of old growth forests allows establishment of time and space boundaries, and identification of control and replicate sites for experiments. The old growth forest ecosystem changes slowly and this ecosystem is therefore less affected by natural variability than the T1 ecosystem. Measurements are thus possible. One major complication for controlled research in the T2 ecosystem is the limited accessibility to some parts of the ecosystem. The T2 ecosystem was rated low for equivocality in table 5.9.

The baseline information for M1 ecosystems is somewhat patchy and coarse-grained. The highly fluid, variable, and open characteristics of these ecosystems make the definition of time and spatial boundaries more difficult. The same factors affect the identification of scientific controls and replicates, and the measurement of change. These ecosystems were rated high for equivocality (table 5.9). M2 ecosystems are also part of the highly variable and open marine environment, but

Table 5.10 Factors Affecting Conduct of Controlled Scientific Studies in Ecosystems

TERRESTRIAL CASES

T1 Subalpine Marmot Ecosystem

- Baseline habitat conditions for T1 ecosystems have been established by interpretation of air photography records, resource inventory studies, and standardized vegetation plot analyses (hypothesis 3; indicators 3, 4, 5, and 6).
- Baseline information on marmot abundance and range has been established by annual censuses of populations (indicators 1 and 2).
- T1 ecosystems are well defined and stable, thus representing a relatively closed system allowing habitats to be bounded spatially (indicator 3 and 6).
- The variability of T1 environmental systems has a major effect on year-to-year environmental conditions of marmot meadows (indicator 6).
- Recovery time from principal threat, logging, is measured in decades. Forest growth can be monitored (indicator 7).
- The existence of subalpine meadows in discrete units, both occupied and unoccupied by marmots, provides a basis for selecting controls and replication sites for field experiments. The extreme rarity of marmots makes experimentation on marmots risky (indicator 1, 2, and 3).
- Environmental factors are monitored. Fixed habitat locations and existence of baseline information makes it possible to measure many changes.

T2 Old-Growth Murrelet Ecosystem

- Baseline habitat conditions for T2 ecosystems have been established by interpretation of air photography records, resource inventory studies, and standardized vegetation plot analyses (hypothesis 3; indicators 3, 4, 5, and 6).
- Baseline information on murrelet abundance and range is short term and incomplete (indicators 1 and 2).
- T2 ecosystems are well defined and stable, thus representing a relatively closed system allowing habitats to be bounded spatially (indicator 3 and 6).
- The variability of T2 environmental systems has a slow effect on old growth forests, measured in decades (indicator 6).
- Recovery time from principal threat, logging, is measured in decades. Forest growth can be monitored (indicator 7).
- The existence of extensive stands of old-growth forest in discrete semi-isolated watersheds provides a basis for selecting controls and replication sites for field experiments (indicator 1, 2, and 3).
- Environmental factors are monitored. Fixed habitat locations and existence of baseline information make it possible to measure many changes.

Continued

MARINE CASES

M1 Pelagic Humpback Ecosystem

- Baseline habitat conditions have been studied in general (hypothesis 3; indicators 3, 4, 5, and 6).
- Baseline information on humpback abundance and range is sketchy (indicators 1 and 2).
- M1 ecosystems are fluid and highly variable spatially, thus representing a relatively open system that is difficult to bound spatially (indicator 3 and 6).
- The high variability of M1 environmental systems has major effects on annual marine productivity (indicator 6).
- Recovery time from the principal threat, fishing for prey species, is measured in years and decades. Fish abundance is difficult to monitor (indicator 7).
- Marine M1 ecosystems are open systems where it is difficult to establish control and replicate sites.
- Environmental factors are monitored at a general scale. Fluid environmental systems and habitat locations, and inadequate baseline information make it difficult to measure many changes.

M2 Benthic Octopus Ecosystem

- Baseline habitat conditions (hypothesis 3; indicators 3, 4, 5, and 6).
- Very little baseline information exists on octopus abundance and range (indicators 1 and 2).
- The water columns of M2 ecosystems are fluid and highly variable spatially, thus representing a relatively open system that is difficult to bound spatially. The substrate, however, is relatively fixed and stable, allowing seabeds to be bounded spatially (indicator 3 and 6).
- The variability of M2 environmental systems has major effects on annual marine productivity. Environmental conditions in benthic environments are more stable (indicator 6).
- Recovery time from the principal threat, fishing for prey species, is measured in years and decades. Fish abundance is difficult to monitor (indicator 7).
- The water column components of M2 ecosystems are open systems where it is difficult to establish control and replicate sites. The benthic components are more spatially defined, and thus some measure of control and replication can be achieved.
- Environmental factors are monitored at a general scale for water columns but are not monitored frequently for deep waters. Fluid environmental systems and habitat locations and inadequate baseline information make it difficult to measure many changes.

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are fixed in terms of bottom habitats. The existence of relatively stationary habitats, however, provides for greater stability, control, and measurability. M2 habitats were thus rated as medium for equivocality.

Comparative Approaches

Ecological methodologists concede that many of these conditions defined in the above section are difficult to establish in ecological studies (Beanlands and Duinker 1983). Baseline information is often lacking, and ecological systems are often highly variable, open systems, which create serious difficulties for establishing controls and taking and interpreting measurements. An alternative approach is to compare how perturbations such as logging or fishing affect different ecosystems. For example, Glanz (1992) studied the effects of climate change on fisheries by comparing different ecosystems. Comparison of ecosystems requires adequate baseline information and measurements of change to enable researchers to quantify changes that may occur in response to perturbations.

There is evidence that comparative approaches could, or have been, used in all of the ecosystems. The comparative approach's requirements for baseline information and measurability overlap with controlled scientific studies. Ratings for comparative studies thus parallel those for controlled studies, and are thus not independent.

Professional Experience and Anecdotal Evidence

Another approach for acquiring causal knowledge is through personal experience and anecdotal information. In most cases, ecologists do not have sufficient information for making scientifically derived judgements. Professional opinion is relied upon for many types of ecological decisions, including listing species for protection and identification of habitats for protected status. Professional opinion is often informed by anecdotal information, such as reports of fishers that octopus are abundant and are located in certain areas. In some cases, infrequent observations can verify the potential for certain types of causation, such as observing marmot fur in predator scat as proof that predation occurs (Bryant, interview). Researchers are aware that such information is risky to use, but often necessary in the absence of more systematic information (Bryant, interview; Ellis, interview).

The development of professional experience with an ecosystem occurs through direct observation and extended exploration of the ecosystem in various locations and times. Direct observation develops intimate and rich knowledge of the dimensions and normal changes in the ecosystem.

A limited number of researchers have developed a strong familiarity with the T1 ecosystem over a long period through regular visits and observations as part of marmot studies, detailed habitat studies, and research on other species. These visits have occurred at biologically important times, and have included protracted observation. The ecosystems are relatively accessible. The T1 ecosystem was thus rated as low for equivocality.

A large number of researchers have been involved in murrelet and old growth forest research. Many researchers have been involved in extended backcountry surveys of T2 habitats. These surveys have occurred at biologically important times, and have included protracted observation. Accessibility to this ecosystem is limited (indicator 8), and the ecosystem exhibits a complex biodiversity (indicator 4). Accordingly, there is much still to learn. This ecosystem was rated medium for equivocality.

Both marine systems involve extreme difficulties for long term observation or observation at biologically important times. As terrestrial animals, humans are unfamiliar with the functioning of marine ecosystems on a day-to-day basis. Humans also lack the advanced sensory systems developed by marine species for gathering information about their ecosystems. Accordingly, both marine ecosystems are rated as high for equivocality.

Aboriginal people and local resource users often have considerable experience and knowledge that could be useful in understanding both terrestrial and marine resources. This will be discussed further in chapter 7.

Conclusions

Hypothesis 6 proposed that that capabilities of research technologies for establishing causal knowledge are less clearly developed for marine ecosystems than for terrestrial. This hypothesis is *not rejected*, and is strongly supported by the data.

Null hypothesis 6b proposed that capabilities of research technologies for establishing causal knowledge are more clearly developed for marine ecosystems than for terrestrial ecosystems. Null hypothesis 6c proposed that there would be no difference between the marine and terrestrial ecosystems in the capabilities of research technologies for establishing causal knowledge. Both of these null hypotheses are rejected.

Based on this analysis, it is concluded that marine research technologies are underdeveloped relative to their terrestrial counterparts. The ability to test hypotheses is complicated by the characteristics of the marine environment such as the scale, fluidity, and inaccessibility of marine areas. Marine research will require more sophisticated and expensive technologies than land research, thus the ability to resolve equivocality through application of research technology is impaired in the marine environment.

5.4 Hypothesis Concerning Action Planning

Equivocality for the action planning function was assessed through one hypothesis. Hypothesis 7 assessed the relative level of information available for identifying and defining protected area sites for marine and terrestrial areas.

Hypothesis 7: Site Selection Guidance

> The guidance given by selection information for defining protected area sites is less clear for marine protected areas than for terrestrial protected areas.

In order to test this hypothesis, three types of spatial decisions were reviewed, including location, size, and secondary areas (table 5.11). These decisions are required to define a protected area.

Location Decisions

Row 1 addressed the ability to identify the best location for a protected area. A low equivocality rating applied where information was fully adequate for choosing the best locations for protected areas. This rating applied to the T1 habitat. The marmot meadow locations are well known, and the occupancy by marmots has been verified. Strathcona Park also provides an area of formerly used habitat that is suitable for reintroduction of marmots.

The medium rating applied to the T2 ecosystem because although some nesting areas have been identified, many areas have not been. Further, biologists do not know which of the potential murrelet habitats are the most important for nesting. Considerably more information would thus be required to make optimal decisions on protected areas, although such decisions are urgent because of progressive logging of their habitats. Managers thus have partial information for identifying protected areas.

Both marine habitats were rated high. For both of the case species, only a small proportion of their ranges have been surveyed, and biologists are unable to delineate the most important areas. No basis thus exists for defining protected area locations.

Size Decisions

Row 2 addresses the best size for protected areas, given the ecological requirements for the species. The ratings for row 2 parallel the ratings for row 1. Managers have sufficient information for determining the size of marmot protected areas. These would include the existing meadows, which are discretely defined by vegetation. In addition, adequate buffers would be required, which would be determined on a site-by-site basis.

Table 5.11 Site Selection Guidance

Sub-Indicator (Indicator number)	Rating Criteria for Equivocality: Low	Medium	High	Ratings: Low	Mid	High
Location						
1. Availability of information for clearly identifying the best location for a protected area to protect the core habitat of the case species (2, 3, 6, 7, 10, 13, 16)	Managers have extensive information	Managers have partial information	Managers not have sufficient information	T1	T2	M1 M2
Size						
2. Availability of information for clearly defining the adequate size necessary to protect the core habitat of the case species (1, 2, 3, 6, 7, 10, 13, 16)	Managers have sufficient information	Managers have partial information	Managers no not have sufficient information	T1	T2	M1[1] M2
Secondary Areas						
3. Availability of information for clearly determining the locations of secondary areas that need to be set aside[2] (2, 3, 5, 6, 7, 10, 13, 16)	Managers have sufficient information	Managers have partial information	Managers do not have sufficient information		T1 T2	M1 M2

1. This subindicator may not be applicable to the humpback because the species is free ranging rather than confined to certain areas and unpredictable in its habitat use.

2. Secondary areas is defined here to include areas set aside as buffers to address impacts of peripheral uses on the core protected area, to protect dispersal or migration routes, or to conserve habitats of food species.

For the T2 ecosystems, biologists have not defined the minimum area required for murrelet nesting, although regulations have established that 88 to 90 percent of murrelet habitat is eligible for logging. Although information is weak for making size decisions, the preservation of existing nesting sites plus adequate buffers would be a minimum size necessary for defining the size of a protected area. Available data on existing nesting areas in areas where logging has occurred could give some idea of the size requirements.

For the marine M1 and M2 ecosystems, information is lacking on habitat use for most of the areas where the species are believed to occur. Thus no basis exists for defining what size protected areas might be, other than the suggestion that areas should be large.

Secondary Area Decisions

Row 3 addresses secondary areas that might need to be set aside or regulated to buffer the protected area, to protect dispersal or migration routes, or to conserve food species.

Both the T1 and T2 ecosystems were rated as medium. For the T1 ecosystem, biologists do not know the dispersal routes followed by marmots between colonies. It is likely that they disperse somewhat randomly. For the T2 murrelets, buffer areas may be required around primary nesting habitats to insulate murrelets from logging and other practices that would attract predators such as crows and jays.

The M1 and M2 ecosystems were rated high for equivocality. For the M1 ecosystem, the key secondary areas would be feeding areas. Biologists do not have good information on the distribution of humpback prey species, nor do they have information on the areas where humpbacks feed, except in a few places. Similarly, for the M2 ecosystems, little information is available on prey species distribution, and in addition, biologists do not know the migration routes of octopus between shallow and deep water.

Conclusions

Hypothesis 7 proposed that that the guidance given by selection information for defining protected areas would be less clear for marine protected areas than for terrestrial protected areas. This hypothesis is *not rejected*, and is strongly supported by the data.

Null hypothesis 7b proposed that the guidance given by selection information for defining protected areas would be clearer for marine protected areas than for terrestrial protected areas. Null hypothesis 7c proposed that there would be no difference between the marine and terrestrial ecosystems in the guidance given by selection information for defining protected areas. Both of these null hypotheses are rejected.

It is concluded that information for defining marine protected areas is less available than such information for terrestrial areas. Marine resource managers typically do not know the ranges of marine species and the habitats they occupy, except through indirect information. Information on habitat conditions is often quite limited except in shallow water. Thus planning for protected areas in marine environments is affected by higher levels of equivocality than for similar planning in terrestrial areas.

As discussed above, in relation to Hypothesis 2, the appropriateness of using a protected areas strategy may be more equivocal for some marine species or ecosystems. Consequently, the fact that information is not available on location, size, and secondary areas for marine species, may not be particularly relevant if indeed there are other strategies that are more appropriate and that require different information. While hypothesis 7 focused only on protected areas strategies, in retrospect, it would have been useful to examine the availability of information for other conservation strategies. This is an area for future research.

5.5 Summary Observations Concerning Hypotheses

This research examined the extent and characteristics of equivocality as a source of difficulty for decision making in ecosystem management. The primary research question was, what are the similarities and differences in patterns of equivocality in information processing as they affect decision making for selection of protected areas for target species in different ecosystems (section 2.2)? The primary hypothesis was as follows:

> *The patterns of equivocality in selection information* ***differ*** *between marine and terrestrial protected areas.*

The assessment of the primary hypothesis was based on the evaluation of the seven hypotheses considered in this chapter. None of these seven hypotheses was rejected. All hypotheses were supported by the research data. Thus, the primary hypothesis was not rejected, and was supported by the data. For each hypothesis, equivocality was higher for marine environments—a consistency that provided strong support for the primary hypothesis. *It is therefore concluded that the patterns of equivocality for marine environments differ from the patterns for terrestrial ones.*

The problem formulation function was analyzed in terms of hypotheses on listing decisions and decisions on mode of protection. This function is fraught with equivocality in the marine environment. Listing decisions are not easy in either the terrestrial context because biologists must interpret the significance of many factors on the abundance and survival of a species (section 5.1.1). For marine species, biologists generally do not even know the number or their distribution. For protection decisions, terrestrial biologists often have a good idea on the range of a species, but marine species are often highly migratory, interactive, and footloose (section 5.1.2).

The information gathering function addressed the amount of information and its richness. For these hypotheses, information was found to exist in greater amounts and higher richness in the terrestrial compared to marine environment. Although the murrelet case illustrates that information may be quite sparse for some terrestrial ecosystems and species, information for the marine cases was usually sparse and often non-existent (section 5.1.3). In terms of richness, the picture provided to biologists for terrestrial ecosystems is much richer than that provided to marine biologists (section 5.1.4).

The causal analysis function was examined with respect to the amount of information on causal factors and the capability for doing causal research. For these factors, the amount of causal information was found to be higher for terrestrial environments than for marine areas (section 5.1.5), and the capability for doing causal research was much more developed for terrestrial than marine areas (section 5.1.6).

Finally, action planning was addressed in terms of the amount of information for site selection guidance. For action planning, protected areas managers generally had better information for site selection in terrestrial than for marine environments.

Equivocality was thus higher for marine than terrestrial ecosystems for the four decision functions.

5.6 Research Quality and Limitations

This research used a positivist, qualitative, and grounded theory building approach. The approach, modeled after the work of Eisenhardt and others (section 3.1), was effective for refining the concept of equivocality as a phenomenon of importance in ecosystem management decision making. Measures to address reliability and validity were built in from the beginning, and hypothesis testing was used to improve scientific rigor (section 3.2, appendix 8). The following sections address reliability and validity, and limitations on research quality.

5.6.1 Reliability and Validity

The research process was designed to gather qualitative and highly contextualized data, while promoting reliability and validity (appendix 8, chapter 3). In qualitative research, reliability is referred to as confirmability. It consists of two aspects: (1) objectivity and (2) reliability of procedures (appendix 8, table A8.1). Two types of research procedures were used to address these aspects. First, study procedures were thoroughly documented to maintain quality control and replicability. This is to enable other researchers to reproduce the study. Second, data from the study were reported in a form that could be reviewed easily by other researchers. Data were for the most part recorded verbatim and entered into a case study database. Beyond these measures, the researcher deliberately sought disconfirming evidence, which is an integral feature of grounded theory building. Such evidence provides new insights into the shaping of theory.

Study procedures also addressed validity (appendix 8, section A8.1). Construct validity was addressed through careful specification of the phenomenon of equivocality and the use of grounded coding to further specify the construct. Consistent with the grounded theory building perspective, the researcher's understanding of the concept evolved throughout the study. Multiple sources of data were consulted to ensure a balanced perspective, including documents, literature, interviewees, and participant observation.

Internal validity is referred to as credibility in qualitative research. Credibility was pursued through grounded research procedures that kept observations founded on data. Following the Eisenhardt approach (chapter 3), the approach also tested hypotheses and null hypotheses to evaluate predictions concerning equivocality. These hypotheses were directed at nonequivalent dependent variables so that each hypothesis provided a different window on equivocality. The hypotheses were nonequivalent in their testing of different attributes of equivocality, such as evaluating the mode of protection (hypothesis 2) and the richness of information (hypothesis 4). Nonequivalence of hypotheses allowed a triangulation of hypotheses to address the phenomenon of equivocality. Cases were also selected to support internal validity. The cases were dissimilar because of the significant natural variations among the ecosystems considered. This allowed the consideration of the hypotheses in very different contexts. At the same time, the cases were comparable because they dealt with same subject matter, that is, selection of protected areas for species-at-risk. The use of nonequivalent hypotheses and nonsimilar cases thus provided a broad perspective and converging measures for testing hypotheses (Pashler 1998).

Finally, external validity is referred to as generalizability in qualitative research. For qualitative research, generalization is based on the ability to compare the extent to which the cases used in this study reflect the situation that other researchers might be considering. For example, a researcher interested in considering whether the results of this study might generalize to environmental impact assessment in different ecosystems can examine the case data for similarities and differences. In this respect, generalizability was supported by the use of four nonsimilar subcases that were analyzed separately and sequentially, and then compared. Furthermore, the broad range of indicators, as reported in chapter 4, provide further basis for comparison.

5.6.2 Other Limitations

This research addressed a number of limitations. Primary among these was the lack of definition of the concept of equivocality, the personal judgments required for data gathering and coding, the limited transferability of learning, the potential for simplistic use of the results, and the labor intensiveness of the research mode that limits replication. These are discussed below.

First, the lack of an accepted definition of the concept of equivocality was a significant limitation. The phenomenon of equivocality is both elusive and obvious. Though instantly recognized as a common problem by managers and ecosystem scientists, equivocality is not as well defined or differentiated in the literature from other types of information quality such as uncertainty. While considerable efforts have been made to develop quantitative approaches to reduce uncertainty, previous researchers have assigned equivocality to a residual place in their thinking. This research thus ventured into uncharted waters in trying to specify the concept sufficiently for research. The lack of research precedents and the poor previous specification of the concept or equivocality demanded that a grounded theory building approach be used. The grounded approach is well adapted to exploratory analyses (chapter 3). Because this is an early study of equivocality in ecosystem management, however, the limited specification and past research and theory concerning the equivocality phenomenon was and is a handicap on interpretation. Further research will be needed to improve understanding of this phenomenon especially as it affects decision making in organizational systems.

A second consideration in this research was the necessity for the personal judgments of the researcher in the gathering and coding of data. For example, to what extent does the cover of thick forests for the murrelet compare to the cover of 300 meters of water for the octopus? A survey of biologists would likely rate octopus habitat as less accessible, but the issue is a matter of degree. Murrelet habitat can be virtually inaccessible. The qualitative method addresses judgmental data by delving deeper into the differences, which requires gradual elaboration of mental models and theory. Each coding decision involved much thinking about the data and the emerging mental models of the phenomenon. This raises a question whether different researchers would code the data in a manner consistent with this research.

A third limitation of this research is that it involved a learning process that is only partly portable from the mind of the present researcher to the minds of others. The elaboration process is hard to duplicate and transfer to other minds. To replicate the study, the reviewer must either conduct a new case examination or become immersed in the details and coding decisions of the cases in this report. The researcher’s work can be audited using the case reports and other research materials, but close study or replication is required to duplicate the learning involved in grounded theory.

The second and third limitations above could be mitigated in part by the participation of multiple researchers, which would allow the development and testing of emerging theory. The use of multiple researchers was not possible in this research. To the extent that there are differences of opinion in coding and theory, discussion of these differences among the researchers would facilitate the emergence of new thinking and new theory.

A fourth limitation, common to many scientific studies, is the concern that results might be overly-simplistically used. All ecosystems of all types appear to exhibit significant equivocality. Marmot ecosystems were found to be the least equivocal of the ecosystems studied. This might lead readers to assume (incorrectly), for example, that marmot ecology is not equivocal. This would be erroneous and dangerous for conservation of a highly endangered species. Scientists continue to be baffled by the reasons for the decline in marmot abundance. A more sophisticated approach would be to isolate those factors that are most equivocal and focus on the means for reducing equivocality in these areas – something that the marmot recovery committee is presently doing.

A fifth limitation is the labor-intensive requirements of qualitative research. This limited the number of cases and sources that could be tapped for perspectives. Each case involved immersion in the details for several weeks. Interviews were lengthy and required transcription and intensive and rigorous analysis. While qualitative research provides a deeper understanding of data, the effort would deter many researchers. On the other hand, this research is productive for generating theoretical propositions, and much of the work can be used in related contexts. For example, the species-at-risk research would be relevant to other areas of ecosystem management, such as environmental impact assessment, as suggested in section 5.6.1.

5.7 Conclusions

This chapter has reviewed the evidence for differences in equivocality among ecosystems. *Limitations aside, this evidence strongly supports the prevalence and seriousness of equivocality in ecosystem management, and demonstrates that ecosystems vary in the patterns of equivocality they exhibit.*

These are important conclusions for ecosystem management. Although ecosystem managers must address uncertainty by gathering more information, they must also become proactive in addressing equivocality. Equivocality may be a much more serious impediment to effective ecosystem management than uncertainty. If so, research efforts may be wasted in gathering large amounts of unrich and inconclusive information. Worse, management decisions may be based on poor interpretations of data. Such failures will not enhance the survival of species-at-risk.

Once equivocality is recognized as a prevalent and troublesome factor in ecosystem management, governments and other institutions must begin to consider how it can be recognized and addressed. Figure 5.1 is based on figure 2.1 of chapter 2. Column 1 illustrates the conclusions drawn in this chapter. Column 2 identifies two steps that are required to complete this research. First, methods must be developed for recognizing and evaluating the significance of equivocality. Chapter 6 describes a proposed filter for doing this. Second, alternative management systems must be devised that can resolve equivocality and allow ecosystem managers to make decisions in the context of high equivocality. Chapter 7 identifies some proposed equivocality resolving management systems.

Figure 5.1 Conceptual Framework for Case Study

Col. 1

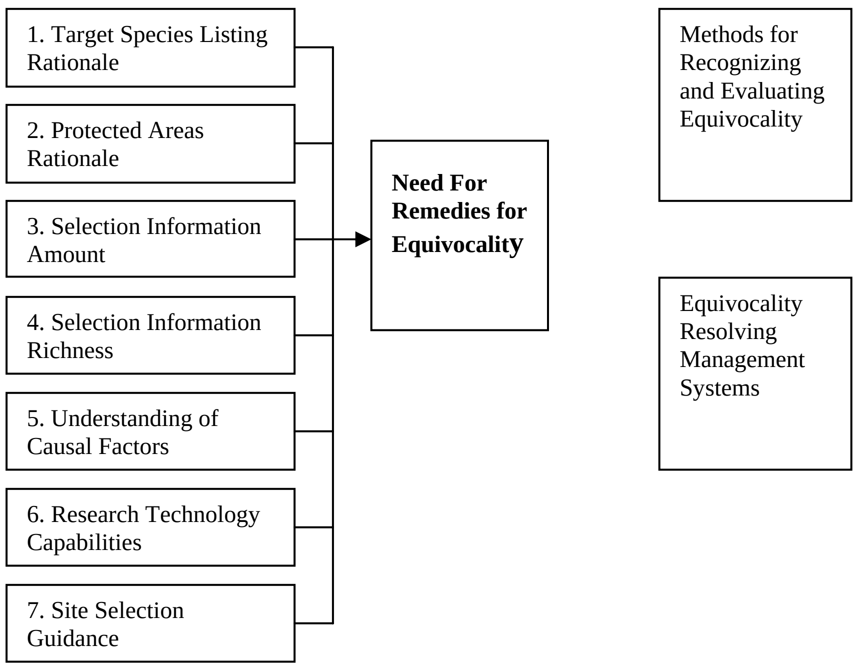
EVIDENCE FOR EQUIVOCALITY
IN RESOURCE MANAGEMENT
(Chapter 2, 4, and 5)

Equivocality is evident
with respect to….

Col. 2

REMEDIES FOR
EQUIVOCALITY
(Chapter 6 and 7)

Equivocality can be
addressed by….



CHAPTER 6: AN EQUIVOCALITY FILTER

> "When a plan is grounded in defensible science, it will be more immune to political interference and lawsuits and more likely to achieve its biological goals. The art of conservation planning, on the other hand, comes with experience and intuition. It has to do with synthesizing all sorts of quantitative and qualitative information – something the human brain does much better than any computer – and putting it all down on a map. The art is more difficult to put into words. And without a scientific foundation, the art has no substance" (Noss et al. 1997).

Recognition of patterns of equivocality in ecosystem management is a management challenge of great priority in this research. The results discussed in chapter 5 suggest that equivocality is a major issue in decision making for ecosystem management. This research project developed a method for recognizing patterns of equivocality in ecosystem management. That method was then applied to four different ecosystems, which demonstrated its scientific validity and value. The research thus operationalized a procedure for discriminating among different types of information quality and patterns of equivocality among ecosystems. With further research and development, this method can be applied to other ecosystems and decision contexts. This chapter describes a "filter" that can be used to sense or recognize equivocality in ecosystem management decision situations. A filter, in this sense, is a systematic and broadly applicable procedure for identifying equivocality and evaluating its significance for management. It develops a four-step process for adapting the approach used in this dissertation to other decision situations. Chapter 7 summarizes tools and options for addressing equivocality once it is recognized.

6.1 Introduction

6.1.1 Tasks an Equivocality Filter Should Accomplish

An equivocality filter should accomplish several tasks. It should identify research strategies. It should also highlight issues susceptible to polarization. Finally, it should point to necessary institutional reforms. These requirements are all accomplished by the filter developed in this research. These tasks are discussed below.

First, an equivocality filter should provide an approach for identifying when equivocality is present, and it should identify issues that are amenable to resolution by research. Where some aspects of a decision problem are uncertain, managers need to focus research on those areas where these efforts will be most cost-effective in reducing uncertainty. Where the issue is equivocality, a filter should identify when the richness of information should be enhanced and more discussion promoted to address this equivocality. By providing better direction for research planning, an equivocality filter would thus enhance the effectiveness and efficiency of research.

Second, an equivocality filter should identify issues that are susceptible to "polarization" because of equivocality. Polarization is a social process in which various groups harden their positions and move apart on the solution to a common problem. Where information is equivocal, disputing parties may use the confusion precipitated by equivocality to argue for different positions (Hume 2000; Shindler and Cheek 1999). Positional argumentation and partisan research thus undermine the efficiency and quality of decisions. The resolution of issues in dispute may require further research to narrow the scientific questions, but decisions may ultimately depend on interest-based negotiation (Fisher and Ury 1981) and the political process. Gathering of large amounts of data may do little to reduce uncertainty. Rather, the electorate may be rightfully concerned about there being "more study and no action."

Third, beyond the individual dispute, an equivocality recognition filter may identify contexts where institutional systems must be redesigned to cope better with equivocality. Marine environments, as found in this research, are laden with extreme equivocality. The management of resources, such as marine fisheries, may require specially designed institutional mechanisms (chapter 7). Presently, for example, salmon fisheries are managed largely with unrich information that all agree is inadequate and that provides only a vague picture of the overall state of the resource. Increased priority might be given, therefore, to developing technology for enriching fisheries information and facilitating discussion. Given that most ecosystems are equivocal, such measures would also apply to many terrestrial ecosystems, such as the old growth forests.

6.1.2 Adaptations Necessary for Using the Filter in Different Contexts

An equivocality filter should be adaptable to a variety of decision contexts. This research identified areas of equivocality for the narrow, researchable topic of the selection of protected areas for species-at-risk in marine and terrestrial ecosystems. However, the approach was grounded in a specific type of decision issue, and must be adapted before it is applied to other situations.

The species-at-risk case focused on information about species and the factors that might enhance their capability for survival. This led to the development of a method that consists of *16-indicators, seven-information-factors, and a three-rating-level method*. These components are the core of the equivocality filter detailed in this research. This approach was highly grounded in the particular case context of this research project. To apply this approach to other situations, decision analysts must repeat a grounded approach similar to that used in this research.

The coding process involves indicators, information factors, and rating levels. The 16 indicators are partly generalizable to other areas of ecological management. However, the subcodes were based on the specific ecosystem cases and used in this particular study for the protected areas function. The seven information factors are common to many decision situations, but have not been tested with this method in other situations. The technique for deriving the high, medium, and low equivocality ratings is transferable to other situations, but the specific codes the technique was applied to are not. In summary, this research followed a grounded qualitative research method that provides effective analysis of an individual case, but cannot be applied to other contexts without adaptation. This chapter will therefore outline a process for adapting the method to other contexts (section 6.2).

6.1.3 Example Cases

Two example cases are used to illustrate some of the adaptations that would be required to apply the equivocality filter. These examples are (1) erosion and sediment control and (2) transportation accident risk analysis (section 6.2). The examples demonstrate how the core model can be applied as a filter for new applications. These case applications discussed here are tentative and illustrative, and have not been tested in practice. Further descriptions of these examples follow in the discussion of the procedures in section 6.2.

Erosion and sediment regulation addresses a common environmental issue, that is, a low toxicity, chronic, nonpoint source pollution problem. Erosion and sedimentation are natural processes, and ecosystems and species have adapted to natural sediment conditions. Unfortunately, human activities have caused major changes to the underlying environmental dynamics as well as the natural conditions. Denudation of forests and landscapes and urban development have increased long-term sediment loadings in streams, caused episodic high loadings from construction and other activities, and altered the peak and minimum flows of streams. All of these effects may have significant effects on river species, such as salmon, which are adapted to natural conditions. This is a well recognized problem that has prompted substantial action planning. For example, Fisheries and Oceans Canada is presently considering ways to reduce sedimentation of salmonid habitats. Equivocality occurs because of the complex interrelationships between stream hydrology and ecological communities, and the hard-to-measure effects of sediment load variations on fish.

The second example is the analysis of transportation accident risks. This example was chosen to test what changes might be necessary to apply the method to a non-ecosystem situation. Accident analysis involves some natural forces such as weather conditions, but focuses also on technological failure and human error. Accident analysis involves a low-frequency, high-impact event. Accident risk analysis is a complex field of inquiry that attempts to determine the causes and likelihood of accidents in order to design prevention strategies (Foster et al. 1999; M.G. Morgan 1993; Sutter, Barnthouse, and O'Neil 1987; Grima et al 1986). Transportation accidents include aircraft, automobiles, trains, boats and ships, and other conveyances. In this example, the concern is with the *exposure to risk* rather than the *effects of risk*. Equivocality is substantial because many risks are not clearly known. Because of the rapid evolution of transportation technology, many transportation hazards are novel and have few precedents. This means that data may not be available for calculating accident probabilities. Analysts must therefore undertake failure mode analyses to map or identify all of the ways that an accident may occur (M.G. Morgan 1993). Typically, failure modes may include equipment or technology failures, and human error.

6.2 Steps in Adapting the Approach

The equivocality filter consists of four steps (table 6.1). The steps are based on the methodology described in detail in chapter 3 and systematically applied in chapters 4 and 5. The filter is illustrated using the sediment regulation and accident risk examples described above.

Step 1. Evaluate Information Factors Affecting the Decision

Procedure

In this research project, selection decisions for protected areas for species-at-risk were analyzed based on seven hypotheses based on a rational decision making model. These seven hypotheses are now articulated as seven *information factors* within the decision process (table 6.2). These factors are used in the first step of this process to evaluate whether equivocality is present in the decision situation. The table defines each factor and lists criteria to help in determining if equivocality is present. The information factors address several questions. What decision needs to be made? Why is it urgent and important? Who is affected? What is the decision process? What types of descriptive and causal information are required for making decisions? What procedures and technologies are required for gathering this information? What type of information is required to instruct decision making processes?

There are precedents for the use of criteria for evaluating other types of information quality concerns. Foster et al. (1999) used a criteria approach in the field of epidemiology in their efforts for determining if sufficient information was available for evaluating whether or not extremely low levels of toxins might be implicated in causing cancer.

Now, in ecosystem management, the primary purpose of species-at-risk decisions is clearly to protect the species from extinction. Equally clearly, managers need information on the population of a species and what factors affect that population over the long term. Such factors can range from direct threats to long-term changes to ecosystems. Data collection methods thus need to focus on population measurement and on determination of various threats to population. The evaluation of the information factors for the sediment regulation and accident risk analysis are discussed below.

Table 6.1 Summary of Steps for Adapting Equivocality Filter to New Contexts

Procedure	Sediment Regulation	Accident Risk Analysis
Purpose	To reduce damage to ecosystems and fisheries from anthropogenic sediment pollution.	To identify the sources and causes of accidents to propose preventative measures.
Step 1: Evaluate Information Factors	All of the seven information factors appear relevant to decisions.	All of the seven information factors appear relevant to decisions.
Step 2: Identify Information Indicators and Subcodes	The 16 indicators are somewhat useful for evaluating sediment pollution, but must be adapted for this use. The subcodes are relevant, but they would require major adaptation using a grounded coding process.	The 16 indicators are not relevant or adaptable for evaluating transportation accident risks. New indicators would need to be developed from a grounded coding process. The subcodes are generally not relevant, and they would need to be developed from a grounded coding process.
Step 3: Conduct Rating Process	Ratings process would focus on information on the sources and effects of sediments.	The ratings process would focus on information related to the accident sequence and the technological, human, and environmental factors that lead to accidents.
Step 4: Assess Implications for Research and Management	Regulators would seek to resolve equivocality in environmental data for use in designing regulations and prosecuting violators.	Regulators would seek to resolve equivocality in technological, human, and environmental data for use in preventing accidents and prosecuting persons responsible for accidents.

Table 6.2 Information Factors

1. **Importance of decision**

   Definition: The rationale and need for making a decision

   Criterion: Equivocality is higher when there is disagreement about whether an issue should be addressed

2. **Appropriateness of means**

   Definition: The merit of the means for implementing a decision

   Criterion: Equivocality is higher when there is disagreement about whether a proposed mode of resolving the issue is appropriate

3. **Amount of descriptive information**

   Definition: The comprehensiveness and relevance of descriptive information

   Criterion: Equivocality is higher when descriptive information is sparse or irrelevant

4. **Richness of information**

   Definition: The capacity of available data and technologies to provide rich information

   Criterion: Equivocality is higher when existing information does not provide a clear picture of the decision context

5. **Amount of causal knowledge**

   Definition: The level of understanding of underlying causal factors

   Criterion: Equivocality is higher when underlying causal factors are not clearly understood

6. **Capabilities of research technology**

   Definition: The potential effectiveness of access and information gathering technologies to gather data

   Criterion: Equivocality is higher when existing research technologies are nonexistent, infeasible, or ineffective for improving understanding of underlying causal factors

7. **Guidance for action planning**

   Definition: The value of information for planning decisions

   Criterion: Equivocality is higher when existing information does not have the capacity to assist managers in planning a clear course of action

Alternative Applications

The primary purpose of sediment control decisions is to reduce sediments or their impacts on key species in a river, such as salmon. Managers need information on the biodiversity and bioproductivity of the stream ecosystems, and how these variables are affected by the volumes and patterns of sediment input to the stream ecosystems. Salmonids support very important commercial, recreational, and subsistence fisheries in North America. For this case, the seven information factors all appear to be potentially relevant. The decision appears important because of the importance of salmonids. Regulation appears to be at least one valid option for sediment control. There is a significant amount of descriptive information on the levels of sediments in streams, as well as the biodiversity and productivity of some streams. This information varies in coverage and intensity. Information richness is compromised by the cover of water and the cloudiness of sediment plumes. Causal knowledge is being developed through laboratory and field experiments. New technologies are being developed to observe fish underwater (Quigley, 2000), but the application of these methods is still rare. Finally, decision makers believe they have sufficient justification to take action, but they are also aware that legally defensible measurement technologies are required to provide sufficient evidence for prosecution of sediment regulation violators. In summary, the information factors of the equivocality recognition model developed in this dissertation would appear to be applicable to the sediment control case. A more detailed case examination would be required to verify this opinion.

The purpose of accident risk analyses is to identify the accident causes to enable preventative actions to be taken. The seven information factors are also relevant to this example. The decision to identify and mitigate risk factors is obviously important for avoiding accidents. The mode of response of prevention is better than the alternatives of ignoring risks or of avoiding flying. Managers need descriptive and causal information on natural environmental factors that affect transportation operations, such as climate, weather conditions, topography, and hydrography. In addition, however, risk analysts also require information on technological and human factors that might enhance risk. For example, for aircraft safety, analysts need descriptive and causal information on aircraft design and operation. They also need information on human responses to emergencies. Much of the data for probability analyses are statistical and often unrich in identifying the actual causes of accidents. Although aircraft accidents are laboriously studied, traffic accidents are often summarized in statements such as “failure to stop at stop sign.” Richer information might indicate the driver was sleepy, distracted by a cell phone, or unable to see a sign that is obscured by trees. Analysts do have extensive technology for conducting causal research, such as crash tests, video records of accidents, simulators, and accident reports. Finally, analysts believe their procedures produce reliable information for reducing accident risks. No one suggests, however, that all risks are known or can be addressed. In summary, the seven information factors appear to be applicable to the accident risk analysis case.

The seven information factors are thus somewhat portable to new situations. In the sediments case, the decision is whether to prosecute and convict violators. In the accident analysis case, the decision is which preventative measures should be implemented. In each case, the decision maker needs to address each of the seven information factors.

Implementation

This step is best carried out by a small working group of specialists and managers. It requires one or more meetings. The principal activity in this step is discussion to apply the information factors in evaluating information quality related to the decision. Once the decision has been specified, the working group would initiate a broader study as outlined in steps 2 through 4.

Step 2. Identify Information Indicators and Subcodes for the Decision

Procedure

In the protected areas for species-at-risk case, 16 information indicators were devised to provide broad yet selective coverage of types of species and ecosystem information for making selection decisions for protected areas (section 3.2.3, table 3.1). The use of indicators ensured the research acquired comparable data from each of the four subcases to allow for testing of hypotheses.

The indicators were initially developed from official species status reports and the scientific literature. They addressed four broad information areas, including species information, ecosystem information, information gathering technology, and application of information to decisions.

Each indicator was further subdivided into subcodes based on grounded analysis of the case data (section 3.2.7). The process involved asking questions that illuminated potential subcategories, such as obstacles to visibility, and the characteristics of these categories, such as water cover, terrain, vegetation cover, or subterranean burrows (table 6.1). The indicators were tested and refined through the species-at-risk case studies. A summary report of coding was included in tables in chapter 4.

Table 6.3 Examples of Subcodes for the Visibility Constraints Indicator

The following subcodes are summarized from table 4.11 which compared visibility constraints of the four case ecosystems.

- Environmental constraints on visibility, such as weather, fog, light, and water clarity.
- Habitat constraints, such as the cover provided by rugged terrain, vegetation, deep forest cover, habitat variety, and habitat accessibility.
- Space constraints, such as the geographic extent of distribution, variability in habitat use, remoteness, accessibility, species mobility, seasonal use of habitat, and depth and vertical distribution of habitat use.
- Subsurface constraints, such as the amount of time a species spends underground, underwater, or in deep forest habitats.
- Identification of individuals, such as the availability of markings or other indicators that would allow scientists to distinguish one individual from another for purposes of counting or otherwise monitoring the animals.

Alternative Applications

The choice of indicators and indicator subcodes was grounded in the case data and the subcodes are thus limited in generalization to the substantive case of selection of protected areas for species-at-risk. Many of the indicators would be required for other ecosystem-based decisions.

Sediment Regulation

For sediment control decisions, managers require information on species and ecosystem variables. For example, this would include information on the abundance and distribution of salmonids in various streams. Managers would also be interested in biogeography, biodiversity, key species roles, ecosystem driving factors and ecosystem threats. These data sets are represented in the 16 indicators. As in the species-at-risk case, subcodes would be developed for each indicator. The subcodes for this case would reflect the management decision they are addressing, that is, the regulation of sediment discharges. This may result in different subcodes being developed or emphasized. For example, for sediment control, managers might want population data to be subcoded for various streams with different levels of natural sediment loads. Stream flow, substrate conditions, instream vegetation, fish refuges, woody debris, and several other codes might be relevant. For sediment control, gross data on sediment loads may be less rich than underwater observations of fish avoidance of sediment plumes or coughing reflexes due to exposure to sediments (Quigley, 2000). Episodic events such as extreme rainfall and landslides may be more emphasized in subcodes under the "ecosystem driving factors" and "ecosystem threats" indicators. Extreme weather events also affect the "sampling coverage" indicator because a sudden pulse of sediment from an extreme rain event may last only hours, but have significant ecological effects (Chilibeck, 2000).

Other indicators are also relevant to sediment control. Sediment regulation would use some of the same technology as endangered species protection. It would also require an ability to effectively use the data in decisions, although data must be legally defensible because of the regulatory nature of sediment regulation.

From this discussion of sediment regulation, it is clear that modifications would be required to adapt the indicators and especially the subcodes for a different application. The same indicators might be considered, but the importance of specific indicators might be weighted differently. For example, sediment control is intensively focused on the effect of natural and human-caused sedimentation on key species, such as salmon. This requires attention to sediment sources, composition, erosion, and diffusion. It also considers the behavior of key species, such as avoidance of plumes by salmon, sublethal and lethal effects on salmon, and effects on food sources and predators.

Indicators for sediment control should be developed by examining the pollution control decision. A sediment control program would require information on the biodiversity of a stream, existing sediment loads, and the effects of additional sediment inputs. Appropriate indicators can be identified from literature reviews, interviews with knowledgeable persons, or workshops among specialists.

Accident Risk Analysis

Transportation accidents are sociotechnical events only incidentally related to ecosystem, which means the two species and five ecosystem indicators are mostly irrelevant. One could find more generalized categories that might fit the risk analysis context. However, the appropriate procedure would be to develop new indicators through a grounded research coding approach similar to the procedures used in this dissertation. The use of indicators from one study for another context would break the grounded connection to the data.

Indicators addressing access capability, sampling coverage, visibility constraints, sensor capability, contextual capability, and field research technology may all be relevant. However, the analyst would be seeking different types of data, such as mechanical malfunctions, pilot alertness, or wind shear events. Access to accident sites may differ among different transportation modes. This means that subcodes will be different, and once again, a grounded coding process will be necessary.

Indicators 14, 15, and 16 are specific to species-at-risk, but could be modified somewhat for other uses. Realistically, these indicators should also be modified through a grounded coding process to address accident risks.

Summary

From these two examples, it is clear that some of the indicators are relevant, especially for the ecosystem-oriented sediment regulation case. However, they can only be used with caution and refinement. On the other hand, subcodes would need extensive refinement for both applications. Therefore, a grounded coding process is required to adapt the indicators and subcodes to new applications.

Indicators and subcodes are an essential component for analyzing equivocality. For application to alternative cases such as sediment and accident risk analysis, management analysts must redevelop the indicators and subcodes through a grounded research process. Because the codes are dependent upon the particular data sets relevant to a decision, there are no short-cut methods.

Implementation

The species-at-risk indicators relate to species and ecosystems. For other species and ecosystem applications, such as sediment control, the 16 indicators may be used as a starting point for developing subcodes. Analysts would consider what data sets within each indicator might be relevant to a decision. For sediment control, for example, subcodes for episodic events, as discussed above, might be refined and adapted. These subcodes must be developed based on the decision problem. This can only be assessed by careful analysis of the decision case. The coding process is labor intensive, and requires analysis and much iteration.

Step 2 could be carried out by an individual analyst working in cooperation with a small working group of specialists and managers. The working group would provide initial guidance to the analyst on sources of information and decision issues. The analyst would then review past decision documents to identify decision requirements, such as reviews of sediment violation prosecutions, impact assessments of sediment events, and other reports. In addition, the scientific literature on sediment effects should be considered. Finally, the analyst would interview key managers and scientists in depth to identify additional factors that should be considered. From such an analysis, the analysts would identify relevant subcodes for review by the working group.

Based on the experience of research on protected areas for species-at-risk, the professional time commitment for this step would involve a few weeks of effort. The time commitments for the analyst would involve document and literature reviews, interviews, subcoding, and ongoing discussion of coding results with the working group. The working group would require at least three short meetings, including an initial workshop type meeting to define the scope of the project and initial research sources, a progress meeting, and a coding finalization meeting. The results of step 2 may be circulated to a wider group of specialists and stakeholders for comments and consensus building.

In most cases, step 2 could overlap with other activities associated with a decision. For example, the equivocality analyses could be integrated into adaptive management workshops, species recovery committee work, environmental impact assessments, or integrated resource management planning processes. In these cases, the work and meetings required would be reduced.

Step 3. Conduct Rating Process

Procedure

The procedure for developing equivocality ratings for sediment regulation and accident risk analysis is similar to the approached used in this research for protected areas. Step 3 would involve two tasks: the assignment of subcodes derived in step 2 to the seven information factors, and the development of rating levels for each subcode.

The rating process is based on the indicator subcodes. In the species-at-risk case, several subcodes were identified for each of the seven information factors. The subcodes were derived from one or more indicators, as illustrated in table 4.1 and chapter 5. Thirty-nine subcodes were thus used for evaluating equivocality. These subcodes are highly specific to the selection of protected areas for species-at-risk.

Once the relevant subcodes were selected, a three-level rating of high, medium, or low equivocality was conducted to evaluate the level of equivocality. The procedure was described in section 3.2.12 and the ratings were reported in chapter 5. As discussed in section 3.2.12, the rating categories were designed to produce verifiable ratings. The scaling for the extent to which the range of a species has been surveyed was arbitrarily divided into thirds. If more than two-thirds of the range had been surveyed, this was rated as “low equivocality.” The key to designing the categories was to define the three levels so that each rating should be discrete and confirmable from the case research.

Alternative Applications

For sediment regulation, the key indicators and subcodes would be related to ecological and human issues. Thus, the indicators would be similar to the species-at-risk case. On the other hand, the subcodes would likely be substantially different, as noted in step 2. The selection of subcodes should reflect the nature of the decision. The species-at-risk application addressed a decision process for selecting a protected area. The key questions are: which species are at risk? And, how should these species be protected? The sediment regulation application considers a decision process for setting sediment pollution limits on resource users and land developers. The key questions are: what species are vulnerable to sediment discharges? And, how should sediment discharges be addressed? Analysts for the latter question will focus to a greater extent on issues of ecosystem driving factors, such as hydrology; human threats, such as sediment releasing human activity; and analysis of the effects of sediments on organisms. For the ratings process, the selection of subcodes may be narrower because the question is more focused on the effects of one stressor on a limited range of fisheries species.

For accident risk analysis, a new set of key indicators and subcodes would have to be developed. These would only relate tangentially to ecosystem factors, except for climate and terrain. Emphasis would be on human and technological issues that were only addressed incidentally in the species-at-risk application. The most sophisticated accident analyses occur for aircraft crashes. The decision focus is on modes of failure. Because human lives are at stake in future accidents, investigators collect any information that is feasible to gather. In these cases, investigators often recover and rebuild disintegrated aircraft to isolate what happened. Some information also comes from flight recorders or witnesses. In some cases, information may be relevant to litigation. The selection of subcodes would focus on the quality of information for reconstructing the accident sequence and factors that influence that sequence. For example, is information on aircraft functioning clear and unequivocal? Can pilot error be ruled out? Were environmental factors such as wind shear or icing involved?

Implementation

As in step 2, the ratings scheme can be developed by one or more analysts working in cooperation with a small working group of specialists and managers. The analyst reviews each indicator subcode identified in step 2 for its relevance to the seven information factors identified in step 1. The analyst then proposes a list of relevant subcodes for each information factor.

The identification of rating levels for the subcodes could be done by the analyst and reviewed by the working group. Alternatively, it could be done in a facilitated workshop, which would be a superior approach for reaching consensus about the relevant factors to be considered in ratings. For example, an alternative to the division of sampling coverage into thirds, as used in the species-at-risk case, may be the top 10 percent, middle 80 percent, and bottom 10 percent. The criteria used to rate the level of equivocality require judgment of the group, and thus the workshop approach is preferred. The results of this step should thus be reviewed by a wider audience to allow a broader based discussion and to work toward consensus.

The labor involved in this step depends on the approach taken. The proposed rating subcodes and rating levels need to be developed by the analyst or workshop. The working group needs at least two or three meetings to review, discuss, and refine the codes and rating scheme. Because the subcodes have already been identified in step 2, the analysis and development of coding proposals should require only a few days. Finally, the working group would require resources to circulate the draft for comments, review and consider the comments, and make appropriate changes to the ratings results.

Step 4. Assess Implications for Research and Management

Procedure

The final evaluation involves determining the implications of the subcode ratings identified in step 3 for research and management.

Research implications depend upon the level of equivocality. Where equivocality is high, the decision making organization should emphasize discussion and rich information in its research program (section 1.5). For example, scientific consensus on the causes for population declines for the Vancouver Island marmot may only be reached through intensive discussion and gathering of richer field data. On the other hand, for the sediment case, the volume of sediment runoff from construction sites can be observed and measured unequivocally. The effects on fish behavior and abundance are presently more equivocal. For accident risk analysis, richer information might be provided by a greater variety of sensors in aircraft black boxes.

Management implications also depend on the level of equivocality. If equivocality is high, decision makers should make allowances for errors. Fish regulators may establish interim standards for some streams until further studies are completed to determine what levels of sediment are harmful to various species of fish. Aircraft regulators may also determine that some design faults might be corrected even if data on their effects are equivocal because human lives are at stake.

Many public and private decision contexts involve some level of equivocality. Where a decision context is laden with equivocality, decision making organizations should be organized to facilitate discussion and produce rich information. This is further discussed in section 6.4.

Alternative Applications

Step 4 is a necessary phase in any analysis of equivocality. For sediment regulation, the decision makers include the environmental agencies and the courts. Prosecutors need relatively strong evidence to enforce sediment discharge regulations. Scientific evidence is important if it is incontrovertible. However, lawyers also use “demonstrative evidence” such as vivid pictures and water samples to help judges and jurors visualize the evidence (Langer and Cliff, 2000). Pictures of dead fish, whether scientific or not, provide rich information that significantly influences decision makers including judges. In this case, environmental agencies seeking a conviction should summarize the low equivocality scientific data and address the equivocal issues with rich information and argumentation.

For aircraft safety regulation, safety concerns are paramount. The public considers it unacceptable to allow a second major aircraft accident for the same correctable cause. On the other hand, some automobiles have design faults that are not corrected even though they may put a greater cumulative number of persons at risk. In terms of research, transportation safety analysts need evidence sufficiently rich and unequivocal to change public policy, regulations, or court decisions. An evaluation of the sources of equivocality in these areas would be valuable. Emphasis would be on mechanisms for discussion and rich information collection, as described in chapter 7.

Implementation

The evaluation of equivocality results can be combined with other procedures for design of research strategies for decision making. For example, species recovery committees obtain scientific data to determine the status of a species. If steps 1 to 3 have been completed, the results can be evaluated by the research planners to determine which potential research projects might contribute most to reduction of equivocality and improvement in understanding. Decision making organizations need time to discuss the implications of equivocality ratings and determine the best approach to addressing problems. This step would require additional meeting times to discuss results and formulate responses.

6.3 Summary of Overall Implementation Requirements

The development of an approach for each new decision context requires administrative resources for analysis and deliberation. The management of the information process would require a coordinator, and if necessary, a small team of generalist information analysts and process facilitators. The key personnel required are analysts with an integrative perspective and sufficient background knowledge on the decision context. Specialists may also be required for relevant indicators. These would include species, ecosystem, technology, and planning information sets. In addition to the specialists, discussions are required with a wider audience. Such discussions can occur in facilitated scoping workshops. Such workshops would require assignment of facilitators, specialists, and stakeholders, and expenditures for facilities and travel.

Labor costs for the adaptation of the equivocality model would involve a period of a few weeks or months. The research for this dissertation involved interviews with approximately two-dozen specialists. The level of effort for analysis also would vary depending on the complexity of the decision context. The principal tasks are to complete literature searches, analyze information sets, conduct interviews, facilitate workshops, circulate drafts for comment, analyze data, facilitate rating processes, and write reports. Where a previous analysis has been conducted for a decision context, costs will be substantially reduced. For example, application of the approach in this dissertation to other species-at-risk and protected area cases would be relatively straightforward.

Much research work is often conducted as part of ecosystem decision making. For example, teams of specialists are involved in ecosystem inventories, adaptive management processes, and ecosystem planning processes. The analysis of equivocality can be combined with these analyses at the scoping stage. The results of the equivocality analysis will assist planning teams to identify information deficiencies, in terms of amount and richness, technology issues, ambiguities and multiple interpretations, and the great unknowns – areas of surprise potential. This would assist planning teams to design more efficient and focused data collection efforts, and allow decision makers to make better decisions.

6.4 Further Research and Development

The species-at-risk protected area case provides a provisional analysis based on the work of a single researcher supplemented by input from natural resource specialists and literature. Further work and discussion among ecosystem and species specialists would refine the analysis and assist in setting information gathering and management priorities. As additional input and discussion occurs, the analysis would no doubt evolve and improve.

The approach suggested in section 6.3 provides an outline of an approach that could be followed in other aspects of ecosystem management. For example, the analysis would be relevant to pollution management, environmental impact assessment, risk and hazard analysis, integrated natural resource planning, adaptive environmental management, stream conservation, and other areas. The approach may also have applications to social science topics, such as health and safety, social impact assessment, and education.

This research on equivocality asks questions about the unknown. Resource management has traditionally focused on the known. In resource management, decision makers strive for unequivocal information, which is often in short supply. To make decisions, information is often re-perceived as clear and unambiguous. For example, indicators are often used for assessing the state-of-the-environment, resource capability, or some other factor. In choosing indicators, analysts focus on information that is available or obtainable for practical reasons. Potential indicators that are difficult to measure are discarded. After the set of feasible indicators is identified, the chosen set becomes unequivocal in our minds. This raises the question of what we discard in making decisions. What would the discarded indicators tell us? Would it be feasible to gauge equivocality by considering the discarded indicators? In a broader picture, how large is the unknown component? Rather than focusing exclusively on the known, perhaps researchers should seek to understand how much is unknown and how the unknown can be managed. This also has implications for use of the precautionary principle. By considering what is not known, resource managers will understand whether enough information exists to make a decision for resource use or caution.

The equivocality recognition method is a grounded research based tool. It could be evaluated based on two questions. Is it useful? Is it usable? It would be useful if applications were developed by users in a way that meets the needs of decision makers. At the same time, training and practice in a variety of situations would be required to improve the usability of the method. There are no short cuts or off-the-shelf models that could be applied without adaptation. In time, however, the method can be applied to a variety of contexts and practitioners can look at previous models for instruction.

6.5 Summary Conclusion

The equivocality filter involves four steps: evaluating information factors affecting the decision, identifying information indicators and subcodes, conducting the rating process using the three-level rating method, and completing the evaluation. This method was successfully used in the case studies in this research project, and adapted for two additional contexts: sediment regulation and accident risk analysis. Based on these cases, the equivocality has been shown effective in recognizing the patterns of equivocality affecting a particular decision. The illustrating cases in this chapter also show that the equivocality filter is adaptable to a variety of situations. Chapter 7 addresses methods for resolving equivocality once it is recognized.

CHAPTER 7: EQUIVOCALITY-RESOLVING MANAGEMENT SYSTEMS: A RECOMMENDED APPROACH

> "Managers literally must wade into the ocean of events that surround the organization and actively try to make sense of them" (Daft and Weick 1984, referring to organizational management).

Previous chapters have outlined the nature of equivocality, and evaluated the extent of equivocality in marine and terrestrial ecosystems. Equivocality was found to be extremely high for management in many ecosystems, and especially marine environments. Several interviewees instantly recognized the phenomenon of equivocality when it was identified for them, and expressed the need for methods of coping with this problem more effectively. This chapter is a response to that need.

This chapter discusses ways and means for *resolving* equivocality. The term *resolving* has several meanings, including solving, clearing up, explaining, breaking into parts, changing, transforming, focusing, making certain, and deciding (section 1.1.1). Resolve "can be used in the sense to clear up, explain, settle, a problem, difficulty, puzzle, etc." (Fowler 1965). One definition from Webster's dictionary (1965) is "to clear from perplexities: to free from any doubt or difficulty; as, to *resolve* an enigma." Enigmatic is a word related to equivocality. Other definitions from Webster's include "to settle in an opinion; to make certain," "to change; transform," and "to determine; reach as a decision: as, we *resolved* to go." In graphics technologies, when an image is highly resolved, it is clearer and more detailed. High-resolution images are richer. The essence of these definitions is that when something is resolved it is made clearer and more decisive. In other words, it provides rich, high-resolution information that allows clear decisions. Thus, this chapter refers to equivocality as being *resolved* when information is richer and less susceptible to multiple interpretations.

This chapter proposes a set of tools and approaches for facilitating collaboration and production of rich information for making decisions in equivocal situations. This set of tools and approaches represents a prototype for an institutional system. This prototype, referred to as an *equivocality-resolving management system* (ERMS), is a mixture of existing institutional arrangements, off-the-shelf organizational designs, and new proposals.

As a prototype, ERMS is a prescriptive proposal that illustrates important features for designing management systems for resolving equivocality. At the same time, ERMS is a testable approach that a system so designed will resolve equivocality. It can be tried and tested, in whole or in part, as part of an adaptive learning process that improves organizational effectiveness.

ERMS is not a prescription for a particular system design. It is a heuristic. Empirical studies have repeatedly confirmed that the differences in organizational form do make a difference to effectiveness, but the model that works in one situation may not work in other situations. “There is no one best way to organize” (Galbraith 1973). The choice of which features to use is dependent upon the contingencies facing an organization (Fulmer 1988).

Figure 7.1 provides an overview of the components of ERMS based on a general systems model. This specific systems model was borrowed from Beer (1980) and modified. The modified form has been used by the researcher for previous coastal and marine organizational studies as a means of conceptualizing complex organizational arrangements (Wolfe 1982b, Fraser River Estuary Study 1982; Marine and Coastal Sector Definition Mission 1987; Medium Term Planning Support Project Team 1988; Marshall and Wolfe 1989; Wolfe and Marshall 1989). Beer’s general concept has also been used by other researchers (Marczyk 1991).

The general systems model consists of seven components: environment, desired outputs, tasks, structures, activities/processes, facility and technology elements, and inputs. Redesign of an organization would begin with an analysis of an organization’s environment, which determines what types of organizational design would be most appropriate. The designer also considers the outputs that an organization is expected to achieve. In this case, ERMS is intended to resolve equivocality. The tasks are operations considered necessary to achieve the desired outputs. ERMS would increase discussion and produce enriched information. To perform these tasks, the organization requires certain organizational structures and processes. It also requires facilities and technology. Finally, it also requires inputs to maintain the system, including authority, money, personnel, motivation, or creative ideas.

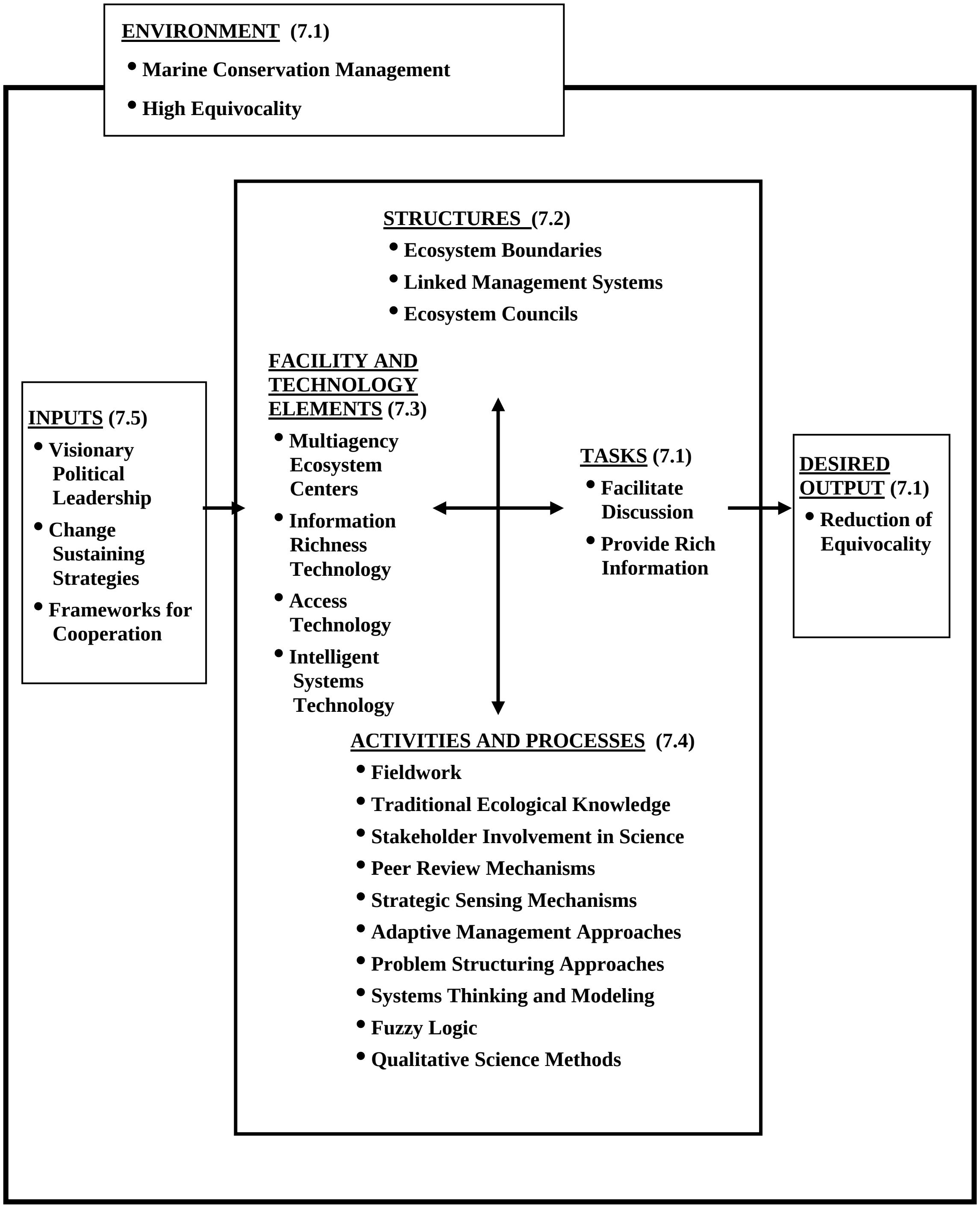
The components outlined in table 7.1 will be discussed in the following sections. Section 7.1 discusses the environment, as well as the desired outputs and tasks that ERMS must accomplish. Section 7.2 discusses institutional structures and section 7.3 identifies institutional activities and processes. Section 7.4 identifies facilities and technology elements that are required to support the system. Finally, section 7.5 identifies the institutional inputs that are necessary to launch and sustain change.

Caveat

The tools and options discussed above are not panaceas and cannot remove the underlying equivocality in many resource management decisions. Rather, what follows is a first step, a beginning, in the search for better methods of resolving with equivocality.

Figure 7.1 Conceptual Structure for an Equivocality-Resolving Management System

Note: Numbers in brackets are references to sections that follow


ENVIRONMENT (7.1)
• Marine Conservation Management
• High Equivocality
STRUCTURES (7.2)
• Ecosystem Boundaries
• Linked Management Systems
• Ecosystem Councils
INPUTS (7.5)
• Visionary Political Leadership
• Change Sustaining Strategies
• Frameworks for Cooperation
FACILITY AND TECHNOLOGY ELEMENTS (7.3)
• Multiagency Ecosystem Centers
• Information Richness Technology
• Access Technology
• Intelligent Systems Technology
TASKS (7.1)
• Facilitate Discussion
• Provide Rich Information
DESIRED OUTPUT (7.1)
• Reduction of Equivocality
ACTIVITIES AND PROCESSES (7.4)
• Fieldwork
• Traditional Ecological Knowledge
• Stakeholder Involvement in Science
• Peer Review Mechanisms
• Strategic Sensing Mechanisms
• Adaptive Management Approaches
• Problem Structuring Approaches
• Systems Thinking and Modeling
• Fuzzy Logic
• Qualitative Science Methods

7.1 Environment, Desired Outputs, and Tasks

Chapter 1 described the characteristics of equivocality, and its effects on decision making. Chapters 4 and 5 evaluated the extent of equivocality in marine and terrestrial environments. Equivocality was found to be a prevalent phenomenon that must be addressed in both terrestrial and marine environments. Section 1.5 identified two design requirements for addressing equivocality (table 1.7):

~~2.~~1. Rich Information: Information support systems need to produce appropriate amounts of rich information in order to provide a clearer picture of decision problems and their contexts.

~~1.~~2. Discussion: Organizational structures and processes need to facilitate interactive communication, information sharing, and collaboration in order to construct shared interpretations of information.

These systems requirements define the tasks that the ERMS must accomplish to resolve equivocality.

7.2 Institutional Structures

Reorganization of existing organizational structures is essential for implementing equivocality-resolving management systems. As discussed below, the need for major overhauls of existing resource management structures has long been recognized. Based on the conclusions of this research project, a major rationale for this reorganization is that current management structures do not cope well with equivocality. They retard gathering of rich information on specific ecosystems and discussion among ecosystem experts and stakeholders. Reorganization is a primary tool for resolving equivocality in resource management. Sections 7.2.1 through 7.2.3 outline three types of reorganization:

- Reorganization around ecological boundaries
- Ecosystem-focused linked management systems
- Ecosystem councils

7.2.1 Reorganization Around Ecological Boundaries

One of the key principles for ecosystem management is the organization of management around ecological boundaries (Grumbine 1992, 1994; Fox 1991). Typically, however, government agency boundaries are not consistent with ecosystem boundaries. The regional territories of government resource management agencies are presently defined based on convenience of access and other human factors. The boundaries often differ among different agencies. As a result, scientists and resource managers often have responsibilities for very different types of ecosystems, such as interior and coastal systems.

To focus research and management on ecosystems, governments should *reorganize the territory of government agencies around ecological boundaries*. This would mean, for example, that government bureaus might be established to manage continental shelf ecosystems, offshore oceanic ecosystems, coastal forest ecosystems, and inland sea ecosystems such as the Georgia Basin.

Rationale for Reorganizing Boundaries

Reorganization of government agencies around ecological boundaries would be an important part of an equivocality-resolving management system. First, because all agencies would have the same ecological boundaries, greater discussion of ecosystem issues would be facilitated among scientists, managers, and stakeholders associated with each ecosystem. This enhanced and focused discussion would be a powerful tool for resolving equivocality. Second, agencies would focus on ecosystems, which would allow the agency scientists and managers to develop greater knowledge of these ecosystems. It would enable managers to focus their attention on a specific type of land- or seascape to develop intense familiarity with components and processes of constituent ecosystems (Fox 1991). This would provide richer information for resolving equivocality. With the focus on ecosystems, local agencies could attend more consistently to the needs and trends of an ecosystem, and scientists working on research on particular ecosystems could work within the same agency unit.

Options for Reorganizing Boundaries

The definition of ecological boundaries for resource management could be achieved by organizing around previously-identified marine and terrestrial biogeographic areas, such as ecoregions and ecoprovinces, biogeoclimatic zones, watersheds, or landscapes (Noss 1983; Urban, O'Neil, and Shugart 1987; Scott et al. 1987; Grumbine 1990, 1992; Fox 1991; Bottom et al. 1993; Pickett and Cadensasso 1995; Ray and Hayden 1993; Caddy and Bakun 1994; Burroughs and Clark 1995; Schoonmaker, von Hagen, and Kellogg 1997). Boundaries could be adjusted somewhat to accommodate gradual transitions between ecosystems, or logistical difficulties with large or geographically extended ecosystems.

At a macroscale in marine environments, cooperation must be international. The humpback whale, for example, roams freely among many jurisdictions across all the world's oceans (section

4.2). For the northeast Pacific Ocean, cooperation is needed between the United States and Canada to manage the Gulf of Alaska Large Marine Ecosystem (LME) (J.R. Morgan 1987, 1993, 1994; Sherman 1991; Ray and Hayden 1993). According to Hempel and Sherman (1993),

> The LME concept provides a practical means for overcoming the present 'sectorization' of ocean studies and management by focusing attention on entire marine ecosystems and programs pertinent to their long term development and sustainability within the already stressed environments and resources of areas around the margins of ocean basins.

An analogous macroscale terrestrial ecosystem designation is a *bioregion* (Schoonmaker, von Hagen, and Wolf 1997; Schoonmaker, von Hagen, and Kellogg 1997). For example, the Coast and Mountains Ecoprovince is a component of the coastal temperate rainforests bioregion that extends along the coastal mountains from southeast Alaska to northern California. In British Columbia, it includes the windward slopes of the coastal mountains, Vancouver Island, and the Queen Charlotte Islands (Campbell et al. 1990). Similarly, a Georgia Basin/Puget Sound Bioregion has been defined to include the watersheds that drain into the Strait of Georgia and Juan de Fuca, and Puget Sound. A Puget Sound/Georgia Basin International Task Force was established in 1992 under an agreement between British Columbia and Washington State to work on a variety of common environmental issues. The government of British Columbia also established a bioregional Georgia Basin Initiative to work on Canadian issues in this bioregion.

Similar large ecosystem proposals involve the *greater ecosystem concept* (Grumbine 1990), although the concept is still being defined and criteria for boundaries are "fuzzy" (Grumbine 1992). Greater ecosystems usually encompass large areas such as the Greater Yellowstone Ecosystem, which includes the national park and large areas of the surrounding states, or the Greater Georges Bank Ecosystem (Grumbine 1992). More locally, the Greater North Cascades Ecosystem includes the Cascade Mountains in southern British Columbia and northern Washington State (Grumbine 1992).

Hierarchical Definition of Boundaries

Ecosystems are hierarchical, meaning that smaller ecosystems are nested within larger ecosystems. This means that subdivisions of administrative regions could follow ecosystem hierarchies rather than administrative convenience. Subdivisions of bioregional areas could be defined by biogeographic boundaries, following hierarchical ecosystem classifications (Schoonmaker, von Hagen, and Kellogg 1997; Grumbine 1992; Cortner and Moote 1994). For British Columbia waters, delineation of biogeographic classifications is proceeding quickly (Zacharias et al. 1998; Levings, Pringle, and Aitkens 1998a; Watson 1997). According to Zacharias et al. (1998), biogeographic classifications are "a powerful new tool for marine and coastal management, planning, and the identification of marine protected areas" that will be used by the Canada-British Columbia Marine Protected Areas Strategy.

Feasibility

Proposals have been made for decades to organize around ecological boundaries including watersheds, landscapes, and ecosystems (MacKenzie 1996; Fox 1991). Agency and jurisdictional boundaries have been slow to change, but initiatives identified above demonstrate that the interest in this approach has been growing. The Province of British Columbia is a very large jurisdiction, and reorganization of existing resource management regions and districts along ecological boundaries would be incremental and manageable. The major benefits of focusing management on ecosystems as a means of resolving equivocality suggest that it is time to take action.

Recommendation

> **It is recommended that the governments of Canada and British Columbia reorganize resource management, as far as possible, around ecological boundaries.**

7.2.2 "Linked" Management Systems Focused on Ecosystems

A key structural component of the proposed ERMS model is the establishment of an *ecosystem-focused linked management system* for each ecosystem. A linked management system is a cooperative management process that retains existing organizational entities, but links these agencies together through common objectives and linking structures and processes (Wolfe 1982a, 1982b; Fraser River Estuary Study 1982).

Fraser River Estuary Management Program Linked Management

The linked management concept was developed for the Fraser River Estuary Management Program (FREMP) (Wolfe 1982a, 1982b; Fraser River Estuary Study 1982; Healey and Hennessey 1994). FREMP has been evolving and operating successfully for almost two decades. It has had "impressive achievements," and has been "increasingly recognized for its achievements not only in Canada but also internationally" (Dorcey 1991). According to Day and Gamble (1990), "FREMP has the potential to achieve the most ambitious intergovernmental coordination of any coastal management initiative to date in the province." Unfortunately, while the model has been imitated in other jurisdictions, it has not been duplicated in British Columbia (Day and Gamble 1990).

The FREMP design included a package of institutional components that collectively sought to link the management activities of various agencies without trying to consolidate the agencies themselves (Fraser River Estuary Study 1982; Fraser River Estuary Management Program 1994; Wolfe, McPhee, and Wiebe 1987). For example, a federal-provincial-local government management committee was established and funded under an intergovernmental agreement. A set of *common estuary policies* was agreed upon, and implementation of these policies was delegated to selected *lead agencies*. A *coordinated project approvals process* was developed to provide for joint reviews of projects. A series of *activity programs* were developed addressing areas where there were overlapping government management functions, such as water quality management, fish and wildlife habitat management, navigation and dredging, emergency management, recreation, and port-industrial development and transportation. An *environmental review committee* was established to provide environmental advice on projects. An *area designation map* was developed through an interagency process involving 18 government agencies. A number of cooperative *technical studies* were carried out to identify resource management issues and propose solutions.

Single Agency Approach

Another institutional option was proposed by Fox (1991), who recommended that a single *ministry of renewable resources* be created for "water, crown lands including forestlands, wildlife, fisheries, and the atmosphere"— resources that are "highly interrelated and must be management on an integrated basis." The ministry would also have input to agriculture and mines management. It would be organized along ecological boundaries, namely, river basin boundaries. The ministry would be a provincial agency, and no mention is made of federal participation.

New Zealand Approach

The government of New Zealand carried out an even more comprehensive approach for ecosystem-based institutional design, which would address equivocality. This required sweeping government reorganizations in the 1980s to implement sustainability. According to Furuseth and Cocklin (1995)

> Among the most fundamental reforms was the establishment of sustainable management as the guiding principle for decisions affecting the allocation and use of natural resources and the maintenance of environmental quality. The adoption of sustainability has been accompanied by numerous changes in land use and environmental planning processes and institutions. Prescriptive planning models have been replaced by a performance based planning paradigm. Environmental impact assessment has been strengthened. There has been a widespread consolidation of governmental units and the creation of new, more powerful local (regional) governments, with boundaries drawn using

> hydrologic criteria. Decision making processes have been shifted from central government agencies to the local level.

The New Zealand model demonstrates that comprehensive government reform can be achieved quickly, and that a government willing to change legislation and structures could reshape institutions extensively.

Rationale for Linked Management

Equivocality provides compelling reasons to initiate reorganization of government agencies and jurisdictional boundaries. By building government research, policy, and planning activities around ecosystems, the ecosystem becomes the focus for management. As governments and their constituencies wrestle with the equivocality surrounding decisions within a particular ecosystem, their discussions will resolve equivocality and improve understanding. Research focused on ecosystems will produce knowledge and information bases that provide a richer picture of the state of an ecosystem and trends that affect that state. For conservation management, the habitats of endangered species will more likely be included within the jurisdiction of a single government administrative region. Each administrative region would also have responsibility for establishing protected areas that conserve important ecosystem components.

Recommendation

> **It is recommended that governments establish "linked management systems" to coordinate resource management activities within the proposed new ecologically-defined administrative boundaries.**

7.2.3 Ecosystem Councils

The ERMS model requires an independent, extragovernmental entity to provide leadership to develop new solutions and build consensus to support implementation. This entity is referred to here for convenience as an *ecosystem council*.

Rationale for Councils

The council would operate on a shared decision making basis where all stakeholders work toward consensus on the major issues facing an ecosystem. The council would also animate and monitor progress of the linked management system in implementing strategies for conservation. It would sponsor local community-based initiatives and action plans on ecosystem-wide problems. For the marine environment, a council would include coastal communities, First Nations, fishing and tourism interests, academic interests, environmental groups, regional districts, and other stakeholders. At present, there are no marine models, but marine ecosystem councils could be adapted from terrestrial experiences, as described below.

The Original FREMP Model

Although FREMP, as a linked management system, has achieved strong coordination among government agencies, it has also been criticized for not providing leadership for change. For example, Healey and Hennessey (1994) stated that

> The FREMP was never intended to have an independent voice about pollution and the development in the Fraser estuary. Rather, it was to implement the consensus position of its parent agencies. The FREMP was intended to serve as a source of information for public interest groups but fulfilled that role passively, to the annoyance of some environmentalists . . . . The FREMP has survived because it facilitated rather than challenged the function of powerful agencies.

The original designs for FREMP did include provisions for greater participation than the final version. For example, Phase I recommended a "constituency" comprised of government agencies and nongovernmental groups that would "meet at regular intervals to exchange views and understandings" (Fraser River Estuary Study Steering Committee 1978a, b). Phase II recommended a program committee to include key user interests in an advisory role to the key agency management committee. It also included a participation process "to provide opportunities for affected interests and agencies to discuss and comment on policies that affect them." The purpose was to improve "consensus, acceptance and understanding" (Fraser River Estuary Study 1982). In developing the final design of FREMP, the recommended participation element was not included, perhaps because this study predated government acceptance of the legitimate role of stakeholders in participating in the decisions affecting their interests.

Evolution of Provincial Planning Models

Since the early 1980s, considerable progress has been made toward "more inclusive approaches" for land and water planning (Williams, Day, and Gunton 1998). Fox (1991) recommended a provincial-level council to review policies and programs of a proposed ministry of renewable resources (section 7.1.5). He also recommended regional councils for planning and monitoring of management activities at the regional level.

The Commission on Resources and Environment (CORE) was one of the most ambitious efforts in British Columbia to establish consensus building and shared decision making processes for resource management (Williams, Day, and Gunton 1998; see also Owen 1998; Penrose, Day, and Roseland 1998). CORE had a large degree of independence from government structures, although it was disbanded in 1996 and its functions brought back into government.

The Land and Resource Management Planning (LRMP) process, established by the provincial government in 1993, is an inclusive approach that delegates responsibility to multistakeholder round tables for preparing subregional plans. Eighteen plans had been completed or are underway, covering 80 percent of the province by 1997 (B.C. Integrated Resource Planning Committee 1993; B.C. Land Use Coordination Office 1997).

Fraser Basin Council

Another example of an inclusive approach is the Fraser Basin Management Program created in 1992 and its successor, the Fraser Basin Council established in 1997. This initiative was established to facilitate shared decision making and action for creating sustainability for the Fraser River basin, an enormous area as large as Great Britain. The council is a nonprofit coalition of government and nongovernment stakeholders that operate at arms length from government while including government representatives. Its focus is on the basin, which is an ecological entity, and on subbasins defined by watershed boundaries (Marshall 1998; Fraser Basin Management Program 1997).

The Fraser Basin Council is a step toward the type of extragovernmental entity that the ecosystem council is intended to be. While the linked management system would serve as a governmental coordinating body, a council would provide the animator and conscience of the process to keep it moving toward sustainability. The risk of a council model is that by being inclusive of all interests it would lose its ability to champion the painful steps needed to achieve effective conservation, such as supporting fisheries closures, or establishing large protected areas on expensive lands for species such as the murrelet. The Fraser Basin Council also lacks the authority to step in to order changes, a power that CORE had, but was lost with CORE's demise (Owens 1998).

Recommendation

> **It is recommended that ecosystem councils be established for marine and terrestrial areas with broad membership and that these councils be funded to provide a locus for animation and monitoring of ecosystem management activities.**

7.3 Facility and Technology Elements

Implementation of the ERMS model would require capital investment in facilities and technology. Sections 7.3.1 through 7.3.4 outline four types of capital elements that are essential:

- Multiagency ecosystem centers

- Information richness technology
- Access technology
- Intelligent systems technology

7.3.1 Multiagency Ecosystem Centers

To facilitate the linked management system approach, it is proposed that *multiagency ecosystem centers* be considered as a venue to enable researchers and managers associated with a specific ecosystem to work in close proximity to that ecosystem. Ecosystem centers would be developed, for example, for the outer Pacific shelf marine ecoregion or the coastal temperate rainforest bioregion. The centers would consist of one or more ecosystem-focused office facilities or office parks that would provide a one-window location for collaboration and information sharing related to ecosystem management.

Rationale Ecosystem Centers

The center concept would address the physical separation that now exists among many government agencies dealing with ecosystems. The idea is parallel to social services agencies that have cooperated in multiservice centers to concentrate services in one location to serve clients more efficiently and facilitate interagency cooperation. The goal is to encourage discussion and sharing of rich information through closer physical location. People tend to use information that is accessible in making decisions, rather than searching for quality information (O'Reilly 1982). This suggests that managers and scientists should be close to the ecosystem they are responsible for managing.

An Ecosystem Center as an Information Hub

The participants in such a center could include staff with research, policy making, planning, and major project approval functions of line resource management agencies. The center would include research facilities, meeting and conference venues, databases, information technologies, and libraries to enable academic and government scientists to work together, and to have access to ecosystem managers on an ongoing basis. The center could also include office space for nongovernment organizations and businesses. Finally, it would provide a base for sharing the use of advanced infrastructure including access equipment such as ships, as well as remote sensing, geographic information systems, and rich information technologies. The incentive for agencies to locate in a center would be the economies of scale, access to services, and collaboration with other agencies and stakeholders.

The ideal location for an ecosystem center would be near the location of stakeholders and accessible to means of transportation to the ecosystem. Preferably, the location would form around existing facilities. An example would be the Institute of Ocean Sciences in Sidney, British Columbia, which has attracted government and private organizations to locate nearby.

The ecosystem centers would concentrate policy, planning, research, and major project approval staff in one location for an ecosystem. The ecosystem staff could remain under existing agencies, or they could be consolidated into coordinating agencies. Because equivocality is resolved by discussion and rich information, the ecosystem centers would provide for improved sharing of ideas and information. At the same time, operational staff could remain at field offices closer to their work activities and continue to specialize on specific operations or resource sectors. Mechanisms would need to be developed to ensure linkage between ecosystem center staff and operational staff.

Recommendation

> **It is recommended that governments establish multiagency ecosystem centers for concentrating staff with research, policy making, planning, and major project approval functions in proximate locations to facilitate collaboration.**

7.3.2 Technology for Improving Information Richness

The acquisition of rich information has been proposed as an important remedy for equivocality. Available rich information technologies need to be used more extensively, and new technologies need to be developed.

Advantages

Rich information addresses equivocality because it provides more cues that suggest what incoming data mean (Strauch 1975; Weick 1979a; Daft and MacIntosh 1981; Putnam and Sorenson 1982; Daft, Lengel, and Trevino 1987). Information technologies differ in terms of their selectivity of data sampled and range of data-gain (Knight and McDaniel 1979). Technologies usually are selective in sampling specific types of data, such as sound or light. Their range also varies, with perception of light, for example, ranging from narrow, black and white frequencies to broad, full-color light. These differences also occur in nature. Similar differences exist with data technologies.

Humans are primarily visual creatures, obtaining most of their information from their eyes. Dogs, on the other hand, have better-developed senses of hearing and smell compared to humans.

Humans and dogs perceive very different environments on a walk together. Most marine species have advanced sensory systems adapted to the aquatic milieu, such as echolocation in dolphins (Evans 1980); advanced vision in marine vertebrates (Levine 1980); equilibrium and orientation in cephalopods (Budelmann 1980); geomagnetic guidance in sharks, skates, and rays (Ryan 1980); electroperception in fish (Moller 1980); hearing in fish (Blaxter 1980); and smelling and tasting in fish (Atema 1980b). Similar sensory adaptations exist terrestrial species, such as the hearing of bats, the olfactory senses of dogs and elephants, and the vision of raptors.

A human diver relying on his or her visual and limited hearing senses will have a much less rich perception of the undersea environment than a marine animal such as a whale which can hear and echolocate a picture of that environment. In most of the marine environment, humans can only see a short distance. Vision is not the premier sense in deeper water. To operate in this environment, humans will need levels of visual perception in that environment comparable to resident species. This will require some technological adaptations to collect electroperception, audio, olfactory, and other sensory data, and translate these data into information that can be used by humans, such as a visual format, for example. The principle is that animals have developed complex organic technologies to perceive their environments, and humans must develop imitating artificial technologies to gain an equivalent understanding.

Using Existing Rich Information Technologies

The first opportunity to adapt technology is to improve on existing technologies and employ these technologies more aggressively. Visual information gathering technologies such as photography, underwater video cameras, multibeam sonar, dual and multiple beam profiling acoustics, night vision glasses, laser line scanners, video plankton recorders, and similar technologies should be adapted and used more in research in shallow waters (Broad 1997; Robison 1993; Wiebe, Davis, and Greene 1992). Since the end of the Cold War, intelligence agencies have begun to release previously secret information and technologies for scientific use (Richelson 1998; Bell 1998). This will provide a major improvement to the coverage and resolution of environmental information.

Information display technologies are critical to providing rich information for marine resource management. Cornett (1994) suggested that geographic information systems (GIS) communicate complicated information in a more usable form for both scientists and the public. He argued "the complexities of ecosystem management virtually require the use of GIS technology." Further, he stated "humans are visual creatures. It is much easier for most people to relate to 'pictures' of information than to text or numbers." Ryan (1992/93) noted that, at sea,

> there are no mountain tops one can scale to directly gaze at vast expanses of abyssal seafloor. Instead, we visualize the hidden seascape with digital data sets, picture element by picture element, as tiles of a growing quilt, each stitched in the course of month long expeditions.

GIS shows primarily two-dimensional pictures of terrestrial environments. These technologies need to be adapted to a three-dimensional, dynamic, and less information rich marine environment (Bottom et al. 1993).

Information can be enriched by the broad deployment of remote observatories. One example is the proposed Neptune Project (McInnes 2000; Neptune Project 2000; Neptune Canada 2000). Proposed for completion by 2005, this $300 million project would deploy a network of underwater unmanned observatories spanning the Juan de Fuca Plate on the seafloor of the Northeast Pacific Ocean off the United States Pacific Northwest and British Columbia coasts. The system would be connected by a system of over 3,200 kilometers of high-speed fiber-optic cables linking the seafloor observatories to land-based research laboratories and classrooms. This would allow real-time flow of information from a variety of sensors located at the observatories, enable interactive control over robotic seafloor vehicles, and provide steady power to the observatories. Sensors would range from sampling tools to video cameras, some of which have space exploration uses. The network of 30 or more observatories would enable an ecosystem-wide simultaneous monitoring of several parameters, including seafloor spreading, plate processes, subduction processes, sediment transport, upwelling and productivity, biological diversity, organic carbon fluxes, and other variables. This system, if developed, would provide the first opportunity for continuous, broad scale, and enriched observation of seafloor ecosystems. Scientists promoting the system have referred to it as the "Hubble telescope to inner space" (McInnes 2000). While this system has obvious value for marine research, such remote observatories could equally be deployed in terrestrial ecosystems.

Simulation and virtual reality technologies can also simulate a perception of being in an environment (Rheingold 1991). Fred Sharpe, a doctoral student at Simon Fraser University, illustrated the use of three-dimensional simulation of underwater bubble feeding of humpback whales using computer technology to provide an informationally enriched picture of how humpbacks feed (Sharpe 1999). Adaptation of these technologies should improve the ability to perceive and represent marine environments in graphic, pictorial, or metaphoric forms that provide multiple cues. Sylvia Earle (1995) promoted the use of "creative ways for people to see creatures that they might encounter during real dives in the deep sea, perhaps with films or special viewing techniques."

Development of New Rich Information Technologies

New technologies can also be developed for information gathering and interpretation. One approach is to mimic or imitate sensory systems of marine animals. For example, Buckingham, Potter, and Epifanio (1996) described a technique being developed for "acoustic-daylight imaging." This technology uses background ambient underwater sounds to passively 'illuminate' submerged objects rather than actively broadcasting sound waves like sonar. By analogy, this is similar to humans seeing a forest in daylight without requiring artificial light. Using this imaging equipment, scientists were able to observe on a monitor, the shadowy but recognizable visual images of whales swimming by the hydrophones. Some whales, of course, use similar organic technologies in their echolocation. The imaging technology is being enhanced with a higher density of hydrophones and image enhancement software that will allow researchers to use sound underwater to see the same way that we "see" visually above water. Such technologies could also be developed to perceive electroperception technologies that could mimic a shark's ability to perceive prey at great distances, including under the seabed. The principle is that marine animal sensory capabilities should be reverse engineered to enhance human capabilities for obtaining novel sensory data and translating these data into rich images of marine environments.

Recommendations

To improve technology for information richness, it is recommended that:

- **Governments ensure that ecosystem managers and scientists have access to existing rich information gathering technologies, such as video and photographic technologies, multibeam sonar, and laser technologies.**
- **Governments ensure that ecosystem managers and scientists have access to existing rich information display technologies, such as marine geographic information systems, and simulation and virtual reality systems.**
- **Funding agencies invest in research and development of new rich information technologies that provide sensory inputs that mimic natural sensory systems of marine animals, and that convey this information to researchers in formats compatible with human sensory systems.**

7.3.3 Access Technology

Fieldwork in the ocean requires special equipment, such as surface vessels, SCUBA, remotely operated vehicles (ROV), and submersibles, along with the supporting shore-based infrastructure. Unfortunately, the scarcity of such equipment hampers research (sections 4.8, 4.13, and 5.1.3). It is proposed that government and private funding agencies increase funding for access technologies.

Marine access technologies are rapidly developing as a result of work of persons such as Robert Ballard, the discoverer of the *Bismarck* and *Titanic*; David Packard, cofounder of Hewlett-Packard and patron of the Monterey Bay Aquarium Research Institute (MBARI); Phil Nuytten, former owner of Can-Dive Services and the inventor of the Newt Suit; Sylvia Earle, a former chief scientist for the National Oceanographic and Atmospheric Administration and partner in Deep Ocean Engineering, Inc.; and Graham Hawkes, a submersible developer and partner with Earle (Broad 1997; Earle 1995). American government agencies and Japanese companies are also investing heavily in underwater technology (Earle 1995). Robison (1993) and Broad (1997) described new ship designs that provide more surface stability for research vessels. Such technology may allow them to operate in slightly rougher seas.

Advanced ROVs laden with extensive instrumentation have provided rich, high-resolution information. Nevertheless, as Robison (1993) noted, submersibles are necessary because “there is no substitute for having the human eye and mind on site.” Earle (1995), in arguing for submersibles rather than relying solely on ROVs for “telepresence,” stated “there is no completely satisfactory substitute for being there. To really decipher the nature of this unique part of the planet, direct access, with human eyes and brains as well as instruments is essential.”

ROVs will not replace the need for submersibles. Earle, Nuytten, and others are therefore working toward low-cost, user-friendly underwater submersible or diving capabilities that would allow easy access to marine habitats. Earle (1995), for example, has worked for the development of low cost technologies that would allow a marine biologist to be “able to drop in on the ocean of . . . choice for a few minutes or hours, just as scientists go into a forest or desert.”

For equivocality to be resolved in marine research, there must be direct access. The development of low cost “poor man’s” submersible technologies and facilities for support of diver research is essential.

Access technologies for terrestrial research are also important, but are much more widely available. New, quieter helicopters, for example, are available and should be available for terrestrial researchers.

Recommendations

It is therefore recommended that:

- **Government and private research funding authorities invest in research and development of underwater access technologies such as submersibles and diving equipment to develop low cost, flexible**

technologies to reduce the costs of exploration.

- **Government and private research funding authorities ensure that adequate funding exists for underwater exploration, including acquisition and deployment of access technologies to directly observe marine ecosystems.**

7.3.4 Intelligent Systems Technology

Cognitive psychologists and artificial intelligence scientists have advised that machines are not likely to *replace* human intelligence in the near future, notwithstanding science fiction androids (Pinker 1997; Capra 1996). According to Pinker (1997), a cognitive psychologist,

> An intelligent system, then, cannot be stuffed with trillions of facts. It must be equipped with a smaller list of core truths and a set of rules to deduce their implications. But the rules of common sense, are frustratingly hard to set down. Even the most straightforward ones fail to capture our everyday reasoning.

With those caveats in hand, information technologies have contributed enormously to environmental management. Simple computer spreadsheets, relational databases, and computer simulation software have contributed processing power that has allowed scientists to manage large masses of data in efficient ways. The Internet has created a vast knowledge network that is still in its infancy. To the extent that equivocality is an information processing problem, information technologies may *support* human decision making, even though it should not *replace* human thinking.

Bielawski and Lewand (1991) define an *intelligent system* as a computer system "combining knowledge-based technologies, such as expert systems, hypermedia, and data bases." Such systems have evolved into user friendly, interactive, responsive, and adaptive tools that are now regarded as an *intelligent assistants* rather than esoteric technology for the exclusive use of computer geniuses. Programs are now inexpensive and can be operated on personal computers. In fact, these technologies are now being incorporated into the day-to-day word processing, spreadsheet, and database software that are commonplace in offices.

The genius of intelligent systems is the combination of different information technologies, such as expert systems and hypermedia, with a user-friendly interface. An *expert system* is "a computer program that simulates the performance of a human expert in a specific field or domain" (Bielawski and Lewand 1991). Wright et al. (1993) described the extensive use of expert systems in environmental planning, environmental impact assessment, spatial planning, geographic information systems, environmental regulation, and other applications. *Hypermedia* is "a relational data-base structure that links and accesses different types of media, such as text, graphics, sound, and film, in a nonlinear way" (Bielawski and Lewand 1991).

*Decision support system*s are another type of tool that are "computer-based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models" (Sprague and Watson 1986; Daft 1992). These systems combine ease of use and access to a wide variety of data with tools for analysis and modeling to assist managers in making decisions for "semistructured problems," that is, problems "in which only parts have a clear-cut answer provided by a well-accepted methodology" (Laudon and Laudon 1991). Technologies such as this that are being developed and adapted for ill-structured or semistructured problems (Cats-Baril and Huber 1987) may contribute to addressing the equivocality in ecosystem management.

Recommendations

It is recommended that:

- **Government and industry should identify and share information on existing intelligent systems that may be used to address equivocality and improve environmental management.**
- **Government and industry should invest in the development and application of intelligent systems for addressing problems of equivocality and cognitive failures in environmental management.**

7.4 Institutional Processes and Activities

The implementation of the ERMS model proposes the addition or enhancement of several institutional processes to address equivocality. Sections 7.4.1 through 7.4.10 outline ten types of processes:

- Increased fieldwork
- Traditional ecological knowledge
- Stakeholder involvement in science
- Peer review mechanisms
- Strategic issues sensing mechanisms
- Adaptive management approaches
- Problem structuring approaches
- Systems thinking and modeling
- Fuzzy logic approaches
- Qualitative methods in science

7.4.1 Increased Fieldwork

Researchers often obtain the richest information from work in the field. It is proposed that ecosystem managers place greater emphasis on fieldwork. This will require increased support and funding from governments and other institutions.

Rationale

The richest information on a natural environment comes from being actually present in that environment and freely observing what is occurring there. For this reason, some ecologists have argued that high technology tools such as satellite-based remote sensing cannot replace fieldwork. However, Ray and Grassle (1991) argued "the essence will continue to be the scientist slogging about in the field or diving underwater with a face mask or in a submarine observing nature directly and intimately." When conducting fieldwork, a scientist is immersed in the environment and context of his or her research. Organizational researchers have documented that business managers can often learn much more from "walking around" a manufacturing plant than from sterile statistics on operational performance (Daft and MacIntosh 1978). Slobodkin (1988) made the same point about ecosystems. Through walking around, they can see and feel the "sense" of ongoing activities; that is, they can make sense of what is happening and resolve equivocality. Thus, in terrestrial environments, people orient to visible landmarks, slopes, and pathways (Okabe et al., 1986).

Marine environments create difficulties for such experiences because "walking" is more difficult at sea. In a documentary on the rare six-gill, deep-water shark in the Georgia Strait in British Columbia entitled "Walking Among the Sharks," research scientists used a deep-diving “Newt Suit” and two submersibles to explore shark habitat at a depth of over 1,000 feet, with a surface vessel to support them. After the dive, one of these scientists stated that one such dive was worth a year of research on the surface (Kurtis 1997).

Earle (1995) lamented “few people, even experienced divers, have spent weeks or even days, as residents underwater.” Wiebe, Davis, and Greene (1992) suggested that

> except for short periods viewing the surface from the deck of a research vessel or the ocean interior from a submarine or in a wetsuit, an open ocean ecologist cannot ‘see’ into this fascinating three-dimensional habitat to visualize the spatial arrangement and daily activities of the organisms living there. This is in stark contrast to terrestrial ecologists who can stroll through forests, meadows, savannas, or deserts, simultaneously viewing the structural complexity and the patterns of the ecosystem.

Gamble (1984) reported that *in situ* observations by divers have led to important behavioral information about community associations, feeding behavior, and food webs. Earle (1995) described the value of underwater laboratories that allow divers to remain underwater for long periods. She suggested that these labs allowed

> the gradual accumulation of knowledge that provides something more than a superficial inventory of what lives where. Details come into focus, relationships among the reef residents gradually become known, the subtleties that make a system really work become evident.

Bruce Robison, a deep-sea biologist with the Monterey Bay Aquarium Research Institute (MBARI), found that the ability to visit intermediate depths between the surface and the seabed was essential to observe species that were so delicate and unusual that nothing could be learned from collection of specimens (Broad 1997). Underwater fieldwork provides direct information to multiple human senses. It provides a *context* for interpreting information and for resolving equivocality (Strat 1992; see also Einhorn and Hogarth 1986). This context provides a richer milieu of cues that assist in the interpretation of information. Strat (1992) stated that "individual objects may exhibit a multitude of appearances under different imaging conditions, and many different objects may have the same image appearance. Their correct interpretation must be entirely by context." Broad (1997) described how the crew of a US Navy ship misidentified a picture of the anchor of their own ship for the crumpled hull of a missing submarine because the images lacked context. Improvements to access and observation technologies in marine systems are thus crucial (Edmunds 1996; Miller 1996).

Recommendation

> **It is recommended that government and private research funding authorities should ensure that adequate resources are available for conducting field research to enable rich direct observation of ecosystems.**

7.4.2 Traditional Ecological Knowledge

Rationale

Aboriginal people have a rich information base in their *traditional ecological knowledge* (TEK). Berkes (1994) defined TEK as follows:

> TEK is a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. Further, TEK is an attribute of societies with historical continuity in resource use practices; by and large, these are non-industrial or less technologically advanced societies, many of the indigenous or tribal.

TEK is the product of "thousands of years of direct human contact with the environment" (Berkes 1994). This information is derived from living, hunting, gathering, and other activities and becomes embedded in the resource use practices, culture and language of social groups (Brody 1975). Such knowledge was essential for survival (Hobson 1992). Unfortunately, much TEK is being lost as aboriginal societies are influenced by western cultures.

TEK has been tapped for economic use in agriculture, pharmacology, and botany, but has only been considered important for ecology in the past couple of decades (Berkes 1994). Berkes (1994) argued that use of TEK has been "questioned by those who regard the knowledge of other cultures as *pre-logical* or *irrational*, thus playing down the validity of TEK." Perhaps more kindly, some have considered TEK as "anecdotal and unsubstantiated" (Johannes 1994).

Despite these prejudices, TEK can be a rich source of practical and experiential knowledge. This information may be contained explicitly in cultural stories, country wisdom, and folklore, or implicitly in the customs and taboos of a society. TEK may be developed through careful observation and experimentation extending over very long periods (Berkes 1994; Johannes 1994). For ecologists, TEK can provide important and sophisticated taxonomic information on species and their habitat assemblages, such as the microclimates and soil regimes supporting certain species and communities (Johannes 1994; Freeman 1992; Nakashima 1990). TEK can also inform ecologists on the spatial and temporal distribution of living and nonliving resources, such endangered species, migration pathways, and aggregation sites. TEK extends beyond description of ecological resources into a holistic ecological understanding of causal processes (Freeman 1992). TEK may contain information about the potential effects of human activities on environmental resources or the sustainable limits of such activities (Johannes 1994; Nakashima 1990; Brody 1975). Such information has broad use in resource inventories, ecological studies, environmental impact assessment, planning, and other resource management functions (Freeman 1992).

Approach

The broader society would obviously benefit from the gathering of TEK. From an ethical perspective, the proprietary value and rights of aboriginal groups to TEK must be protected. TEK can be exploited for profit by third parties. It can also be used in competition with the groups who share it. Legal protection may be necessary to prevent misuse of TEK. As a starting point, the broader society must recognize that TEK is proprietary, and thus aboriginal people must retain the choices concerning the use of this information. Recognizing that TEK has value, incentives may also be appropriate to compensate for the sharing of a valuable information resource, such as skills development, contracted projects, employment, (Johannes 1994) royalties, or patents.

As for any type of research, the validity of TEK must be established (Johannes 1994). Nakashima (1990) argued that "guided by inflexible norms, environmental scientists reject the traditional knowledge of Native hunters as anecdotal, non-quantitative and amethodical" (see also Hobson 1992). TEK indeed may contain biases due to social or strategic factors, as may "Western science." TEK researchers may also exaggerate the significance of findings (Johannes 1994). Johannes (1994) suggested that validity and reliability could be tested by asking questions for which the answers are already known or for which answers could not be available. As with any science, methods for testing and verification of TEK must be devised.

An important requirement for using TEK is the formal recognition of this form of knowledge in public decision making and science. Scientists familiar with TEK have argued that western science must find avenues for including TEK in decision making (Hobson 1992). A considerable published scientific literature now exists documenting the utility and scientific value of TEK (Freeman 1992).

Recommendation

> **It is recommended that government and private research funding authorities recognize the value of traditional ecological knowledge, and develop an equitable, reliable, and valid basis for integrating this knowledge into resource management.**

7.4.3 Stakeholder Involvement in Science

Science has often been within the exclusive domain of professional scientists. It is proposed that stakeholders be more involved in scientific research. This includes aboriginal communities who may possess traditional environmental knowledge and resource users such as fishers.

Rationale

An important requirement in a democracy is for affected interests to have a say in decisions that impact on their interests. In participating in these decisions, stakeholders must also cope with high levels of equivocality in ways that allow them to understand how these decisions affect their interests. Application of ecosystem science to decision making requires more scientific input to public knowledge, as well as more public input to scientific knowledge.

Joint stakeholder-scientific research can assist the public to better understand resource management decisions, and for scientists to identify information that is important for public decision making. The goal is to develop shared understandings and visions for management. Consensus-building processes have been used in British Columbia and elsewhere to involve the public in developing shared concepts for how to manage natural resources. Within many government resource management agencies, internal corporate visions have been developed as a means of mobilizing organizational cultures in support of environmental management. Shared visions and values that motivate coordinated thinking and action have been identified as key components of the "new paradigm" for management and a factor in the effectiveness of businesses and government (Senge 1994; Collins and Porras 1993; Gaster 1992; Peters and Waterman 1982). Environmental science must be democratized if it is to have influence on public decisions.

Approach

The published literature suggested a number of approaches that could be used for two-way science – public dialogue. Kirchhoff, Schoen, and Franklin (1995) and Brosnan (1995) proposed that scientists engage in public education paralleling their scientific work, but going to the public with summaries in popular publications, videos, and other channels. The purpose is to raise public awareness and support for environmental management. Lee (1993) described an interactive approach civic science for managing environmental resources using metaphors of a "compass" representing adaptive management addressing both physical and social science, coupled with a "gyroscope" representing democratic debate that subjects scientific answers to public scrutiny (see also Slocombe 1993; Shindler and Cheek 1999). Such an approach would involve scientific involvement in public discussions of environmental issues. Kirchhoff, Schoen, and Franklin (1995) argued such an approach engages in political realms that are risky but necessary. Carley and Cristie (1993) proposed using action-centered networks for natural resource management. These networks would involve flexible government-nongovernment teams, networking, broad information exchange, multidisciplinary analysis, and facilitation and mediation to reach consensus. The case ecosystems provide examples of cooperation of scientists and citizens. Marine tourism vessels, including cruise ships, have reported the locations of whales. Recreational divers provide information on undersea distributions of species. Amateur bird watchers have been an essential source of information for bird abundance. Volunteers have assisted in mounting marmot recovery programs.

Another approach is to strengthen data gathering from users and traditional sources. The Department of Fisheries and Oceans already analyzes catch data from fishers, and data gathering and processing are improving through use of onboard observers and georeferencing technology. This will contribute richer information on a variety of marine species. The whale watching industry provides another opportunity for scientific observation (Lochbaum, interview). Whale watching boats are on the water frequently over the period that whales are present in British Columbia waters. Their observations add up to extensive understanding over a period of years. Approaches for capturing this knowledge in a rigorous way would provide useful scientific knowledge, and resolve equivocality. Aboriginal groups also have special knowledge, in some cases passed down from periods before European settlement changed ecosystems dramatically. Some of this knowledge is perishable as elders age and information is not documented.

Stakeholder involvement also affects the perceptions of stakeholders. Rich information is only rich for the persons that see it. Where stakeholder groups are potentially affected by resource management decisions, they need to be involved in the research so they can better understand the science used in decision making.

The current scientific paradigm involves strict disciplines that control how science is conducted to ensure scientific validity and reliability. Public science requires a scientist to be an educator and monitor of research projects to ensure that the results are not contaminated by bias or poor procedures.

Recommendations

It is recommended that:

- **Government processes be reviewed to identify opportunities and approaches for involving stakeholders in gathering and analyzing scientific data, and for ensuring scientific reliability and validity.**
- **Governments develop approaches for obtaining scientifically reliable and valid information from users and traditional sources.**

7.4.4 Peer Review and Publication

Rationale

Journals and scientific publications use peer review and publication as standard procedures for quality control (Goldbeck-Wood 1999). These procedures involve the submission of scientific papers to the detailed review and scrutiny of knowledgeable scientists and experts before publication, and then publication in scientific literature for broad scrutiny of the broader scientific community (Maccoun 1998). Scientists have suggested "studies that are found unacceptable through scientific peer review do not provide adequate basis for assessing impacts" (Beanlands and Duinker 1983). Peer review is a check on the reliability and validity of research. It also encourages comments, input and suggested improvements from other scientists through comments on draft papers, which allows a better linking with the concepts of other thinkers. Through peer review, it is hoped that "junk science" will be identified and discounted. Journalist

Ken Drushka (2001) indicated that junk science “refers to the misuse, deliberate or not, of scientific methodology and language to support a particular agenda, and it is used extensively by all sides in environmental debates.” Junk science is obviously a serious risk when information is equivocal because there are competing interpretations of scientific data (Maccoun 1998). Because of the risk of bias, ecologists have favored the adoption of peer review to “the greatest extent possible” (Beanlands and Duinker 1983).

Although peer review has obvious benefits, it also entails some risks. First, commentary on unpublished papers comes from scientists that are usually part of established paradigms. Paradigms are a consensus of opinion of scientific peers, but such consensuses can be wrong (Goldbeck-Wood 1999). Further, where a paper agrees in methodology or findings with the reviewer’s own paradigm, the reviewer is more likely to evaluated more favorably (Maccoun 1998). Peer reviews can also be institutionally bound, that is, unduly influenced by the corporate culture or structures of the publishing or sponsoring institution (Maccoun 1998; Goldbeck-Wood 1999; Hume 2000; Hutchings et al. 1997a; Doubleday et al. 1997; Hutchings et al. 1997b). Finally, the process can be prone to abuse and biases (Maccoun 1998; Goldbeck-Wood 1999). In all of this, evaluation of peer review will depend on some independent measure of the quality of a scientific paper, and the instrument for doing this is not available (Goldbeck-Wood 1999). Despite these reservations, peer review has considerable utility in assessing and improving the quality of research.

Approach

Peer review is a form of discussion, albeit often indirect in some cases. It does assist in the development of shared interpretations of contradictory and conflicting evidence. A number of scientists in the biomedical science community have conducted research to evaluate the efficacy and reliability of peer review methods (Goldbeck-Wood 1999), with a view to determining their value and suggesting improvements. Such reviews are important for ecological sciences as well.

An important concern is what is published. Interviewees in this research indicated that significant data sets relevant to some ecosystems and species-at-risk have not been published because of time constraints and lack of financial incentives. Interviewees suggested that the commitment to publish is lower in Canada than the United States, for example. This means that data used for decisions is not published for broad scrutiny and use of other scientists, managers, and the public.

There is also a bias against publication of negative or nonsignificant results (Maccoun 1998; Rodger 1995). Scientific journals tend to publish papers that have results confirming the author’s hypotheses, but articles refuting or not confirming hypotheses are not printed. The risk is that other researchers continue to waste time on dead end research because previous unsuccessful studies were not published. Further, the disproof of a researcher's hypothesis is very important to theory generally.

In recent years, there has been a rapid growth in the publication of scientific, peer-reviewed papers on the Internet. Where the distribution of scientific journals may be limited by the high costs of purchase, Internet publications are free and very easy to access. The National Research Council Canada (2001) has placed 14 environmentally-related journals online. Other environmental and ecology journals have recently been made available through other services (Findarticles.com 2001). This form of publication should enhance scientific discussion and peer review. This is a major fulfillment of the original purpose of the Internet, which was to facilitate scientific exchange, and a counter to the often unreliable material found on the Internet.

Starr et al. (1998) proposed "contested stock assessments" as a measure to improve peer review. This process, which has been used in New Zealand, involves the solicitation of alternative assessments of the likely response of fisheries stocks to harvesting scenarios from different user groups. This is differs from the traditional approach of assessments that are carried out by single fisheries agencies. Such an approach would highlight the equivocality in assessment information. According to the authors, "contested assessments would provide a number of benefits including (i) intense peer review, (ii) the ability to bring data from all parties into the assessment process, and (iii) better understanding and trust of the assessments by different interest groups." Maccoun (1998) defined science used in advocacy as "the selective use and emphasis of evidence to support a hypothesis, without outright concealment or fabrication." This form of science is "normatively defensible provided that it occurs within an explicitly advocacy-based organization, or in an explicitly adversarial system of disputing." While exposure to equivocal evidence may polarize attitudes (Maccoun 1998), contested assessments would expose positions to discussion, which is essential to remedying equivocality.

Recommendations

It is recommended that:

- **Governments and funding institutions give greater emphasis and incentives for the publication of research findings and ecological information.**
- **Journal editors should consider publication of negative and insignificant results.**
- **Scientists should consider submitting their research to peer-reviewed Internet-available journals for publication.**

- **Governments and resource management institutions should review the effectiveness of existing peer review mechanisms and consider improvements such as contested reviews.**
- **Governments should expand the use of peer review mechanisms for ecological information.**

7.4.5 Strategic Issues Sensing Mechanisms

Before a problem can be acted upon, scientists and managers need to sense that a problem exists and put the problem on the agenda for further consideration (Swets 1998; Weick 1979, 1995; Dutton 1988; Dutton and Duncan 1987; Dutton and Ottensmeyer 1987; Daft and Weick 1984; Dutton, Fahey, and Narayanan 1983; Meyer 1982; Kiesler and Sproull 1982; Fahey and King 1977). It is proposed that ecosystem managers and stakeholders develop sensing mechanisms for identifying strategic issues.

Rationale

Organizations differ in the extent to which they actively or passively scan their environments for sensing potential problems (Daft and Weick 1984). Ability to detect environmental changes depends on the amount of scanning activity, as well as organizational issues such as decentralization (Sutcliffe 1994). The detection of environmental changes is a prerequisite to mobilizing sustainable action, so a scanning system is a key element in ERMS (section 7.1.9).

Because marine ecosystems, and ecosystems in general, exhibit high levels of equivocality, problem sensing may be very difficult. An equivocality-resolving management system must therefore develop special capabilities for problem sensing. Which marine species are endangered or threatened? On what basis would scientists sense that a whale species or subpopulation is endangered? How would changes in fishing harvests affect euphausiid abundance? Would changes in euphausiid abundance affect rare or endangered species? Do large-scale regime shifts in the North Pacific have implications for management of endangered species or fisheries? In addition, equivocality can lead to premature closure of thinking due to a decision maker's need for certainty and reduction of equivocality (section 7.3.1).

Ansoff (1975) defined *strategic surprises* as "sudden, urgent, unfamiliar changes" that involve a threat or opportunity. Holling et al. (1978) indicated that surprises are to be expected in environmental management. Ansoff (1975) suggested that strategic surprises are often foreshadowed by "weak signals" that may convey "*content-rich* information" [emphasis in the original]. Often such information "arises from a familiar prior experience." Over time, the nature of a threat becomes clearer. In the conceptual frame of this research, this would suggest that early warnings of surprises are equivocal, and are perceived by qualitative, rich information.

Area Wide Impact Assessments

Ansoff (1975) suggested *impact analysis* as an approach for sensing strategic surprises. In Ansoff's definition, this involves a "threat/opportunity analysis." The procedure involves identifying strategic issues, trends, and possible events, and assessing the impact of these factors on a firm. This process would be done by geographic area, which is consistent with the ecosystem-focus recommended in this research.

Impact analysis is common in environmental management. Impact analysis methodologies have a wide range of tools identifying potential environmental impacts (Wolfe 1987). Impact analysis evolved as a procedure for assessing the effects of specific development projects rather than as a broader problem-sensing tool for ecosystems. However, the tool has evolved to consider wider ecosystem issues. Marshall et al. (1986) recommended the use of area-wide assessments, defined as

> the environmental analysis of an area or region focusing on the implications and consequences of its general development potential or of a number of specific development proposals. Area wide assessments can be conducted at the policy, program or regional planning level.

Area-wide assessment is similar to strategic environmental assessment (Wood and Dejeddour 1990). It is also a corollary of the long-established practice of regional planning and watershed-based management. An example of an area-wide assessment was the joint federal-provincial West Coast Offshore Exploration Environmental Assessment (WESCAP) that reviewed offshore oil exploration on the northern British Columbia coast (Chevron Canada Resources Limited 1982; Petro-Canada 1983; West Coast Offshore Exploration Environmental Assessment Panel 1986; McPhee 1982; Higham and Day 1989). WESCAP provided a project-focused summary of available information on the marine environment of the northern British Columbia coast.

State-of-the-Environment Reporting

In the past decade, governments and other institutions have sought more comprehensive ways to measure ecosystem health. State-of-the-Environment (SOE) reporting is defined as "the systematic measurement, collection, storage/retrieval and publication of environmental and resource data that focus on the interactions between human activity and the environment" (Stakeholder Group 1987). SOE reports have been prepared for British Columbia (Environment Canada and B.C. Ministry of Environment 1993), the Lower Fraser River Basin (McPhee, Wolfe, and Ferguson 1991; Environment Canada and B.C. Ministry of Environment 1992), and the

Fraser River estuary (Kennett and McPhee 1988). These reports summarized scientific opinion on a variety of issues, including some relevant to the topic of this dissertation, such as endangered species, protected areas, overviews of marine issues, and overviews of environmental issues in terrestrial ecoprovinces.

The “report card” is another approach for problem sensing. For example, the Sierra Club of Canada has issued annual report cards on progress towards commitments made by Canada at the 1992 Earth Summit in Rio de Janeiro. A similar report card approach has been used in India for evaluating urban services. Paul (1996) reported that the news media gave prominent coverage to the report card, which he attributes to the use of public feedback and the ability to compare government performance on different issues. Further, he reported that media found that reporting one “grade” in each Sunday edition of a newspaper kept the issues alive in the public’s mind for a longer time. Agencies also sought strategies to improve performance in areas where grades were low.

In Canada, the Don Watershed Regeneration Council and the Metropolitan Toronto and Region Conservation Authority (1997) issue report cards every three years to report progress on regenerating the Don River watershed. The Fraser Basin Management Program (1996) and Fraser Basin Council (1998) prepared report cards evaluating progress toward sustainability for a variety of resources, including fisheries, water, forests, and agriculture, as well as human activities, decision making, and planning processes. The important innovations in the Fraser River exercise are the focus on regional watersheds, broad participation of stakeholders and scientists, and the development of measures of sustainability. The process was efficient and cost-effective.

The tools are available for broad or focused scaled threat assessments for sensing emerging problems. These tools have been developed primarily for terrestrial environments, and need to be adapted for marine environments. Marine stakeholders do not live at sea, and technical information is much more sparse.

Recommendation

> **It is recommended that governments and other institutions establish ecosystem-focused environmental sustainability reporting processes and discussion conferences to identify emerging environmental issues, threats, and opportunities.**

7.4.6 Adaptive Management

Carney (1997) argued that concepts of deep-sea ecology have been accepted with too little debate among a “small and dwindling pool of experts.” The lack of debate and “critical attention” to test theories has resulted in the use of untested theories for resource management. In referring to “various explanations for high biological diversity,” he suggested that the “progression of ideas has not been driven by tests, falsification, and alternative hypotheses.”

The concepts of adaptive environmental management were developed in the mid-1970s by a team of scientists, managers, and government agencies led by Dr. C.S. Holling (Holling et al. 1978). Adaptive management was a response to the prevalence of uncertainty in ecological decision making, science, and resource management. Equivocality would be included within Holling’s definition of uncertainty. Adaptive management provided some new conceptual and methodological tools for addressing this uncertainty. Adaptive management is particularly important for marine ecosystems because prediction is difficult and risky (Bottom et al. 1993).

Approach

The adaptive environmental management approach uses interdisciplinary workshops among scientists, and joint workshops between scientists and managers, for developing shared ecological understanding among scientists and resource managers (Holling et al. 1978). In these workshops, diverse disciplinary perspectives are brought together in a group process to mold an explicit model of an environmental system. The models serve as theories that generate hypotheses that can be tested through normal management actions and monitoring. Rigorous scientific standards must be applied to ensure that valid scientific understanding develops from observing the effects of management actions (Smallwood, Beyea, and Morrison 1999).

Learning is a major component of adaptive management. Walters (1986) indicated “this approach begins with the central tenet that management involves a continual learning process.” He suggested that a major issue for adaptive management is the “design of policies that provide for continuing resource production while simultaneously probing for better understanding and untested opportunity.” Adaptive management "applies to situations where the best action for any system cannot be fixed a priori but must instead be established through sequential reassessment of system states and dynamic relationships" (Holling et al. 1978; Walters and Hilborn 1978; Walters 1986; Sherman 1991; Lee 1993; Gunderson, Holling, and Light 1995; McLain and Lee 1996; Brunner and Clark 1997). It is an alternative approach to traditional long-range planning, which assumes a broad understanding of current conditions and future trends. Such broad understanding may not be possible in an equivocal environment (Allen and Gould 1986;

Connolly 1988; Grumbine 1997).

In adaptive management, management decisions are designed as experiments. The approach can be illustrated for management of marbled murrelets. Scientists do not know how large protected areas need to be for marbled murrelet nesting areas. Researchers could use a comparative approach to correlate nesting density to nesting patch size. These data will come from current studies being done on murrelet nesting habitat requirements (chapter 4). From this analysis, hypotheses could be developed as to the effects of patch size on nesting success. These hypotheses, for example, could specify the expected success for different patch sizes such as 200, 500, and 1,000 hectares. Then, because government and industry plan to log almost 90 percent of murrelet habitat, logging could be scheduled to leave various sizes of nesting habitat patches. Nesting density could then be measured to evaluate the hypotheses. The experiment is *built into the management decision*. Research is not separate from management.

Failure to Use Approach

Despite the apparent logic of the adaptive approach in environmental management and evidence of success in using the approach, there is a surprisingly widespread failure to use it more widely (Walters 1997; Carpenter 1998; Rogers 1998). Although adaptive management, as an approach, has been evolving for over two decades, many management decisions continue to be made on a traditional reactive mode that wastes opportunities to gain causal knowledge of ecosystem functions through experiments. Opportunities for learning are wasted, and equivocality is not addressed. Much of the blame for this may be due to the fear of public or political reprisals for experiments that appear to harm ecosystems, such as an experiment causing a serious decline in certain fish stocks. Another reason may be the need for new learning and thinking styles for resource scientists and managers. Agencies are constrained by past agency history to operate in familiar patterns. Traditional corporate resource management cultures may not fit with management-by-experiment approaches. This has implications for training and incentive programs for staff (Senge 1994; Kolodner 1997; Carpenter 1998; Rogers 1998) and broader education programs.

Recommendations

It is recommended that government

- **agencies review decision making processes to determine how management decisions could be redesigned to ensure that adaptive information is acquired when natural resources are used.**
- **agencies should educate the public concerning the value of adaptive**

management programs to improve public acceptance of possibly negative management results.

- **agencies should take small steps, through pilot-testing of initiatives, and carefully assess impacts before committing to full-scale implementation.**
- **hiring, training, promotion, and incentive programs should encourage and reward adaptive approaches to management.**

7.4.7 The Problem Structuring Focus

Problem structuring is the process of framing a problem for analysis (Dutton, Fahey, and Narayanan 1983). Framing involves defining and structuring confusing questions and ill-structured problems into forms that are tractable for decision making (Lyles 1981).

An example of problem structuring in an equivocal decision situation is the process for listing an endangered or threatened species. The information for determining the status of a species is often fraught with equivocality, especially in marine ecosystems (sections 4.1.4 and 5.1.1). Listing authorities, such as the Committee for the Status of Endangered Wildlife in Canada (COSEWIC), receive status reports from scientists who provide advice on the level of risk faced by a species. Despite efforts to derive quantitative measures for endangerment, status reports often present subjective information and professional judgements about the factors that endanger the species. The impetus for preparation of a status report may come from the initiative of a scientist or conservation organization, from a biodiversity survey, or from COSEWIC. The actual status decision is made by COSEWIC through discussion (section 1.3.3). The process for framing the problem of endangerment for a species is thus initiated by the author of the status report, and deliberated by COSEWIC.

Rationale

Although this dissertation did not formally evaluate the effectiveness of existing programs in coping with equivocality, the present listing process does involve both discussion and an attempt to obtain rich information. This is consistent with the approach recommended in this research for dealing with equivocality. Extensive collaboration has also occurred for the identification of marine protected areas in B.C. (section 1.3.1). The present approach does therefore address the existence of equivocality, at least partially.

Simple discussion and rich information, however, are not sufficient in many cases. In the process of framing a problem, managers must sometimes consider massive amounts of data, only some of which are relevant to the decision (Walsh 1995). Managers and others may also face vague and ambiguous data that undermine their faith in the facts. When this occurs, they press scientists for scientific or professional opinions that might help them interpret those data (Barker 1974; Beanlands and Duinker 1983). They also reach down into their own experience for schemas or mental models that suggest what impacts their decisions might have. Managers "filter and evaluate issue-relevant information. In the process, the participants construct the meaning of issues by labeling them in particular ways" and "act as interpreters and packagers of issues" (Dutton and Ottensmeyer 1987). Filtering and framing are important because they determine what issues reach the policy agenda and which actions are taken (Dutton, Fahey, and Narayanan 1983; Starbuck and Milliken 1988). In the COSEWIC case, someone decides which species are evaluated, and the authors of status reports are expected to produce unequivocal recommendations.

Approach

Cognitive scientists have identified numerous cognitive strategies for coping with uncertain and equivocal decision situations. These strategies are not appropriate in all situations, and can lead to cognitive failures that can lead decision makers to make ill-considered choices. Examples of cognitive failures include simplification of issues, satisficing, anchoring, mindless enactment of scripts or standard operating procedures, pessimistic or optimistic perception, and labeling (section 1.6.1, table 1.10; Piattelli-Palmarini 1994).

To address equivocality, decision makers must learn to identify and neutralize cognitive failures in their decision making (Walsh 1995; Barker 1974). Pinker (1997) indicated that cognitive psychologists are seeking to understand cognitive failures through "reverse-engineering" of cognitive processes. In other words, they are studying why the mind accepts cognitive misinformation as a means for improving thinking effectiveness. For resource management decision makers, a first step is to become aware of the effects of equivocality and the adoption of false cognitive strategies for dealing with it. According to Abualsamh, Carlin, and McDaniel (1990)

> People need help in thinking about complex situations or they will result to ineffective simplifying heuristics for coping with information. . . . An increased understanding of the basic nature of problem structuring would enable designers of problem structuring heuristics to be better able at helping achieve more effectiveness and efficiency in their problem structuring activities. This suggests the need for more research into the cognitive processes associated with problem structuring as well as the kinds of matches that might be sought between typical cognitive processes and the structure of decision aids.

Unfortunately, although the pervasive effects of cognitive failures have been documented (table 7.2), decision makers "seldom use formal problem structuring strategies" (Abualsamh, Carlin, and McDaniel (1990).

Recommendation

> **It is therefore recommended that government agencies sponsor training for managers and scientists in problem structuring and in the identification and mitigation of cognitive failures in research and management decision making.**

7.4.8 Systems Thinking and Modeling

Systems thinking and modeling have been proposed as integrating principles for the learning organization (Senge 1994). As noted in section 1.4, people represent causal understanding in "mental models" (Johnson-Laird 1983). A mental model is a cognitive representation of the world, a metaphor that organizes presumed causes and effects into an understandable conceptual map of reality (Norman 1983; Boland and Greenberg 1988; Clark 1993; Senge 1994). Interpretation of causality enables people to predict sequences of events and use this information to adapt to their environment (Geminiani, Carassa, and Bara 1996; Barr, Stimpert, and Huff 1992). It enables them to comprehend chaotic patterns in nature more effectively (Smithson 1997), to avoid ineffective strategies for coping with uncertainty (Lipschitz and Strauss 1997), and to improve information processing to address equivocality (Hedberg and Jonsson 1978).

Systems thinking is an important element of adaptive management. The adaptive management modeling approach is premised on stated assumptions that ecosystems are organized systems that are spatially diverse and dynamically variable (Holling et al. 1978). According to Holling et al. (1978),

> systems ecology, in partnership with the physical sciences, has now matured enough to be capable of producing succinct representations of key elements of ecological and environmental systems. The resulting models mimic not simply static properties, but the dynamic ones that shift and change because of natural and man-induced influences.

As part of the modeling process, analysts "abstract the essential properties of at least some ecological and environmental systems and . . . represent them in a model that mimics behavior over time for a variety of conditions." The analysts consider only "essential properties" necessary for ensuring the models mimic natural systems and address management questions. Holling et al. (1978) indicated "the models, therefore, are not designed for general scientific purposes but for very specific management ones. Hence, they attempt to be both parsimonious (and hence tractable) and realistic (and hence useful)." Morgan and Henrion (1990) suggested “most of the best policy models are small and simple,” although “large and complex models” may be justified when “the inclusion of these details in the model is essential to the insight or answer that is sought.”

Traditional management approaches are also based on causal models of ecosystems. However, these models are often not designed for testing theory. For example, fisheries managers have had population models that assumed an unlimited resilience of fish stocks to harvesting pressure. This model has led to serial depletion of fish stocks (Marliave, interview; Kurlansky 1997).

Holling et al. (1978) recognized that adaptive management models could also be incorrect representations of reality. Mental models are causal theories filled with assumptions (Lipshitz and Strauss 1997). People have difficulty seeing causal systems that are nonlinear and have feedback loops (White 1995). An important question is how mental representations of reality are formed by scientists and managers involved in both traditional and adaptive management modes. Methods are available within cognitive psychology for identifying patterns of thinking and responses to information that confirms or refutes a person’s existing mental models. By understanding mental models, management approaches can be adapted to capitalize on natural model formation processes in the mind, and to mitigate constraints on forming and testing mental models (Hall 1984). This sort of research, for example, could address the effects of surprises that have occurred during recent oceanographic regime shifts related to relative species abundances and distributions, which scientists are now struggling to explain (section 4.6).

Ecological modeling has been used in resource management decision making in a number of contexts (Huggett 1993). Practitioners have used workshops, involving both scientists and resource managers, to develop these models cooperatively (Holling et al. 1978), which should address equivocality. This provides common understanding of the complexities that underlie the formal models. However, Baskerville (1995) found that learning has been uneven among various agencies and stakeholders, and that some stakeholders and professionals see modeling as a "Nintendo" exercise, that is, as merely a computer game.

Recommendations

It is recommended that:

- **Cognitive research be conducted to identify how scientists, managers, and others develop mental models representing ecosystem functions to cope with equivocality.**
- **Information and training be made available to assist scientists, managers, and others to understand how mental models are formed,**

potential pitfalls in developing mental models, and ways to improve causal thinking.

7.4.9 Fuzzy Logic Approaches

Many types of data are inherently "fuzzy" because the categories or "sets" used to classify information are not crisply defined. Minimum population viability analyses, for example, attempt to define when a species is "rare" by specifying a minimum number of individuals necessary for avoiding extinction given genetics, variability, and other factors. Ecologists would not, however, consider a species with one animal more than the minimum as "not rare" simply because it exceeds the minimum. As numbers increase, the species gradually becomes "less rare" suggesting that "rare" is an approximate, broad, or "fuzzy" category. The analysis of "fuzzy sets" of data is referred to as "fuzzy logic" (McNeill and Freiberger 1993; McCloskey and Glucksberg 1978; Zadeh 1965) or “fuzzy mathematics” (Smith 1994). This form of analysis has been “applied widely” to “pattern analysis, decision making and artificial intelligence” (Equihua 1990). The procedure is valuable because it “more adequately acknowledges the vagueness, inexactitude, imprecision and fuzziness characteristic of multi-objective assessment and decision making than conventional quantitative mathematics” (Smith 1994). Fuzzy sets may explain some of the equivocality in ecological information (Equihua 1990; Smith 1994).

As proposed by fuzzy set theory, most environmental systems do not change state in discrete categories, such as the transition of a species from abundant to endangered. Yet, governments seek hard quantitative criteria to make judgements about environmental risks and health. Decision makers should avoid excessive and spurious quantification of evaluative criteria. For example, crisp quantitative criteria might imply that at 500 whales, a species might be endangered, but at 501 whales, the species could be hunted. Clearly, endangerment is a fuzzy category, and one that depends on the implications of being endangered or not endangered. Todd and Burgman (1998) described a method for using fuzzy logic in species listing decisions.

Protected areas provide another example of the use of fuzzy logic. A traditional approach might propose a discrete boundary around 200 hectares of murrelet habitat, and allow logging outside that habitat without concern for murrelets, though murrelets would clearly be affected. Fuzzy logic could be used in defining protected area boundaries, such as gradations of regulation within concentric buffer zones. For example, fuzzy logic approaches have been used successfully for modeling coral reefs (Meesters et al. 1998). Such approaches are especially crucial in marine environments where ecosystem boundaries are inherently fuzzy (section 4.3).

Governments, including British Columbia, have also adopted another “magic number” in policies that propose to protect 12 percent of their geographic territory, although such numbers are no guarantee of the persistence of ecosystems or species (Merrill, Wright, and Scott 1995). This policy now applies to murrelet habitats in British Columbia and to the government's protected areas strategies.

Recommendation

> **It is recommended that governments and conservation organizations develop and apply fuzzy logic procedures for conservation evaluation and planning, species listing decisions, protected areas design, and other functions.**

7.4.10 Qualitative Methods in Science

While considerable progress has been made in quantitative methods in ecology, it is proposed that additional emphasis be given to qualitative approaches. Qualitative studies can provide reliable and valid information with considerable richness.

Rationale

Interviewees often cited anecdotal evidence of processes that they perceived were important to the case ecosystems. Bryant (interview), for example, noted evidence of predation on marmots, but argued that statistically rigorous analysis was not possible because of small sample sizes. He also insisted that predation was obvious from observation of a few predator attacks and the presence of marmot fur in predator scat. Bryant and other interviewees supported positivist science with quantitative testing of hypotheses. Yet, frequent qualitative speculations by all interviewees about ecological phenomena and their causes suggested that they possess a level of knowledge that goes beyond quantitative study.

William Resetarits noted that ecologists have made considerable progress in the past three decades by replacing assumptions about natural systems with testable theories and rigorous statistical analysis (Roush 1995). However, he contended that this effort has gone too far and tends to reduce nature to oversimplified caricatures that have little to do with the real world. He stated that "experiments can do something for ecology that no other approach can do: establish cause and effect. But they don't tell you what questions to ask, or whether you are testing your questions appropriately" (Roush 1995). Roush (1995) cited ecologists who believed that many "mindless, stupid experiments" are being conducted by young ecologists who have no "intimacy with nature." At the same time, ecological journals refuse to include tables with field observations in reports of experiments. On the optimistic side of this debate, other ecologists see a trend toward combined and balanced approaches involving theory, natural history, and experimentation to understand the complexity of ecosystems.

The interview participants were intimately familiar with the ecosystems they were asked about in this research. In many cases, they had spent years studying the species or ecosystem, and had spent weeks or months observing the ecosystem close-up in the field. As a result, they were able to offer rich insights that were not necessarily statistically rigorous, but were probably quite accurate nonetheless. In many cases, these observations cannot be captured through quantitative studies, either because of technical infeasibility or because of limits to their budget or time resources. Holling et al. (1978) proposed the use of "qualitative techniques" to

> effectively analyze systems that possess insufficient information to allow construction of a normal simulation model. Often, all that is known is the major variables and how they interact qualitatively – when A is large, B will decline. We realized that most environmental studies do not rely on simulation models, but the techniques that are employed in these studies often fail to utilize the information that is available.

Holling and associates described the use of "qualitative simulations" and gaming exercises to qualitatively model ecosystem functions.

Considerable progress in the rigorous and positivist analysis of qualitative data has been made in the social sciences. Hypotheses are rigorously tested using qualitative data. Qualitative theory-building methodologies also have considerable potential for exploring, developing, and confirming theory. Smallwood, Beyea, and Morrison (1999) argued that procedures should be developed to make the judgments of experts and professionals more scientifically reliable.

Management researchers Daft, Lengel, and Trevino (1987) have found that managers and executives need information that is both "subjective and qualitative." Managers work in a context where "issues are fuzzy and ill-defined" and situations are "ambiguous and unstructured." They stated that

> for these situations, alternatives cannot be obtained and objectively evaluated, and outcomes are unpredictable. . . . To survive, individuals and organizations must develop information processing mechanisms capable of coping with an ambiguous, unstructured environment.

Ecosystem managers must also rely on qualitative information to make conservation decisions because information from controlled scientific studies is not obtainable.

Realistically, full knowledge of ecosystem processes is not feasible in the near term, and perhaps never (Capra 1996). Qualitative methodologies would provide another avenue of research for improving understanding, especially for issues that are not amenable to quantitative experimentation. These methodologies could address anecdotal evidence and traditional knowledge, as well as qualitative ecological methods such as natural history. Resource managers will continue to be required to make decisions using qualitative information. There is therefore an urgent need to improve methods for analyzing qualitative scientific data.

Recommendations

It is recommended that:

- **Research be conducted to identify, develop, and apply qualitative approaches for ecosystem research, and to develop ways to improve scientific reliability and validity of qualitative studies, anecdotal evidence, and traditional environmental knowledge.**
- **Governments and conservation organizations integrate qualitative research methodologies and findings with the more traditional quantitative research methodologies to inform decisions regarding ecosystem management.**

7.5 Institutional Inputs

Implementation of the ERMS model would require major changes to the management systems for marine resources. Proposals for some of the components discussed above, such as ecological boundaries, linked management systems, and adaptive management have been around for decades, but governments have been extremely slow in implementing them. Clearly there is a need for traditional inputs such as legislated authority, funding, and additional staff. These things are needed and are not adequately supplied. The most important inputs, however, precede authority, dollars and people. Sections 7.5.1 through 7.5.3 outline three critical inputs that are, with a few exceptions, fundamentally lacking:

- Political leadership
- Strategies to sustain institutional change
- Frameworks for cooperation

7.5.1 Political Leadership

Most of the scientists and managers who were interviewed suggested that the technologies exist to conduct reasonably good research both on land and at sea. However, the financial and staff resources are so meager that there is no reasonable prospect of reducing the amount of uncertainty and equivocality that exists in ecosystem management in the foreseeable future. Major funding has been acquired for conservation of the charismatic marmot and for studying the murrelet and its commercially valuable old growth forest habitats. This funding, however, does not address the broader management needs for a truly ecosystem-based management of these habitats.

As noted in section 1.2.3, the scope and scale of research required for describing and understanding ecosystems is enormous, and may require decades of work. According to Slobodkin (1988), "ecology may be the most intractable legitimate science ever developed." At the same time, he argued that "we are nevertheless left with the fact that only ecology can provide the empirical base for satisfactory environmental management." Slobodkin suggested that "the best course for both ecology and for the public would seem to be to focus on practical questions, in the way that medicine focuses on actual diseases." He observed that advances in medicine resulted from the accumulated experience of physicians and information from their practical work. This is analogous to an adaptive management approach where managers learn from the experience of making decisions and evaluating the results. Slobodkin, however, expressed concern that

> There are severe and urgent problems on the level of administration and support for applied ecology. . . . A great deal of significant data have not been collected. Worse, critical data are lying fallow for lack of funds and logistic support for analysis.

This conclusion is certainly supported by the present research.

The adequacy of budgets and regulations depends on the vision and will of the public and their governments to insist on adequate and responsible management. At present, the political vision and will are not sufficient to improve environmental management to the degree that is necessary, and budgets and staff are generally declining (Ward 1999). Interviewees frequently stressed the crippling inadequacy of research budgets. If ecosystems are to be managed and conserved, a major shift in human thinking is required. Humans must invest in the knowledge and information necessary to resolve equivocality in ecosystem management. According to Slobodkin (1988)

> Human activity must be subject to regulation if the world is not to be most severely damaged. The goals or motivation for these regulations may be practical, aesthetic, or even philosophical, but the proper techniques of regulation depend on empirical information and scientific theory. Unfortunately the regulatory agencies do not perform adequate scientific analyses, and ecological research support is generally inadequate.

Thus science is essential for environmental management and avoidance of severe damage to our environment. The loss of our natural environment also has spiritual and aesthetic consequences. Slobodkin also stated that

> national life is enriched by sensitivity to national organisms. A people that has lost a sense of its own landscape is severely limited in its capacity to develop rich poetic images, and this limitation must have deep social consequences.

Political decisions are about compromise, but environmental systems operate by a different code. The human impact on earth has been a severe biological catastrophe. According to Myers (1993), “the mass extinction gathering force will, if it proceeds unchecked, not only eliminate half or more of all species, but will leave the biosphere impoverished for at least 5 million years – a period twenty times longer than humankind itself has been a species.” There is no return from extinction. Concerning budgets Myers (1993) continued

> Right now, we are effectively asserting that we can afford to allow large numbers of species to become extinct on the grounds that we cannot economically deploy the funds or other conservation resources necessary to save a good share of the vulnerable species. The corollary of this stance is that we are implicitly deciding that at least 200,000 future generations can certainly do without large numbers of species, and that we feel sufficiently certain we know what we are talking about when we make that decision on their unconsulted behalf.

A government that acts solely based on opinion polls and election prospects, and other “practical” considerations, is not visionary. Peter Senge (1994) stated that

> A shared vision is not an idea. It is not even an important idea such as freedom. It is, rather, a force in people’s hearts, a force of impressive power. It may be inspired by an idea, but once it goes further – if it is compelling enough to acquire the support of more than one person – then it is no longer an abstraction. It is palpable. People begin to see it as if it exists. Few, if any, forces in human affairs are as powerful as shared vision.

Visions are not extrapolation of past trends (Costanza 2000). Nor is vision “a fixed focus or agenda, sometimes known in the United States as ‘tunnel’ vision” (Tyson 2000). Rather, “a vision can provide… a listening device, an integrator of conversations, a means to converge dreams into reality” (Rogers, Roux, and Biggs 2000). Visionary leaders *shape* public opinion and election prospects by articulating a vision. In the early 1990s, the government of British Columbia promoted an environmental vision for British Columbia in its protected areas strategy, integrated resource planning, shared decision processes, watershed management programs, and other bold environmental initiatives. Political leadership is an essential but often illusive component of any strategy for sustainable management of natural resources.

Recommendations

> **It is recommended that the governments of Canada and British Columbia and nongovernment organizations and academic institutions demonstrate leadership in articulating visions and providing the resources to refocus resource management on sustainable equivocality-resolving management initiatives.**

7.5.2 Strategies to Sustain Institutional Change

Adopting new organizational approaches, such as the ones recommended above, will require extensive changes to organizational structures and processes. Organizations tend to be conservative about change, and continue to operate in familiar ways despite some level of inefficiency or ineffectiveness.

Prerequisites to Change

Often change will only occur when an organization experiences sufficiently strong stimuli to provoke modifications. Once committed to action, an organization may consider a broad range of possible actions, ranging on a continuum from simple incremental changes in procedures and policies, to broadscale reorganizations (Dutton and Duncan 1987; Eisenhardt and Tabrizi 1995). Several factors affect the likely scope and speed of organizational change, including perceived performance gaps, stakeholder demands, urgency, feasibility, and ideologies (table 7.1).

Before an organization makes a decision to reorganize, it must perceive a gap in its performance. For example, there is very little knowledge about species extinctions at sea, so no gap is perceived. There are roughly 45,000 murrelets in British Columbia, so many stakeholders do not believe there is a performance gap in protecting the species. A perceived gap must be perceived as a real or potential failure if it is to motivate change. Perceived gaps are often brought to the attention of decision makers because stakeholders make demands and raise the profile of an issue.

Governments generally realize, at least nominally, that there is a biodiversity crisis, if all of the international conventions, legislation, policies, and public statements are to be credited. However,

Table 7.1 Factors Affecting the Speed and Scope of Organizational Change

	SOURCES	EFFECTS
Perceived Performance Gap	Perception of gap between actual and desired performance based on past or projected trends, standards of comparable organizations, expectations of other people, or theoretical models.	Organization recognizes and diagnoses an issue Perception may occur either slowly or rapidly. Rapid recognition may occur because of "jolts" or "surprises."
Stakeholder Demands	Managers, staff, government agencies, nongovernment organizations, and the public may make demands.	Organization recognizes and diagnoses an issue. Managers may exercise strategic power to initiate action.

Urgency	Pressures exerted by stakeholders. Issues may be visible such as when the press or media are involved. Issues may contain embedded deadlines or other time pressures that force early action. A decision maker may feel personally accountable for action or inaction.	Organization moves from interpretation towards action. Urgency determines speed of action.
Feasibility	Organization perceives there are viable means of acting, and that these means are available and accessible.	Organizations tend to initiate change only when they assess action as feasible. They are reluctant to act when they see no apparent solution.
Ideologies	Preconceived organizational concepts or resource management paradigms in the minds of resource actors, such as sectoral resource ministries, sustained yield, sustainable development, or ecosystem and adaptive management.	Ideologies facilitate or constrain choices concerning the speed and scope of change.

Sources: Pounds 1969; Child 1972, 1997; Mintzberg et al. 1976; Billings, Millburn and Schaalman 1980; Miles and Randolph 1980; Meyer 1982; Daft and Weick 1984; Cowan 1986; Dutton and Duncan 1987; Gortner et al. 1987; King 1995; Gunderson, Holling, and Light 1995.

the required dramatic action is not happening. Organizational theory suggests that before action occurs, decision makers must feel that the decision is urgent and feasible. Urgency can occur from stakeholder pressures, media coverage, deadlines, or a sense of accountability. For the murrelet, the equivocality of population numbers blinds some decision makers to the urgency of acting before a greater crisis occurs, such as the one facing the marmot. Not enough marmot habitat was protected until there was little left to protect. Now, murrelet habitat is being logged except for a magic number of 12 percent of the residual of the already drastically diminished original amount. Feasibility means that a decision maker has a clear and viable means for initiating change. Some biologists are skeptical that anything can be done to save the marmot from extinction. The recovery committee has seen a feasible solution in the capture and reintroduction approach. They are assisted because the public has also seen a desperate urgency to avoid the loss of a charismatic species. If it were not for the perception of feasibility, the marmot would indeed be doomed. The limited numbers of marmots and their small range present a manageable problem. Murrelets are harder to protect because so much land has to be preserved in a natural state. Species in open seas are difficult or impossible to protect without international cooperation and surveillance.

Finally, all decisions are premised in some way on ideology. For many, the loss of a species due to human action is ideologically unethical. For others, the loss of a species is the price of progress. Most people are concerned about the loss of charismatic species such as the elephant, whale, tiger, or marmot. At the same time, society presently tolerates loss of numerous species such as insects, invertebrates, or plants. As issues of biodiversity are considered, each side seeks to use public education and propaganda to influence the ideologies of society to bring about a "responsible" attitude.

As the above discussion demonstrates, performance gaps, stakeholder demands, urgency, feasibility, and ideologies are all equivocal concepts. They are thus amenable to the equivocality-resolving measures outlined in this research.

Recommendations

It is recommended that proponents of change, including government and nongovernment organizations:

- **Focus on measuring and reporting gaps in the performance of resource management organizations and society generally in achieving conservation of ecosystems.**
- **Promote the use of action-forcing and accountability mechanisms such as stakeholder pressure, requirements for public disclosure of performance, enforceable resource use standards, and time requirements for performance in legislation.**
- **Identify, develop, and promote practical and feasible strategies for implementing conservation programs.**
- **Continue to implement public awareness and education programs to influence ideologies of the public and political decision makers.**

7.5.3 Frameworks for Cooperation

The first component of ERMS is some form of framework that would provide a context for organizational design.

Environmental scientists and managers have long criticized traditional fragmented resource management that is organized around sectors, jurisdictions, levels of government, and scientific disciplines. The extensive fragmentation of resource management structures and jurisdictions frustrates ecosystem management (Caldwell 1994; MacKenzie 1996; Day and Gamble 1990; Grumbine 1990, 1994; Franklin 1993). Ecosystem management requires an integrated approach to managing human activities that affect ecosystems, with a priority on the conservation of the ecosystem integrity (Juda and Burroughs 1990; Slocombe 1993; Grumbine 1994; Caldwell 1994: Alpert 1995; MacKenzie 1996; Roe 1996).

Approach

As noted in section 1.3, government agencies with protected areas responsibilities have established working arrangements for cooperation in the establishment of marine protected areas under a variety of jurisdictions. Such measures are an appropriate response to equivocality, resulting in increased discussion and sharing of information. Governments have also established some of the legislative frameworks for integrated management through provisions of the *Oceans Act*, which mandate cooperative planning processes, and creation of the Land Use Coordination Office by the provincial government. The federal government has consolidated some of its marine operations under the Department of Fisheries and Oceans, including fisheries management, oceans management, and coast guard. In addition, governments have shown leadership in developing land and resource management processes for terrestrial areas that are broadly participative and integrate the policies of diverse agencies. In the past, the federal and provincial governments have cooperated on estuarine management programs, such as the Fraser River Estuary Management Program, and on area-wide assessments of oil and gas development for the northern coast (Marshall, Wolfe, and Scott 1987; Day and Gamble 1990). The trend is thus toward cooperation, but cooperation has been ad hoc, local, and not firmly institutionalized.

The relatively simple administrative structures affecting marine areas (Burroughs and Clark 1995) and the recency of stronger emphases on the management of marine environments provide an opportunity for new institutional forms for marine management. The challenge for addressing equivocality is to focus scientific and managerial discussions on ecosystems, and facilitate adequate amounts and quality of information. The broader challenge for ocean governance is to agree on policy goals and objectives, simplify government administration, manage government administrative resources more efficiently, and assure accountability of all agencies (Fraser River Estuary Study 1982).

In order to enhance integrated management of human activities in the marine environment, the governments of Canada and British Columbia should develop an institutional framework for the integration of specific policy, management, and research activities. A formalized joint framework would strengthen the legal and institutional basis for ongoing initiatives such as the Canada-British Columbia Marine Protected Areas Strategy and emerging cooperation in integrated coastal and marine planning. In this sense, it would build a stronger foundation under a house that is already under construction.

Recommendation

It is recommended that the governments of British Columbia and Canada

establish a framework agreement under existing or new legislation to enable broad delegation of integrated resource management functions to coordinating bodies comprised of key agencies and stakeholders.

7.6 Overview and Concluding Comments

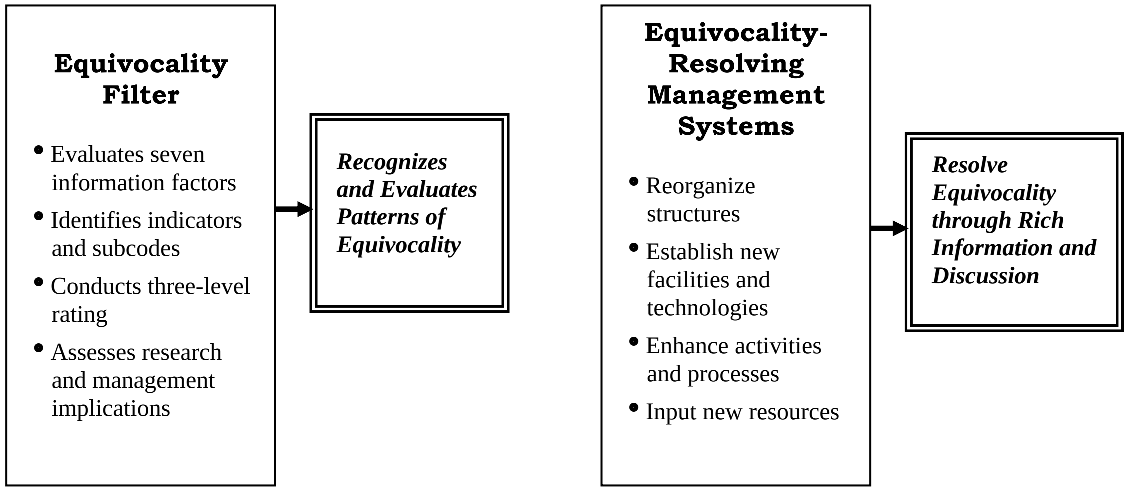
This volume began with definitions of equivocality in chapter 1. Chapter 2 discussed differences among ecosystems and specified hypotheses and case studies. A grounded qualitative research method was described in chapter 3 and applied in chapters 4 and 5 to four case ecosystems. The conclusion from chapters 1 through 5 is that ecosystems exhibit strong differences in patterns of equivocality.

For applied research, it is necessary but not sufficient to demonstrate the prevalence of a phenomenon such as equivocality. Chapters 6 and 7 thus offer approaches for recognizing and resolving equivocality (figure 7.2).

Chapter 6 suggested a design for an *equivocality filter*. Based on the methodology and case applications in the first five chapters and comparison with other examples in chapter 6, the equivocality filter has a demonstrated ability to recognize and evaluate equivocality patterns. The equivocality filter is also able to identify research and management implications of these pattern differences. The equivocality filter is thus effective in recognizing equivocality and operationally feasible for use by ecosystem managers.

Recognition of equivocality would be more frustrating than productive if there were no approaches that could be applied to resolve equivocality and make decisions. Resource management decisions will continue to be made regardless of uncertainty and equivocality. Fortunately, approaches either exist or can be developed which can greatly assist resource management institutions to resolve equivocality. Chapter 7 proposed *equivocality-resolving management systems* that can be designed to produce richer information and enhance discussions in order to resolve equivocality. The choice of components and the design of management systems will depend on the specific circumstances of the agency or program. The range of tools and options currently available provide ready-made actions that can be taken to make resource management institutions more capable for resolving equivocality and making sound decisions.

Figure 7.2 Overview of Equivocality Filter and ERMS



This research has identified and evaluated a major complicating factor in ecosystem management: the phenomenon of equivocality. Equivocality is not a peripheral issue, but may well be the most important issue affecting ecosystem management. Ecosystem managers have tended to address uncertainty because they have the tools to analyze and address it, and ignore that "other stuff" that is "unknown." If ecosystem managers continue to focus on reducing uncertainty while ignoring equivocality, decision making will be less effective and opportunities for enhancing the sustainability of natural resources will be lost. Problems are often not recognized until feasible solutions are available (section 7.5.2). Chapters 6 and 7 thus framed feasible remedies for the problem of equivocality. Chapter 6 proposed an equivocality filter for recognizing and evaluating this phenomenon. Ecosystem managers can now venture to address these "unknowns" in a more deliberate and rigorous manner. Chapter 7 proposed equivocality-reducing management systems as a set of tools and options for coping with equivocality. Using these tools and options, responses to equivocality can be designed into the fabric of ecosystem management institutions.

The next step in addressing equivocality is to implement the equivocality filter and equivocality-resolving management systems in specific jurisdictions. As experience is gained and evaluated, ecosystem management institutions can be strengthened and new ways to can be found to resolve equivocality. The resolution of equivocality is thus a major field for applied research and ecosystem management.

As a concluding caveat, one should not assume that equivocality can be eliminated from resource management decision making. First, this research has found that equivocality has a pervasive and profound effect on the management of even the simplest ecosystems. For example, the subalpine ecosystem was the least equivocal case reviewed, but the level of equivocality is very serious in this ecosystem. Equivocality differences among ecosystems are a matter of degree rather than either the presence of equivocality or not. Second, although this research explored equivocality in scientific information, equivocality is also strongly influenced by the values and paradigms of scientists, resource managers, and the society, which are widely divergent. Social values and attitudes are at least as equivocal as the scientific information. Equivocality will remain strong in resource management because of competing values. Even where an answer can be found on the science side, there may well be reluctance to accept these answers on the social side. Equivocality may be reduced, but it will still significantly impair resource managers' ability to make unequivocal decisions.

APPENDICES

Appendix 1: Hypotheses and Case Questions

This is a summary of hypotheses and case questions for each hypothesis.

Hypothesis 1: Target Species Listing Rationale

Information Processing Function: Problem Definition

Equivocality Attribute: Confusing Questions

Hypotheses:

Hypothesis 1a: The ecological rationales for listing particular marine species as target species for protection are less clear than the ecological rationales for listing terrestrial species.

Null Hypothesis 1b: The ecological rationales for listing particular marine species as target species for protection more clear than the rationales for listing terrestrial species.

Null Hypothesis 1c: The ecological rationales for listing particular marine species as target species for protection do not differ in clarity from the rationales for listing terrestrial species.

Case Questions:

How do organizations sense that a particular species is at risk and that it merits listing as a target species for some type of protection or management? Which population or other ecological models have been used to justify these decisions? What data have been used, with these models, to arrive at listing decisions? Which issues do listing authorities consider in making listing decisions? To what extent is there consensus among government and scientific listing authorities that the criteria for listing species are appropriate and defensible for the target species?

To what extent is there consensus that important potential target species are recognized on target species lists? How is it known whether or not species have been missed? What proportion of the species in relevant ecosystems have been inventoried and evaluated? How many species are on evaluation lists for future study? Is it possible, given existing information and technology, to confirm the biodiversity of an area?

How do the rationales for listing target species differ between marine and terrestrial environments? Have differences in marine and terrestrial environments been considered? Are the listing criteria used for terrestrial species transferable for marine species?

Hypothesis 2: Protected Areas Rationale

Information Processing Function: Problem Definition
Equivocality Attribute: Confusing Questions

Hypotheses:

Hypothesis 2a: The ecological rationale for using a protected area approach to conserve case species is less clear for marine ecosystems than for terrestrial ecosystems.

Null Hypothesis 2b: The ecological rationale for using a protected area approach to conserve case species is more clear for marine than for terrestrial ecosystems.

Null Hypothesis 2c: The ecological rationale for using a protected area approach to conserve target species does not differ in clarity for marine and terrestrial ecosystems.

Case Questions

To what extent is there consensus on the level of threat posed to the target species, habitats, and ecosystems, from the each of the following types of threat (Norse 1995):

- overexploitation?
- physical habitat alteration?
- pollution?
- introduction of alien species?
- global or regional environmental change?
- natural factors such as disease?

To what extent have these types of threat been investigated? What is the nature of each threat to the target species, habitats, and ecosystems?

In what ways would a protected area provide increased protection for target species, habitats, and ecosystems for each of these threats? Should policy focus on conserving or protecting areas, or on addressing and mitigating threats to the areas from outside?

How do the purposes for using protected areas differ between the marine and terrestrial environments? What is a protected area supposed to accomplish in each environment? How does the protected areas approach address the threats arising in the respective environment? For example, how would a protected area for Dungeness crabs protect the species from invasive blue crabs?

Hypothesis 3. Selection Information Amount

Information Processing Function: Information Gathering

Equivocality Attribute: Unclear Information

Hypotheses:

Hypothesis 3a: A lesser amount of descriptive ecological information is available for target marine species and ecosystems than for target terrestrial species and ecosystems.

Null Hypothesis 3b: The greater amount of descriptive ecological information is available for target marine species than for terrestrial target species.

Null Hypothesis 3c: The amount of descriptive ecological information available does not differ for target marine species versus terrestrial target species.

Case Questions

What is known or not known about parameters affecting target species, habitats, and ecosystems such as:

- abundance and distribution of target species?
- life cycles and seasonal distribution of the target species?
- location of habitats for reproduction, feeding, cover, resting, movement, and migration of target species?
- habitat characteristics and conditions supporting the target species, such as temperature, chemistry, nutrients, substrate, and space?
- biodiversity and numbers of different species forming the target species communities?
- boundaries and linkages of ecosystems associated with target species?

How extensive is the spatial and temporal coverage of this information? Is there information available for the full geographic range of the target species? For all relevant habitat and ecosystem areas? Is this information available for all life stages and seasons?

What monitoring or other information is available for sensing change in ecological parameters affecting target species, such as trends in abundance and distribution?

To what extent does the amount and adequacy of descriptive ecological information differ between marine and terrestrial environments?

Hypothesis 4. Selection Information Richness

Information Processing Function: Information Gathering

Equivocality Attribute: Unclear Information

Hypotheses:

Hypothesis 4a: Marine selection information exhibits less information richness than terrestrial selection information.

Null Hypothesis 4b: Marine selection information exhibits more information richness than terrestrial selected information.

Null Hypothesis 4c: Marine selection information does not exhibit different information richness than terrestrial selected information.

Case Questions

What technologies are currently being used for gathering information about target species? About habitats and ecosystems of target species?

To what extent are technologies, such as the following, used to gather data:

- direct field observation and sampling.
- remote sensing and sampling, including use of satellite, aircraft, land vehicle, marine vessel, and submersible platforms.

Given the available information gathering technologies, how extensively can the target species, habitats and ecosystems be sampled in terms of the location, distribution, density, number, rate, frequency, timing, and duration of observations?

What is capacity of existing data gathering technology, and data analysis and display technology, in terms of data content, range of resolution, and qualitative detail? For example, to what extent can technology distinguish species, gender, age, and other parameters of organisms?

What are the strengths and weaknesses of data gathering technologies in terms of providing a clear picture of target species, habitats, and ecosystems?

How does selection information richness differ between marine and terrestrial environments?

Hypothesis 5. Understanding of Causal Factors

Information Processing Function: Causal Analysis

Equivocality Attribute: Poor Causal Understanding

Hypotheses:

Hypothesis 5a: There is a lesser amount of knowledge of causal factors and functional interrelationships affecting the *ecology* of marine species than for terrestrial species.

Null Hypothesis 5b: There is a greater amount of knowledge on causal factors and functional interrelationships affecting the ecology of marine species than for terrestrial species.

Null Hypothesis 5c: The amount of knowledge of causal factors and functional interrelationships affecting the ecology of marine species does not differ from terrestrial species.

Case Questions

What are the causal factors and interrelationships that affect the abundance and survival of the target species? To what extent is there understanding of these causal factors and interrelationships, including issues such as:

- the role habitats play in life functions, such as reproduction, feeding, cover, resting, movement, and migration?
- the effects on species abundance and survival of environmental conditions of habitats, such as temperature, chemistry, food and nutrients, substrate, and extent of space?
- the effects of interspecific interactions and predator-prey dynamics?

What are the natural and human factors that affect the status of target habitats and ecosystems? How clearly are the causal factors and interrelationships affecting target species ecology identified? To what extent is there consensus on the identification of causal factors?

What impacts do these factors have on targets habitats and ecosystems? How well are these impacts understood? Have impact assessments been conducted to analyze these impacts for key threats to the species?

How does the adequacy of causal knowledge differ between marine and terrestrial environments? How clearly understood are the interrelationships and connections among these causal factors in each environment?

<u>Hypothesis 6. Research Technology Capabilities</u>

Information Processing Function:	Information Gathering
Equivocality Attribute:	Unclear Information

Hypotheses:

Hypothesis 6a: The capabilities of research technologies for establishing causal knowledge are less clearly developed for marine selection information than for terrestrial selection information.

Null Hypothesis 6b: The capabilities of research technologies for establishing causal knowledge are more clearly developed for marine selection information than for terrestrial selection information.

Null Hypothesis 6c: The capabilities of research technologies for establishing causal knowledge are not different in clarity of development for marine selection information than for terrestrial selection information.

Case Questions

What is the scientific and practical knowledge base for identifying and evaluating the significance of causal factors, and their interrelationships? To what extent are technologies, such as the following, used for establishing or validating this knowledge base:

- extension of theoretical models from other contexts?
- laboratory analysis? zoos, aquaria, and other conservatories?
- experimental research?
- field research?
- adaptive management, modeling, and monitoring?
- traditional information? local information?

How does level of development of research technologies differ between marine and terrestrial environments?

What impact does this level of development have on the quality of scientific and practical understanding of causal factors and their interrelationships for marine versus terrestrial target species, habitats, and ecosystems?

Hypothesis 7. Site Selection Guidance

Information Processing Function: Action Planning

Equivocality Attribute: Uncertain Response

Hypotheses:

Hypothesis 7a: The guidance given by selection information for defining protected area sites is less clear for MPAs than for TPAs.

Hypothesis 7b: The guidance given by selection information for defining protected area sites is less clear for MPAs than for TPAs.

Hypothesis 7c: The guidance given by selection information for defining protected area sites does not differ for MPAs and TPAs.

Case Questions

What type of spatial areas should be included within the protected areas for the target species?

How are the habitats and ecosystems of target species defined? Given existing ecological information, what is the level of consensus on the factors to be considered in defining these habitats and ecosystems? Do ecologists generally agree or disagree on the locations of boundaries or transitions between these habitats and ecosystems? Are the spatial boundaries of these habitats and ecosystems considered to be shifting or relatively stable? To what extent? How do these issues affect the criteria for selecting areas for inclusion within protected areas for the target species, habitats, and ecosystems?

To what extent does selection information contribute to agreement or disagreement on the selection of specific sites as protected areas?

Assuming that not all sites with presumed value for protecting target species can be designated in marine and terrestrial environments, does the selection information provide a sufficient basis for:

- identifying candidate site areas for consideration?
- evaluating the merits of each site?
- comparing and ranking sites?
- selecting one or more candidate sites for designation as protected areas in preference to others?
- resolving differences of opinion as to which sites are the most appropriate for designation?

To what extent does the selection information provide clear guidance for determining:

- what *types of areas* should be included within protected areas to protect target species within MPAs and TPAs?
- where to locate protected areas for protecting the habitats and ecosystems of target species?
- how large protected areas should be?
- how core preservation areas, buffers, and corridors should be configured for protection of the target species, habitats, and ecosystems?

- what management restrictions should apply to areas linked to the protected area that may adversely affect its success in conservation and protection of target species?

What are the differences between marine and terrestrial environments in terms of the ability to define the spatial foci for protected areas? Are spatial boundaries more fluid in the marine environment? Is there really a "protected area" when it comes to the water? How does designation confer protection?

Modification of Hypotheses

This research followed a “grounded” approach, which means that the hypotheses defined in the original proposal were subject to modification and shaping based on information arising from the research (Eisenhardt 1989a). In this approach propositions can be refined until “accumulating evidence from diverse sources converge on a single, well-defined construct” (Eisenhardt 1989a). The proposed hypotheses were based on published literature that is limited, and were not grounded in substantive data. The hypotheses were therefore refined based on the initial research and case studies. The major change to the hypotheses occurred before research data were gathered. The following hypothesis was dropped from the research: “Marine selection information suggests a greater number of competing but plausible explanations for ecological states and trends within marine ecosystems than terrestrial selection information suggests for terrestrial systems.” In operationalizing the hypotheses, this hypothesis was found to be more of a test of the overall state of equivocality than of any decision function. It was therefore redundant to the primary hypothesis.

Appendix 2. List of Interview Participants

The following is a list of persons interviewed as part of this research.

Interviewees were provided a written notice that the interviews would be nonanonymous and nonconfidential unless they requested otherwise (appendix 3). The Simon Fraser University Research Ethics Review Committee approved this procedure. The identification of participants allowed a more open research process, and ensured that the major contributors received credit for ideas and information that they so generously provided.

The interview participants below have contributed enormously to this research. They are leading figures in the management of ecosystems in British Columbia. These individuals are among the most knowledgeable persons for the case species and ecosystems. Almost all have been directly involved in field research. This research would not have been possible without their contribution, and for this, their generosity is greatly appreciated.

T1 Vancouver Island Marmot – Subalpine Ecosystem

Mr. Dennis A. Demarchi **Interview: January 15, 1999 (1.50 hours)**
BC Ministry of Environment, Lands and Parks, Victoria, BC.
- Unit Head / Provincial Habitat Correlator, Strategic Information Unit, Wildlife Inventory Section, Resource Inventory Branch
- Coordinated Biophysical Analysis of Vancouver Island Marmot Habitat (Demarchi et al. 1996)
- One of the pioneers in the development and application of biogeographic classification systems for classifying ecosystems in British Columbia
- Demarchi's input was useful for the T1 and T2 ecosystems

Dr. Andrew A. Bryant **Interview: January 19, 1999 (2.25 hours)**
Andrew A. Bryant Services, Nanaimo, BC.
- Scientific Advisor, Vancouver Island Marmot Recovery Team
- Completed doctoral and masters research on Vancouver Island Marmot
- Published extensively on marmot
- Also an expert in orthinology

Mr. Doug W. Janz **Interview: January 19, 1999 (1.25 hours)**
BC Ministry of Environment, Lands and Parks, Nanaimo, BC.
- Chair, Vancouver Island Marmot Recovery Team
- Regional Wildlife Section Head
- Extensive experience as a wildlife biologist on Vancouver Island

Dr. Karel Klinka **January 20, 1999 (0.75 hours)**
Faculty of Forestry, University of British Columbia, Vancouver, BC.
- Expert in forest ecology
- One of pioneers in biogeoclimatic classification of forest lands
- Klinka's input was useful for the T1 and T2 ecosystems

M1 Humpback Whale – Pelagic Ecosystem

Dr. Norman Sloan **January 8, 1999 (2.00 hours)**
Gwaii Haanas National Park Reserve / Haida Heritage Site, Haida Gwaii, Queen Charlotte, BC.
- Marine ecologist for Parks Canada and the Gwaii Haanas national marine conservation area
- PhD with research in invertebrate biology
- Registered Professional Biologist

Dr. James D. Darling **January 13, 1999 (2.25 hours)**
West Coast Whale Research Foundation, Vancouver, BC
- One of the leading whale researchers for the Pacific Ocean. He was one of the first to use photographic identification techniques to verify humpback migration
- Doctoral studies at University of California, Santa Cruz addressed humpback whales

Mr. Graeme Ellis **February 2, 1999 (2.25 hours)**
Whale researcher, Pacific Biological Station, Department of Fisheries and Oceans (DFO), Nanaimo, BC
- DFO's only whale specialist for gathering data on whales on the west coast
- Most knowledgeable person on the numbers and status of research on all whale species on the west coast

Dr. John Harper **February 6, 1999 (1.25 hours)**
Coastal and Ocean Resources Inc., 107- 9865 West Saanich Road, Sidney, BC.
- A coastal geomorphologist and oceanographer
- Extensive experience conducting inventories and research studies on the continental shelf of BC and elsewhere
- An expert on the applications of state-of-the-art technology for marine monitoring
- Harper's input was useful for the M1 and M2 ecosystems

Mr. Lee Harding **February 6, 1999 (1.25 hours)**
Canadian Wildlife Service, Environment Canada [retired]
- Registered Professional Biologist, trained as a wildlife biologist
- Coauthored major volume on biodiversity in British Columbia
- Major contributions to the development of marine biogeography across Canada
- Harding's input was useful for the M1 and M2 ecosystems

Dr. Ron Tanasichuk **February 24, 1999 (1.50 hours)**
Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, BC
- Biologist working as part of the herring group at the Pacific Biological Station
- Conducted extensive offshore work on the role of herring and euphausiids in driving oceanic food webs
- Recently completed doctoral work at University of Bergen, Norway, on krill (euphausiids) on the BC coast
- Published several articles on euphausiids
- Tanasichuk's input was useful for the M1 and M2 ecosystems

Mr. Ed Lochbaum **June 21, 1999 (1.50)**
Department of Fisheries and Oceans, Nanaimo, BC.

- Marine mammal coordinator for west coast, one of only two DFO positions (with Ellis) responsible for whales in the region
- Extensive background in fisheries management guy
- Mr. Lochbaum also invited the researcher to assist with a whale watching industry workshop that provided many valuable insights and exposure to numerous industry persons and scientists

T2 Marbled Murrelet – Old-Growth Forest Ecosystem

Mr. Gary Kaiser **March 1, 1999 (2.00 hours)**
Canadian Wildlife Service, Delta, BC

- Orthinologist since 1968 when he joined CWS as a wildlife biologist
- British Columbia since 1974, doing aerial waterfowl surveys for 15 years, including organizing seabird surveys on British Columbia coast
- Writing a book on the marbled murrelet

Ms. Irene Manley **March 26, 1999 (1.75 hours)**
Graduate Student, Department of Biological Sciences, Simon Fraser University

- Completed Master of Science thesis on the behavior and habitat selection of Marbled Murrelets nesting on the Sunshine Coast, 1999
- Irene Manley and John Kelson, then researchers for the Western Canada Wilderness Committee, found the first officially sanctioned nest discovery in British Columbia in the Walbran Valley just south of the Carmanah Valley, on a mossy limb 40 meters up an old growth Sitka Spruce
- One of the key researchers in the province for identification of murrelet habitat requirements

Mr. Chris Niziolomski **May 27, 1999 (1.00 hour)**
Hugh Hamilton Limited, North Vancouver, BC.

- Registered Professional Forester
- Developed Geographic Information System model for identifying murrelet habitat on Vancouver Island
- Niziolomski's input was useful for the T1 and T2 ecosystems

Ms. Trudy Chatwin **May 31, 1999 (1.50 hours)**
Rare and Endangered Species Biologist, Ministry of Environment, Lands and Parks, Nanaimo, BC

- Conducted extensive fieldwork in Clayoquot Sound and other regions
- A primary researcher for the marbled murrelet for the BC government

Mr. William T. Dawson **June 6, 1999 (1.00 hour)**
Triathlon Mapping Corporation, MacDonald Dettwiler Associates, Burnaby, BC

- Mapping and sales consultant for Triathlon Mapping Corporation, a wholly owned subsidiary of MacDonald Dettwiler
- Dawson has 28 years experience in British Columbia's forestry and photogrammetric industries and has played a key role in the development of TRIM II enhanced forestry mapping
- Dawson's input was useful for the T1 and T2 ecosystems

Mr. Mike Dunn **June 15, 1999 (0.5 hours)**
Canadian Wildlife Service, Delta, BC
- Chair of the marbled murrelet recovery team
- Biologist with over two decades experience in ecosystem studies

Ms. Louise Waterhouse **June 16, 1999 (0.75 hours)**
Ministry of Forests, Nanaimo, BC
- Wildlife Ecologist and researcher for BC Forest Service
- Old-Growth forest expert

M2 Giant Pacific Octopus – Benthic Ecosystem

Dr. E. Brian Hartwick **June 18, 1999 (0.75 hours)**
Department of Biological Sciences, Simon Fraser University, Burnaby, BC
- Supervises research on the biology and population ecology of marine invertebrates and a broad variety of studies in applied ecology, including the fisheries biology of octopuses
- Collaborated with molecular biologists to investigate phylogenetic relationships of west coast octopus species and have a continuing interest in the biology and ecology of benthic octopuses
- Extensive field-oriented involving SCUBA diving

Mr. Graham E. Gillespie **June 21, 1999 (1.25 hours)**
Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, BC
- Biologist with Stock Assessment Division
- Co-authored report "A review of Octopus Fisheries Biology and British Columbia Octopus Fisheries" with G. Parker and J. Morrison

Dr. Glen Jamieson **June 22, 1999 (1.5 hours)**
Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, BC
- Research Scientist, Coastal and Marine Habitat Science Section
- UBC Fisheries Centre, Invertebrate Fisheries specialist
- Project Leader for scientific evaluation of marine protected areas, marine ecosystem studies, and effects of El Nino on inshore marine communities

Mr. James A. Cosgrove **June 27, 1999 (1.50 hours)**
Royal British Columbia Museum, Victoria, BC
- Chief, Natural History Collections, Curatorial Services
- Master's thesis was on the Giant Pacific Octopus
- Has continued underwater octopus research for several years
- Referred by other researchers as an expert on octopus

Dr. Jeff Marliave **July 7, 1999 (1.25 hours)**
The Vancouver Aquarium Marine Science Centre, Vancouver, BC
- Director of Marine Sciences
- Extensive experience with underwater research on marine ecosystems

Appendix 3: Research Ethics Notice

Notice to Participants in this Doctoral Research

<u>Researcher</u>: Larry D.S. Wolfe, PhD Candidate
Doctoral Program, School of Resource and Environmental Management, Simon Fraser University
<address>

<u>Research Topic</u>: Unique information challenges in managing ecosystems and protected areas: Implications for organizational structures and management processes

This notice provides advice to participants in the above referenced research, as part of Simon Fraser University's research ethics requirements. It includes advice concerning any interview related to the research, whether as part of telephone or in-person interviews, conversations, email correspondence, or other media. Please be aware of the following:

First, participation is <u>voluntary</u>. You have the right to withdraw from the interview at any time. You may decline to answer any question or to pursue any line of discussion.

Second, participants will <u>not</u> be <u>anonymous</u>. The limited number of participants in this research makes it difficult to maintain anonymity. It also allows acknowledgment and documenting of sources, who have special knowledge of the species or ecosystems because of their past work.

Third, the content of interviews will <u>not</u> be <u>confidential</u>. This is because of the need to reference sources and quotes.

If you wish your identity or any part of the interview to be kept confidential, however, you can advise me and I will keep this information confidential. Otherwise, the interview is 'on the record'.

Fourth, I would like your <u>permission to tape-record</u> this interview. This will save time from taking notes and improve the accuracy of the analysis and of any quotes. The tapes will be used only by the researcher and for research purposes only.

Finally, you may raise any concerns or questions about this interview either now or later, either directly with me (<phone number>), or with Dr. Chad Day, the Chair of my Supervisory Committee (<phone number>), or with Dr. Peter Williams, the Director of the School (<phone number>).

<Biographical Note>

Appendix 4. Interview Package

<Letterhead>
<Date>

To: **<Interview Participant>**

From: **Larry D.S. Wolfe, PhD. Cand.**

INFORMATION PACKAGE FOR INTERVIEWS

This interview is part of the dissertation research for a doctorate at the School of Resource and Environmental Management at Simon Fraser University.

The University establishes rules for protecting interviewees from unfair or unethical research practices. I have attached a note concerning these rules that you should review. If you have any concerns, I would be pleased to discuss these with you any time before, during, or after the interview.

The purpose of this research is to explore the unique information challenges associated with managing ecosystems and protected areas. In particular, it explores variations in *clarity or equivocality* between different types of physical environment. Equivocal information is *vague or ambiguous, and suggests two or more meanings or interpretations for a person's observations*. Equivocality is hypothesized to vary between different environments. Organizational research suggests that such variations will have significant implications for organizational arrangements and resource management practice.

This research follows a qualitative theory-building methodology. The proposed interview is designed to obtain your perspectives on the types and quality of information available for the **<ecosystem>** of British Columbia such as those occupied by the **<*species*>**.

The attached list of indicators provides a preview of the content of the interview. The indicators focus on comparison of the *quality* of information for the ecosystems, rather than the detail of actual information itself.

To confirm the time of the interview, I will call you on **<day, date, time>**.

Thank you very much for sharing your time with me for this research. Your perspectives are very important.

<Insert: Table listing Indicators of Information Quality for Ecosystem and Protected Area Management>

<Insert Notice to Participants in this Doctoral Research>

Appendix 5: Interview Protocol

The following questions were developed to serve as a highly flexible checklist of the types of information required for this research. The questions were tailored to the backgrounds of the interview participant. For example, a species expert may not have been asked certain ecosystem questions, and vice versa. An attempt was made to ensure that at least three persons contributed to information on each indicator. In a few cases, this meant specialized interviews to focus on a few indicators.

Questions listed in *italics* were intended as optional cues to follow up on certain points.

Preliminaries

Interview Package (faxed in advance)

- Ethics Note
- List of Indicators

Introductory Comments

- Provide a short description of the study
- Review ethics with participant:
  -- Non-anonymous
  -- Non-confidential
  -- Permission to tape

Follow-up

- Ask participants if they would complete a questionnaire
- Note references to documents or other scientists or managers

What is your background in studying this ecosystem/species?
Who are the most knowledgeable experts on this species or ecosystem?

1. Target Species Population Abundance and Trends

> The quality of information available about the target species' population abundance and trends in this abundance, and factors that affect abundance.

What is your estimate of the current population of this [species]?

> *What is the highest and lowest range of this estimate?*
> *What difficulties must you overcome to count this [species]?*
> *What kind of qualifiers would you apply to this information?*

Would it be feasible to carry out a full population census for the [species] within this ecosystem?

> *What environmental factors would make this feasible or not feasible?*
> *How would a full census be conducted?*
> *What procedures or equipment would be used?*

How much do we know about trends for the [species]?

> *Is the population growing or declining?*
> *What evidence is there for trends?*

Are population estimates and forecasts generally accepted by scientists as accurate (close to real parameters)?

2. Target Species Range and Distribution

The quality of information available on the present, past, and potential geographic extent of occurrence and distribution of the target species.

What is the present range of this [species]? [patterns of concentration]

What are the habitat requirements for this [species]?

How much information is available on the past range of the [species]?
What factors affect the quality of information on the [species] range?
To what extent is there consensus on this information?

Does the [species] migrate or disperse?

What is their seasonal distribution?
How much do we know about their migration and dispersal routes?

3. Ecosystem Biogeography

The availability of clear and consistent information for defining the scale and boundaries of biogeographic areas and ecosystems within range of the target species.

What ecosystems or biogeographic areas does the [species] use in British Columbia?

To what extent does the [species'] habitat conform to the boundaries of biogeographic areas?

Would designation of representative ecosystems as protected areas be an effective way to protect the [species]? [Indictor 13]

How would we select these areas? (e.g., by vegetation type? type of physical environment?)

For Ecosystem Interviewees:

How is this biogeographic area / ecosystem different from other areas?

What factors or variables do scientists consider in defining the boundaries of this biogeographic area?

To what extent is there consensus on the definition of the biogeographic boundaries?

4. Ecosystem Biodiversity

The number and variety of species identified on taxon lists compared with the potential biodiversity or richness of the ecosystem.

How would you describe the biodiversity of this ecosystem? [Continue below if interviewee has knowledge.]

Ecosystem:

What factors affect the quality of information on the biodiversity of the ecosystem?

What proportion of this ecosystem has been surveyed or inventoried for:

plant biodiversity?
vertebrates?
invertebrates?

e.g., presence or absence, probability of occurrence, abundance or density, carrying capacity, biomass, geographic distribution, mortality or natality, animal condition, population dynamics.

What kind of qualifiers would you apply to this information?
Do the data provide a trustworthy picture of the biodiversity of the ecosystem?

5. Key Species Roles

The quality of the information used for identifying the roles of key species for the ecosystem, such as primary producers, prey and predator species, keystone species, and indicator species.

Species Food System

Species:

What are the main forage or prey species for the [species]?
What do we know about the ecology of these forage/prey species?
How "good" is this information? What studies have been done?

What other species compete with the [species] for these food sources?

Ecosystem:

What studies have been done to identify the food chain for the ecosystem?
What are the primary producers for the ecosystem?
What are the main prey species for the ecosystem?
What are the main predators competing for these food sources?

Predators

Species:

What are the predators for the [species]?
Do the predators have alternative primary or secondary prey species?
How "good" is the information on the predators? forage/prey andfor the [species]?

What are the important shelter or cover species for this species?

Ecosystem / Species:

What is the role or significance the [species] within the ecosystem it occupies?
What would happen if the [species] disappeared? Do we know?

6. Ecosystem Driving Factors

The quality of information for the identification of major driving factors that affect the abundance, distribution, and status of key species in the ecosystem.

For Species/Ecosystem Interviewees:

What are the most important driving or limiting environmental factors that could cause change in this ecosystem?
Physiographic: topography, terrain, bathymetry
Environmental processes: climate (snow, precipitation, temperature, winds), oceanographic processes

In what ways do these factors drive or limit the species/ecosystem?
How much variability is there in these factors? What causes this variability?
How much information do we have on the driving or limiting factors?
What factors affect the quality of information on the driving or limiting factors?

For Ecosystem Interviewees:

How much is known about the current state of driving forces in the ecosystem?
Have models been developed linking these driving factors?

How much field data do we have to test these models?
What kind of qualifiers would you apply to these models?
To what extent is there consensus on the identification of driving factors?

7. Ecosystem Threats

The identification of key threats that affect the operation of the driving factors that affect abundance, distribution, and status of key species in the ecosystem.

What are the greatest human threats affecting the species/ecosystem?
How much information do we have on the impacts of the threats on the species/ecosystem?
What factors affect the quality of information on the threats?
To what extent is there consensus or conflict over the threats (identification, evaluation)?

8. Access Capability

The constraints imposed by the natural environment on the physical access of researchers to that environment for conducting field research work.

What means of transportation or access do you use to get to the species' habitat?

What are the physical obstacles or limitations that limit or complicate your access to the habitat?
e.g., Water: depth, sea state, currents, temperature, dangerous animals
e.g., Land: terrain, weather, dangerous animals

How does ability or inability to travel to the habitat or ecosystem affect the quality of information?

9. Sampling Coverage

The spatial and temporal coverage of data gathering for descriptive information on the ecosystem, including the ability to gain access to the ecosystems.

Spatial Coverage

What proportion of the ecosystem or area has been surveyed or inventoried for:

- case species
- physiography
- environmental processes
- vegetation
- animal life (predators, prey/forage)

How intensive would you describe the sampling as being within the inventory areas?

e.g., number of samples per unit of area; size of areas sampled

Temporal Coverage

How frequently are resource inventories conducted for important resource factors:

- case species
- physiography
- environmental processes
- vegetation
- animal life (predators, prey/forage)

Is sampling conducted often? periodically? occasionally? continuously?
How soon would a major change in the resource factor be detectable?
In what season or time of year are these estimates conducted?
What times of year is sampling feasible? most appropriate?

How much time is required for the sampling procedure?

10. Visibility Constraints

The constraints imposed by the natural environment on the ability of researchers to observe the case species in that environment.

Visibility Constraints: What environmental factors affect the ability to observe the species/ecosystem clearly?

- *weather, fog*
- *the cover of terrain or vegetation*
- *the extent of geographic area*
- *the cover of water, depth*

How does the behavior or ecology of the species affect the ability to observe them?

- *mobility, rapid movement, shyness*
- *grouping or density of species*
- *underground, undersea existence*
- *camouflage, cryptic behavior*
- *patchiness of habitat*

11. Sensor Capability

The number and variety of observation technologies used for gathering important information on key species and driving forces for the ecosystem, and the variety and richness of data forms produced.

What are the most important procedures and equipment you use for observing the species/ecosystem?

e.g., binoculars, photo identification, mark-recapture, radio telemetry, remote sensing, satellites.

What technical factors affect accuracy or reliability of these approaches?
e.g., range of instruments, sampling net size
e.g., qualitative detail about key species and ecosystem processes

What are the physical capabilities and limitations of the data gathering technology?

e.g., forms of data produced, such as visual, audio, chemical?
e.g., resolution, visibility, depth of vision, breadth of spectra?
e.g., scale; number of dimensions shown?

12. Contextual Capability

The capability of the information to provide an overview of an entire system, or large portion of it, rather than isolated detail.

Contextual capability means the same as the expression, "a picture is worth a thousand words."

What technologies are the most effective for conveying a rich picture of the species/ecosystem?

Models or reports

What data sets can the display and analysis technologies integrate? Which data sets cannot be integrated?
How much of the available information on the species/ecosystem is published?

GIS or mapping inventories

Does this mapping inventory include sufficient detail for the species/ecosystem? What's missing? e.g., data content, range of resolution, and qualitative detail

Visual technologies

e.g., camera, videotaping, simulations

13. Field Research Technology

The technological capability to conduct experiments, monitor key environmental parameters, or undertake other studies 'in the field' to test hypotheses about ecological theories or models in order to develop causal knowledge about key driving factors and threats.

To what extent can hypotheses and causal models be tested through controlled field studies and experiments?

Other: making and verifying predictions, testing hypotheses and causal models, monitoring changes or trend, or evaluating the causes of environmental variations

What research approaches or technologies are currently used/available?
What are the capabilities and limitations of these approaches or technologies?

Have comparisons been made to other species/ecosystems?

To what extent does personal experience or anecdotal information help or hurt our understanding of what is happening to the species/ecosystem?

14. Defining Listing Criteria

The level of consensus among ecosystem and species experts and wildlife managers on the logical relationship of the criteria to the driving factors and threats affecting the ecosystem and species, and the consequent suitability of the listing criteria for the particular species and ecosystem.

For species experts only:

What level of management or protection status should the species have?

Why do you believe this [species] should be managed or protected?

What are the most important criteria or factors that suggest that the [species] should be considered 'at risk' or managed?

The current ranking of the species is [threatened, endangered, not listed]. Is there general agreement among government, scientists, and the public on this ranking?

Why / why not?
What are the points of dispute, if any?

Are the standard ranking criteria and evaluation system used by listing agencies, such as COSEWIC, appropriate for use for this species / ecosystem?

Are there additional factors or criteria that should be considered in this case?
What modifications could be made to these criteria, if any?

15. Matching Mode to Threat

The suitability of using protected area option for the types of threat that might affect the target species or ecosystem.

For species experts only:

How might a protected area enhance protection for the [species]?

Is a protected area necessary? a good approach? the best approach?

> *Why? Why not?*
> *How will threats from outside a protected area be mitigated or addressed?*
> *What other approaches have been considered?*

Is there consensus among scientists concerning the need or non-need for a protected area? other stakeholders?

> *Why / why not?*
> *What are the points of dispute, if any?*

<u>16. Making Spatial Decisions</u>

> The suitability of available descriptive and causal information for making spatial planning decisions.

Assume that not all vulnerable sites can be designated.

Does available descriptive and causal information provide a clear and consistent basis for deciding what types of areas should be included within protected areas to protect [species]?

> *Is there consensus among scientists? other stakeholders?*
> *Have habitat evaluation criteria been identified for evaluating habitat for the [species]?*

Does available descriptive and causal information provide clear and consistent guidance and support for developing management plans for protected areas to conserve [species]?

> *Does it provide information for:*

- *identifying the most appropriate sites?*
- *evaluating the merits of each site?*
- *comparing, ranking, and choosing between two candidate areas?*
- *selecting one or more sites for designation as protected areas in preference to others?*
- *resolving differences of opinion as to which sites are the most appropriate sites for designation?*
- *defining the boundaries of the protected area should be?*
- *defining size?*
- *defining zoning, core and buffer areas?*
- *deciding what corridors might be necessary?*
- *specifying management restrictions forsurrounding areas?*

Is there consensus on the factors that should be considered in site planning?

Appendix 6. Member Check Covering Letter

The following memorandum was sent to interviewees along with a copy of the transcripts for the interview.

<date>

To: <Interview Participant>

From: Larry D.S. Wolfe

I want to thank you again for your generosity in providing time for an interview for my research. You provided many insights and observations that have contributed greatly to my research on <case ecosystem and species>.

I am attaching a copy of the transcripts that were prepared from the interview tapes. These are in "rich text format" that is compatible with most word-processing programs. If you have a problem reading them let me know.

My main reason for sending these transcripts is to provide you an opportunity, if you wish, to review what was recorded, and correct anything that was transcribed incorrectly or which, on reflection, you would like to retract or edit. This includes any statements that you might be uncomfortable with. If you have any changes, please scribble on the text and fax it to me, or email your comments. Anything is welcome.

The interviews provide important information for the research, and a few quotes. In general, the transcripts are verbatim, except for minor grammatical edits. Some personal or off-topic discussions may have been abridged or not transcribed, and my explanations of methods and questions are often shortened.

If there were any insights from our conversation that might be useful to your work, this is a special benefit. Sometimes that happens when you look at issues from another perspective.

As a personal note, I applaud the work that you and others are doing to understand and conserve sensitive ecosystems and species.

Larry Wolfe
<Telephone number, fax number, and Email address>

Appendix 7. Postinterview Questionnaire

This appendix reports and analyzes data from a questionnaire distributed to interviewees following the interview. The questionnaire was titled: "Supplementary Questions on Information Quality for Ecosystem Management"

A7.1 Participation in Questionnaire

The survey was distributed to 20 interviewees and 14 responded (70 percent).

Table A7.1 Participation in Interviews and Questionnaire

	Interviews Completed	Forms Distributed	Forms Returned
T1 Subalpine Marmot Ecosystem	4	4	3
T2 Old Growth Murrelet Ecosystem	7	4	3
M1 Pelagic Humpback Ecosystem	7	7	4
M2 Benthic Octopus Ecosystem	5	5	4
Total	**23**	**20**	**14**

A7.2 Analysis Procedures

Caveats

The responses to this questionnaire should be interpreted with caution. The following caveats apply:

1. The interview participants were chosen based on a theoretical rather than representative or random sampling procedure. In other words, the participants were chosen because of their expert knowledge of the species or ecosystem.
2. The sample sizes for ecosystems are very small, and cannot be statistically analyzed. Raw data were provided to show the variation in answers.

Statistics

For numerical responses, three types of statistic are shown in the tables.

1. High-Low Difference. The tables report numeric responses to questions. This statistic shows the difference between the highest and the lowest response. It is a crude measure of variation. Where variation is high, say 3 or greater, responses obviously indicate disagreement.
2. Mean. This is an average of the responses. Because of the small sample size, this statistic is a very crude measure of central tendency. It is used to rank ecosystems. It provides a measure of the level of equivocality for each variable.
3. Rank. This is the ranking of averages among the ecosystems. Caution should be used in interpreting small differences among small samples.

A7.3 Target Species Information

For table A7.2, the following define the response column headings.

1. Amount of information means the adequacy of information for this species or ecosystem* in terms of proportion of space, time, and variables covered by the data, compared to that available for other species or ecosystems. This definition may relate to the target species, or to the ecosystem, depending on the question.
2. Quality of information means the information is clear and unambiguous for decision making and management.

Analysis

Indicator 1

Questions 1, 2, 3, and 4 asked interviewees to rate the amount and quality of information on target species population parameters (table A7.2).

Question 1

The T1 and T2 cases rated higher for *amount* of information on population abundance than the M1 and M2 cases. The rating was particularly high for T1 (4.7), with the other cases being relatively close.

For *quality* of information on abundance, the T1 case was the highest and the M2 was the lowest. On the other hand, the quality of the M1 case was better than for the T2 case. The high-low variance was high for quality of information for the T2 case. The ratings for the T1 and T2 cases were particularly high.

Question 2

The T1 and T2 cases rated higher for *amount* of information on population trends than the M1 and M2 cases. The high-low difference for the T2 case was high. The rating for the T1 case is very high, and for the M2 case fairly low.

For *quality* of information on population trends, the T1 case was the highest and the M2 was the lowest. On the other hand, the quality of the M1 case was better than for the T2 case. The rating for the T1 case is very high.

Question 3

The *amount* of information on population characteristics was higher for the T1 and M2 ecosystems. The T1 case rated very high and the M1 case rated very low.

For *quality* of information on population characteristics, the T1 and M2 ecosystems were again highest. The T1 and M2 cases were rated very high for information quality.

Question 4

The information *amount* and *quality* for making predictions about population trends, the T1 and T2 cases were higher than the M1 and M2 cases. For information amount, the T1 case was rated as high, while the other three cases were rated as low. For information quality, the M1 and M2 cases were rated low.

Table A7.2 Target Species Information

	Amount of Information				**Quality of Information**			
	T1	**T2**	**M1**	**M2**	**T1**	**T2**	**M1**	**M2**
1. The information available on the population	5	2	2	3	5	4	4	3
abundance the target species	4	4	3	1	4	3	4	1
	5	2	2	1	5	1	3	1
			X	3			X	3
High – Low Difference	*1*	*2*	*1*	*2*	*1*	*3*	1	*2*
Mean	*4.7*	*2.7*	*2.3*	*2.0*	*4.7*	*2.7*	3.7	*2.0*
Rank	*1*	*2*	*3*	*4*	*1*	*3*	2	*4*
2. The information available on the trends in target	5	1	1	2	5	1	3	3
species' abundance	4	3	3	1	4	3	3	1
	4	4	2	1	4	n	3	1
			X	2			X	3
High – Low Difference	*1*	*3*	*2*	*1*	*1*	*2*	0	*2*
Mean	*4.3*	*2.7*	*2.0*	*1.5*	*4.3*	*2.0*	*3.0*	*2.0*
Rank	*1*	*2*	*3*	*4*	*1*	*3*	2	*3*
3. The information available on the population	5	n	1	4	5	n	3	4
characteristics of the target species, such as ages,	4	2	X	4	3.5	3	X	4
gender, family groupings, and fecundity	5	n	1	2	5	n	2	2
			X	4			X	4
High – Low Difference	*1*	*na*	*0*	*2*	*2*	*na*	1	*2*
Mean	*4.7*	*2.0*	*1.0*	*3.5*	*4.5*	*3.0*	*2.5*	*4.7*
Rank	*1*	*3*	*4*	*2*	*2*	*3*	4	*1*
4. The information available for making and testing	4	1	1	2	4	5	X	3
predictions about the future abundance of the target	4	3	1	1	3	3	1	1
species within British Columbia	3	1	2	1	3	2	2	1
			X	2			X	2
High – Low Difference	*1*	*2*	*1*	*1*	*1*	*2*	1	*2*
Mean	*3.7*	*1.7*	*1.3*	*1.5*	*3.3*	*3.3*	*1.5*	*1.8*
Rank	*1*	*2*	*4*	*3*	*1*	*1*	4	*3*
5. The information available on the geographic	5	1	2	4	4	3	2	4
range and distribution of the target species with	5	4	2	2	4	5	2	4
British Columbia	5	4	3	4	5	4	3	2
			X				X	3
High – Low Difference	*0*	*3*	*1*	*2*	*1*	*2*	1	*2*
Mean	*5.0*	*3.0*	*2.3*	*3.3*	*4.3*	*4.0*	*2.3*	*3.3*
Rank	*1*	*3*	*4*	*2*	*1*	*2*	4	*3*
6. The information available for making and testing	4	1	1	4	3	5	1	4
predictions about the future distribution of the target	4	2	2	1	4	2	2	2
species within British Columbia	3	4	2	2	3	3	2	2
			X	3			X	2
High – Low Difference	*1*	*3*	*1*	*3*	*1*	*3*	1	*2*
Mean	*3.7*	*3.7*	*1.7*	*2.5*	*3.3*	*3.3*	*1.7*	*2.5*
Rank	*1*	*1*	*4*	*3*	*1*	*1*	4	*3*

Conclusions for Indicator 1

For *amount* of information, the data suggest that information is generally better for the T1 and T2 cases and than for the M1 and M2 case, except for population characteristics.

For *quality* of information, the data suggest that the T1 case is the strongest. No composite pattern emerges for the other categories.

Indicator 2

Question 5

The amount of information for the T1 ecosystem was rated highest, with moderate ratings for the other three cases. The high-low difference was high for the T2 ecosystem.

The quality of information was high for the T1 and T2 ecosystems, and moderate for the M1 and M2 ecosystems.

Question 6

The amount of information was rated high for the T1 and T2 ecosystems. The M1 case was rated very low. The high-low difference was high for the T2 and M1 ecosystems.

The quality of information was moderate for the T1 and T2 ecosystems, and low for the M1 ecosystem.

These data suggest that information amount and quality are generally higher for terrestrial than for marine cases. The exception is that the M2 case was rated higher than the T2 ecosystem, though the difference was minor.

A7.4 Ecosystem Information

For table A7.3, the following define the response column headings.

1. Amount of information means the adequacy of information for this species or ecosystem* in terms of proportion of space, time, and variables covered by the data, compared to that available for other species or ecosystems. This definition may relate to the target species, or to the ecosystem, depending on the question.
2. Quality of information means the information is clear and unambiguous for decision making and management.

The results of the table are analyzed below.

Analysis

Indicator 3

Question 7 asked interviewees to rate the amount and quality of information for defining ecological limits or geographic boundaries of the target species ecosystem (table A7.3).

The T1 and T2 cases were rated better for information amount than the M1 and M2 cases. The amount of information was rated strong for the T1 case and moderate for the T2 case. The M2 case had a large high-low difference.

The T1 and T2 cases were rated better for information quality than the M1 and M2 cases. The M2 case had a large high-low difference.

Although not statistically rigorous, the data suggest that the amount and quality of information is better for the T1 and T2 cases than for the M1 and M2 cases.

Continued. . .

Table A7.3 Ecosystem Information

Ecosystem is defined as the ecosystem or biogeographic area(s) that the target species uses or occurs in most often in British Columbia.

	Amount of Information				**Quality of Information**			
	T1	**T2**	**M1**	**M2**	**T1**	**T2**	**M1**	**M2**
7. The information available for defining the *ecological limits or geographic boundaries* of the target species' ecosystem (see definition above)	4 4 4	3 4 3	2 3 2 2	4 1 1 3	4 4 4	4 4 3	2 2 2 2	4 2 1 4
High – Low Difference	*0*	*1*	*1*	*3*	*0*	*1*	*0*	*3*
Mean	*4.0*	*3.3*	*2.3*	*2.3*	*4.0*	*3.7*	*2.0*	*2.8*
Rank	*1*	*2*	*3*	*3*	*1*	*2*	*4*	*3*
8. The information available for describing the *number and variety of species or taxa* (biodiversity) occurring in this ecosystem	4 3 5	1 3 2	3 5 2 1	4 2 2 5	2 3 5	2 3 3	2 3 2.5 2	4 3 2 4
High – Low Difference	*2*	*2*	*4*	*3*	*3*	*1*	*1*	*2*
Mean	*4.0*	*2.0*	*2.8*	*3.8*	*3.3*	*2.7*	*2.4*	*3.3*
Rank	*1*	*4*	*3*	*2*	*1*	*3*	*4*	*1*
9. The information available that could be used for identifying the *roles of key species** for the ecosystem *Examples: primary producers, prey and predator species, keystone species, and indicator species.	2 3 5	1 3 2	3 3 2 1	4 2 3 4	2 2 5	2 3 3	2 2 3 1	4 3 3 3
High – Low Difference	*3*	*2*	*2*	*2*	*3*	*1*	*2*	*1*
Mean	*3.3*	*2.0*	*2.5*	*3.3*	*3.0*	*2.7*	*2.0*	*3.3*
Rank	*1*	*4*	*3*	*1*	*2*	*3*	*4*	*1*
10. The causal information available for identifying *major driving facto*rs that influence the abundance, distribution, and status of key species in the ecosystem	2 3 4	4 0 3	3 3 2 2	3 1 2 2	2 2 3	3 0 3	2 2 3 2	3 3 2 1
High – Low Difference	*2*	*4*	*1*	*2*	*1*	*3*	*1*	*2*
Mean	*3.0*	*2.3*	*3.3*	*2.0*	*2.3*	*2.0*	*2.3*	*2.3*
Rank	*2*	*3*	*1*	*4*	*1*	*2*	*1*	*1*
11. The information for identifying *key threats* that affect the operation of the driving factors that affect abundance, distribution, and status of key species in the ecosystem	3 2 3	5 5 5	1 3 2 2	4 1 3 1	2 2 4	3 5 4	1 3 3 2	4 3 3 1
High – Low Difference	*1*	*0*	*2*	*3*	*2*	*2*	*2*	*3*
Mean	*2.3*	*5.0*	*2.0*	*2.3*	*2.7*	*4.0*	*2.3*	*2.8*
Rank	*2*	*1*	*4*	*2*	*3*	*1*	*4*	*2*

Notes:

1. Comments regarding question 7, M1 Pelagic Humpback Ecosystem: • Re biodiversity: There's somewhat reasonable information for commercially important or politically sensitive ones, but there are a large number of plant and animal species which don't fit in either category.

Indicator 4

Question 8 asked interviewees to rate the amount and quality of information for describing the number and variety of species or taxa in the ecosystem (table A7.3).

For amount of information, the T1 case rated highest and the T2 case the lowest. The M1 and M2 cases exhibited large high-low differences.

For quality of information, there was relatively little difference among the cases, although the T1 case had a large high-low difference.

Although not statistically rigorous, the data suggest that the amount and quality of information is better for theT1 and M2 cases than for the T2 and M1 cases. This may reflect the fewer species present in the M1 ecosystem as well as the greater human activity associated with the M1 fishing and T2 forestry activities.

Indicator 5

Question 9 asked interviewees to rate the amount and quality of information for identifying the roles of key species in the ecosystem, such as prey and predators (table A7.3).

For both amount and quality of information, the T1 and M2 cases were moderate, and were rated higher than the T2 and M1 cases. The T1 case had a large high-low variance.

Although not statistically rigorous, the data suggest that the *amount* and *quality* of information is better for the T1 and M2 cases than for the T2 and M1 cases. This is the same order as for question 8.

Indicator 6

Question 10 asked interviewees to rate the amount and quality of information for identifying major environmental driving factors that would affect key species in the ecosystem (table A7.3).

The *amount* of information was rated higher in the T1 and M1 ecosystems than for the T2 and M2 ecosystems.

There was very little difference in the *quality* of information among the four ecosystems.

Indicator 7

Question 11 asked interviewees to rate the amount and quality of information for identifying key human threats that affect environmental driving factors in the ecosystem (table A7.3).

The amount of information for the T2 case was very high. There was little difference among the other ecosystems.

The quality of information was highest for the T2 case. There was little difference among the other ecosystems.

<u>Conclusions for Indicators 3 – 7</u>

The T1 ecosystem dominated ratings for information amount and quality. No clear pattern can be established overall among the other ecosystems.

A7.5 Application of Information

Analysis

Indicator 14

Question 12 asked interviewees to rate the extent to which the ranking criteria normally used by endangered species authorities to assess the risk status of the target species was appropriate for the ecosystem (table A7.4).

Although not statistically rigorous, the data suggest the interviewees generally gave relatively strong ratings for the criteria for all four ecosystems. The M1 and M2 ecosystems each received one moderately low rating.

Table A7.4 Application of Information

1=Not at all. 5 = Fully.	Applicability			
	T1	**T2**	**M1**	**M2**
12. To what extent are the ranking criteria* normally used by endangered species authorities to assess the risk status of the target species appropriate for this ecosystem? *Abundance, range, protection, trends, threats, etc.	5 3.5 5	3 4 4	4 2 X X	5 5 3 2
High – Low Difference	*2*	*1*	*2*	*3*
Mean	*4.5*	*3.7*	*3.0*	*3.8*
Rank	*1*	*3*	*4*	*2*
13. To what extent would the option of establishing a protected area be appropriate to the types of threat that might affect the target species or ecosystem, assuming such an option is feasible?	1 2 5	4 5 4	2 4 2 X	4 5 3 2
High – Low Difference	*4*	*1*	*2*	*3*
Mean	*2.7*	*4.3*	*2.7*	*3.5*
Rank	*3*	*1*	*3*	*2*
14. To what extent does available scientific information provide an adequate basis for making spatial planning decisions for protected areas, such as defining protected areas boundaries, size, configurations, core areas, corridors, etc.?	X 3.5 5	1 4 3	2 1 2 X	3 1 2 2
High – Low Difference	*2*	*3*	*1*	*2*
Mean	*4.3*	*2.7*	*1.7*	*2.0*
Rank	*1*	*2*	*4*	*3*

Indicator 15

Questions 13 asked interviewees to rate the extent to which establishing a protected area would be appropriate for addressing the type of threat affecting the target species in the ecosystem (table A7.3).

Although not statistically rigorous, the data suggest the interviewees gave the strongest applicability ratings to the T2 and M2 cases. The T1 and M1 cases were tied. The very high rating for the T2 ecosystem reflects concern that the continued logging of the old-growth ecosystem will inevitably lead to a decline in murrelet numbers.

Indicator 16

Questions 14 asked interviewees to rate the extent to which available scientific information provides an adequate basis from making spatial planning decisions for protected areas in the ecosystem (table A7.3).

Although not statistically rigorous, the data suggest the interviewees gave the strongest applicability ratings to the T1 and T2 terrestrial cases and lowest ratings to the M1 and M2 cases.

A7.6 Ecological Research Methods

For this section, please suggest adjectives or other descriptive words to answer the following questions. For example, for "the effectiveness of DNA studies for determining gender" adjectives might be "very accurate," "extremely reliable," "highly effective, but hard to do with this animal." For "the extent of funding for insect research," adjectives might be "limited," "scarce," "unknown," or "adequate." The purpose is just to get an impression of the quality of information produced by current research methods.

15. What word[s] would you use to describe the *extent or proportion of geographic coverage* for important information on key species and driving factors in this ecosystem?

T1 Subalpine Marmot Ecosystem

- Relatively good due to rather limited extent of the subject ecosystem (Mountain Hemlock, Vancouver Island only).
- Limited, they live in small pocket habitats.

T2 Old Growth Murrelet Ecosystem

- Discontinuous, inconsistent.
- Forest cover mapping is useful for defining habitat for murrelets. Forest cover information for Vancouver Island especially is very variable.
- Limited. Most important areas are at least surveyed.

M1 Pelagic Humpback Ecosystem

- Very limited.
- Limited.
- Limited.
- West coast of Vancouver Island limited; remainder of B.C. scarce.

M2 Benthic Octopus Ecosystem

- Low – moderate. Limited to particular sites of interest or to areas fished.
- Almost no deep water or paralarvae data.

- The shallow water (<30m) data are improving for specific locations. Deep water data are almost nonexistent.
- Very inadequate.
- Limited, especially in fjords.

16. What word(s) would you use to describe the adequacy of long term sampling for key species and driving factors in this ecosystem?

T1 Subalpine Marmot Ecosystem

- Relatively poor because of poor logistics (high elevation) and history and fewer resource conflicts versus lower elevation ecosystems.
- Exhaustive. We probably know more about this species than any other in BC.

T2 Old Growth Murrelet Ecosystem

- Restricted to harvest management of forests.
- Good information for late 90's. Poor before that.
- Inadequate.

M1 Pelagic Humpback Ecosystem

- Very inadequate.
- Unknown.
- Poor.
- Biological sampling, except for plankton, inadequate and ineffective. Driving factors inadequate.

M2 Benthic Octopus Ecosystem

- Not very adequate.
- Has not been done.
- Long term sampling of octopus has not been a priority, hence has not been done.
- Increasingly inadequate.

17. What word[s] would you use to describe *the adequacy of short term or seasonal sampling* for key species and driving factors in this ecosystem?

T1 Subalpine Marmot Ecosystem

- Relatively poor because of poor logistics (high elevation) and history and fewer resource conflicts versus lower elevation ecosystems.
- Exhaustive.

T2 Old Growth Murrelet Ecosystem

- Absent.
- Seasonal research on activity only occurs May – July. Habitat research can occur all year. Both should be used.
- Presently in decline. Much new information in past five years.

M1 Pelagic Humpback Ecosystem

- Inadequate.
- Scarce.
- Poor.
- Herring and Barkley Sound plankton adequate; the remaining key species inadequate.

M2 Benthic Octopus Ecosystem

- Limited to a few species and sites.
- Inadequate.
- Sampling of octopus has not been a priority, hence has not been done.
- Sporadic, patchy.

18. What word(s) would you use to describe *the capability of existing field observation technologies* to provide rich information* on key species and driving forces for this ecosystem?

*Rich information has the ability to provide a richly detailed picture of the environment: 'A picture is worth a thousand words'.

T1 Subalpine Marmot Ecosystem

- Open habitats conducive to good observation of many system components (subject to the vagaries of weather)
- Again, exhaustive for the above ground habitats. But, we know almost nothing about their below ground habitats or life.

T2 Old Growth Murrelet Ecosystem

- Adequate (good for forests). Data poor at this time.
- Technology is available, but not accessible to current budgets.

M1 Pelagic Humpback Ecosystem

- Limited for short term, but useful for long term studies.
- Limited.
- Adequate (i.e., technology is in hand).
- Reasonably capable for determining [faunal] distribution etc. through hydroacoustics; physical parameters sampling very capable.

M2 Benthic Octopus Ecosystem

- Significant.
- Current technology is adequate but expensive and labor intensive.
- Appropriate technologies exist, but all appropriate ones relative to octopus have not been systematically utilized.
- Increasingly inadequate with increased depth.

19. What word(s) would you use to describe *the capability of information display and presentation technologies to provide an overview of entire system, or large portion of it, rather than isolated detail?**

*Examples: Geographic Information Systems, three-dimensional display, data integration

T1 Subalpine Marmot Ecosystem

- Good overview capability by remote sensing, GIS, due to rather distinct characteristics (higher elevation, open habitats, snowfields, etc.).
- Comprehensive. We can show their habitats at three different spatial scales, and show the interpretation of each.

T2 Old Growth Murrelet Ecosystem

- Adequate, low power, misapplied, not applied.
- GIS information technology has been very useful for portraying existing habitat suitability, calculations.
- Promising, but needs integration over large areas, i.e., TFL and TSA have different coverage.

M1 Pelagic Humpback Ecosystem

- Deceptive. Flashy presentation makes our level of understanding appear higher than it really is.
- Unknown.
- Adequate
- Very capable.

M2 Benthic Octopus Ecosystem

- Good.
- Broad data do not exist. Technology could use the data if it existed.
- Inadequate scientific data on octopus to make these technologies potentially useful.
- Limited reliability; recently improving.

20. What word(s) would you use to describe the ability of researchers *to undertake studies "in the field" in order to test ecological hypotheses or models* about key species and driving factors, using current technologies?

T1 Subalpine Marmot Ecosystem

- Restricted by shorter growing season, restricted visibility due to low clouds/fog, harsh winter conditions, limited access.
- Limited. Marmot colonies are both remote and separate, with few marmots in each one. Difficult to gather simultaneous data from several colonies.

T2 Old Growth Murrelet Ecosystem

- Well funded, poorly led, scientifically sound.
- Moderate ability when funding is available through FRBC (1995-98).
- Not quite within reach, due to funding and high work loads. Most have to deal with simpler questions.

M1 Pelagic Humpback Ecosystem

- Limited more by imagination or lack thereof of researchers rather than technology.
- Unknown.
- Adequate.
- Unsupported.

M2 Benthic Octopus Ecosystem

- Good.
- Research can be done but octopuses are not a priority for funding agency.
- It depends on the specific hypotheses being tested! Too general a question.
- Logistically and financially constrained.

21. Which *physical environmental conditions or factors create the most serious obstacles* for gathering information, making observations, and testing hypotheses concerning key species and driving forces in this ecosystem in the 'field'?

T1 Subalpine Marmot Ecosystem

- Restricted access, rough terrain, weather, narrow window (seasonally and daily)
- Remoteness, damp foggy weather, separation

T2 Old Growth Murrelet Ecosystem

- Easily overcome.
- Difficult to access at times. Very wet. Thick bush. Difficult and expensive bird to research.
- Funding has a lot to do with it. More expensive to work in remote areas.

M1 Pelagic Humpback Ecosystem

- Lack of funding. Limited field season.
- Weather exposure can be extreme in north B.C. pelagic areas.
- Sea conditions; undefined boundaries of Vancouver Island ecosystem.

M2 Benthic Octopus Ecosystem

- Seasonal variation in weather and sea conditions and visibility underwater. Limited access to deeper water.
- Open ocean weather, depth of water, limited visibility.
- Octopus occur at low density over a large area, are cryptic, and occur in deep water. Any work under these conditions is expensive and difficult.
- Bad weather and increased depth (including currents and visibility).

22. What word(s) would you use to describe the extent to which these *physical environmental conditions and factors* affect the ability to gather information and make observations within this ecosystem?

T1 Subalpine Marmot Ecosystem

- These conditions can have great adverse influence on the ability to gather data compared to more "friendly" environs.
- Remoteness, damp foggy weather, separation

T2 Old Growth Murrelet Ecosystem

- Nocturnal activity
- Bird is very secretive. Difficult to see. Cannot easily catch. Variable activity patterns. Bird is easily disturbed.
- Funding, remoteness. Loss or alteration of study areas.

M1 Pelagic Humpback Ecosystem

- Difficulty of seeing what is happening in the aquatic environment.
- Very restrictive.
- Highly limiting.
- Sea conditions – not insurmountable. Ecosystem boundaries – crucial implications.

M2 Benthic Octopus Ecosystem

- Significantly
- Significant.
- Significant problem.
- Potentially prohibitive under current funding venues.

Appendix 8: Research Quality

This appendix summarizes how the case study analyses addressed reliability and validity.

A8.1 Reliability

Reliability in quantitative research asks whether research results would produce consistent results if the research was replicated. In a positivist frame, a reliable measure is one that provides stable, consistent, and predictable measurements of a phenomenon. The results should be similar if replicated by different researchers. The issue is thus one of bias and procedural clarity and rigor. Two subcategories are thus important: objectivity and reliability in a procedural sense.

Qualitative research substitutes the term *confirmability* for objectivity. It acknowledges that researcher bias and subjectivity can affect research results. Such biases can be lessened by procedures that promote a balanced and diverse perspective is sampled in the research (table A8.1). In this study, the researcher used consistent protocols and procedures and multiple data sources to examine four cases in order to provide multiple frames for analysis. All material was transcribed literally and exhaustively coded to place differing perspectives side-by-side in the text bases. A hypothesis testing mode was adopted to force a comparison of evidence that could be reported in an auditable manner.

Another approach to objectivity is to acknowledge researcher biases. The researcher is not neutral with respect to protected area decision making and ecosystem management. As a practitioner in the field, the researcher has made numerous applied decisions. It is, in part, this work that led to recognition of the importance of some missing quality of equivocality that affects management decision making. To counter these biases, the researcher developed a more structured research design than is typical of qualitative studies, as described in chapter 3 and tables A8.1 and A8.2.

Reliability also requires that procedures be reliable. In qualitative research, the corresponding terms are *dependability* and *auditability*. In a sense, this type of reliability is "quality control" (Miles and Huberman 1994). This research followed a structured and detailed research design to ensure that procedures were transparent and repeatable by other researchers. This required the use of a set of indicators as high level codes to ensure structured querying of the cases, as well as structured cross-case comparisons based on comprehensive databases that included all data. One measure that would contribute to reliability would be the involvement of multiple researchers, but this was not possible in this research.

Table A8.1 Research Reliability

Tests	Methods Recommended	Methods Used
Objectivity: Minimization of effects of research biases; neutrality. Synonyms: External Reliability Qualitative tests: Confirmability	• Documentation and use of case study procedures (see "reliability" below) • Providing means for research reviewers to confirm analyses and conclusions for themselves	• Interviews with diverse participants to accommodate different perspectives • Application of consistent interview protocols to all cases to ensure comparability of interviews • Direct interview questioning concerning equivocality and its implications to maximize participant perspectives in data • Detailed recording of all interviews with exhaustive coding of interview notes into database • Use of hypotheses testing and explicit rating systems to allow inspection and confirmation
	• Acknowledgement of potential subjective biases	• Researcher is a practitioner in field, and experience is not neutral
Reliability of Procedures: Demonstration that research procedures are consistent, stable over time and across researchers and methods, and procedures can be repeated, with the same results. Synonym: Accuracy; Confidence Qualitative tests: Dependability; Auditability	• Documentation and use of case study procedures to maintain quality control and capability for replication	• Research methods and interview protocols were predesigned and consistently applied across cases • Indicators were established as a predefined coding framework to ensure consistent querying of case data • Consistent with grounded qualitative methods, constructs and coding were refined as understanding of the phenomenon grew • Multiple methods were used for triangulating or cross-checking data
	• Use of case study database to document data and procedures for audit or replication	• Detailed research design, interview protocols, database, and case reports provide extensive documentation of data and procedures
	• Coding by two people, with monitoring of interrater reliability	• Not possible because study involved one researcher

Sources: Yin 1994; Miles and Huberman 1994; Mason 1996; Marshall and Rossman 1995; Cresswell 1997; Boyatzis 1997; Rosenburg 1993; Lincoln and Guba 1984.

A8.2 Validity

Validity in positivist research is "the capacity of a measurement to reflect accurately the variable under study" (Rosenberg and Daly 1993).

Construct validity refers to the operationalizing of a concept and its attributes. As a first step, the variable of equivocality was defined in terms of vague and obscure data that produces multiple interpretations. This definition arises from the literature, and was further refined through this research, consistent with qualitative research practice. While easily recognized as an issue by interviewees, the phenomenon has only been tangentially addressed in the literature (chapter 1). Improving the construct validity of the term equivocality was thus a major activity in this research. A grounded research approach was used that involved detailed coding of data to identify and describe the attributes and dimensions of equivocality. This process involved multiple sources and informants, and was documented extensively.

Internal validity refers to the development of sound causal models that describe the causal factors and effects of a phenomenon. This research used grounded theory-building approaches to build explanations for data. For example, the researcher assumed that the cover of seawater would render marine species more equivocal. The coding process led to a broader concept that the cover of a dense forest canopy or the cover of soil over subterranean dens could also lead to equivocality. The extent of cover thus becomes a causal factor in equivocality.

To carry the process further, these emerging ideas were used in hypotheses to test whether patterns differed among different ecosystems. An important check on validity was the phrasing of hypotheses that addressed equivocality in the four decision stages. Since each of these stages involves different decision making practices and technologies, they provided diverse and nonequivalent domains for testing the presence of equivocality. Thus equivocality can be probed from different perspectives, which enhances validity.

External validity refers to the *generalizability* or *applicability* of the research findings to other contexts. In positivist research, the question relates to the extent to which the data sampled the population of data that could be sampled. In case study research, each case may be considered a replication (Yin 1994; chapter 3). The four cases were highly diverse: subalpine, old-growth forest, open ocean marine, and sea bottom marine. While this is a broad sampling, all cases were temperate west coast marine ecosystems.

In qualitative research, applicability of research results is delegated to other researchers who examine the researcher's cases to determine if these are relevant to their situation. This research provides a detailed description of each case, and the dimensions and attributes of equivocality associated with it. The intent is to provide for comprehensive audits by any reviewer, but also to enable practitioners to consider how these cases compare to other situations.

Table A8.2 Research Validity

Tests	Methods Recommended	Methods Used
Construct Validity: Correspondence between phenomenon of interest and correct operational measures for the phenomenon (ensuring that study is observing, identifying, and measuring the intended concept).	• Specification of phenomenon to be studied • Operationalizing of variables or measures presumed to be associated with and/or predictive of the phenomenon	• Equivocality construct operationally defined, including attributes related to decision making • Grounded coding was used to identify, define, and illuminate properties and dimensions of equivocality concept
	• Use multiple sources of evidence	• Evidence sources included documents, interviews, literature, participant observation • Interview subjects included a cross section of government, nongovernment, and academic experts.
	• Establish chain of evidence	• Evidence chain provides a comprehensive audit trail including taping and transcription of interviews; development of databases and case reports; linking data to cross-case analysis (chapter 4) and analyses of hypotheses (chapter 5).
Internal Validity: Establishing a credible link between causes and effects. Qualitative tests: Credibility; Authenticity; Truth Value	• Explanation building	• Grounded coding procedures were used to develop intensive coding below the indicator code level to match patterns and build explanations for observations
	• Conduct pattern matching: comparing empirically based pattern with predicted patterns	• Hypotheses and null hypotheses were specified to test predictions concerning patterns of equivocality among cases • Hypotheses directed at nonequivalent dependent variables, the four decision stages, provided triangulation
External Validity: Identifying situations to which findings can be generalized. Qualitative tests: Generalizability; Applicability; Transferability; Fittingness	• Triangulation or replication logic of multiple case studies.	• Two marine ecosystems were compared with two terrestrial ecosystems; cases were analyzed separately and sequentially, and then compared.
	• Careful description of case parameters to enable other researchers to determine relevance to their situation	• Cross-case comparison (chapter 4) provides details of cases to allow comparison with other situations to determine applicability

Sources: See table A8.1.

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