APPLYING SUSTAINABLE DEVELOPMENT TO RESOURCE ASSESSMENT AND ENVIRONMENTAL PLANNING: MEANING, METHOD AND APPLICATION

by

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We accept this dissertation as conforming to the required standard

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ABSTRACT

The concept of sustainable development has become widely accepted as an instrumental objective of resource planning and environmental policy analysis. Nevertheless, despite considerable academic and institutional activity, there have been few efforts to apply empirically the concept to real-world resource allocation and environmental problems. Lacking are frameworks that integrate the conceptual, methodological, and measurement components necessary for this task. Current and unsatisfactory interrelationships between environment, economy, and society will remain fundamentally unchanged, subject to partial and opportunistic intervention for what of more substantive underpinnings. This dissertation attempts to give the concept of sustainable development a logically consistent and operational content.

Presented is a conceptual framework in which sustainable development is characterised by two components: a set of dynamic ecological constraints and; a series of human development goals. It is suggested that the conceptual framework can be applied to resource assessment and environmental planning problems via a multi-dimensional planning approach. Multi-criteria plan evaluation approaches and programming models are two classes of multi-dimensional approach that have the ability to incorporate the ecological, social and economic dimensions of sustainability-related resource analysis. Moreover, these methodologies have robust data handling capabilities allowing, to a varying degree depending on the actual method used, the integration of quantitative and qualitative information. Their flexibility also makes them particularly relevant tools in today's climate of participatory and consensus based planning.

Success in applying the concept of sustainable development to resource assessment and environmental planning also depends on the selection of appropriate environmental and social indicators. A way must also be found to integrate diverse ecological, social, and ecological variables. An approach for resolving these problems is presented based on indicator measurement at the landscape level. Such measures can be used as indicators of resource stocks. The landscape level of analysis also facilities the integration of indicators, and provides a means with which to inculcate human values with the study of ecological systems.

Based on the articulated approach to sustainable development, a case study centered on Clayoquot Sound, British Columbia is presented. The case study contains two related components. The first is a partial analysis (using a simple multi-period programming model) of the potential of Clayoquot Sound's resources to support sustained development activities. The second part of the case study integrates the results of the programming model with a multi-criteria plan evaluation model. This allows for the evaluation of prior specified development alternatives involving quantitative and qualitative criteria scores and ordinal criteria weights. The study concludes that Clayoquot Sound's current contribution to human wellbeing can not be sustained without a restructuring of the present ecosystem-socioeconomic interrelationship.

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Chapter One

Sustainable Development, Geography and the Research Problem

1.1 Introduction

The concept of sustainable development has become widely accepted as an instrumental objective of resource planning and environmental policy analysis. Its general endorsement has been due to a persuasive sustainable development literature, perhaps best exemplified by the publication of *Our Common Future* by the World Commission on Environment and Development (WCED) in 1987. The WCED describes sustainable development as "meeting the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs." (WCED 1987, p. 43). Presented in this manner, it is difficult to disagree with the goals of sustainable development. Nevertheless, despite considerable academic and institutional activity, there have been few attempts to formally incorporate criteria for sustainable development into applied resource assessment and environmental planning. The response to sustainable development has been predominantly normative in nature and the empirical relevance of the concept to real world resource and environmental issues has yet to be established. It remains to be demonstrated whether or not sustainable development is a realistic or achievable state for human society and economy.

1.2 Sustainable Development and Geography

The application of sustainable development to real-world problems represents both an opportunity for, and a challenge to the practice of geography. Manning (1990, p. 290) in a recent presidential address to the Canadian Association of Geographers (CAG) wrote:

> "Sustainable development presents a major challenge to geography to demonstrate its capability and relevance to what may be the most important public issue of our time. The human/biosphere relationship is at the core of growing global problems, and geography has comparative advantage in spearheading attempts to make this relationship more sustainable.

He elaborated further (p. 291):

> "Geographers have unique comparative advantage in helping to produce solutions; their spatial and regional traditions and their history of work in integration of biophysical and socioeconomic information are germane to this challenge."

Three dominant themes in geographical research - spatial analysis, ecological analysis, and regional analysis - therefore appear to have particular relevance to the analysis of sustainable development issues.

1.2.1 Major Themes in Geographical Research

Spatial Analysis

The theme of spatial analysis in geographical research is expressed in a diversity of ways. In brief, the intent of spatial analysis is the understanding of how spatial phenomena on the earth's surface are influenced by physical, biotic and social processes (after Ackerman 1958; McCarty 1963). Mitchell (1989) suggests spatial analysis focuses on locations and distributions of phenomena; social, economic and ecological interactions between places and regions; spatial structures, arrangements and organisations; and spatial processes. An understanding of how location, spatial structure, and spatial processes influence human development and of how location, structure and process will be influenced by additional constraints imposed by the concept of sustainability is fundamental to the geographic study of sustainable development.

Ecological Analysis

The importance of the human-environment relationship as a theme in geographical research has varied considerably during the twentieth century (Mitchell 1989). Its most recent incarnation, beginning in the late 1960s, reflects a wider societal concern with resolving pressing environmental problems. This focus differs markedly from geographical research in the first half of the century which was primarily concerned with explaining human behaviour in terms of the physical environment. The explanatory and predictive intent of contemporary ecological analysis gained impetus when Ackerman (1963, p. 435) argued that geography should be concerned with systems and that its task was "...an understanding of the vast, interacting system comprising all humanity and its natural environment on the surface of the earth." In terms of geographical research and sustainable development, analysing the human-environment relationship is central to explaining and predicting the sustainability of evolving environmental and human systems.

Regional Analysis

Regional analysis at an appropriate spatial scale is a prerequisite for applied sustainability research. Required is an understanding and accounting of the attributes of an area that give rise to character, problems and issues, and range of opportunities for solution. Properly implemented, regional analysis integrates the ecological and human welfare related elements of sustainable development within a defined area.

The regional analysis theme of geography may also provide a vehicle for the integration of the spatio-temporal aspects of contemporary ecological research with more traditional resource management decision theory. Emerging research areas in ecology such as landscape ecology and the hierarchical approach to measuring biodiversity have important implications for interdisciplinary research into sustainable development at the regional level. For example, landscape ecology studies the nature, distribution and abundance of landscapes; the dynamics of landscapes; and the local and distant interactions of landscapes (Pickett *et al.* 1992; Stenseth 1992). Landscape ecology has been widely applied to the problem of habitat fragmentation and attendant losses of biodiversity brought about by human development (Stenseth 1992). Similarly, Noss (1990) adopts a hierarchical approach to the measurement of biodiversity in which the relevance of landscape structure to biodiversity is particularly emphasised.

1.2.2 The Failure of Geography to Respond

Many of the ideas underlying sustainable development are not new to geographical inquiry. For example, over twenty years ago, Zelinsky (1970, p. 499), wrote:

> "The reader is asked to consider what I have come to regard as the most timely and momentous item on the agenda of the human geographer: the study of the implications of a continuing growth in human numbers in the advanced countries, acceleration in their production and consumption of commodities, the misapplication of old and new technologies, and of the feasible responses to the resultant difficulties."

Zelinsky went on to argue that material accumulation could no longer be considered progress for it is not maintainable, and that there was a major geographical task involved in the sensible reallocation of effort toward a more ecologically responsible society. Smith (1971. p. 154) suggested that North American geography was about to undergo another revolution because: "...geography is preoccupied with the study of the production of goods and exploitation of natural resources, while ignoring important conditions of human welfare and social justice."

The idea of sustainable development can thus be characterised in part as a contemporary articulation of a reoccurring theme(s) within geography. But, despite the apparent potential of geography to take a lead in sustainable development research, it has been the positivistic disciplines of economics and ecology which have dominated subsequent research and discussion. Some of the reasons for the failure of geography to feature more prominently in the sustainable development debate were perhaps foreseen by Zelinsky, who concluded his paper thus:

> "...how woefully deficient we are in terms of practitioners, in terms of both quantity and quality, how we are still lacking in relevant techniques, but most of all that we are totally at sea in terms of ideology, theory and proper institutional arrangements." (Zelinsky 1970, p. 529).

Stoddart (1987, p. 334), nearly two decades later, also found it necessary to say of geography:

> "We need to claim the high ground back: to tackle real problems: to take the broader view: to speak out across our subject boundaries on the great issues of the day... . We need to forget the trivia and the tedium of much that has passed for geographical research and erudition over the last twenty years... . Land and life is what geography has always been about."

Two themes seem evident in these statements: (i) geography is still coming to terms with its own relevance and role in providing solutions to societal problems; and (ii) geography is searching for a central philosophy to replace positivistic spatial science which has been judged inappropriate for the task of building a base of knowledge on which social policy can be built. These disciplinary undercurrents perhaps explain the general lack of attention given to sustainable development by the geographic literature.

The absence of a substantive geographical contribution to the sustainable development debate has hindered meaningful discussion of some of the most important concerns raised by the notion of sustainable development. Geography, unlike the more positivistic disciplines, brings with it a greater ability to synthesise and understand the array of ecological, economic, and social influences that impact sustainable development. Such a holistic perspective is necessary if human interference with natural systems is to result in a minimum of negative feedback (repercussions). For example, of particular relevance to environmental planning and policy formulation is the extent of potential conflicts among ecological, social, and economic systems that may be realised in attempts to bring about sustainable development. The determination of the extent to which the achievement of sustainability may compromise the ability to fulfil other important societal goals and objectives is also pertinent to resource planning and environmental policy formulation.

1.2.3 A Potential Role for Geography

There is a pressing need for the applied study of the implications of the concept of sustainable development for the human-environment relationship. Without this advancement there is a risk that sustainable development will languish as a 'good idea' that cannot be put into practice, and which may be manipulated by established interests in order to give an appearance of respectability while maintaining the status quo (O'Riordan 1988). Too often sustainable development serves as a virtuous concept used by government, resource developers, and environmentalists alike, for differing and often conflicting reasons.

Making the concept of sustainable development operational (i.e. responsive to real-world management and regulatory issues) is a task to which geography is well suited. Geography's central concern with human-biosphere relationships and general rejection of reductionist and/or uni-dimensional approaches, means it is better able to integrate necessary concepts from other disciplines such as economics and ecology. Sustainable development requires that the boundaries of resource analysis and environmental decision making be expanded (after Nelson (1984), cited in Manning (1990)): (i) vertically, to encompass more complex causal relationships within ecological and socioeconomic systems; (ii) horizontally, in terms of extended time horizons; and (iii) cross-sectorally, to include more complex interrelationships between ecological and socioeconomic sectors/systems. Manning (1990) suggests that the spatial dimension may be the only effective way to integrate information from all the disciplines and sectors involved in sustainable development related study.

The remainder of this Chapter describes the components of a research programme intended to offer insight into some of the real world implications of sustainable development for resource assessment and environmental planning. It begins with a discussion of the definition of sustainability and related concepts and then describes the objectives and structure of the research programme.

1.3 The Definition of Sustainable Development

There is no universally accepted single definition of sustainable development. The concept has been described as inherently ambiguous and heavily context dependent (Boulding 1988; Brown *et al.* 1987; Cocklin 1989c; Colby 1991; Daly 1990; Liverman *et al.* 1988; Nijkamp *et al.* 1991; O'Riordan 1988; Turner 1991). It has been argued that in order to achieve clarity of discussion, sustainability must be explicitly defined (Brown *et al.* 1987). This has resulted in extensive academic effort to comprehensively define sustainable development. Barbier (1989a p. 185), for example, writes that the concept of sustainability must be:

> "...made more concise, systematic and rigorous before it can usefully be applied in policy making and planning."

For the purposes of this research the commonly encountered terms "sustainability", "sustainable development" and "sustainable economic development" are treated as related but distinct concepts, separated by the degree of anthropocentrism contained in each.

- *Sustainability* is used to refer to the ability of any given system to maintain its self-organising ability. It does not imply a static state, allowing for the coevolutionary development of system composition, structure and function.

- *Sustainable development* introduces the needs and aspirations of humans and hence anthropocentrism to the concept of sustainability. It is used to refer to the continued ability of humanity to meet its needs and fulfill its aspirations within the constraints imposed by environment, society, and technology.
- *Sustainable economic development* is not only an anthropocentric concept, but derives from the dominant western world view and its inherent ideologies, implying that the means by which humanity will continue to meet its needs and aspirations will be provided by economic activity and its inherent mechanisms, also within the constraints imposed by environment, society, and technology.

When referring to sustainability in the context of socioeconomic systems the term sustainable development is used in this research. In this manner, the anthropocentric nature of the term is explicit but the emphasis is on human development rather than furthering the economic process. Chapter Two, section 2.5 describes in more detail what are believed to be the key operational elements of the concept of sustainable development. Briefly these are: (i) a set of ecological and socioeconomic interlinkages that act on the expression of social systems, and (ii) a series of development goals relating to the condition and evolution of socioeconomic systems.

There are many other definitions of sustainable development and related concepts. The following selected definitions are considered representative of these. Sustainable development has been variously described as:

> "...a process in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change, are all in harmony, and enhance both current and future potential to meet human needs and aspirations." (WCED 1987, p. 46).

> "..the indefinite survival of the human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of

> infrastructure and institutions which distribute and protect the components of these systems." (Liverman *et al.* 1988, p. 133).
>
> "...as the persistence over an apparently indefinite future of certain necessary and desired characteristics of the socio-political system and its natural environment." (Robinson *et al.* 1990, p.39).

There are also definitions of sustainable development which are more context specific than the preceding holistic definitions. For example:

> "Sustainability is a relationship between dynamic human economic systems and larger dynamic, but normally slower-changing ecological systems, in which 1) human life can continue indefinitely, 2) human individuals can flourish, and 3) human cultures can develop; but in which effects of human activities remain within bounds, so as not to destroy the diversity, complexity, and function of the ecological life support system." (Costanza 1991, p.8).
>
> "We thus define agricultural sustainability as the ability to maintain productivity, whether of a field or farm or nation, in the face of stress or shock." (Conway and Barbier 1988, p. 653).
>
> "Sustainable development... involves providing a bequest to the next generation of an amount and quality of wealth which is at least equal to that inherited by the current generation." (Pearce *et al.* 1989, p.48)
>
> "The broad objective of sustainable economic development is to find the optimal level of interaction between three systems - the biological and resource systems, the economic system, and the social system - through a dynamic and adaptive process of trade offs. This optimal level would therefore be the most sustainable development that these three crucial systems can support." (Barbier 1989a, pp. 185-86).

A preoccupation with defining sustainable development may be ultimately self-defeating, however. There is a fine dividing line between the institutional conditions required to bring about sustainable development and the overall goal of sustainable development (O'Riordan 1988; Shearman 1990). The conditions influencing the achievement of sustainable development, for example prevailing institutional structures, environmental conditions, ecological consciousness etc., are highly context dependent. As context changes so do the conditions influencing sustainable development. The meaning of sustainable development (the maintenance of human and natural systems in perpetuity, or some variant of this) remains more or less constant despite the context in which it is used. O'Riordan (1988) suggests that incorporating conditions for the achievement of sustainable development within definitions of sustainable development results in a dissipation of meaning and consequently, threatens to make the concept meaningless.

It is perhaps appropriate, in light of the above discussion, to consider sustainable development a general development goal. Over time, the concept may become defined by successful research programmes which give rise to social actions which are consistent with a set of accepted conditions for sustainable development. Lack of a precise, generally agreed upon definition need not hinder the empirical investigation of sustainable development. The task required of researchers is the development of conceptual and methodological frameworks for addressing applied issues in sustainable development with regard to environmental planning and policy. As Daly (1990, p.2) suggests there is an immediate need to:

> "...take up the challenge of giving the basic idea of sustainable development a logically consistent and operational content."

1.4 Structuring the Research Programme

Given the breadth and diversity of literature concerning sustainable development, it is somewhat surprising that few researchers have attempted to take up Daly's challenge. Most research, as demonstrated by the context specific definitions presented in the previous section, has attempted to incorporate sustainable development and related ideas into existing research programmes and agendas. This contrasts with more limited research that has explicitly focused its efforts on exploring the broader implications of sustainable development for real-world resource issues. This neglect of the broader perspective leaves a substantial void in the sustainable development literature and weakens the relevancy of the concept for real-world planning applications. Needed is a broader discourse that: articulates the conceptual dimension of sustainable development; describes potential methods for the application of agreed upon concepts; and/or outlines the development of measures of social and ecological wellbeing that may act as objectives, inputs, and/or constraints in applied studies.

This research, then, attempts to create a framework for the application of the concept of sustainable development to real-world resource assessment and environmental decision making[1]. It treats each of the tasks necessary to create such a framework as separate but related research challenges. These tasks are reflected in the formal research objectives described below. The concepts and methodologies developed in process of achieving these goals are intended to further sustainable development discourse by aiding in the creation of other conceptual and methodological frameworks that respond to the strengths and weakness of this research.

1.4.1 Research Objectives

The proposed research has the following objective: To develop a framework that can apply the concept of sustainable development to real-world resource assessment and environmental decision making. Related to this primary objective are several related secondary goals. These are to:

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[1] For the purposes of this research the term "resource assessment" refers to the process of determining the extent to which resources have the ability to satisfy development goals (Cocklin 1985). "Environmental decision making" (or planning) refers to the process of making decisions regarding the allocation of environmental resources for development purposes.

- Establish a set of conditions consistent with the ideal of sustainable development. These conditions together form a conceptualisation of sustainable development, thereby defining the nature of the problem, identifying its parts and their relationships.
- Review the capability of planning oriented evaluation methods and processes to effectively apply the suggested concepts in the context of environmental decision making and resource assessment.
- Discuss the types of social and ecological measures that could act as indicators in sustainable development and other sustainability-related research[2].
- To demonstrate the usefulness of the conceptual and methodological components of the research in an application to sustainable development planning in the Clayoquot Sound region of Vancouver Island.

1.4.2 Dissertation Structure

Consistent with the above objectives, this research has four related but distinct components. Chapters Two, Three, and Four each examine a particular aspect of applying sustainable development to real-world resource problems. Chapter Five applies aspects of this work in a sustainable development planning case study. Each Chapter is intended to make an individual contribution to the sustainable development literature. Significantly, they attempt to examine the epistemological and ontological dimensions of creating a framework for applying sustainable development. This perspective is largely absent from the current sustainable development literature.

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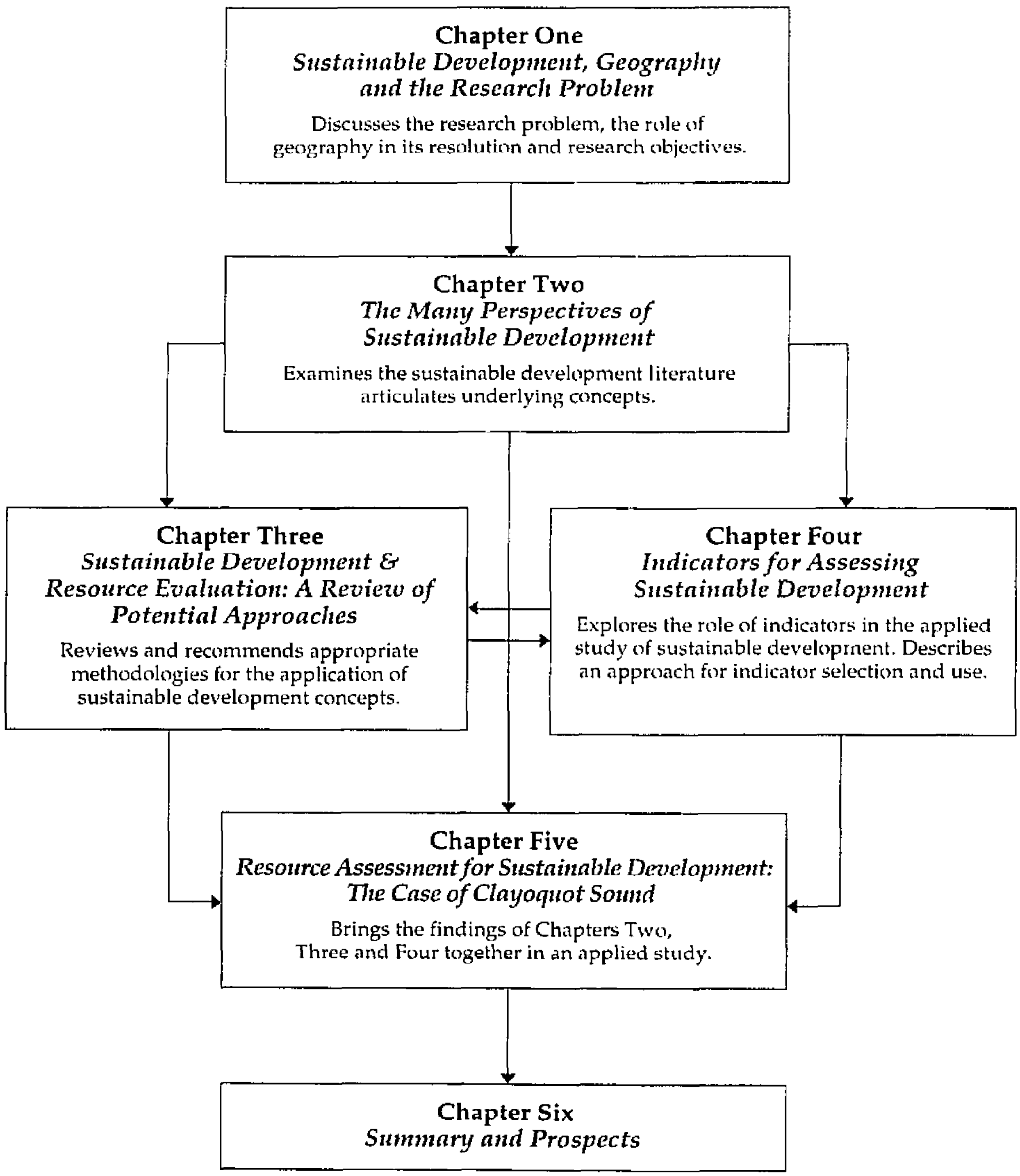
[2] When referring to the applied aspects of research carried out in this dissertation the terms "resource assessment for sustainable development" and " environmental decsion making (or planning) for sustainable development" are used. When referring to other authors research that may be carried out in other contexts, or to the wider application of the ideas developed in this research, the term "sustainability-related" is used.

The structure and contribution of the research is shown in Figure 1.1. Subsequent Chapters also contain similar diagrams outlining their structure and the linkages between Chapter sections. Chapter Two reviews the many different and often competing perspectives of sustainable development. It focuses in particular on methodological approaches to sustainable development. These approaches tend to offer rules and procedures that indicate how sustainable development research should be conducted. This is in contrast to broader normative approaches which tend to treat sustainable development as a policy objective and are distinctly programmatic in nature. The Chapter concludes with its major contribution to this research, an articulation of three general conditions for sustainable development. These conditions are intended to act as guides for subsequent sustainable development research that is more applied in nature.

A second important component of this research involves the review of various evaluation methods and processes that might be suited to the real-world application of the concept of sustainable development for resource assessment and envronmental planning. In Chapter Three, the role of resource analysis, resource management, and resource evaluation in sustainable development research is examined. It is argued that any method that is applied to resource assessment and/or environmental decision in the context of sustainable development should be used with heuristic, rather than predictive or descriptive intent. A number of methods for resource allocation, simulation, and analysis are then reviewed. This review of methods in Chapter Three has relevancy to two levels of resource analysis and evaluation. First, it recognises that the reviewed methodologies are applicable to a wide range of resource assessment and environmental decision problems that contain varying degrees of consideration for sustainable development and related concepts. A critique of method can therefore make a

Figure 1.1 Dissertation Structure



contribution to the literature in this wider context. Second, it outlines the strengths and weaknesses of these methods and processes for resource assessment and environmental planning in the narrower context of sustainable development. This may aid other sustainable development researchers in their search for appropriate applied methodologies. The duality of the review recognises that while the concept of sustainable development is a unique construct, its component parts are found in varying forms and to different degrees throughout the resource and environmental literature.

Chapter Four complements Chapter Three by examining indicators of sustainable development. Applying the concept of sustainable development to resource assessment and environmental planning is necessarily complicated by the need to find and integrate measures of social and ecological wellbeing. Moreover, these measures must be applicable across a range of development contexts and spatial scales. The Chapter begins with a critique of indicator use in the sustainable development literature. This critique is followed by a review of the major analytical considerations necessary for the development and use of indicators for sustainable development. Approaches to developing social welfare and ecological indicators are then examined. It is argued that the selection of welfare indicators will depend on the political economy of the problem at hand. Ecological indicators receive special attention because consideration of the ecological dimension and its integration with social systems has largely been absent in the sustainable development literature. An approach to developing ecological indicators and integrating them with social indicators based on landscape measures of ecological attributes is then articulated and its advantages discussed. The Chapter concludes with the description of an approach for indicator selection and use in sustainable development planning applications.

In Chapter Five, a case study centered on Clayoquot Sound, British Columbia is used to draw the concepts, methods and indicator frameworks discussed in preceding Chapters together. First, an overview of the physical, culture, economic, ecological and institutional aspects of the region are reviewed. Second, a simple optimisation model is used to examine the trade-off between resource stocks, intragenerational equity and intergenerational equity. Third, various development options for the region are evaluated in the context of sustainable development through a combination of the programming model and mixed data multi-criteria analysis. While the main objective of the Chapter is to synthesise and demonstrate the application of some of the concepts and methods articulated in previous Chapters, the case study also reveals something of the nature and prospects for sustained socioeconomic and ecological linkages in the region. The research concludes with a summary of findings and a discussion of the prospects for future sustainable development and related research.

Chapter Two

The Many Perspectives of Sustainable Development

2.1 Introduction

The principle of sustainable development is appearing with increasing frequency in the literature associated with economic development and resource planning. Concomitantly, governments, international institutions, and industry are adopting the idea as the objective of environmental management. This development represents a substantial alteration to the conventional wisdom of resource planning and policy formulation. Traditional concerns regarding economic and technical efficiency are giving way to a broader, more holistic planning approach in which there is explicit recognition of the dependency of society and economy, and hence human welfare, on the continued wellbeing of environmental systems.

It is not always clear what is meant by sustainable development, however. As discussed in Chapter One, the concept is inherently ambiguous and context dependent. To some extent the use of the term sustainable development in different contexts to refer to disparate things is a reflection of disciplinary biases, separate paradigms, and differing ideologies. The vagueness of the concept is sometimes regarded as its strength, increasing acceptance by a wide range of disparate interest groups (Redclift 1991).

The purpose of this Chapter is to review the multiple perspectives of sustainable development. This will aid in the establishment of a set of operational concepts consistant with the definition of sustainable development presented in Chapter One section 1.3. Once developed, the operational concepts serve a dual purpose. First, they provides a foundation for applied sustainable development research and analysis. Second, and perhaps more importantly, they serve to stimulate discussion and debate regarding the appropriate components of such a framework. A particularly pertinent issue is the implication of particular schools of thought in economics and ecology for sustainable development planning policy.

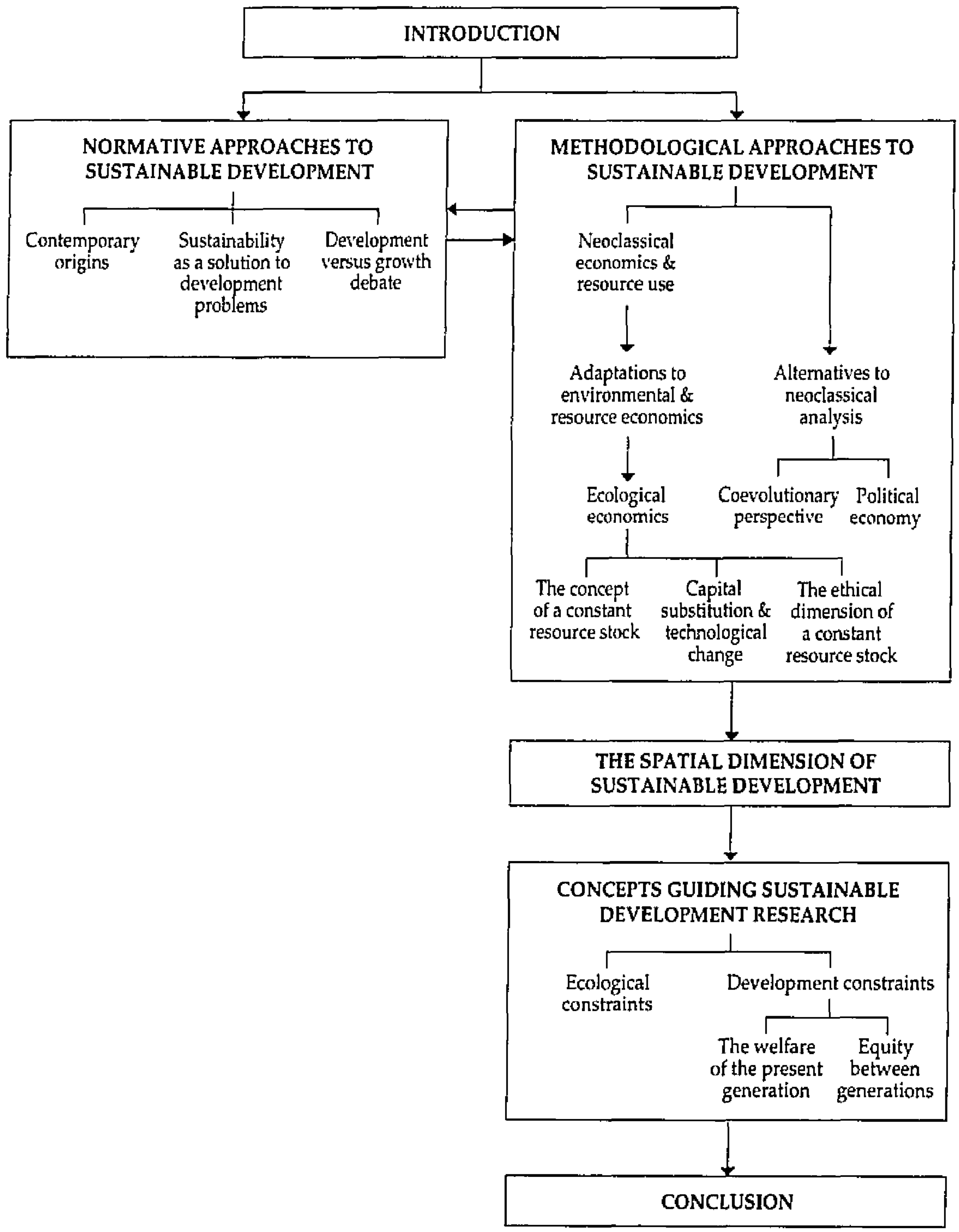
The review makes a fundamental distinction between normative and methodological treatments of sustainable development and related concepts. Normative approaches tend to treat sustainable development as a policy objective and are distinctly programmatic in nature. Methodological treatments are narrower in scope, primarily concerned with the implications of sustainable development for the investigation of human-environment interaction. The Chapter concludes with the articulation of concepts consistent with the overall goal of sustainable development. These form the basis for subsequent discussion and research in this dissertation. The structure of the Chapter is outlined in Figure 2.1.

2.2 Normative Approaches to Sustainable Development

2.2.1 The Contemporary Origins of Sustainable Development

The normative, and to a lesser extent the methodological, approaches to sustainable development issues can be characterised, in part, as a contemporary articulation of the environmental principles popularised in the late 1960s and early 1970s. For example, Kenneth Boulding's "The Economics of the Coming Spaceship Earth" first published in 1966, argues for a new economics, where pollution control and

Figure 2.1 The Structure of Chapter Two



resource conservation are part of the economic growth equation and "throughput" is something to be minimised rather than maximised. E. F. Schumacher (1975) also suggests that pollution must be controlled and that humankind's economic and social systems be directed towards a permanent and sustainable equilibrium. Herman Daly (1973, 1980) similarly describes the conditions required for a steady state economy. In *The Closing Circle: Nature, Man and Technology,* Commoner (1971, p. 299), writes:

> "Humans have broken out of the circle of life, driven not by biological need, but by the social organisation which they have devised to 'conquer' nature... . The end result is the environmental crises, a crises of survival. Once more to survive, we must close the circle. We must learn to restore to nature the wealth that we borrow from it."

Concerns about the ability of the earths resources to maintain economic growth are also expressed by Forrester (1971), Meadows *et al.* (1975) and Georgescu-Roegan (1971, 1977, 1980) among others.

The concept of sustainability also originated during the 1960s and early 1970s. Caldwell (1984) describes the term as being implicit in two conferences held in 1968, the Paris "Biosphere Conference" and the Washington, D.C. Conference on the "Ecological Aspects of International Development". O'Riordan (1988) suggests that the trend toward equating sustainable utilisation with nature conservation and wildlife management became established following a series of African based conferences in the mid-1960s. Further recognition of the concept of sustainability followed the "United Nations Conference on the Human Environment" held in Stockholm in 1972 (Caldwell 1984).

It was not until the late 1980s, however, that sustainable development became subject to widespread discussion and scrutiny. The publication of the *World*

Conservation Strategy in 1980 by the International Union for the Conservation of Nature (IUCN) provided much of the initial stimulus for the widespread political acceptance of sustainable development. This report defines development as:

> "...the modification of the biosphere and the application of human, financial, living, and nonliving resources to satisfy human needs and improve the quality of human life." (IUCN 1980, p. 1).

Conservation is defined as:

> "...the management of human use of the biosphere so that it might yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations." (IUCN 1980, p. 1).

Sustainable development would thus be brought about by such conservation (Tisdell 1988).

Normative approaches to sustainable development received further impetus following the 1987 publication of *Our Common Future* by the World Commission on Environment and Development (WCED). This report contains a more concise definition of sustainable development:

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987, p. 43).

The process of sustainable development is described as:

> "...a process in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change, are all in harmony, and enhance both current and future potential to meet human needs and aspirations." (WCED 1987, p. 46),

and following the sentiments expressed in the environmental writings of the late 1960s and early 1970s:

> "In its broadest sense, the strategy for sustainable development aims to promote harmony among human beings and between humanity and nature." (WCED 1987, p. 65).

This normative perspective has been widely adopted in the literature associated with the development of human society. For example, Brown *et al.* (1987) and Liverman *et al.* (1988, p. 133) following an extensive and systematic review of the sustainable development literature, define sustainability as:

> "..the indefinite survival of the human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of infrastructure and institutions which distribute and protect the components of these systems."

Similarly, Robinson *et al.* (1990, p. 39) suggest in regard to the creation of a sustainable society that:

> "Sustainability is defined as the persistence over an apparently indefinite future of certain necessary and desired characteristics of the socio-political system and its natural environment."

These definitions of sustainable development reflect an anthropocentric value structure concerned with human needs and the betterment of the human condition through the long term maintenance and improvement of social and economic systems and the relationship of these systems with the environment. This value structure is shared by the definition of sustainable development used in this research (see Chapter One, section 1.3). Sustainable development is, as a consequence, regarded as a policy and political objective that is increasingly used as an all embracing concept.

2.2.2 Sustainability as a Solution to Development Problems

Normative discussion of sustainable development has tended to focus on the issues of poverty and environmental degradation. Brundtland (1987, p. 292), for example, writes that "...poverty is a main source, as well as an effect, of environmental degradation. This applies equally to poverty of the individual and to the impoverishment of nations." Adding in regard to sustainable development that:

> "It is a form of progress for social and economic generation that enhances the resource-base rather than degrades it. It requires a more equitable distribution of wealth than currently prevails within and among nations, and it aims at the eradication of global mass poverty, keeping options open for the future." (Brundtland 1987, p. 292).

Consequently, considerable attention has been paid to the problems of the developing world where the mismanagement of capital investment and/or ecological systems has resulted in economic failure, social inequity and degradation of the natural environment[1]. The normative perspective places both the responsibility for such problems, and the will to overcome them, in the hands of human actors (Redclift 1991).

Economic development is often advised as the solution to the social, environmental, and economic problems of developing nations. It is implicitly assumed that the process of economic development will provide the commodities and services required to improve individual well being (Barbier 1987; Pearce *et al.* 1989; Shearman 1990). Although different approaches have been taken to achieve development goals, the conventional method has been to set development in the context of economic growth. In this manner economic development becomes the process where real per capita income

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1 See, among others, Biswas (1986), Conway (1985), Conway and Barbier (1988), Gowdy (1994), MacNeill (1989), Manning (1990), Mellor (1988), Myers (1993), O'Riordan (1988), Redclift (1987, 1988b, 1991) and Ruckelshaus (1989).

of a country or region rises over a long period of time, subject to the distribution of income not becoming more unequal (Barbier 1987; Shearman 1990). The concept of sustainable development has been used to further argue that economic development must provide lasting and secure livelihoods that minimise resource depletion, environmental degradation, cultural disruption, and social instability (Myers 1993). Barbier (1987, 1989a, 1989b) adds that economic development must also be consistent with social values and institutions, and encourage grass roots participation in the development process.

2.2.3 The Development Versus Growth Debate

The emphasis placed on the achievement of sustainable development through economic growth as argued for by Brundtland (1987) and the WCED (1987) among others, has been subject to considerable debate, however. The WCED (1987, p. 16) states:

> "Many essential human needs can be met only through goods and services provided by industry, and the shift to sustainable development must be powered by a continuing flow of wealth from industry."

Critics suggest, nonetheless, that mismanaged economic growth and industrialisation are often responsible for the environmental, social, and economic difficulties faced by developing, and to a lesser extent developed, nations (Daly 1987, 1990; Etkins 1989; Hueting 1990; Simon 1989; Tisdell 1988). This is not to say that economic growth is not without merit. It is apparent that economic growth is vital to economic development in many developing countries, but it must be recognised that growth is simply a means and not an end in itself (Shearman 1990). Fundamental and pragmatic questions about whether economies should, or indeed can continue to increase the rate of flow of matter and energy through the economy should not be ignored. For example, Gowdy (1994, p.

55) argues that there is "no convincing evidence that past economic growth has led to an unambiguous improvement in the human condition".

Daly (1987, 1990) suggests that the significant difference between growth and development is often ignored in discussions of sustainable development. Growth implies a quantitative increase in the scale of the physical dimensions of the economy, while development, in contrast, refers to the qualitative improvement in the structure, design and composition of physical stocks and flows, that result from increased knowledge of technique and of purpose. O'Riordan (1988), from a western ecocentric perspective, further argues that development in contrast to growth comprises ethical concerns relating to the survival of living matter, the rights of future generations, and to institutions to ensure that such rights are included in policies and actions.

The debate surrounding the issue of achieving sustainable development through economic growth demonstrates the ambiguity and lack of clear theoretical basis of the normative view of sustainable development concepts (O'Riordan 1988; Simon 1989; Tisdell 1988). By stressing only what should be, many fundamental conceptual issues are neglected. Significantly, there appears to be little debate about whether or not sustainability, sustainable development, or sustainable economic development are realistic or achievable states for human society and economy. Treated as policy objectives without theoretical foundation, sustainability-related concepts tend to be ambiguous. For example, in the form presented by the WCED and IUCN sustainable development serves as a virtuous concept, used by politicians, resource developers, and environmentalists alike within differing and often conflicting contexts (O'Riordan 1988). Before sustainable development concepts can be incorporated into decision making and planning they need in the very least to be made more systematic and precise.

2.3 Methodological Approaches to Sustainable Development

There is a growing recognition that the implementation of sustainable development requires the articulation of methods of study rather than political rhetoric (Brundtland 1987; Barbier 1987, 1989a, 1989b; Pearce and Turner 1990; Pearce *et al.* 1989; Pearce *et al.* 1990; WCED 1987). A substantial contribution to the sustainable development literature has thus come from researchers who regard sustainable development as a methodological problem. Sought are sets of rules and procedures which indicate how sustainable development research is to be conducted. Methodological approaches tend to be narrower than those in the normative tradition, having a more explicit philosophical and/or ideological basis.

Among those who consider the achievement of sustainable development to be a methodological problem there is little consensus. Diverging methodologies reflect disciplinary biases, differing paradigms and ideological conflicts. Often, however, the resulting methodologies have in common that they have evolved in response to the conventional wisdom of neoclassical economics which underlies current economic, and hence development, theory. There are those approaches, for example, which represent a reaction against the neoclassical economic paradigm. Examples include Norgaard's (1985, 1988) co-evolutionary view and Redclift's (1987, 1988a, 1988b, 1991) political economy approach. In contrast to outright rejection of the neoclassical paradigm, there are also adaptive approaches which work from within a neoclassical framework and attempt to extend its scope to include the analytical tools necessary to model sustainable development. The following section briefly reviews the foundations of neoclassical economics and subsequent discussion concerns the critical reaction to its dominance of the analysis of economic-ecological interactions[2].

2.3.1 Neoclassical Economics and Resource Use

Neoclassical economic analysis has been steadily refined since its inception late last century. The validity of the paradigm is now widely accepted and it has come to dominate western economic thinking and subsequent public policy. Central to the conventional wisdom of economists and policy makers are the notions that capital substitution and technological progress are more than sufficient in overcoming resource scarcity, and that the operation of a competitive market will allocate natural resources efficiently. There is no single neoclassical theory of resource use to which all economists subscribe, however, and the following discussion is a simplified generalisation of neoclassical resource theories.

The fundamental principles of neoclassical economics were developed by John Stuart Mill, William Jevons, and Alfred Marshall, beginning around 1870. Their work was instrumental in creating a paradigm shift which saw the methodological emphasis of economics move from production dynamics to an analysis of exchange value. This emphasis subsequently lead to the development of the principles of optimisation, efficiency, and equilibrium in the market. A new methodology, marginal analysis, based on the study of relationships between incremental changes also evolved. The basic intention of the early neoclassical economists was to define a set of laws which governed

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2 It is beyond the scope of the dissertation to critique in detail individual research paradigms. Rather, the next section summarises major aspects of a vigorous discourse that has arisen in several fields of study in response to the notion of sustainable development. This discourse is particularly useful in helping to turn sustainable development from a normative goal into a set of related concepts with the potential for applied study.

economic activity. Consequently, economic analysis within the neoclassical paradigm became almost solely concerned with the investigation of price determination and market structures. The evolution of neoclassical economics has been characterised by the application of increasingly rigorous mathematical techniques to economic parameters measured by more disagregate indicators.

Dominance of economic analysis by market theory created an analytical indifference to the production process and its use of natural resources. Production was commonly treated as an aspect of the allocation and pricing of factors of production (land, labour and capital) and the capacity of the environment to provide inputs to the production process elicited little interest among economists. However, concern with the lack of economic growth in western economies during the 1930s and the need to stimulate post war economic production caused neoclassical analysts to reassess their neglect of production and economic growth patterns. Attention turned to developing models of economic growth based upon the macroeconomic ideas of John Maynard Keynes. Neoclassical growth models typically use an aggregate production function for an economy. Inputs of capital and labour are combined to generate an output which can either be consumed or reinvested to increase the stock of capital.

Heightened environmental awareness during the 1960s caused a further re-evaluation of neoclassical theory. Of concern was the central role of the environment and resource flows in determining aggregate levels of welfare and production functions. Two economic subdisciplines subsequently evolved, environmental economics, and resource economics. In very general terms environmental economics reflects a concern with the theoretical operation of the market and the price mechanism as it relates to the issues of pollution and environmental quality. The dominant utilitarian approach to economics[3] suggests that the economic value of marketable commodities and un-priced environmental goods and services is determined by the amount of personal utility yielded. The utility of an individual depends not only on the level of their consumption, but also on environmental quality. Tradeoffs are made by individuals at the margin to determine positions of equal satisfaction. Such preferences are revealed by the rational decisions people make, and are in turn reflected in the operation of the market mechanism. Future utility is incorporated into welfare through discounting.

Equilibrium in the market represents a Pareto optimum situation in which collective societal welfare is maximised. The market thus allocates scarce environmental resources in an economically efficient manner on the basis of rational human behaviour. When rational behaviour occurs but markets do not maximise collective welfare, market failure is deemed to have occurred. Governments fulfil the role of ethical agent, intervening to correct market failure by easing the tension between individual rationality and collective ethics. Significantly, ethical and moral obligations are not recognised at the level of the individual by dominant utilitarian approaches to economics.

In contrast to the market orientation of environmental economics, resource economics places less emphasis on the operation of the market mechanism, and is instead concerned with the way in which resource dynamics affect the intertemporal allocation of the natural resource stock to competing demands. McInerney (1981) suggests that three features serve to distinguish natural resource economics from the study of other economic problems. First, problems are viewed at the societal level rather than individual level, therefore focusing attention on societal choice. Second, with minor qualifications, there is no completely static theory of natural resource economics, and

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[3] See Sen (1984), Essays 12 and 13 for an excellent discussion of alternatives to utilitarianism.

temporal considerations take precedence. Third, social choice is constrained by factors outside the control of humans, for either resource stocks are fixed or change at natural rates. The foundations of the economics of natural resource use appear in works of Hotelling, carried out in the 1930s, and Scott in the 1950s. These early contributions focused on the market's ability to efficiently allocate resources over time, rather then on the implications of its failure to achieve this task, however (Victor 1991).

The theoretical work of Herfindahl and Kneese was instrumental in the development of resource economics in the early 1970s. Herfindahl and Kneese (1974) extended standard formulations of the aggregate growth function to include natural resources. They defined the capital component of growth models to be "anything which yields a productive flow of services over time and which is subject to control in the production process." (Herfindahl and Kneese 1974, p. 68). The environment was considered to provide two services: the provision of material inputs,and be a sink for residuals. Theoretical models based on the extended notion of capital, led Herfindahl and Kneese to the conclude that overall economic output (and hence welfare or utility) was constrained by limited supplies of resources. They also concluded that technological progress could overcome these limits (Victor 1991).

A more detailed analysis of the economics of exhaustible resources was carried out by Dasgupta and Heal (1979). Natural resources were again held to be essential for production, but it was assumed that output can be maintained by the substitution of manufactured capital for resources. They concluded that exhaustible resources do not represent a problem if manufactured capital is considered substitutable for natural resources, even in the absence of technological change (Dasgupta and Heal 1979; Solow 1974).

Renewable resources were considered to be less problematic by early resource economists since they were assumed to grow according to a natural growth function. Clark (1976) describes the availability of renewable resources as being a function of initial resource stock, its natural growth rate, and the carrying capacity of the environment. Since the resource is renewable there is a theoretical level of extraction which can be sustained forever even without technological change and substitution. If the extraction rate is higher than the maximum sustained yield the resource is being depleted. In this case production can still be maintained through continuous technological progress and the substitution of manufactured capital for renewable resources (Baumol and Oates 1988). Consequently, the conventional position on the role of renewable and non-renewable resources in production, and hence economic growth, is that even without technological change, economic output can be sustained or increased indefinitely through substitution. Introducing technological progress increases the possibility of sustained or improved output further.

Neoclassical environmental/resource economics is not without methodological limitations despite its theoretical elegance and apparent comprehensiveness. These limitations bring into question the ability of the market to ensure the present welfare of humanity through the efficient allocation of natural resources, and perhaps more significantly, the provision of future welfare for humanity via the intertemporal allocation of the natural resource stock. Three areas of concern can be identified, the homogeneic and separate treatment of resource inputs, the principle of equilibrium in natural and economic systems, and the treatment of time. The issues of substitution between manufactured capital and resources and the role of technological change will be addressed more fully in a subsequent section.

The common assumption that all resources are owned and are divisible is derived from an ontology that gives little recognition to heterogeneity and complementarity of resources in the natural environment. From a physical perspective the factors of production are a diverse interdependent mixture of material, energy and information flows, and of the physical and biological structures and agents which convert, transmit or apply these flows (Christensen 1989, 1991). Moreover, land and capital are heterogeneous aggregates that perform many different functions in environmental and social systems.

It is also problematic to assume that economic and environmental systems move freely between equilibrium positions. The market cannot allocate environmental commodities and services in an optimal or efficient manner because environmental systems are not divisible, do not tend to reach stable equilibrium positions and undergo usually irreversible evolution (Norgaard 1985, 1988; Redclift 1987, 1988a, 1988b). Environmental factors also prove difficult to predict, measure and quantify. Species, cultures and valuable ecosystems have are extinct because ecological and social systems are not mechanical systems to be pushed to new equilibria and brought back as desired (Norgaard 1989).

The ability of neoclassical theory to deal effectively with long run time horizons has also been argued against (Redclift 1988b). Appropriate discount rates and whether or not long term environmental changes should be discounted at all is a particularly contentious area which has been studied in some detail[4]. The implications that differing

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4 Extensive discussion of the discounting issue can be found in Barbier (1987, 1989a 1989b), Hueting (1991a), McAllister (1982), Nash and Bowers (1988), Nijkamp (1977a), Pearce and Turner (1990), Pearce *et al.* (1989), and Redclift (1988b).

concepts of discounting have for the level of the allocation of resources vary markedly. Variations of only two or three percentage points can make the difference between accepting or rejecting many large scale public projects. Projects most sensitive to discount rates are those whose benefits and costs coincide least in time. Hueting (1991a, p. 43) reflecting on the problem of discounting in the context of sustainable development writes:

> "Using the market interest as the discount rate for calculating the present value of long term costs and benefits means that the preferences for sustainable use of the environment amount to zero...."

Positive discount rates thus discriminate against future generations. This theoretical neglect of future generations severely limits the extent to which neoclassical principles can be applied to the analysis of sustainable development and its inherent assumption of intergenerational equity. It has been suggested that it is the utilitarian ethical basis of neoclassical economics which is at fault in this regard and that economics most adopt a new theory of justice rather than new methods of analysis (Junger 1979; Oelschlaeger 1979; Sen 1979, 1984, 1987).

2.3.2 Sustainable Development Based Alternatives to Neoclassical Analysis

The apparent limitations of neoclassical analysis in general, and especially the utilitarian paradigm have caused many analysts to question its applicability to modelling the relationship between the environment and economy. Norgaard (1985, 1988), Redclift (1987, 1988a, 1988b) Sen (1979, 1984, 1987) and Henderson (1990) among others, suggest that economics can only handle environmental and social factors effectively if it undergoes a significant alteration of its mainstream epistemology. The following discussion outlines some of these alternatives that have contributions to make to the study of sustainable development.

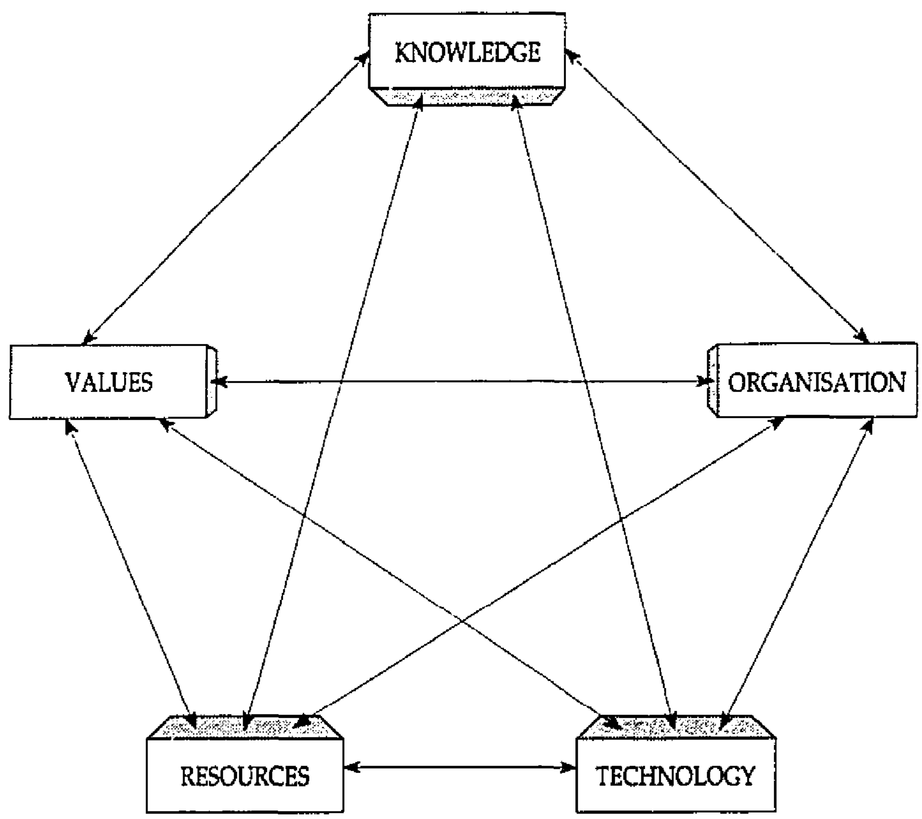
The Co-evolutionary Perspective

Norgaard (1985, 1988, 1994) has called for a new economic pluralism which incorporates a more flexible co-evolutionary view so that both development and ecological sustainability can be achieved. The co-evolutionary perspective emphasises the interrelationships, including feedback mechanisms, that exist between evolving social and ecological systems. In this context the nature of the development process, and hence the human condition, is determined by the nature of the interrelationships between the social and ecological systems.

Figure 2.2 illustrates the co-evolutionary perspective of development. Norgaard (1988) suggests that not only is each subsystem related to all others, but that each system is changing and influencing the evolution of other systems. Changes in each subsystem, arising as a consequence of random actions, chance discoveries, and purposeful intent change both the distribution and qualities of components and relations in the subsystem. The long term existence of such changes depends on whether they prove compatible with both the elements and processes within subsystems and with those of other subsystems. The interaction between subsystems results in co-evolution where each subsystem reflects the others. The linkages demonstrated in Figure 2.2 are maintained because the linkages themselves determine the nature of change.

Redclift (1987, 1988a), Nijkamp and Soeteman (1988a), and Pearce and Turner (1990) writing from different philosophical positions have highlighted the potential ability of the co-evolutionary perspective to consider the interaction of the social, environmental, and economic systems within an appropriate policy context. Co-evolution appears to take for granted a balance between economic development and

Figure 2.2 A Co-Evolutionary View of Development



Source: Adapted from Norgaard (1988)

ecological sustainability (Nijkamp and Soeteman 1988a). Pearce and Turner (1990) utilise the co-evolutionary perspective to explain the current non-sustainable development process in thermodynamic terms. It is suggested that energy surpluses are generated within systems during co-evolution, and these surpluses are then available for stimulating new interactions between systems. Favourable interactions result in the continuation of the development process. As development continues, however, co-evolutionary feedback systems may shift from the ecosystem to the social and economic systems as evidenced by more complex productive systems and increased environmental exploitation. Physical limits to growth arise as a result of the increasing complexity of the productive system. A similar analysis leads Norgaard (1988, p. 617) to conclude that the "...policy challenge of sustainable development consists of finding a path towards a positive social and ecological co-evolution."

The co-evolutionary perspective also has limitations, however. As yet it is not theoretically sophisticated enough to provide a practical analytical framework within which to analyse sustainable development. Further, the co-evolutionary perspective lacks any explicit consideration of the political economy within which decisions will be made. The political and economic context in which any development process occurs is fundamental to the determination of the possibilities for, and limitations to change (Caldwell 1984; Redclift 1987, 1988a; Simon 1989).

The Political Economy Alternative

Redclift (1987, 1988a, 1988b, 1991) adopts a position of historical materialism from which to assess sustainable development processes. The role played by the political economy is thus explicitly recognised and this recognition serves to demonstrate how the evolution of the current, unsustainable world order has dramatically transformed and internationalised local relations of production, local environments and peoples perception and knowledge of them. Such a perspective suggests it is necessary to address the political and economic forces behind unsustainable practices.

Redclift (1988b) argues that the environment and theoretical work on development has been confined to the margins of most research in the social sciences, particularly theoretical work on development. As a consequence the environment has lacked a historical focus which would allow for a broader, more comparative view of how nature is transformed under the impact of capitalist development. It is suggested, for example, that geography has treated the environment seriously but un-problematically. Environmental managerialism is similarly criticised because it pays no attention to either the conceptual framework within which environmental problems are understood nor the international economic framework in which these problems are manifested.

Neglecting political economy gives rise to two important contradictions in the discussion of sustainable development (Redclift 1987, 1991). First, important differences in ideology tend to occur. Some view sustainability as an important issue because the environment is a major constraint on human progress. Their solution is to develop technologies that avoid the ecological consequences associated with current growth, and/or develop methods to assess environmental degradation in a more realistic way. Others take a less anthropocentric view, suggesting that human progress itself has implications for the environment and that concern should be expressed about the ends of the development process as well as the means. Technical solutions to environmental problems are seen as ultimately self-defeating (Devall and Sessions 1985; Naess 1988; O'Riordan 1988; Shearman 1990).

The second contradiction, Redclift (1987, 1991) suggests, arises from the structural inequalities of the global system. In marked contrast to developed nations where environmental degradation may cause a decline in social welfare, economic and social practices which degrade the environment are often the only means of improving individual, if not collective welfare in many developing regions. As a consequence, neoclassical notions such as willingness to pay as a measure of environmental costs and benefits have little conceptual relevance. Equity considerations, in many instances, are a fundamental cause of resource degradation, and deserve recognition beyond inclusion in an aggregate welfare function. Of greater analytical relevance are concepts such as human agency in relation to the environment and the relationship between knowledge and power (Redclift 1991).

Redclift (1987, 1988b, 1991) argues that a consideration of the economic, political, and epistemological dimensions of sustainable development is essential to its adequate conceptualisation. Economics, it is argued, must undergo a fundamental shift in regard to the way the environment is viewed. Needed is a perspective that places humankind within nature, rather than external to it (Redclift 1987, 1991). Within developing nations attempts to replicate the growth processes of developed countries should be replaced with development strategies that are sensitive to differing cultural and environmental contexts (Redclift 1987, 1991).

The political dimension of sustainable development comprises two components: the role of human agency and social structure in determining the political process through which the environment is managed; and the relationship between knowledge and power in resisting dominant world views of environment and resources (Redclift 1991). It is argued that power relationships, such as human domination of the environment and the way in which some humans dominate others, play a central role in the evolution of conflicts over the environment and the management of these conflicts. Sustainable development thus has important implications for the way in which power is understood by people, as well as for the environment.

Redclift (1991) further uses the relationship between knowledge and power in an attempt to explain resistance to the universalising influence of modern society by cultures within less developed countries. Three "fields of resistance" are used to delineate responses by marginalised groups to outside environmental control. The first type of resistance is termed "resistance against exploitation". It arises from the marginalisation of rural societies from traditional production relations. Ethnic and gender categories form the basis for the second form of resistance. This type of resistance seeks to prevent the domination of individuals by more powerful groups whose gender and/or ethnic identity has conferred on them a superior political position. Finally, there is "resistance against subjection" in which rural people resist the imposition of a world view which they cannot endorse and which may devalue their own knowledge systems.

The last dimension of sustainable development considered by Redclift (1991) is the epistemological. How knowledge is acquired, transmitted, altered and integrated into conceptual systems, and thus how the world is viewed, has profound implications for the human-environment interrelationship. Redclift (1991, p.41) claims that the "...ubiquitousness of Western science, however, has led to traditional knowledge becoming fragmented knowledge in the South today, increasingly divorced from that of the dominant scientific paradigm." Knowledge held by other societies is often implicit in everyday cultural practices, and consequently, there is little separation between knowledge and culture. External attempts to bring about development often neglect the way environmental knowledge is used in such societies, and thus cause further marginalisation of people and environment.

The principles of political economy suggest that as decision makers we should "...interrogate our assumptions about both development and the environment, and give political effect to the conclusions we reach... ." (Redclift 1987, p.204). However, while providing many insights into the structural problems of achieving sustainability, especially within the context of developing regions, the political economy perspective is also subject to limitations. As articulated by Redclift, the political economy perspective emphasises the role of human agency while giving ecological constraints on human action little explicit consideration. Further, the reality of the current dominant planning paradigm means that analytical frameworks must be amenable to predictive and prescriptive usage as well as descriptive. This is not a shortcoming of political economy, but the challenge of sustainable development requires action as well as understanding.

2.3.3 Adaptations to Environmental/Resource Economics

Neoclassical economics, as previously discussed is subject to much criticism. Sustainable development implies that responsible resource use requires more than the efficient allocation of natural resources between competing uses. The weakness of neoclassical economics in this regard derives, paradoxically, from its strength. By analysing separately each resource problem and type of resource, conventional approaches have greatly increased the understanding of the economic implications of each discrete set of problems. But the its characteristic of nomothetic reductionism also limits its broad application (but not necessarily its contribution) to the wider issues implied by notion of sustainable devlopment.

The analysis of resource related problems and the development of appropriate policy responses requires a more integrated approach than has traditionally been employed by those within the neoclassical paradigm. Recognising this, the newly emergent field of ecological economics, and developments within the fields of environmental and resource economics have attempted to overcome the reductionism of mainstream economics while still drawing on the theoretical foundations of neoclassical economics.

Ecological Economics

Ecological economics studies how ecosystems and economic activity interrelate (Proops 1989). It includes neoclassical resource and environmental economics, institutional economics, and ecological studies, and also encourages new ways of thinking about the linkages between economic and ecological systems (Costanza 1989, 1991). Significantly, ecological economics emphasises the need for conceptual pluralism since there is unlikely to be a single approach that gives rise to a complete understanding of the relationship between economic and ecological systems (Costanza 1989, 1991; Norgaard 1989; Norton 1991).

Neoclassical economics generally views production as the result of the combination of labour, capital, and natural resources, with pollution regarded as an externality. Other parameters such as institutional arrangements, technology, and preferences and needs are assumed to be fixed. Economic growth is regarded as an increase in production or consumption. In contrast, production is viewed by ecological economics as the transformation of materials using energy, capital and labour, with waste created as a by-product. The parameters of the economic process are characterised by circular interdependencies which incorporate environmental processes and ecological constraints. Economic processes must remain within the constraints imposed by the biosphere in order to preserve or support ecological systems. In addition to economy and environment, culture, technology, and political economy are viewed as part of an interacting ecological complex. Any increase in the physical dimensions of the economy is viewed as economic growth (Klaassen and Opschoor 1991).

Ecological economics may also reject the notion of rational economic behaviour as the determinant of societal welfare (Klaassen and Opschoor 1991). For adherents of this perspective, values are held to go beyond the expression of aspirations of individuals. Aspirations, shaped by the economic process, influence individual behaviour. Values, in contrast, determine overall welfare and societal behaviour, forming a hierarchical system of separate and semi-connected values at different levels (Klaassen and Opschoor 1991; Page 1991). This position suggests that values may not be reduced to a single measure. Institutional economists have argued for the existence of "ultimate" values such as continuity of human life, sustainability, and environmental compatibility. (Klaassen and Opschoor 1991; Pearce and Turner 1990). Moreover, the value attached by society to natural resources and the environment may not be the same as the sum of all individual values. The life expectancy of society is longer than that of individuals and, therefore, societal values are likely to deviate from individual values (Klaassen and Opschoor 1991).

In a series of sustainable development papers by Barbier (1987, 1989a, 1989b, 1991a, 1991b), Pearce (1988), Pearce and Turner (1990), and Pearce *et al.* (1989) and

(1990) methodological emphasis is placed on the new ecological and modified environmental economics. They seek to determine the useful economic functions that the environment provides and how these functions are altered by the process of economic-environmental interaction. Encompassed is an alternative theoretical view of resource and environmental problems. This in turn provides a foundation for applied analysis and practical methods of ameliorating environmental degradation (Barbier 1989a).

Environmental resources are recognised as performing three related functions. First, as suggested in conventional theories, the environment provides useful material and energy inputs for the economic process. Second, the environment assimilates the waste products generated by this process. Third, the natural environment provides utility yielding services that are essential for supporting economic systems and human welfare, including the determination of health and lifestyle, and of aesthetic satisfaction (Barbier 1989a). These functions illustrate the dependency of economic progress and human welfare on ecological processes and the sufficiency of potentially scarce resources.

Barbier (1987, 1989a, 1989b, 1990) has used these extended principles to refine the concept of sustainability, making it more concise, systematic and rigorous. He writes:

> "The broad objective of sustainable economic development is to find the optimal level of interaction between three systems - the biological and resource systems, the economic system, and the social system -through a dynamic and adaptive process of trade offs. This optimal level would therefore be the most sustainable development that these three crucial systems can support." (1989a, pp. 185-186).

While recognising the wider normative view of sustainable development discussed earlier, Barbier is proposing a more narrowly defined concept of environmentally sustainable development. In this new context sustainable development is concerned with optimal resource management over time and requires the maximisation of the net benefits of economic development, subject to the maintaining the services and quality of natural resources. It is further argued by Barbier (1989a) that the normative and methodological approaches to sustainability need not be mutually exclusive or even conflicting. By taking the two together, sustainable economic development can be considered (Barbier 1989a, p. 185) to be: "...any economic activity that raises social welfare with the minimum amount of environmental degradation allowable within given economic, social and technical constraints."

The Concept of a Constant Resource Stock

Pearce (1988) also comments on the nebulous sustainable development literature and suggests there is a need for a narrower definition that enables sustainable development to be incorporated into practical decision making. He suggests an approach in which sustainable development is characterised by economic change subject to the constancy of the natural capital stock[5]. The stock of environmental assets is held constant while the economy is allowed whatever social goals are deemed appropriate. The concept of a constant natural capital stock is held to accommodate many of the concerns of advocates of sustainable development including equity between generations, equity within a generation, economic and ecological resilience to external shocks and internal stress, and uncertainty about functions and values of natural environments in

5 Also discussed more generally, in terms of sustainable income, by Bartelmus (1987), Daly (1989) and El Serafy (1991).

social systems. It may also redress some of the concerns of deep ecology by respecting rights in nature (Pearce 1988).

Both manufactured capital and natural capital contribute to human welfare. Manufactured capital contributes largely through the economic process while natural capital operates both through the economic process and directly. This raises the dilemma of what is the proper mix of manufactured and natural capital and hence whether manufactured and natural capital are complements or substitutes. An appropriate response may be that they are complementary and only limited opportunities for substitution exist. Natural capital provides humans with a life support system and gives their socioeconomic systems resiliency against shocks, and reduces the destabilising influence of stress (Conway and Barbier 1988). It is also subject to irreversible changes which can cause its permanent loss. It would therefore seem a rational choice to prefer more of natural capital than less of it. A constant stock of natural capital is one possible assurance that the services of the biosphere will always be available to contribute to human well being. The conservation of natural capital can be thought of as a risk aversion strategy (Pearce 1988; Tisdell 1988).

Maintaining a constant stock of natural capital is also consistent with the work of Tisdell (1988) that is based on the "safe minimum standard approach" pioneered by Ciriacy-Wantrup (1968) and Bishop (1978). Tisdell (1988) suggests that sustainable development can be thought of in game theoretic terms. In certain circumstances sustainable systems may be those that maximise minimum possible losses. A sustainable development strategy would thus correspond to extreme risk avoidance (Tisdell 1988).

A constant natural stock can be interpreted in several ways (Pearce and Turner 1990, Pearce *et al.* 1989; Victor 1991). First, resource constancy can be interpreted as requiring that the physical quantity of a resource does not change. The aggregation of incommensurate physical units represents a major problem with this approach. If pecuniary values could be assigned to all resource stocks the initial requirement could be rephrased in terms of a constant real value of the stock of natural assets. Second, the unit value of the services of natural capital, or price, of natural resources can be kept constant in real terms. As long as prices reflect absolute scarcity, constant real prices will translate to a constant natural capital stock. Third, the value of resource flows from the natural capital stock can be kept constant. In this instance quantity can decline as long as prices increase, thus keeping value constant. This latter interpretation is sometimes referred to as a weak sustainability condition (Barbier *et al.* 1990).

The sustainable use of non-renewable resources remains a difficult problem to resolve, however. It is evident that sustainable development requires that the waste generated in the extraction of these resources not exceed the assimilative capacity of the ecosystem into which it is emitted. Nevertheless it is impossible to use non-renewable resources in a sustainable way since continued exploitation will result in their exhaustion. Similarly, it is impossible to use, yet maintain, a constant stock of a non-renewable resource (unless a constant value criterion is used). This problem can be partially resolves by suggesting that it is possible to exploit non-renewable resources in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of renewable substitutes (Daly 1990; Costanza and Daly 1992). This assumes a greater degree of substitutability between the components of natural capital than between natural and manufactured capital.

The use of non-renewable resources in a quasi-sustainable manner requires any investment in the extraction of a non-renewable resource to be matched by a compensating investment in a renewable substitute (Costanza and Daly 1992; Daly 1990). This involves separating the net returns from the exploitation of the non-renewable resource into an income (consumption) component and a capital component (which must be invested in the renewable substitute). By the end of the life of the non-renewable resource, the renewable resource must be producing a sustainable yield equal to the income component of the non-renewable resource net returns. The reduced consumption flow from the non-renewable resource is converted into sustainable consumption because it is continued into the future by the yield on the renewable substitute (Costanza and Daly 1992; Daly 1990; El Serafy 1989).

A number of questions regarding the substitution of renewable for non-resources remain unresolved. They relate to the interpretation of the pairing rule and the administration of substitution process. For example, must the renewable resource be a close substitute for the non-renewable or could any renewable resource fulfil the pairing requirement as long as it generates an equivalent value of sustainable consumption? If the latter less restrictive interpretation is implemented, how are the different resource functions to be valued given the existence of intangible and/or incommensurate functions? Assuming the resolution of the valuation problem and that the important non-renewable resources do have feasible substitutes, is it the responsibility of the firms engaged in resource extraction, the value added industries, and/or government to ensure the paired investment takes place? Can the operation of the market ensure its occurrence? Another concern is the spatial scale at which the principle would operate. Should the geographic basis for calculating the necessary investment level be defined by environmental, economic, or administrative boundaries? If the last, which seems the most reasonable option, should it be regionally, nationally, or globally based?

Capital Substitution and Technological Change

The concept of maintaining a constant natural capital stock represents a major departure from more traditional neoclassical theory which would suggest that natural capital need not be conserved (Herfindahl and Kneese 1974; Dasgupta and Heal 1979). Previous discussion suggested that prevailing economic ideology holds that both the substitution of more productive manufactured capital for natural capital and technological change, which improves the efficiency of resource use, will result in a rising level of welfare, thus making it unnecessary to maintain a constant natural capital stock.

The elasticity of substitution between manufactured capital and natural capital is not high, however (Pearce and Turner 1990). Natural capital is needed directly, or in embodied form, to make manufactured capital. The existence of biophysical laws such as the first law of thermodynamics demonstrate that natural resources must be consumed to make anything. The substitution of manufactured capital for natural capital is therefore limited by the extent to which increases in manufactured require natural capital inputs. Natural capital also fulfils other economic and environmental functions than just the provision of inputs to the production process, including basic life support. Manufactured capital lacks the diversity of natural capital. Diversity adds resilience to systems which in turn acts as a mechanism to protect against shock and stress[6] (Pearce *et al.* 1989). In the context of agro-ecosystems sustainability has been

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[6] Conway and Barbier (1988) define a shock as a large, unpredictable force such as pest or drought, while stress is regarded as a frequent, sometimes continuous, relatively small force having a large cumulative impact such as increasing salinity, erosion or debt.

defined as the ability to preserve productivity when subject to stress or shock (Conway 1985; Conway and Barbier 1988). Because of the above, possibilities for the substitution of manufactured capital for natural capital are more restricted than indicated by neoclassical capital theory.

Increased economic efficiency brought about by technological change does not always mean less pollution or improved environmental quality. In many cases technological innovation has created increased levels of environmental degradation. Continued technological improvement also relies on the existence substitute renewable resources to replace depleted non-renewable resources. The existence of renewable substitutes and the technology required to exploit these new resources is often an article of cornucopian faith (O'Riordan 1981; Pearce and Turner 1990).

Cocklin *et al.* (1989) examine the role of structural change in determining changes in energy use in the New Zealand economy between 1971 and 1982. Their findings warn against an over reliance on technological change as a mechanism to reduce resource inputs to the production process. In their study, structural change consists of two components: (i) changes in the relative composition of economic output (demand effects) and (ii) changes in the energy requirements of production in the individual sectors of the economy (technological change). It was found that although technological change was the most influential factor in determining the change in energy use at the level of the individual sector, the overall effect of on total energy use was minor. Reduced energy intensities in some sectors were balanced by increased energy intensities in other sectors. In contrast, changes in the composition of economic output were less important in determining change in energy use at the level of the individual sector, but were a major cause of change (an increase) in overall energy use (Cocklin *et al.* 1989; Harte 1987). The observed changes in energy use occurred during a period of increasing factor prices for energy resources.

Attempts have also been made to empirically validate the theoretical findings of Herfindahl and Kneese (1974) and Dasgupta and Heal (1979), regarding the role of technological change and capital substitution in alleviating resource scarcity. Following the so called "Hotelling rule", in the absence of market imperfections, the resource rent (the difference between revenues and extraction costs) of a non-renewable resource can be expected to rise at a rate equal to the rate of return on assets of the same degree of risk (Barbier 1989a; Hartwick and Olewiler 1986; Neher 1990). Examination of the actual path of resource prices, production costs, and resource rents have enabled economists to see whether resources are becoming more or less scarce.

Barnett and Morse (1963) examined indicators of resource scarcity over the period 1890 to 1957 and found little evidence of increasing scarcity. Their findings, now part of conventional wisdom, suggested that substitution and technological change, with few exceptions had more than compensated for declining resource stocks. More recent examinations of the same and updated data have conflicted with the findings of Barnett and Morse. A decline in the rate of decrease in resource prices over the decades preceding 1970 was noted by Fisher (1981). Fisher suggested that this trend was evidence of an increasing dependence on resources. The validity of all these findings is however questioned by Victor (1991). It is suggested that since resource markets do not operate according to the neoclassical model, neoclassical indicators of resource scarcity are of little use because the conditions under which they have normative significance do not exist.

The Ethical Dimension of a Constant Resource Stock

The concept of a constant resource stock also has ethical implications that could lead to the replacement of the individualistic utilitarian foundation of neoclassical theory with a collective egalitarian ethic (Pearce and Turner 1990). Pearce and Turner (1990) suggest that adopting a collectivist egalitarian ethic allows for the recognition of generalised obligations to future generations. These obligations can be met by maintaining a stable flow of resources into the future to ensure on-going human life. In this manner intergenerational equity can be interpreted in terms of a justice of opportunity in which "...each generation should leave 'enough and as good for others that follow on." (Pearce and Turner 1990, p. 237).

The rationale for an intertemporal allocation of resources to ensure an adequate resource endowment and a livable environment is based on Rawls' (1971) difference principle (Penn 1990)[7]. The difference principle is drawn from Rawls' second principle of justice that assigns rights and duties to regulate social and economic inequalities. Inequalities are only allowed "...if they work as part of a scheme which improves the expectations of the least advantaged members of society" (Rawls 1971, p. 75). Inequalities resulting from natural endowments or social position are considered as differences, not permanent social differences. Extended intertemporally, an individual's right to exhaust a resource or deteriorate the environment is not as absolute as the societal need to have an on going material standard of living and a satisfying level of environmental quality (Penn 1990).

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[7] See Penn (1990) for a detailed discussion of the intertemporal implications of Rawls' "difference principle".

The ethical dimension of a constant resource stock is further described by Page (1977). Page argues against the almost universal acceptance of positive discounting of the future, and proposes conditions for what he calls "permanent livability" (Page 1977, p. 191). It is suggested that although the intertemporal allocation of resources determined by positive by discounting may be efficient in a Paretian sense, it may not be fair. Page posits that, following Rawls' idealised decision model, each generation follows a "maximin" strategy. Each generation seeks the maximum protection possible (or minimises the risk) against finding themselves allocated to being the poorest generation. Consequently, individual generations attempt to maximise the "primary goods" (rights, opportunities, income, wealth, etc) available to the poorest generation. Page (1977) thus describes his permanent livability condition as requiring that: (i) future generations are possible, and (ii) each generation has equal access to the resource base. Natural resources are held to be a condition for future life, and therefore necessary for primary goods to exist.

Norton (1989) similarly develops a two step model for resource decision making, based on a modification of Rawls' rational decision model. In the first stage, a self interested rational decision maker places pre-emptive constraints on each generations use of natural resources. These constraints limit the ability of any individual within a generation to pursue improvements in economic welfare. In the second stage of the model, each generation may choose a strategy of resource use from those possibilities fulfilling the first stage constraints. The results of Nortons' two step model show considerable similarity with the sustainability rule developed by Pearce and the principle of permanent livability described by Page. Each indicates that the notion of equal access to resources across generations is binding on subsequent decisions.

Optimal planning requires that this condition be met first, and only then do other social objectives become subject to consideration.

Soderbaum (1992), from a public policy perspective, has gone so far as to suggest a set of basic principles for regional resource management which together constitute a possible environmental ethic for sustainable development. In a given region:

> "(1) Alternatives which involve irreversible degradation of the natural resource base within the region should be avoided.
> (2) Alternatives which involve irreversible degradation in the natural resource base in other regions and globally should be avoided.
> (3) In situations where there is uncertainty and knowledge is incomplete with respect to possible irreversible negative impacts on the future natural resource... a philosophy of cautiousness should be chosen.
> (4) Wherever possible, alternatives with a positive or neutral impact on the future natural resource base should be chosen. If no such alternative is available, a search should be initiated to find new alternatives in terms of a different technology, new rules of the game, reconsideration of life styles at the individual level etc." (p. 137).

Soderbaum acknowledges several limitations of this ethic, however. First, it is limited to environmental impacts and does not therefore constitute an ethic incorporating all the dimensions of human development. Second, it is essentially anthropocentric and therefore ignores the wider developmental implications of an ecocentric environmental ethic. The inherent conflict between the anthropocentic concept of development and the ecocentic principle of sustainability pervades the entire sustainable development debate. Its resolution is part of the policy challange of sustainable development and one that will not be easily resolved via the ideological reductism of prevailing economic and ecological paradigms.

2.4 The Spatial Dimension of Sustainable Development

The operationalisation of the concept of sustainable development requires a consideration of spatial implications which has been largely absent in the literature. This absence may be due to the supposed universality of sustainable development and/or because current research takes place within well defined spatial boundaries and systems. Among the few researchers addressing spatial concerns, Nijkamp *et al.* (1991) and van den Bergh and Nijkamp (1991a) have outlined some aspects of the analysis of resource use and sustainable development at the regional level.

At the global level all processes are endogenous, whereas at the regional level some of the relevant economic, social, and environmental processes are exogenously determined. In thermodynamic terms, the global system can be characterised as a closed system (neglecting for the moment incoming solar radiation and emitted heat), while sub-regions of the globe are considered to be open systems. Although global processes will influence all regions of the global system, the impact of these processes will not be constant across the regions. Additionally, the regions themselves form an open set of mutually interacting areas, with changes in one region influencing other regional systems. Consequently, at the regional level there are various spatial trade-off's to consider, those between regions, between global and regional systems, and over time (Nijkamp *et al.* 1991). Subsequent analysis of sustainable development must be cognizant of these trade-off's if it is to be successful.

It is not realistic or pragmatic to expect every region to develop sustainably. The diverse characteristics of different regions in regard to such factors as natural resource and human capital availability, ecological resilience, cultural characteristics and political and economic conditions, will mean that sustainable development will take different forms in different regions (Redclift 1991). Factors such as the disparate distribution of resources, wealth, and capital, imply that some regions and their populations will have to experience environmental degradation or declining welfare in order to achieve sustainable development. Furthermore, a number of spatial distributions of welfare can occur at a global level and still result in overall sustainable development.

The distribution of costs and benefits in terms of enhanced or reduced welfare which arises as a result of the spatial interactions that are part of the determination of sustainable development is a question open to ethical debate. In such cases conventional wisdom suggests that the population within the region which sacrifices its own sustainability or does not benefit directly in terms of improved welfare from global sustainability should ideally be compensated in some manner. Nevertheless, the question of compensation is complicated, for example, in what form is the compensation made, is the compensation substitutable for the loss, how and to whom is the compensation allocated, and what an appropriate time period between the initial loss and compensation.

The ability of society to exercise control over factors affecting its development is also an important spatial consideration. Human activities and their consequences in a region, defined by environmental, economic, or administrative boundaries are generally more amenable to examination and manipulation than at a global level. Furthermore, issues such as the distribution of welfare and the recognition of collective values and preferences are more appropriately addressed at the regional level.

The spatial dimension of sustainable development is of fundamental importance, and the paucity of literature in this regard is a limitation to the development of a conceptual framework for subsequent empirical investigation. It can be argued that the spatial level most appropriate to the empirical analysis of sustainable development is the region, notwithstanding a recognition of the open nature of regional systems. Processes such as global warming, desertification, and deforestation can still be examined without regional reference, however the factors giving rise to these processes and the subsequent outcome of the processes remain regional occurrences albeit, aggregated at the global level.

2.5 Guiding Concepts for Sustainable Development Environmental Planning and Resource Assessment

The foregoing literature review suggests that there is no single, overall, conceptualisation of sustainable development. The absence of a coherent set of definitions, assumptions, variables and relationships represents a significant barrier to applied research in the field of sustainable development. Indeed, given the apparently ambiguous and context dependent characteristics of sustainable development it is unlikely that a single definitive articulation of the concept is possible. Nevertheless the opportunity exists, using elements from the various perspectives reviewed in this Chapter, to develop a set of concepts consistent with the goal of sustainable development. It is intended that these form the conceptual basis for subsequent Chapters of this dissertation.

The idea of sustainable development can be considered to contain two key elements: (i) a set of ecological and socioeconomic interlinkages that act on the expression of social systems, and (ii) a series of development goals relating to the condition and evolution of socioeconomic systems. For the purposes of creating a general conceptual framework to characterise sustainable development, it is easiest to envisage the biosphere as imposing dynamic constraints on the scale and scope of human development.

The concept of sustainable development implies that development within these constraints is sustainable and development that violates these constraints is unsustainable. From a co-evolutionary perspective, sustainable development arises from continued positive feedback between ecological and socioeconomic systems. Negative feedback's are symptoms of unsustainable development. There is no intrinsic reason, however, for development to be sustainable and it is conceivable for humanity to decide that the short term costs of sustainable development out weigh the possible long term benefits. Therefore, there exists a moral and ethical dimension to the idea of sustainable development.

2.5.1 Biophysical and Socioeconomic Interrelationships

Environmental constraints on human activity can be functionally expressed in terms of the biosphere's capacity to: (i) provide inputs to production processes; (ii) assimilate waste material from consumption and production; and (iii) provide other contributory services essential to human wellbeing including life support services. To be sustainable human exploitation of the environment should not exceed the capacity of ecosystems to provide these services. However, it is not inconceivable, though unlikely, that societies can persist and even advance while operating outside these limits (Pearce 1988).

The first two conditions can be addressed by ensuring that the rate of exploitation of renewable resources does not exceed regeneration rates, and that rates of waste emission equal the assimilative capacities of the ecosystems into which the wastes are emitted. The third constraint is conceptually more difficult to deal with, but it can be interpreted in terms of a constraint on the stock of natural capital. Regenerative and assimilative capacities, and the ability of ecosystems to provide other contributory functions can all be considered components of natural capital (Costanza and Daly 1992; Daly 1990; Pearce 1988).

The prominence of the constant stock of natural capital concept in the sustainable development literature may be unwarranted, however. While an interesting theoretical notion, it is an unrealistic concept for applied resource assessment and environmental decision making. Two major problems exist. First, any use of non-renewable resources violates the constraint. With respect to compensating investments in renewable substitutes, it is unlikely that natural resources provide identical contributions to the biosphere, and therefore to human wellbeing. Moreover, the potential exists for the exploitation of renewable resource to create irreversible ecological change.

Second, it can be argued that there is little ecological basis for the maintenance of a constant resource stock. If the term sustainability is used to refer to the ability of a given system to maintain its self-organising ability (integrity), a system's composition, structure, and function (i.e., the resource stock) can change through time. What is important in ecological terms is that human activities do not compromise the integrity of the biosphere. Defined in this way it is possible that some components of the resource stock may be significantly degraded without any impact on sustainable development.

The discussion of dissipative structures and ecological integrity in Chapter Four, section 4.6 explores the theoretical basis for this argument in more detail.

Dismissing much of the rationale for a constant resource stock does not mean that the concept need be rejected, nor does it mean that there are not ecological limits to human development. What it does mean is that a constant resource stock only has relevance for human development if it is inculcated with human preferences for different ecosystem states (again these ideas are elaborated on in section 4.6 of Chapter Four). These preferences are formed within the context of the prevailing political economy and reflect an assessment of the welfare likely to be generated by a given ecological-sociosystem interrelationship. The argument presented above lends support to anthropocentric orientation of much of the sustainable development literature. However, much greater consideration must be given to the ecological dimension of sustainable development than has been previously accorded it.

2.5.2 Socioeconomic Development Goals

The second component of sustainable development concerns two development goals relating to the condition and evolution of socioeconomic systems. These are: (i) the improvement of the welfare of the present generation, and (ii) equity between generations.

The Welfare of the Present Generation

The sustainable development literature considers the purpose of development endeavour's to be the improvement of human wellbeing. This wellbeing is conventionally measured by some aggregate measure of social welfare. It is assumed for the purposes of this research that social welfare is some aggregate function of individual ability to consume, and of the quality of the environment in which the individual lives (Barbier 1990; Daly and Cobb 1989; Klaassen and Opschoor 1991; van den Bergh and Nijkamp 1991b)[8]. Appropriate measures of social welfare are discussed more fully in Chapter Four, section 4.5.

Consumption arises as a consequence of the transformation of matter and energy from the environment by capital and labour into items of utility to humans. An individuals' wellbeing is influenced by the quantity and quality of their consumption. This wellbeing is also affected both directly and indirectly by the quality of the environment; directly in the sense that the environment provides non-market utility yielding services, and indirectly in that the quality of the environment affects the magnitude and quality of matter and energy available for the production of goods for consumption. To some degree the two components of welfare must be considered substitutes, but ultimately one limits the other.

The conditions imposed by sustainable development on the level of welfare can be expressed by requiring either that welfare always exceeds some minimum level, for example a given level of subsistence, or by requiring a non-decreasing change in welfare over time (Pezzy 1989; van den Bergh and Nijkamp 1991a, 1991b; Nijkamp *et al.* 1991). However, expressing welfare improvement goals in this manner ignores the principle of equity. The issue of equity between nations, regions, cultures, and individuals is extensively discussed in the normative sustainable development literature and as a

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[8] For more rigorous discussions of social welfare in the context of social choice theory see (Sen 1979, 1984, 1987).

consequence should be addressed in the discussion of appropriate conceptualisations of sustainable development.

The desirability of an equal distribution of resources and the implications of this for levels of welfare is an ethical issue. The concept of sustainable development places no moral value on equity. Societies are free to develop in whatever manner they so choose as long as it is within the dynamic constraints imposed by the biosphere. Assuming that society considers it desirable to address the issue of social justice, an appropriate welfare function can be derived from one of a number of ethical systems (Pearce and Turner 1990). A utilitarian welfare function would maximise the sum of the cardinal utilities of all individuals in a society, based on the principle of 'the greatest good for the greatest number'. An egalitarian welfare function, as expressed in the writings of John Rawls (1971), would be established on the basis of the level of wellbeing of the worst off person in society. A libertarian ethic would consider the welfare of society to be improved if changes in welfare harmed no one and improved the level of some. Several studies have demonstrated that the choice of an ethical system has a considerable effect on the resolution of societal decision problems[9].

Equity Between Generations

The second development goal within the concept of sustainable development is equity between generations. Stated simply, it is required that the activities of the present generation do not preclude the attainment of the needs and aspirations of future generations. Researchers are faced with a considerable dilemma as to appropriate resource allocation constraints which guarantee this condition. A fundamental issue to

[9] See, for example, Penn (1990), Schulze and Kneese (1982), Schulze *et al.* (1982) and Turner (1991).

be resolved is the moral correctness of the present generation making decisions which affect the welfare of future generations.

Utilitarian and libertarian ethical systems would suggest that intergenerational equity is not a significant problem since future generations do not exist yet and furthermore their existence is dependent on the present generation (Pearce and Turner 1990). Modern resource allocation procedures still tend to reflect a utilitarian ethic and, as a consequence, a position contrary to sustainable development has arisen where the welfare of future generations is subservient to that of the current generation. However, the welfare of future generations will, like that of the present generation, be a function of consumption and environmental quality. Therefore to have equity between generations, future generations must have access to a resource base that is of equal, or enhanced, quantity and quality as that exploited by the present generation. The welfare constraint of equity between generations thus becomes a temporal restriction on the magnitude and nature of the interactions between the ecological and socioeconomic systems. This constraint can be functionally expressed as requiring that some condition be imposed on the intergenerational transfer of natural capital. In the case study in Chapter Five, a flexible interpretation of this constraint requiring that the welfare contribution of natural capital be non-decreasing over time is used.

There is a considerable similarity between the expression of the requirements for intergenerational equity and the initial environmental constraints. Nevertheless there is a fundamental difference in that the former have an ethical basis. The principle of equity between generations suggest that is unethical for the present generation to either: (i) endow future generations with a lesser level of natural capital than it inherited, and/or (ii) to leave a stock of natural resources to future generations which makes sustainable development unlikely. Environmental constraints reflect the influence of interrelationships between the social and ecological systems on the social system. The nature of this relationship is dynamic and interdependent. For example, allowing natural capital to increase increases the possibilities for positive (sustainable) co-evolutionary development (Pearce 1988). The present generation can trade off the welfare of future generations for their own immediate benefit by consuming natural capital. In this circumstance development occurs but it may be unsustainable in terms of creating negative feedback between co-evolving systems.

2.6 Conclusion

The primary purpose of this Chapter has been to provide a synopsis of the prevailing schools of thought regarding sustainable development. It is believed that factors such as perceived ambiguity and limits of conventional paradigms are unnecessary constraints to making the concept of sustainable development responsive to real-world resource management and regulatory issues. It has been demonstrated that sustainable development need not be an ambiguous term of little use except as a basis of programmatic statements on how the world should be. Evolving theoretical frameworks promise to further reduce epistemological limitations to the incorporation of sustainable development in policy initiatives.

In the longer term, sustainable development can only be advanced as an operational concept through applied research. In this respect, analytical frameworks that better reflect the diversity and heterogeneity of development objectives and priorities are needed. It was argued in the latter sections of this Chapter that sustainable development can be characterised for the purposes of applied research by:

(i) a set of ecological and socioeconomic interlinkages that constrain the development of social systems; and (ii) a series of development goals that relate to wellbeing of present and future generations. These components of sustainable development form a conceptualisation which defines the general nature of the research problem, identifying its parts and their relationships. Without these or alternate foundations, environmental and regulatory policies which purport to promote sustainable development will continue to be programmatic. Current and unsatisfactory interrelationships between environment, economy, and society will remain fundamentally unchanged subject to partial and opportunistic intervention and policy for want of more substantive conceptual underpinnings.

The next Chapter focuses on the identification of appropriate analytical frameworks for applying the foregoing principles to applied resource assessment and environmental planning. To be of practical use, a framework must be able to effectively represent the ecological, intragenerational and intergenerational dimensions of sustainable development, and reveal any potential trade-off between them. Furthermore, the framework should be amenable to resource assessment and environmental decision making in varying development contexts. It should also be able to be used at varying spatial scales and under differing ecological, social and economic conditions.

Chapter Three

Sustainable Development and Resource Evaluation: A Review of Potential Approaches

3.1 Introduction

The incorporation of the concepts of sustainable development into resource assessment and environmental planning represents a significant methodological challenge. The review of the sustainable developmnt literature in Chapter Two highlighted the multifaceted and context dependent nature of sustainable development. Holistic approaches to sustainable development provide little insight into the way in which it is to be brought about, or whether or not it is a realistic policy objective. Methodological approaches to sustainable development (e.g., the co-evolutionary, political economy, and ecological economic perspectives), though providing useful theoretical perspectives have been little used in resource assessment and environmental planning related to sustainable development.

There is then, an apparent need for practical analytical frameworks that are capable of addressing the implications of sustainability for human wellbeing and that can be integrated into the planning process as a whole. Nijkamp and Soeteman (1988b, p. 99) similarly write in regard to sustainable development:

> "...there is definitely a need for more meso-oriented models, in terms of spatial scale, economic detail and ecological information, which are able to generate and display a set of feasible developments within certain boundaries set by economic possibilities and ecological desirabilities."

This Chapter addresses two aspects of this problem. First, the role of resource analysis, resource management, and resource evaluation in sustainable development research is briefly examined. This discussion will establish an appropriate ontological context for the development of an applied research framework. It will be argued that a resource evaluation/assessment framework used with heuristic intent is the approach most consistant with achieving the objectives of this research. Second, resource evaluation/assessment frameworks will be reviewed with the purpose of appraising their potential for operationalising the conceptualisation of sustainable development as articulated in Chapter Two, section 2.5. Particular emphasis will be placed upon frameworks intended for use in resolving real-world management and regulatory issues, as opposed to formal, theoretical frameworks[1].

As discussed in Chapter One, the review of methods has relevancy to two levels of resource analysis and evaluation. First, it recognises that the reviewed methodologies are applicable to a wide range of resource assessment and environmental decision problems that may only make cursory reference to sustainable development. A critique of method can therefore make a contribution to the literature in this wider context. Second, it outlines the strengths and weaknesses of these methods and processes for resource assessment and environmental planning in the narrower context of sustainable development. This duality recognises that while the concept of sustainable development is a unique construct, its component parts can found elsewhere in resource assessment and environmental planning literature. Figure 3.1 outlines the structure of the Chapter.

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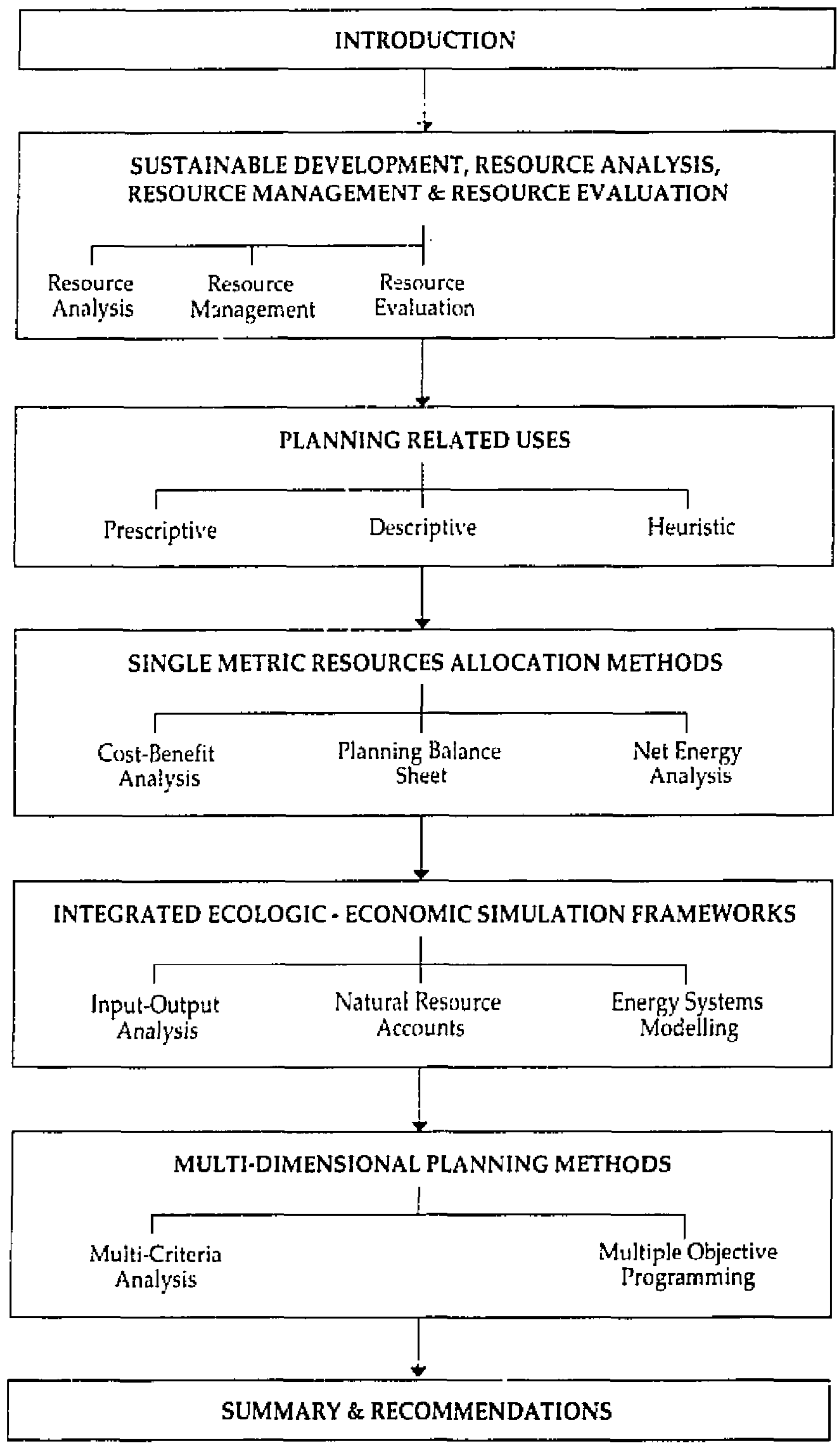
[1] Notable examples of the theoretical analysis of sustainable development include Barbier (1987, 1990), Common and Perrings (1992) and van den Bergh and Nijkamp (1991b). While of use in the development of empirical models, such treatments tend to rendered non-operational by their complexity and abstract nature.

Figure 3.1 The Structure of Chapter Three



3.2 Sustainable Development, Resource Analysis, Resource Management, and Resource Evaluation

The interrelated (sub)disciplines of resource analysis, environmental management, and resource evaluation are central to the applied application of sustainable development concepts. Resource analysis is the broadest of the three areas and seeks to understand the characteristics of natural resources and related processes (Mitchell 1989). In this manner, resource analysis can be considered to provide the analytical foundations for environmental management and resource evaluation. Environmental management represents the actual process of making decisions about the allocation of environmental stocks and functions to end uses such that the well being of society is increased (McAllister 1982). Resource evaluation (or assessment) can be viewed as a bridging discipline that acts to synthesise the partial analyses that characterise resource analysis in an integrated and comprehensive manner so as to facilitate environmental management.

3.2.1 Resource Analysis

Applied sustainable development research can be characterised as part of the wider process of resource analysis. Mitchell (1989, p.3) states that resource analysis "...seeks to understand the fundamental characteristics of natural resources and the processes through which they are, could be, and should be allocated and utilized." As discussed in Chapter One, sustainable development implies a need to expand the boundaries of traditional resource analysis so that there is a better understanding of the complex interrelationships within and between ecological and socioeconomic systems while also having greater regard for the temporal dimension of these relationships.

3.2.2 Resource Management

> "...a responsible natural resources policy on the part of the present generation of society consists of a set of rules, inducements, and actions relating to natural resource use that are sufficient to move the economy to an efficient, indefinitely sustainable, non-declining pattern of aggregate consumption, with no irreversible deterioration of the physical environment, and without the imposition of significantly greater risks on future generations." (Howe 1979, p.331).

Whereas resource analysis focuses upon understanding underlying resource interrelationships and processes, resource management is concerned with the decision making process intended to bring about responsible resource use. In the broadest sense resource management is about power relationships and politics. More narrowly, resource management:

> "...may be defined as a process of decision making whereby resources are allocated over space and time according to the needs, aspirations and desires of man within the framework of his technological inventiveness, his political and social institutions, and his legal and administrative arrangements. Resource management should be visualized as a conscious process of decision involving judgement, preference and commitment, whereby certain desired resource outputs are sought from certain perceived resource combinations through the choice among various managerial, technical and administrative alternatives." O'Riordan (1971, p.19).

Decisions regarding the use and non-use of the environment made as a consequence of resource management practice have major implications for the future wellbeing of society. In a geographical context, the spatial expression of social, productive and environmental relationships is influenced by previous decisions made by, or on behalf of society. The problem faced by the decision maker is whether or not satisfactory theories and methods can be developed that take into account the diversity of the components of individual and collective welfare, so they can be used in an operational policy framework (Nijkamp 1977a). The role of resource analysis in the context of achieving sustainable development is to develop required theory and method and to provide the decision maker with information that is of use in resolving real world management and regulatory issues.

3.2.3 Resource Evaluation

Resource evaluation acts as bridging discipline between the analytical qualities of resource analysis and the planning oriented nature of environmental management. Most often resource evaluation is concerned with assessing the social value of changes in the quantity and quality of environmental conditions, so as to provide a tool for analysing trade-off's between development alternatives with different environmental, social and economic impacts (Nijkamp 1980). Viewed in slightly different way, the evaluation exercise can be used to assess the extent to that resources have the capability to satisfy human development goals (Cocklin 1989b).

Cocklin (1989b) suggests that the "assessment" approach to resource evaluation can be used to answer four types of question. Although originally proposed in the general framework of resource assessment, these questions are equally applicable to the analysis of sustainable development and are presented in this latter context:

(i) Given a general set of operational definitions, assumptions, variables and relationships concerning sustainable development, what allocation of resources best satisfies the conditions for sustainable development.

(ii) Given that the analysis is dependent on the definitions, assumptions, variables and relationships specified, what are the effects upon the assessment of sustainability of changes in these parameters?

(iii) Since many alternative assessments of the relative importance of the different components of sustainable development goals may exist (for example, the wellbeing of future generations versus that of current generations; or the importance of a constant natural capital stock compared to short term resource flows), to what extent is the outcome influenced by the importance assigned to each of the elements of sustainable development?

(iv) Are the some of the components of sustainable development (for example, a constant resource stock and a non-declining level of welfare) in conflict and to what extent?

In the context of the present research, these and related questions are considered fundamental to the applied analysis of sustainable development. Unlike the rhetoric that dominates holistic treatments of sustainable development, and the inconsequential results of theoretical models, research directed at answering these questions begins to have relevancy for real world management and regulatory issues. Within this "evaluative" approach to sustainable development a basic linkage is made between the analysis of the characteristics of natural resources and the processes through which they are utilised, and the actual exploitation of natural resources to meet human needs and aspirations. This perspective has been largely absent from substantive sustainable development research.

3.3 Prescriptive, Predictive and Heuristic Resource Assessment

The resource evaluation process can be used to direct subsequent resource management practice and policy in three different ways. Normative or prescriptive analysis is undertaken with the intent of directing subsequent resource management practice. Simulation analysis is used for the primary purpose of predicting the resource implications of alternative resource management practices. Heuristic analysis is more loosely structured than the former approaches and is closer to a decision support system in its usage. Each of these approaches and their linkage with resource management and planning practice is discussed in more detail below.

3.3.1 Prescription

Carried out with normative or prescriptive intent, the aim of evaluation is to identify a planning solution that is best in terms of the criteria specified in the analysis, and the analytical solution represents a goal to which it is expected that resource policy should be directed. The success or failure of a particular policy is judged by how close it comes to achieving the indicated goal. This approach is consistent with "top down" or "comprehensive" planning philosophies in which centralised planning agencies engage in the formation of detailed development plans.

Comprehensive planning attempts to establish a position of bureaucratic neutrality (Poulton 1991). From this "value free" position particular goals, objectives, or policy priorities are formed on the basis of an assumed capacity to accurately assess key situations and processes affecting development. Walter (1992) suggests that comprehensive planning also assumes the ability to develop a precise set of planning instruments to control development, and the ability to effectively implement these instruments so that the end result is achieved. Most criticisms of the comprehensive approach have concentrated on its failure to achieve its goals and on the inappropriateness of these goals and policies to the actual process of bringing about change in the real world (Poulton 1992; Walter 1992).

3.3.2 Prediction

Resource assessment can also be used for simulation and predictive purposes. Analysis is structured so as to create a framework that emulates the characteristics and processes of the resource systems under consideration. Instead of defining what should be, the framework is used to establish what might be given a specified set of conditions and assumptions. Thus the analysis is used in a predictive rather than prescriptive sense.

Comprehensive approaches to resource management tend to assumes that the decision maker is confronted with a clearly defined problem. More often, however, there is no single identifiable problem and the decision maker is faced with a large number of causes and effects. In these instances, the task of the decision maker is to determine the nature of the problem to be dealt with. For the decision maker no one correct or right solution exists, but development outcomes can be assessed with respect to what should be avoided (for example, a declining stock of natural capital or a declining level of welfare). Developing analytical evaluation frameworks that simulate the functioning of the real world can help identify which possible courses of action are feasible in terms of avoiding undesirable outcomes.

Incrementalism (Lindbolm 1959) and mixed-scanning (Etzioni 1968) are two models of resource policy formulation that emphasise continuous change and policy adjustments in order to avoid poor planning outcomes. These approaches highlight the need to consider a limited range of resource allocation alternatives, that differ only slightly from existing policies (Mitchell 1989). This position arises from a belief that current resource analysis provides an adequate basis of knowledge from which to make decisions regarding future resource allocations. When policy is found wanting, existing analytical frameworks are adjusted so as to account for the imperfections that gave rise to substandard policy.

Incrementalism is a pervasive component of current resource management and resource analysis (Mitchell 1989; Poulton 1991). To varying degrees many of the holistic and methodological approaches to sustainable development described in Chapter Two can be characterised as incremental changes to existing disciplinary frameworks and policy practice. Both incremental resource management and predictive resource analysis assume an existing adequate conceptualisation of the real world from which to derive operational methods and policies. Increasingly, environmental crises and development failures bring into question the capacity to model real world situations. As suggested in Chapter Two, the many dimensions of the interrelationships between co-evolving systems are too complex to be abstractly modelled. Needed are analytical frameworks and management practices that recognise, rather than assume away, the inherent uncertainty associated with the functioning of the real world. Incremental policy adjustments may be a consequence of existing adversarial planning practice, but as an underlying policy approach to sustainable development it may prove inadequate.

3.3.3 Decision Support

Heuristic resource assessment is used for the primary purpose of enhancing the understanding of how systems are structured and how they might behave. The formulation of the assessment framework becomes an important part of the decision process, since it allows different ecological, economic and cultural perspectives to be cast in structured terms. Once constructed the framework can be used to explore conditions of uncertainty and other what if type questions. This approach differs from simulation in its exploratory nature and lesser reliance on the framework as a representation of reality (Cocklin 1989b).

Comprehensive and incremental environmental planning can benefit from heuristic analysis. However, both of these approaches imply a top down centralised approach to sustainable development planning, based in part on objective resource analysis. The significant difference between prescriptive and predictive resource evaluation and heuristic analysis is the way in which the relationship between information and the planning and management process is conceptualised. Explicitly recognised by heuristic analysis is the need to develop information and learning structures that are responsive to real-world management and policy issues. It is not comprehensive in that it does not attempt to define and cope with all aspects of the sustainable development problem, only those that have important implications in the decision making context. Similarly, its predictive and simulation capabilities are recognised to be constrained by the uncertainty created by real-world system dynamics.

Nijkamp and Soeteman (1988b, p. 99), while not explicitly calling for a heuristic approach to resource management, write:

> "...seen from a policy angle in a long-term planning context there is in general less need for a precise prediction of parameter values and of subsequent values of variables, but much more for the... identification of key factors, suprised and feasible boundaries of a compound dynamic economic environmental system. This also implies that in various cases it is more important to know the direction of variables (i.e. the sign of movement) than their quantitative values - which are in the long run in any case questionable."

In keeping with a general trend away from centralised planning processes and toward regional and community based consensus decision making, heuristic evaluation is amenable to the analytical requirements and information needs of environmental decision making carried out at varying spatial levels. Both methodological pluralism and analytical flexibility are inherent in heuristic approaches. Analysis can be reformulated as the nature and weight of system components change within the assessment process. Changing temporal, spatial and cultural characteristics may quickly alter the relative weightings of the components of sustainable development. Greater awareness and application of heuristic resource analysis as a decision support tool may aid in meeting the policy challenge of sustainable development.

It is not the intent of the remainder of this Chapter to provide an exhaustive review of all possible resource evaluation frameworks. Instead, it is considered more productive to use a representative set of methodologies in order to illustrate some of the problems and issues surrounding the application of sustainable development to applied resource evaluation. Frameworks that have been put forward elsewhere as possible vehicles for the operational analysis of sustainable development, or those that appear to have some potential to be used as such are discussed.

Methods with the potential to aid sustainable development related environmental planning and resource assessment are assessed in terms of their ability to fulfil a heuristic role in the resource evaluation process. In this context an "ideal" method would be able to incorporate both objective (scientific) and subjective (judgmental) information. Similarly, it should be able to incorporate quantitative (cardinal) and qualitative (ordinal data). Finally, and perhaps most importantly, it should be able to handle incommensurate data (information represented in different units e.g., apples and oranges). McAllister (1982) also suggests that evaluation methods need to systematic, simple, quick, inexpensive, legally acceptable, and comprehensive in order to become widely accepted and applied.

Failure to fulfil all, or any, of the above criteria does not necessarily invalidate the use of a particular evaluation method Some criteria may not be relevant to a particular research context. Moreover, even a method meeting all the criteria for heuristic analysis may be unsuitable because it is not simple, quick or cheap enough. Also, in many planning contexts only a limited range of evaluation methods may be legally or institutionally acceptable (for example cost-benefit analysis, net energy analysis). For these reasons it is worthwhile examining a broad range of evaluation techniques. Table 3.5 in the Conclusion to this Chapter summarises the findings of the review of methods in regard to the aforementioned criteria.

The review of these frameworks is structured into three parts. First, environmental cost-benefit analysis, the planning balance sheet, and net energy analysis are examined as examples of single metric resource allocation models commonly used for prescriptive purposes. Second, efforts to link ecological and socioeconomic systems via integrated models for the purposes of prediction and description are reviewed. The examples discussed include environmental input-output analysis, natural resource accounting and energy systems modelling. Third, frameworks such as multi-criteria analysis and multiple objective programming and their relevance to analysing the allocative implications of sustainable development are discussed. It is these latter frameworks that appear to have the greatest potential to apply the concept of sustainable development to resource assessment and environmental policy analysis.

3.4 Prescriptive, Single Metric Allocation Models

Single metric resource allocation models are analytical frameworks concerned with the best apportionment of resources subject to given decision criteria as measured by a single metric. Commonly these methods require that alternative resource allocations and their effects on the determinants of sustainable development be stipulated prior to analysis. The method then provides the basis for the evaluation of the alternative allocations. All variables and impacts tend to be specified in terms of a single metric where this is possible. The purpose of allocation models is usually prescriptive.

3.4.1 Environmental Cost-benefit Analysis

Cost-benefit analysis (CBA) is perhaps the most frequently used allocative method in resource planning and has the most fully developed theoretical foundation (McAllister 1982). CBA was developed during the 1930s and 1940s for the assessment of water resource project designs. Since then CBA has found extensive applications in many fields of planning. Consequently there exists an extensive literature documenting the methodology of CBA and its extension to environmental problems[2].

CBA is intended to help make environmental decision making and policy analysis processes more informed and hence rational (Hufschmidt *et al.* 1983; Nijkamp 1977a; Pearce *et al.* 1989). It is usually represented as a comprehensive evaluation methodology and attempts to solve the evaluation dilemma in environmental decision making by calculating a grand index of the social welfare implications of proposed actions. It can be characterised as:

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[2] See, among others, Hufschmidt *et al.* (1983), McAllister (1982), Mishan (1976), and Nijkamp (1977a).

> "...a systematic method of identifying and measuring the economic benefits and costs of a project or program. The benefits of a project are the values of incremental outputs of goods and services, including environmental services, made possible by the project, and the costs are the values of the incremental real resources used by the project. Both project costs and benefits are discounted over time to make them commensurate." (Hufschmidt *et al.* 1983, pp. 2-3).

The wide use of CBA in environmental planning and decision making is in part due to its tautological nature (Junger 1979). Before deciding to do something costs of the act should be compared to its benefits and, if the costs exceed the benefits, the act should not be undertaken. McAllister (1982) suggests additional support arises from a number of features of CBA including: the fact that it is based on an established theory of value; that it attempts to reflect the values of all people based on behaviour in the market place; its use of impact categories and measurement units that are understandable to the majority of people, and; the existence of an extensive body of literature covering a wide variety of evaluation problems.

Traditionally, CBA has only considered direct project costs and benefits, but as project and policy objectives have changed to include social issues such as equitable income distribution and the maintenance of traditional cultural values, CBA has grown to incorporate these new goals. Additional stimulus for the development of CBA has occurred in response to the recent emphasis placed on environmental quality and the long term productivity of natural resource systems in project evaluation procedures. Barbier (1987, 1989a, 1989b, 1991a, 1991b), Barbier *et al.* (1990) and Turner (1991) discuss the development of an expanded CBA approach that incorporates environmental impacts including external and environmental improvement benefits and the costs of and/or environmental damages and of environmental control measures. This requires the identification and measurement of environmental effects and their translation into monetary terms for inclusion in project analysis. As a result of these efforts, organisations such as the World Bank and the Environment Programme of the United Nations are beginning to recognise the importance of incorporating extended environmental criteria, including sustainability, in project evaluation (Goodland 1990; Htun 1989).

Incorporating a sustainability criterion into CBA involves an economic interpretation of sustainable development focusing on economic efficiency and an equitable distribution of income (Barbier *et al.* 1990). This contrasts to the widely held practice of adjusting discount rates to account for long term environmental degradation. Barbier *et al.* (1990) argue that CBA must incorporate three related conditions to ensure sustainability. First, unlike traditional CBA, the Kaldor-Hicks compensation principle which requires that compensation to those incurring a cost need only be theoretically possible must be rejected and actual compensation of future generations by the present generations must occur. Second, this compensation should take place by means of the transfer of capital assets. Finally, transferred capital assets must not be less, in terms of value, than the current capital stock. Normally, they suggest, these conditions can be met by placing a constraint on the depletion and degradation of the stock of natural capital.

There are however a number of inherent problems in extending CBA to the assessment of proposed actions in terms of sustainable development. As an empirical extension of neoclassical economics, discussed in Chapter Two, CBA is subject to many of the same limitations. The incorporation of an environmentally compensating" principle as suggested by Barbier *et al.* (1990) may avoid some of the problems associated with the traditional use of discount rates, but it remains subject to the need to value environmental assets to ensure their constancy. The proper economic valuation of environmental impacts remains an unresolved problem.

For example, valuation is often difficult because environmental benefits tend to assume the characteristics of a public good, while costs are often externalities. As a consequence, the attributes of ecological stocks and flows tend to be unpriced. If an input is unpriced there is no incentive to economise on its use as is the case with priced production inputs. In the same manner environmental costs, if unpriced, become an uncompensated side effect of economic activity. In other words they become externalities. Externalities occur in extra-market situations when the by-products of an activity result in costs (or benefits) to other people that are uncompensated by an exchange of money or goods. When decisions by producers (or consumers) are made on the basis of their own private costs and benefits and the external consequences of their decisions are unconsidered the resulting allocative patterns are unlikely to be optimal or socially desirable (OECD 1975; Rees 1985).

Market failure, which gives rise to externalities, is an almost inevitable consequence of the way in which the economic system deals with the production, consumption and disposal of goods and services. For the reasons stated above, no value is placed by the market on the capacity of the environment to assimilate and renovate waste products (Rees 1985). If market failure is viewed as the cause of resource problems such as pollution, the solution is theoretically simple, externalities must be internalised. In this manner all resources including the environments ability to assimilate wastes would be allocated to maximise their net value in use (Baumol and Oates 1988; OECD 1975, 1976; Rees 1985).

In response to the existence of unpriced environmental impacts a number of methods have been developed to internalise them[3]. Those commonly adopted to measure environmental quality on the benefit side include varieties of market value, surrogate markets and survey based valuation techniques. If resource costs are the focus of concern the basis of analysis becomes the opportunity cost of resources allocated to the mitigation of environmental degradation. Widely used methods of assigning value to such costs are preventative expenditures, replacement cost, shadow project, and cost effectiveness analysis. Although these valuation procedures have been refined considerably in recent years and can probably be advanced further, there remains little consensus regarding methods for the monetary valuation of the more intangible environmental aspects of sustainable development such as gene pool diversity and intrinsic wildlife values.

There are problems with the use of market price, or other economic measures of value, as the sole measure of the value of communal resources. This is particularly true for irreversible decisions where problems of planning adequately for future generations enter. To a lesser extent it is also the case for reversible decisions. Brown (1984) suggests the appropriateness of such measures for communal resource allocation is diminished because: (i) they result from individual valuations often made with the improper ownership of resources in mind, (ii) rely on payment for expression, (iii) reflect trivial market transactions strongly influenced by social settings, and (iv) the actions of actors in the market economy suggest that they sometimes do not act so as to increase their own individual welfare.

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[3] Methods intended to internalise environmental costs and benefits are extensively discussed in Nash and Bowers (1988), Hufschmidt *et al.* (1983), Pearce and Turner (1990) and Pearce *et al.* (1988).

Aside from the valuation problem, the basic structure of the CBA model is not well suited to a number of analytical roles that are a necessary part of the empirical study of sustainable development. It is extremely difficult to assess situations involving complex ecosystem behaviour, cumulative impacts and diffuse spatial effects (Pearce 1976). Under such circumstances more flexible methods are necessary. CBA provides little basis for determining compromise solutions, as the method is designed to evaluate a set of pre-determined alternatives. Any number of non-stated alternatives that provide far better compromise solutions in relation to the full range of sustainable development objectives may exist (Cocklin 1989c). Given these circumstances, CBA is best thought of as a complementary technique, used subject to predetermined environmental constraints derived from other assessment techniques.

3.4.2 Planning Balance Sheet

The planning balance sheet (PBS) proposed by Lichfield (1971) is essentially an extended CBA in which social aspects and distributional effects on individuals and groups are taken into consideration (Lichfield 1971; Lichfield *et al.* 1975; McAllister 1982; Nijkamp 1977a; Poulton 1983). PBS also accommodates intangible and other unmeasured impacts by designating symbols for them in evaluation tables alongside monetised impacts. Poulton (1983) characterises PBS as part accounting balance sheet, part CBA, and part listing of impacts and hypothesised values.

The form of PBS has changed over time, but retains certain characteristics (McAllister 1982; Poulton 1983). As far as possible benefits and costs accruing to individuals are measured in money terms. Individuals affected by an action are grouped into sectors with the producer of the action. The paired producer and consumer groups are considered to be parties to a notional transaction. For each notional transaction there is a descriptive label stating the source of the cost or benefit and an instrumental objective describing the preferences of the individuals in the sector with regard to the action. A summary column records the ordering of alternatives in terms of the net benefits delivered to each sector. No single index is calculated, however, and the decision maker is left to make the final synthesis.

There are disadvantages to the PBS method (McAllister 1982; Poulton 1983). Although intangible impacts are included as part of a formalised procedure, they are somewhat disadvantaged in comparison to the "visible" quantified impacts. Important equity effects may also be ignored since impacts are represented as transactions between unified producer and consumer groups of which disadvantaged and minority groups are rarely part. Further, the central role of transactions means that financial transactions tend to dominate PBS to the detriment of certain types of environmental, social and political impacts.

The emphasis on an accounting balance format for PBS gives rise to producer and consumer divisions and notional transactions that are artificial. Additionally, the need for precise measurement (of monetary costs and benefits) in a methodology that does not make a net benefit summation and includes intangibles and incommensurate is also somewhat spurious. Significantly, little guidance is available to the decision maker as how to reconcile net costs and benefits measured at the interval and ratio level with those measured at the nominal or ordinal level.

In terms of sustainable development and the adoption of attendant analytical procedures, PBS like CBA is limited in that it requires the prior specification of plan alternatives prior to the analysis. The method enables plans to be compared on the basis of more than one assessment criteria but actions can not be compared relative to overall planning goals and multiple objectives. Hence the trade-off's between planning goals remain unknown as does the contribution of each plan to overall planning goals (Cocklin 1985).

3.4.3 Net Energy Analysis

The use of energetic criteria for the determination of resource allocation has its origins in the early 1970s with the emergence of energy analysis as a tool for the quantification of the energy flows inherent in the production of goods and services (Gilliland 1978; Patterson 1987a, 1987b). The earliest stimulus for energy analysis is considered to have been provided by Odum (1971) in his book *Environment, Power And Society*. At the same time other influential works appeared. For example, Georgescu-Roegan's (1971) book *The Entropy Laws And The Economic Process*, Gilliland's (1975, 1978) work on energy analysis in the sphere of public policy and Wright's (1974) and Bullard and Herendeens (1975a) works on energy input-output studies. In 1976, Odum and Odum published their second book, *Energy Basis For Man And Nature*, expanding on the concepts first developed in 1971[4]. After this initial period the discipline continued to grow with the introduction of several new methodologies and concepts, mainly in response to growing scientific and public awareness of the role of energy in economic systems and environmental systems. Of these methodologies net energy analysis has been the most widely adopted in environmental planning and policy formulation.

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4 A second edition of this book was published in 1981 and it is this edition which is subsequently referenced.

Net energy analysis is based on the concept of energy being an ultimately limiting resource. Gilliland (1975, p. 189) in support of the suggestion that energy limits the ability to obtain any input, states:

> "(i) that energy is the only commodity for which a substitute cannot be found, (ii) that potential energy is required to run every type of system, and (iii) that energy cannot be recycled without violating the second law of thermodynamics."

Energy analysts consider that energy resources form long term constraints to economic activity. Net energy analysis is not a unified methodology and the extent to which energetic criteria are used varies, however. The contentious issue surrounding energy analysis focuses upon its role in, or ability to replace economic analysis as a tool for resource allocation (Gilliland 1975, 1978). At one extreme, proponents view energy analysis as a replacement for conventional economics arguing that energy is a more basic unit of account than money (Georgescu-Roegan 1971, 1977; Odum 1971; Odum and Odum 1981; Rifkin 1980). Some believe that this approach is too extreme, suggesting that it is inappropriate to attempt to replace the monetary theory of value with an energy theory of value (Huettner 1976, 1982; Webb and Pearce 1975).

A more moderate view of energy analysis examines the energy costs of technologies and the energy consequences of policy by evaluating energy consumption in terms of the embodied energy content of fuels, goods and services (Bullard and Herendeen 1975a, 1975b; Carter 1974; Costanza 1980). The boundary of the analysis that defines energy, goods, and services is the same boundary as that which defines gross domestic product. Such a boundary assumes that energy is used both directly and is embodied in materials. This approach injects energetic variables into existing economic theory.

Net energy analysis has been subject to criticism on the basis that it is faced with many of the same problems that confront economic models, including externalities, imperfect competition in resource markets, and government involvement in the market place (Huettner 1976). Further, it is suggested that energy analysis is not as comprehensive as claimed, but is extremely narrow both in assumptions and objectives, and that the uses of net energy analysis have already been adequately met by economic and ecological analysis (Huettner 1976; McAllister 1982; Webb and Pearce 1975). However, the importance of the approach especially in relation to energy problems is still recognised by many, including the United States Congress. A 1974 congressional mandate calls for the use of energy analysis as one of the governing principles for researching and demonstrating new energy resources (Gilliland 1975; Huettner 1976).

Net energy analysis has been proven to have a potential role in the assessment of resource allocation problems that involve energy resources and their subsequent use. The exclusive use of an energy value system has no more justification, however, than does a pecuniary value system. Net energy analysis also relies on the prior specification of alternative plans and actions and thus is of little use in identifying unforseen resource conflicts. The explicit recognition of linkages between economic, social and environmental systems and that such systems are open and subject to physical limits represents a significant advancement over more traditional methods such as CBA, however.

As a class, single metric allocation models are of limited use in the empirical modelling of sustainable development. The varied nature of structures and processes involved in the interaction of systems cannot be characterised by a single variable or unidimensional measure. Preference should thus be given to approaches better able to take into account the diverse nature of social, environmental and social objectives, the incommensurate nature of ecological and socioeconomic interactions, and the holistic and action oriented aspects of the planning process.

3.5 Integrated Ecological-Economic Simulation Frameworks

In contrast to single metric allocation models which require the prior specification of alternative actions, integrated ecological-economic simulation frameworks are characterised by their inherent identification and simulation of the linkages between ecological and socioeconomic systems. They are inherently descriptive, and usually have some ability to manipulate statistical data. Integrated frameworks therefore offer enhanced opportunities for dealing with the requirements and demands posed by sustainable development.

3.5.1 Environmental Input-Output Analysis

Traditional input-output (IO) analysis provides a concise representation of transactions between the various producing sectors of an economy. In principle, these flows can be recorded in physical or monetary terms. The IO table is an accounting framework which models these flows. Since the development of IO during the 1930s by Leontief, most western nations have created a national level IO framework and some have developed regional IO tables.

The IO table (Figure 3.2) shows how the output of a single industry is distributed to other industries and final demand sectors in the economy[5]. By employing simplifying

[5] Detailed mathematical descriptions of IO analysis are contained in a number of texts. Most notable among the more recent of these is Miller and Blair (1985).

assumptions about the structure of the economy this accounting framework gains powerful analytical capabilities. Assuming constant technical coefficients, constant production functions, and a single output from each sector, a matrix can be derived in which each element represents the direct and indirect, or longer term effects, on all other sectors of the economy of a unit change in the value of final demand or output of a sector. This property of the Leontief inverse matrix makes it possible to simulate economy wide changes that may result from changes in final demand and output.

Drawing upon the usefulness of IO models in dealing with economic interdependencies, a number of extensions have been made to the economic framework in order to account for the effects of economic activity on the environment and use of

Figure 3.2 The Structure of a Simplified Input-Output Table

Outputs → / ↓ Inputs	Industry	Final demand	Total gross output
Industry 1			
Industry 2			
Industry 3			
Industry 4			
Value Added			
Total			

resources[6]. Augmented IO models represent the simplest extension of IO analysis to environmental matters. They append environmental intensity rows to the technical coefficients of an IO table and usually deal with pollution associated with inter-industry activity. Information is thus made available on the direct and indirect pollution impacts of changes in economic activity. Pollution elimination strategies can also be modelled in this manner.

Economic-ecologic IO models are more complex extensions of IO analysis in which environmental flows are specifically accounted for by creating an ecosystem submatrix that can be linked to interindustry economic flows matrix. Such models are called fully integrated models (Miller and Blair 1985). Two generic types of fully integrated models exist, industry by industry models and commodity by industry models. Daly (1968) and Isard (1972) develop similar integrated models for incorporating environmental activities into an IO framework.

Both approaches employ flow matrices within and between both economic activities and environmental processes. Daly's version employs an aggregated industry by industry characterisation of the economic submatrix and a classification of ecosystem processes. Isard refines the framework (Figure 3.3) by recognising that the secondary production of ecologic outputs is incompatible with the assumption of one product industries inherent in traditional Leontief models. Instead, Isard develops an commodity by industry accounting scheme that permits an accounting of multiple commodities, both economic and ecologic, produced by a single industry.

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[6] Discussion and specification of augmented and economic-ecological IO models can be found in Lonergan and Cocklin (1985), Miller and Blair (1985) and Shopley and Fuggle (1984).

Figure 3.3 The Isard Input-Output Framework

		Agriculture	Textile		Oil refining		Sport fishing		Plankton Production	Herring production	Cod production
Economic commodities	Wheat										
	Cloth										
				Economic system: Intersector Coefficients				Ecological processes: Their input and output coefficients re: economic commodities			
Ecological commodities	Crude oil				-						
	Water use				+						
	Alkalinity				+						
				Economic sectors: Their input and output coefficients re: ecological commodities				Ecological system: Interprocess coefficients			
	Detritus										
	Plankton								+	-	
	Herring									+	-
	Cod										+

Source: Adapted from Lonergan and Cocklin (1985)

Victor (1972) reduces the extent of Isard's fully integrated economic-ecologic model to account only for the flow of ecological commodities from the environment into the economy and the waste products from the economy to the environment. By limiting the scope of the analysis Victor reduces the data requirements of the model and thus makes its implementation more practical. Miller and Blair (1985) describe Victor's approach as a limited model.

The availability of data for the ecosystem submatrix appears to be greatest limitation of the ecologic-economic frameworks. Lonergan and Cocklin (1985 p. 45) comment with regard to Isard's model that it "...must be recognised as a static descriptive tool, albeit potentially an extremely useful one, because the theoretic understanding does not exist to permit its manipulation for simulation purposes". The assumption of fixed technical coefficients also has serious implications with the addition of the ecological system to the basic IO model.

Notwithstanding important limitations, information generated from an IO framework incorporating environmental and resource considerations can aid decision makers in several ways. Hufschmidt et al. (1983) suggest that it provides a systematic, monitoring, estimating, data collecting methodology and provides a framework within which to assemble the results. The framework can also be used to simulate different development scenarios. For example, environmental quality effects can be predicted in temporal and spatial terms. By changing final demand patterns and structural relationships, different options for economic development, residual discharges, and ambient environmental quality can be generated, assisting policy makers in what they consider to be the best development plan. If a given scenario does not meet the multiple objectives of policy makers, required changes in the system can be simulated and conditions repeated until conditions are acceptable.

IO models are of limited use, however, when the assessment of alternative development strategies is required. The best alternative can only be chosen if decisions makers attach values (subjective or objective) to alternative outcomes generated by the model. The strength of an IO model lies in its ability to define the nature of the interaction between the environment and the economy although social relationships cannot be represented effectively. IO models, therefore, have the potential to be one useful input to resource planning and decision making in the context of sustainable development, but as a comprehensive analytical tool their usefulness is somewhat restricted.

3.5.2 Natural Resource Accounting

The conceptually interesting but empirically unsuccessful attempts to endogenise ecological variables via IO tables have a contemporary parallel in the development of natural resource accounting. This area of research has received considerable recent attention[7] because of perceived shortcomings in aggregate measures of welfare as defined by the System of National Accounts (SNA), instigated internationally by the United Nations in 1968. Common macroeconomic indicators of welfare such as gross domestic product (GDP) fail to reflect the contribution made to human wellbeing by the quantity and quality of the environment and its inherent attributes. National accounts currently include income from the exploitation of natural resources but exclude the loss of future income from the deterioration of the natural resource stock and environmental quality. Natural resource accounting involves the creation of frameworks to include both the direct costs inflicted by environmental degradation and the depreciation of natural capital to allow for losses in future production. By considering these aspects of resource exploitation, adjusted national accounts would more accurately reflect the economic welfare of a nation.

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[7] See, for example, Ahmad (1989), Barbier (1987, 1989a, 1989b), Dasgupta and Mäler (1991), El Serafy (1991), Foy (1991), Friend and Rapport (1991), Hannon (1991), Hueting (1990, 1991b), MacNeil (1989), Pearce *et al.* (1989); Peskin (1991) and Repetto *et al.* (1989).

Two types of natural resource accounting model can be identified (Pearce *et al.* 1989). The first type is concerned with linking the use of natural resources to national income accounts. Monetary approaches of this type explicitly recognise the deficiency of current aggregate welfare indicators and attempt to rectify the problem. The second type of accounting model attempts to develop physical accounts for human use of natural and environmental resources. The physical approach to environmental accounting attempts to model at a more fundamental level the empirical links between ecological and socioeconomic systems.

The monetary approach to natural resource accounting attempts to rectify two shortcomings of the SNA (El Serafy and Lutz 1989; Pearce *et al.* 1989). These are: (i) the treatment of defensive expenditures, and (ii) the treatment of depletion and degradation of natural assets. In the first of these cases, expenditure on measures to mitigate environmental degradation, so called defensive expenditures, are often treated as positive contributions to GDP. For example, the increased purchase of fertilizer to compensate for the declining fertility in agricultural soils because of intensive agricultural practices, would be recorded as an addition to aggregate indicators of welfare. Defensive expenditures are thus analogous to capital replacement. But whereas the latter are part of the SNA, no allowance is made for the former (El Serafy 1991; El Serafy and Lutz 1989; Hueting 1991b; Peskin 1989).

In addition to correcting national income for defensive expenditures, measuring welfare requires consideration of environmental degradation and resource depletion. Environmental degradation has a clear impact on the welfare of individuals but is excluded from the traditional accounts. Resource depletion is an important factor in the determination of the potential welfare of a society. A number of natural resource accounting frameworks have been developed to specifically deal with the problem of the depletion of natural capital.

A study by Repetto *et al.* (1989) addressed the problem of the effect of natural resource depletion on national income estimates for Indonesia. Resource stock accounts were compiled for timber, petroleum and soil. Each account consisted of a measure of the initial resource stock, its price, and value. Over the period of the study changes in the resource stock were recorded together with changes in the unit cost. At the conclusion of the study the final stock and its concluding unit price were noted. The study concluded that although the Indonesian GDP grew by seven per cent per annum between 1971 and 1984 by SNA measures, the figure adjusted for resource depletion was closer to four per cent. Economic growth had thus occurred at the expense of the natural resource base. Similarly, Foy (1991) in a study adjusting Louisiana's (United States of America) gross state product (GSP) for the consumption of non-renewable petroleum resources suggests that a significant percentage of Louisiana income over the period 1963 to 1986 was actually due to the consumption of natural capital.

Exactly what monetary approaches to resource accounting seek to measure is an unresolved issue, however, and is a subject of much debate. Immediate welfare is perhaps best measured by a GDP figure adjusted for lost consumption due to defensive expenditures. If it is some longer term aggregate indicator of welfare that is required then an adjusted net domestic product (NDP) estimate is appropriate. NDP is equal to gross domestic expenditure less capital depletion. The valuation problem already discussed in regard to environmental CBA is also equally applicable to pecuniary accounting frameworks.

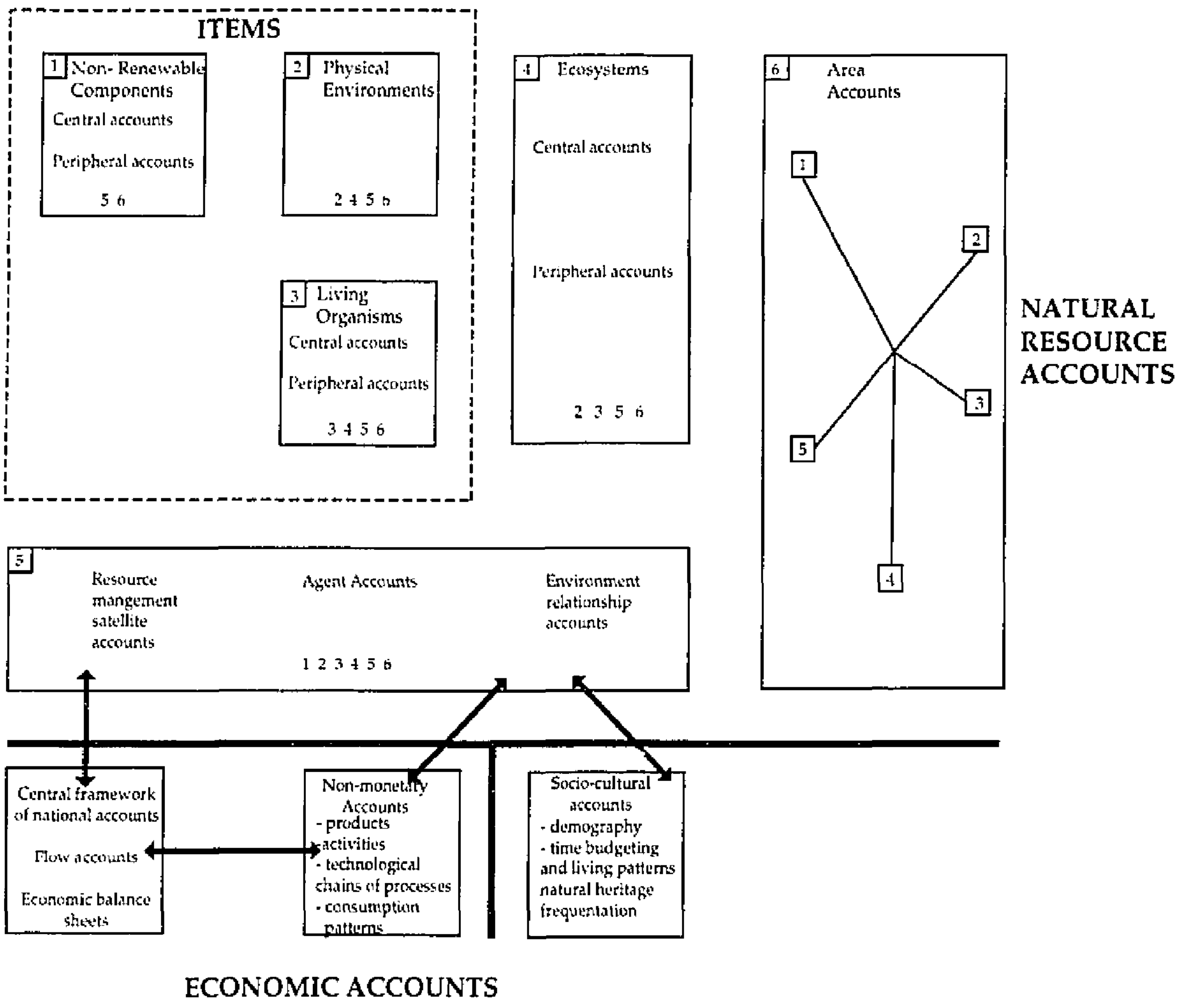
Although accounts are usually thought of in monetary terms, there is no reason why they should not be kept in physical units, as long as both natural resource stocks and flows are considered in a manner such that a balance sheet in any year can be derived from the balance sheet of the previous year plus the flow accounts of that year (Pearce *et al.* 1989). Gilbert (1990, p. 307) describes natural resource accounting in this context as "...a methodology for presenting environmental, resource and economic information." The goal of such frameworks is the provision of information. This philosophy contrasts to the economic derivation of ecologically adjusted national income measures, although some consistency with SNA accounts is usually evident. Physical accounting frameworks have been developed by the Norwegian, Canadian and French governments.

The Norwegian System of Resource Accounts (SRA) is among the earliest examples of physical resource accounts. Natural resources were divided into two categories: (i) material, consisting of mineral, biological, and inflowing resources; and (ii) environmental, consisting of status resources such as air, soil, and water. Where possible geographical information was included. Material resource accounts, with the exception of inflowing resources, proved easier to prepare than environmental accounts (Pearce *et al.* 1989). The data collected within these accounts has been used to prepare 'state of the environment' reports and for forecasts of the future use of natural resources and their implied environmental impacts in the form of 'resource budgets'. Overall, the success of the Norwegian accounts has been limited and the programme is no longer a priority (Aaheim *et al.* 1991; Pearce *et al.* 1989). With the exception of the energy sectors, and to a lesser extent land use, the accounts have not been applied successfully, because the SRA did not meet the needs of users. Also, a complete reliance on physical units prevented wider applications with more political relevance.

Two natural resource accounting programmes are under way in Canada. An independent project at the Institute for Research on Environment and Economy (IREE) is attempting to produce a set of wealth accounts consisting of biological, non-renewable, and cycling system account components. The primary goal of this research is to create a framework for the organisation of such data (Friend and Rapport 1989). It is also intended that linkages occur with the SNA. The Statistics Canada project is less ambitious than that of the IREE and is intended to supplement the SNA. The main goals are to produce satellite accounts for natural resources and to value these assets for inclusion in the SNA (Statistics Canada 1990).

The French natural resource accounts are somewhat similar to the Norwegian system conceptually, but are more ambitious and comprehensive and include some monetary valuations. As such, they are much closer to an integrated ecological/socioeconomic framework and attempt to bring about a better understanding of the multifaceted relationships between society and the environment (Theys 1989). The framework divides resources into categories similar to those used in the Norwegian system. For each category, non-renewable components, physical environments, living organisms, and ecosystems, there are three accounting components. Central accounts describe the state of the resource and variations in it during a given time period. Peripheral accounts show the relationships between resources and between human activities and a given resource. Agent accounts describe the flows between a resource and an economic activity in physical terms. Expenditures on the maintenance and development of the resource are also included in the agent accounts. Figure 3.4 illustrates the set of natural resource accounts for the French system as well as intended

Figure 3.4 Structure of the French Natural Resource Accounts System



Key: 1 = Stock at the beginning of the period
2 = Upward adjustment in known reserves
3 = Downward adjustment in known reserves
4 = Gross natural increase
5 = Natural depletion
6 = Increase due to resource development
7 = Depletion due to withdrawal
8 = Imports

Source: Adapted from Pearce *et al.* (1989)

linkages with economic and other accounts. The complex data requirements of the French system have meant that its implementation has been slow, however.

Resource accounting is an appealing notion with close linkages to state of the environment reporting, macro-information systems, and other sustainable development applications. There are methodological limitations, however. In regard to monetary accounts, valuing environmental goods, and then extending depreciation accounting to the stock of natural capital is major challenge. Also, standard depreciation accounting procedures allow for both physical depreciation and increases in present value. Thus a resource could deteriorate in quality yet still show net capital gain. To counter this some economists argue that depreciation accounting should only include the value of physical changes to the resource stock (Pearce *et al.* 1989). In the creation of physical accounts forests, timber, mineral reserves and fish stocks are readily counted as discrete units. Other resources such as watersheds and soils are not so easily measurable as stocks.

Norgaard (1989) argues that the search for a comprehensive method of combining environmental information with systems of national accounts has been sustained by a false belief in the existence of one best way to understand how economies interrelate with environmental systems. Instead, Norgaard calls for the development of multiple methodologies in which systems of national accounts form but one component. Cocklin (1989c) further suggests that resource accounting approaches do little to bring about sustainable development since they provide no basis for assessing trade-off's, nor are they useful for identifying management strategies, being positive rather than normative frameworks. Despite such limitations resource accounting represents an improvement over the current situation were natural resource stocks are valued at zero and changes in stocks of ecological capital are ignored (Ahmad 1989; Barbier 1987, 1989a, 1989b; Friend and Rapport 1991; MacNeill 1989; Pearce *et al.* 1989; Repetto *et al.* 1989).

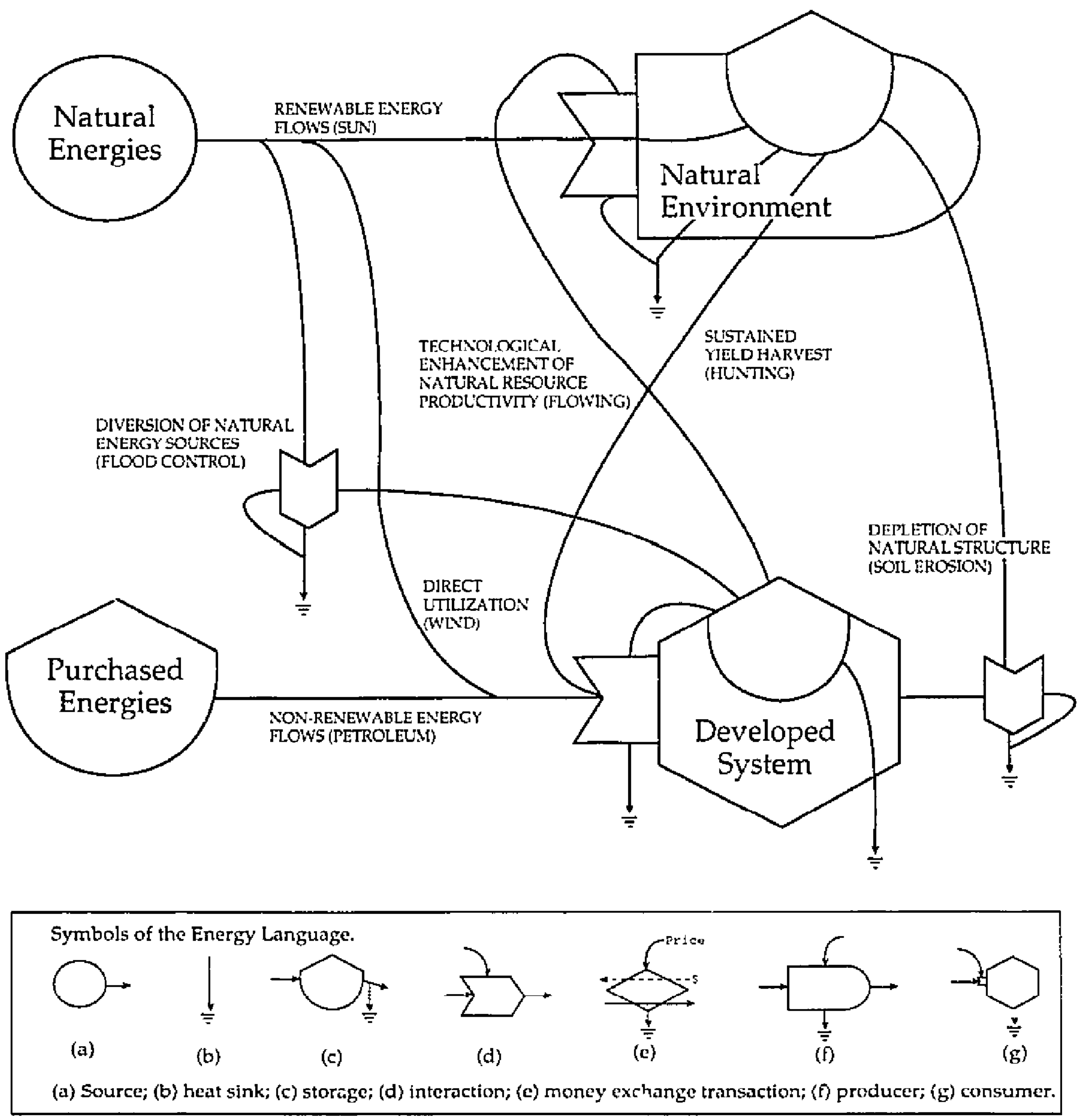
3.5.3 Energy Systems Modelling

Energy analysis, as discussed previously, consists of several different methodologies. Net energy analysis described in section 3.4.3 is an example of the use of energetic criteria to assess prior specified plan alternatives. These same criteria can also be used as the basis for integrated ecological and socioeconomic modelling. This latter practice can be termed energy systems modelling and it has been used extensively to analyse the interrelations and trade-off's among ecological, social and economic processes.

The first and second laws of thermodynamics dictate that the level of work in and by a system is controlled by the input of energy to that system. Energy can thus be used as the common denominator for analysis since it is required by all activities and both limits and governs the structures of systems (Costanza 1980). By studying energy flows through ecological and socioeconomic systems information on structure, function, and temporal change over time can be elicited. Helping those who use energy principles for the study of systems is the existence of a symbolic language called "energy language" or "energese" developed and refined over time by H.T. Odum[8]. Brown (1981) describes the language as a graphic means of depicting systems as Nth order differential equations in which each symbol represents a mathematical relationship of either energy flow, interaction, or storage relative to time. Figure 3.5 uses energy language to illustrate the energy flows and interrelations that have been influential while human socioeconomic

[8] Detailed descriptions of energy language are contained in Odum (1971) and Odum and Odum (1981).

Figure 3.5 Energy Systems View of Ecological and Socioeconomic Interrelations



Source: Adapted from Hopkinson and Day (1991) systems have developed. It also serves to demonstrate the integrated nature of such energy systems modelling.

A number of principles deriving from the first and second laws of thermodynamics have been used in energy systems analysis. There are two, however, that have received considerable attention in the energy systems literature: (i) the theory of dissipative structures, and (ii) the maximum power principle. Each represents a conflicting view of systems evolution and behaviour. The work of Ilya Prigogine (1955, 1980, 1982) on dissipative structures perhaps has the broadest implications of the three theories, raising epistemological questions as well as pragmatic questions relating to specific energy applications. Prigogines work focuses on the existence of self organising systems in thermodynamic non-equilibrium. In general, systems can be described as being: (i) isolated, where there is no exchange of matter or energy with the external world, (ii) closed, where energy is exchanged but not matter, and (iii) open, where both matter and energy are exchanged. In isolated systems there is no possibility of a reversible change of entropy between the system and outside world and hence entropy increases monotonically until thermodynamic equilibrium is reached. Closed and open systems exchange entropy flows with other systems and thus in conditions far from thermodynamic equilibrium, even in the framework of the second law of thermodynamics, new dynamic structures known as "dissipative structures" may arise (Lonergan 1985a; Prigogene 1982). Dissipative structures exhibit order amidst the flow to disorder because their rate of energy acquisition is equal to the rate of dissipation (Lonergan 1985a). In this manner the ordered structures of human systems can be viewed as dissipative structures, acquiring low entropy inputs from the eco-system and exchanging them for high entropy output.

The behaviour of dissipative structures cannot be described in a deterministic manner since it is a function of stochastic processes. Prigogene (1982) demonstrates that in determining the state of a system as a function of one or more variable, bifurcations, branchings, or catastrophes occur, causing the state to move along very different paths. The stochastic nature of system processes creates an uncertainty in systems evolution that causes future behaviour to be unpredictable. This conception of non-equilibrium systems as stochastic processes has important epistemological implications in addition to its methodological significance. Called into question are the basic tenets of scientific inquiry. The existence of stochastic processes implies an irreversible flow of time that challenges the assumption of invariant, and hence reversible, time held by classical mechanics, quantum mechanics and relativity. By demonstrating that bifurcations take place by chance Prigogene also challenges the determinism that underlies scientific methodology[9].

A contrasting theory of the survival self organising systems is the maximum power principle developed by Odum (1971, 1982, 1983). The principle states that systems that maximise the use of energy most effectively will survive in competition with other systems with less useful inflow. Odum (1982, 1983) suggests that maximum power does not imply maximum energy efficiency, or maximum or minimum entropy generation. It assumes instead that energy inflow is used in the manner best suited to meet the needs for survival. This can be achieved by establishing stores of energy, developing feedbacks to increase energy inflows, recycling materials, and in some circumstances using the energy more efficiently (Odum 1982). For example, an ecosystem will evolve over time to contain the components that cause the system to maximise its energy flow, based on available energy, nutrients and rainfall. A less

[9] Further elaboration of the epistemological implications of Prigogines work is beyond the scope of this dissertation. Detailed discussion can be found in Prigogene (1980).

powerful system would not win in competition against it. Similarly, an urban system uses low entropy inputs to develop structure and economy. Those urban systems that put the energy to good use will be those that benefit most from economic competition. In some ways the maximum power principle is a description of Darwinian natural selection in energy terms. The principle has its origins in the work of A.J. Lotka in the 1920s and has characteristics in common with the work of Boltzmann carried out in the 1880s.

Elements of the competing theories of Prigogene and Odum have used to develop a third theory of systems behaviour called the minimax principle (Lonergan 1985aa). This suggests that systems competitively minimise dissipation within a framework of power maximisation. Lonergan (1985) describes developed societies as having high inputs of energy, in order to pay the real costs of society and to raise societal welfare. Extending the minimax principle to this situation suggests that energy throughput should continue to be maximised, but pollution and waste, forms of entropy, should be minimised.

Many studies of the interrelations and trade-off's among ecological, economic and social processes have been carried out using the above principles within the discipline of energy systems analysis. For example, in a study of the energy patterns of development in a coastal region of Louisiana, USA, Hopkinson and Day (1981) concluded that the resilience of the ecological and socioeconomic systems of the region to ecological and economic perturbations had been impaired by the loss of natural energy productivity and an ever increasing dependence on purchased energy. Several suggestions were made in regard to the improvement of the ratio of natural energies to purchased energies. These related to increasing the production of natural energy by returning the area to a more natural state through a reduction of the control of the

Mississippi River. The hierarchical nature of complex systems has also been studied from an energetics perspective. Using data on national and regional patterns of landscape organisation, Brown (1981) examined theories of energy flow control of hierarchies. Energy principles were demonstrated to explain the hierarchical structure and spatial patterns observed in ecological and socioeconomic systems. Also in a spatial context, Lonergan (1985) examined the relationship between energy and regional economic growth in Canada using the minimax principle. He concluded that using energy flows enables a better understanding of past fluctuations in the dynamics of spatial systems and, as a consequence, regional planning should explicitly consider the role of energy in the development process.

Energy systems analysis, despite its considerable popularity and apparent utility, is subject to many of the same shortcomings as net energy analysis. As an integrated modelling approach, energy systems analysis retains many characteristics inherited from its origins in the biophysical and engineering sciences. It is perhaps a consequence of this orientation that while ecological and economic interrelations and trade-off's have been successfully studied in some detail, the application of energetic principles to the empirical analysis of social systems has not been so productive (Lonergan 1985a). The complexity of the human condition renders its understanding via methods relying on nomothetic reductionism unlikely. The inherent reductionism of the energy systems approach may also prove to be a more fundamental limitation to the conceptualisation of the biosphere necessary for empirical study of sustainable development.

3.6 Multi-Dimensional Planning Frameworks

The analytical frameworks discussed in the preceding sections each have some elements that are relevant to the empirical analysis of sustainable development. Each is limited, however, either in respect to its ability to abstractly representation the elements of sustainable development or, in its ability to provide an operational basis able to support the analytical needs of resource assessment and environmental planning in the context of sustainable development. The structures and processes associated with sustainable development cannot be adequately described by means of a single variable or unidimensional measure. Moreover, the multifaceted nature of the planning process demands that frameworks be amenable to varying degrees of predictive, prescriptive, and descriptive usage, thereby better representing the variety and heterogeneity of reality as well as the action oriented aspects of planning problems. Recent developments in modern decision theory have given rise to methodological frameworks that appear to address some of the significant shortcomings of the other approaches.

Multi-dimensional approaches such as multi-criteria analysis and multiple objective programming may represent productive avenues for operationalising sustainable development. Several researchers (Cocklin 1988; Nijkamp *et al.* 1991; Ruitenbeek 1991; van Pelt 1993) have indicated that they feel that multidimensional planning approaches are a productive avenue for research into many of the issues surrounding sustainable development. However, few, if any, such studies have been forthcomming. The increased relevance of multi-dimensional methods to real world planning situations also leads to further analytical complexity.

3.6.1 Multi-Criteria Plan Evaluation Analysis

The last two decades have seen increasing recognition that many decision problems, especially in an environmental context, are multi-dimensional. The relevance of using fictional prices, shadow price or energy quality criteria in techniques such as CBA and energy analysis to translate different criteria into a common measure is being questioned by decision makers (Nijkamp 1977a, 1977b, 1980, 1981). Decision makers are therefore turning to operational methods and theories oriented to the multi-dimensional character of many decision problems (McAllister 1982; Nijkamp 1979, 1980, 1981; van Pelt 1993; Voogd 1981, 1982).

Multi-criteria analysis aids in the evaluation of prior specified alternatives that are characterised by multiple and often conflicting criteria (Maclaren 1985; Massam 1993). Multi-criteria evaluation situations are frequent in environmental planning and policy analysis planning and the criteria being considered are in many instances measured in non-commensurate units. Moreover, units are often a mixture of qualitative and quantitative measurements. The combined problem of incommensurate units and qualitative data makes the evaluation procedure complex.

Data measured on nominal or ordinal scales (qualitative) presents a problem because this type of data cannot be aggregated in a mathematically valid manner (Nijkamp 1977b; Nijkamp and Rietveld 1982). Criteria weights (i.e. measures reflecting the importance of one criterion to another) are almost always based on qualitative data. The increasing popularity of multi-criteria analysis is due to its ability to provide a logical and comprehensive tool for a multi-dimensional evaluation of unpriced impacts. Many of these impacts cannot be measured in monetary or even cardinal units, since many of them are only of a qualitative or ordinal nature. Multi-criteria analysis is therefore better able to incorporate the many dimensions of societal preference that constitute the welfare of society (Nijkamp 1977a, 1979).

Multi-criteria analyses are thus designed to overcome the problems of multiple criteria, incommensurate units, and the occurrence of both qualitative and quantitative information. In general multi-criteria methods are not based on pecuniary valuations, but on a more general weighting system. The weighting system reflects political priorities regarding the outcomes of the decision criteria for the alternative plans. A multi-criteria analysis attempts to select the most desirable plan out of a series of alternatives. The selection is based on a multiplicity of criteria, including intangibles, represented in their own dimensions. This makes possible the consideration of quantitative and qualitative, monetary and non-monetary effects within the same analytical framework thus better reflecting the preference structure of society.

The choice of any one multi-criteria evaluation method will depend on an appropriate matching of the evaluation method to the evaluation problem such that the strengths of the method are exploited and the weaknesses minimised. The most often encountered multi-criteria analysis in resource analysis is probably the goals achievement matrix (GAM). The GAM is an evaluation method devised by Hill (1968, 1973) to overcome the weaknesses inherent in CBA and the PBS. It is based on a set of explicit objectives that are translated into quantitative goals in a manner such that the degree of achievement of each plan with regard to the objective can be calculated. The degree of achievement can be measured by means of an achievement index, so that a set of aggregate achievement indices for all alternatives can be calculated. Impacts are categorised according to a set of explicitly stated community goals, and further subdivided according to community groups that are affected.

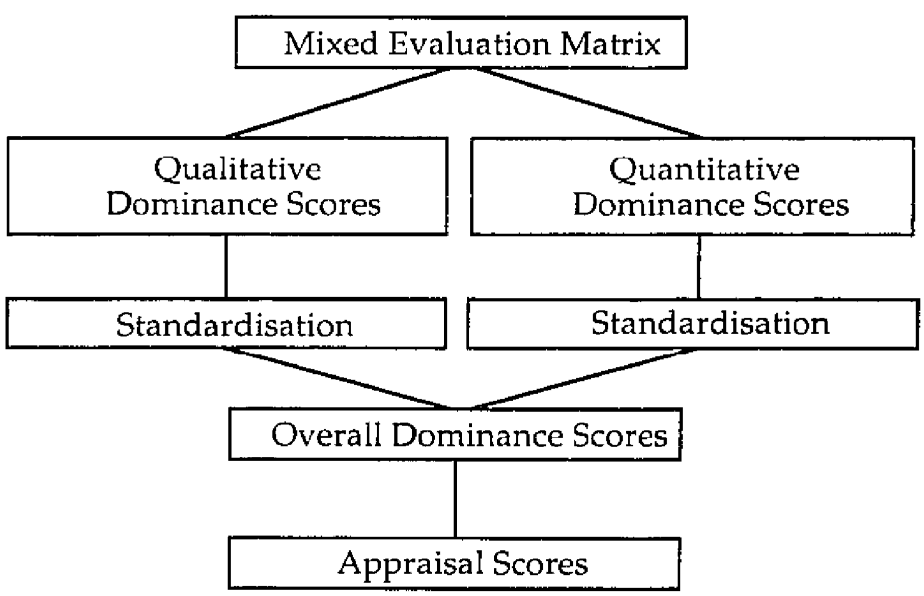
The physical form of the GAM is a matrix with columns representing objectives and rows representing community groups. Each element of the matrix is an assessment of the value to each community group of the degree of achievement of each goal resulting from the adoption of each alternative plan. Objectives and sectors are weighted according to their relative value prior to performing the evaluation.

Three alternative methods of comparing goal achievement levels are suggested by Hill (1968). The simplest presents the decision maker with the goals achievement account without attempting to synthesise the information. In this form the GAM cannot be considered a true evaluation framework. The second alternative is to sum the weighted indices of goal achievement. The preferred plan is becomes the one with the largest index. This methodology is subject to much criticism, however (Lichfield *et al.* 1975; McAllister 1982; Poulton 1983). Concerns relate to the arithmetic of the aggregation process and to the meaning of cell values if used for aggregation (McAllister 1982; Poulton 1983). The third alternative is similar to the second, but measures all costs and benefits on an ordinal scale. This overcomes the aggregation problem to some extent but does not solve the problem of cross multiplication of goal and community group weightings. Clearly at this stage a great deal of uncertainty exists about what is being measured in a GAM and how it is being measured.

Subsequent to the develop of the GAM, a large number of other multi-criteria evaluation methods have been developed. Their forms are varied and include quantitative and.qualitative models, deterministic and schocastic models, and static and dynamic models. Individual methodologies include trade off models, expected value models, multi-dimensional scaling models, correspondence models, permutation models, entropy evaluation models, discrepancy models, and concordance analysis. These more recent methodologies tend to be more sophisticated than the GAM and have been used successfully in many resource planning situations[10].

One particularly promising set of mixed data multi-criteria methods are generically known as the evamix approach (Voogd 1982; Nijkamp *et al.* 1990). The evamix approach consists of a number of different solution methods sharing a common procedural framework (Figure 3.6). This methodology involves the construction of two

Figure 3.6 An Overview of the Evamix Procedure



Source: Adapted from Nijkamp *et al.* (1990)

[10] More detailed discussion of the listed methodologies can be found in Maclaren (1985) Massam (1988, 1993), Nijkamp (1977b, 1979), Nijkamp *et al.* (1990) and Voogd (1981, 1982).

dominance measures. The first measure deals with ordinal criteria and the second deals with cardinal data. A number of different solution methods can be used to standardise and aggregate the two measures. This allows for the calculation of a final appraisal score for each plan alternative being considered. The alternative with the highest appraisal score is the best option for the given criteria and weight sets.

The possible use of the evamix multi-criteria procedure for sustainable development plan evaluations can be demonstrated using a hypothetical land use problem[11]. The case refers to the evaluation of three alternative land uses for an area of tropical forest:

- Preservation of forest.
- Rice production.
- Exotic Tree farming.

The following sustainable development criteria are used to evaluate the alternatives[12]:

- Employment generation (number of jobs created).
- Food production (tonnes of rice)
- Biodiversity impacts (qualitative).
- Impact on indigenous peoples (qualitative).

The impacts of the alternative land uses for these criteria are shown in Table 3.1. The greater the number of positive signs the more preferred the alternative is for that qualitative criteria.

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11 Appendix One contains a full specification of the evamix methodology. Chapter Five demonstrates a practical application.

12 These criteria are arbitrary. Chapter Four contains a detailed discussion of indicators for sustainable development research.

Table 3.1 Hypothetical Land Use Impact Matrix

Criteria	Land Use		
	Preservation of Rain forest	Rice Production	Exotic Tree Farming
Employment generation	50	150	500
Food yield (tonnes)	30	300	0
Biodiversity	+++	+	++
Native impacts	+++	++	+

Weights have been assigned to the criteria reflecting their individual importance in Table 3.2. Three hypothetical weight sets are given, representing employment, food production, and conservation development perspectives. The evaluation criteria ranked four are the highest ranked and criteria ranked one are the lowest ranked

Table 3.2 Hypothetical Criteria Rankings

Criteria	Development View		
	Employment	Food	Conservation
Employment generation	4	2	1
Food yield (tonnes)	3	4	2
Biodiversity	1	1	4
Native impacts	2	3	3

Table 3.3 shows the outcome of the evamix analysis for the three weight sets. The highest ranking option has a score of three and the lowest ranking option a score of one.

Table 3.3 Land Use Option Appraisal Rankings

Land Use	Development View		
	Employment	Food	Conservation
Preservation	1	2	3
Rice Production	2	3	2
Tree Farm	3	1	1

The evamix analysis can be used in a number of different ways. First, it can be used to select the best land use alternative. The preservation and tree farm options represent extreme options and would only be selected if employment or preservation considerations were binding constraints on the decision process (i.e., they have to be achieved at all costs). Food production is the most "robust" alternative in that it ranks first or second under all weight sets. Food production may therefore be the best land use option. A similar process could be carried out for all possible ranking combinations.

Perhaps more significantly the method can be used heuristically to explore criteria relationships. For example, the question can be asked how many jobs must the preservation option provide before it is ranked highest under a given weight set? This question is answered in Table 3.4.

Table 3.4 Additional Employment Required to Attain Highest Rank

Weight Set	Land Use Option		
	Preservation	Rice Production	Tree Farm
Employment	390	65	0
Food	∞	0	∞
Preservation	0	∞	∞

Shown are the increases in employment required to become the highest ranked alternative for each weight set. An additional 390 people would have to be employed by the preservation land use option for it to be the highest ranked under the employment development weights. Only 65 additional people need to be employed by rice production to achieve the highest ranking under the same weight set. No increase in the number of jobs created would result in alternative land uses being ranked higher under food or preservation weight sets[13]. A similar sensitivity analysis could be carried out for changes in the food yield criteria. For the qualitative criteria an approximation of the same sensitivity analysis would be to alternate the qualitative criteria scores.

Multi-criteria analysis thus represents a powerful resource evaluation tool, explicitly able to account to a greater or lesser extent for the multiple dimensions that characterise the problem of sustainable development. Furthermore, it is able to take into account both quantitative and qualitative data components. In respect to the methodological requirements outlined at the beginning of the Chapter, multi-criteria analysis is thus closer to providing an appropriate framework for modelling sustainable development than CBA, PBS, EA or IO.

Multi-criteria analysis, however, lacks the ability to identify alternative resource allocation patterns and relies, like CBA and PBS, on the prior articulation of plan alternatives. The need to specify alternative plans of action presupposes that the decision maker possesses a method of specifying of all possible alternatives and of eliminating less relevant alternatives, prior to carrying out the selected multi-criteria analysis. In environmental decision making, especially in the context of human

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[13] This is a function of using the expected value method of dealing with ordinal criteria rankings. See Chapter Five and Appendix One for more detail.

development, this is seldom the case and alternatives are often generated with methods that lack rigour or are based on limited criteria such as pecuniary value.

3.6.2 Multiple Objective Optimisation

Sometimes also referred to in the literature as multi-criteria evaluation techniques, multi-objective optimisation or multiple objective programming (MOP) approaches are intrinsically different, due to their continuous nature and use of optimisation algorithms. As continuous models they are based on an infinite number of possible values of the decision arguments and hence of the objective functions (Nijkamp 1979). Consequently, MOP models have an advantage over multi-criteria evaluation models in that the techniques do not require the prior specification of resource allocation alternatives. MOP models will allocate environmental stocks and flows in a way that best satisfies the conditions specified in the model.

MOP models have been applied to a wide variety of research questions and planning problems in both the public and private sectors[14]. Cocklin (1989a) identifies three ways in which programming models have been used in public sector planning. Most often programming models have been used in a normative manner to define what should be. Used in this manner the objective function represents the principle decision criterion and the form of the model depicts the decision makers perception of reality. Subsequent policy action is directed towards the achievement of the allocation specified by the model.

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14 For a comprehensive discussion of mathematical programming in the context of resource planning see Cocklin (1989a, 1989b).

Programming models can also be used for simulation purposes in order to establish what might be, given an initial set of conditions. The objective function and constraints of such a model are expressed according to the decision makers perception of how the system under study operates. Instead of being used in a prescriptive manner, the model is used for prediction. The models can thus contribute to the policy formulation process in a number of ways. The final manner in which programming models have been used closely resembles their use as simulation models but places less emphasis on the model as a representation of reality. Programming for heuristic purposes is exploratory in nature and attempts to enhance the understanding of how systems are structured and how they might behave.

MOP methods are a development of simple optimisation theory that gained widespread popularity during the 1960s and 1970s in public sector planning. Simple optimisation models are usually characterised by the existence of a single objective, with the other elements of the decision problem are included as constraints in the modelling framework. The primary objective is often based on an economic efficiency criterion such as maximisation of profit or minimisation of cost and the other decision elements are somehow made commensurate with the objective function. Within the private sector simple optimisation theory has met with considerable success. General consensus exists as to the nature of production relationships relevant to private sector management decisions and there is little difficulty in isolating a single goal as the basis for the objective function. The identification of a single objective function in the public sector is rather more difficult.

Public sector decision problems usually involve the existence of several conflicting and incommensurable objectives. Simple optimisation theory (and related single metric modelling tools such as CBA and energy analysis) cannot reflect the multi-dimensionality and heterogeneity of the constituents of human welfare. The shortcomings of simple optimisation theory in this regard were a significant, although not the sole, contributing factor to the disfavour that all optimisation theory subsequently fell into for decision making in the public sector (Ackoff 1977; Brill 1979; de Neufville and Christensen 1980).

The feasibility of incorporating multiple objectives into optimisation theory was first demonstrated during the 1950s, but it was not until the 1960s that widespread interest in the methods developed among decision makers. Part of this interest was obviously a response to the restrictive nature of simple optimisation theory. Currently there are more than 20 MOP solution algorithms available (Cocklin 1989a; Cohen and Marks 1975) of which there are two generic forms (Cocklin 1989a, 1989b; Ignizio 1982): (i) generating techniques, and (ii) methods incorporating the articulation of human preferences.

Generating techniques are used to identify a set of alternative solutions to a decision problem (Cocklin 1989a, 1989b; Ignizio 1976, 1982; Nijkamp 1979). The preferences of decision makers in terms of the achievement of objectives are excluded from the model and hence no single solution is identified as best. The creation of alternative solutions to decision problems serves to provide better insight into, and understanding of, the nature of the decision problem and of the implications of the solutions. Brill (1979) suggests that such programming stimulates creativity in the design of plans.

The rationale for the use of generating models is two fold. First public sector planning problems are often too complicated to be represented by a mathematical model and hence the solution to the mathematical problem may not be the most appropriate solution to the actual planning problem. Second, a set of feasible solutions lying close to the mathematical optima will exist for most planning problems. Each solution may have a similar value, but the formulation of each solution may be quite different. Although these solutions are sub-optimal in regard to the mathematical optima, they may perform just as well as solutions to the actual planning problem, and as such deserve consideration by the decision maker. In contrast, methods such as CBA enable the choice of the best alternative from a set of specified alternatives, but provide no awareness of the range of alternative actions.

The usefulness of generating techniques is limited if there are more than three objectives, however. The number of solutions required to determine the non-inferior set is usually an exponential function of the number of objectives and this property quickly complicates the interpretation of the model output with the addition of further objectives.

Notwithstanding such limitations, major contributions have been made to the development of generating techniques by the team of Brill, Chang, and Hopkins. A number of generating procedures were developed that are consistent with two requisites in terms of the solution generated: (i) the solutions must meet specified minimum requirements and, (ii) the solutions must be different from each other (Brill 1979; Cocklin 1989b). These procedures are called Hop, Skip and Jump (Brill 1979; Brill *et al.* 1982), the random generation procedure (Chang *et al.* 1982a, 1982b) and Branch and Bound Screening (Chang *et al.* 1982b). All three techniques produced solutions that were good and different from each other, and the alternatives generated by each method were also different from each other (Cocklin 1989b). Chang *et al.* (1982b) in an evaluation of the techniques suggest an appropriate strategy may be to use all three in combination.

MOP procedures relying on the specification of preferences differ from generating methods in that they attempt to identify a single optimal solution to the decision problem. Finding the optimal solution requires that information be elicited in regard to preference held for the attainment of one objective relative to the others. This information is then incorporated into the objective function. A number of approaches can be used to assimilate preferences with objectives. One of the most common is the utility approach in which a set of weights is specified expressing the relative value attributed to the attainment of specified objectives (Cocklin 1989a; Nijkamp 1977a, 1979). The operational value of this approach is limited, however, by the difficulty associated with developing numerical weights due to the uncertainty and lack of information on the spectrum of feasible solutions (Cocklin 1989a; Ignizio 1982; Nijkamp 1977a, 1979). The problems associated with determining preferences at the interval or ratio level can be overcome by an ordinal ranking of the goals according to their perceived preferences. Ignizio (1982) suggests that ranking goals is less ambiguous and abstract than determining numerical weights.

Linear goal programming is one MOP technique that has found widespread application to resource planning and other public sector decision problems[15]. In goal programming procedures all objectives are expressed as goals. Goals consist of an objective and an aspiration level (target) for that goal. The solution procedure involves minimising the deviations from the desired aspiration level. The ability to

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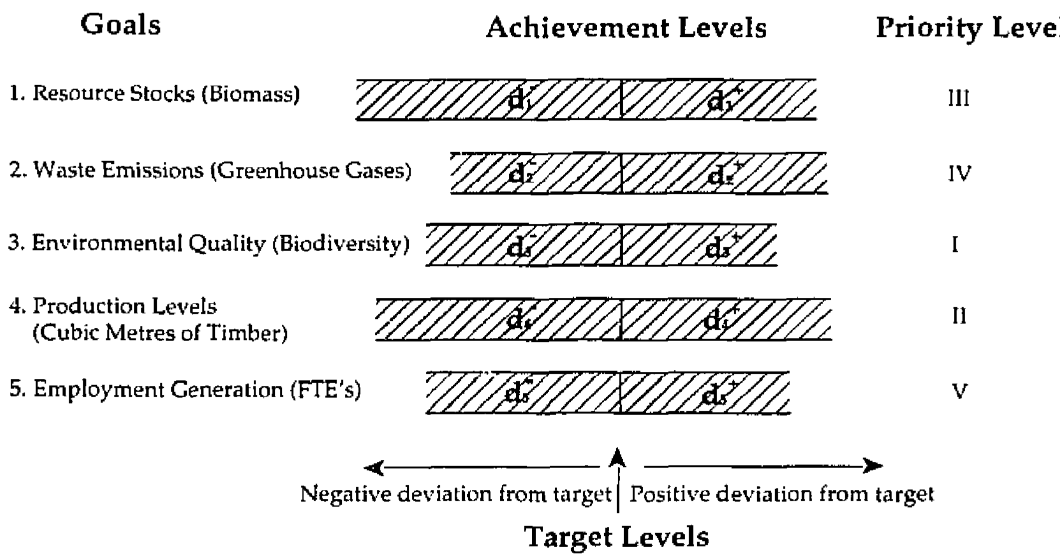
[15] See, for example, Cocklin *et al.* (1986), Dane *et al.* (1977), Lonergan and Cocklin (1988), and Werczberger (1976).

express different goals in incommensurate units is an additional strength of goal programming. Preferences associated with each goal can be incorporated using either mathematical weights or the simple ordinal ranking of goals. A number of analysts have chosen the latter option because of its less abstract nature and lack of ambiguity (Cocklin 1989c; Cocklin *et al.* 1986; Ignizio 1982; Kwak and Schneiderjans 1985; Lonergan and Cocklin 1988; Werczberger 1976). Although lexicographic goal programming does not require the use of numerical weights, it is based on an extreme zero-infinity weighting system. This requires that the ranking of goals be carefully considered.

Cocklin (1989c) presents a hypothetical example of the use of lexicographic goal programming for sustainable development analysis. A general understanding of the approach can be gained from Figure 3.6. The vertical lines within the bars portray target levels for the expressed sustainable development goals. Taking into account the relative importance of each of these goals, the model assists in determining the resource allocation strategy that is closest to meting the target levels specified for each of the goals. For each goal the target level may be achieved, under achieved (the d^- in Figure 3.6) or over achieved (the d^+). The importance of any outcome depends on the nature of the goal. Over achievement of the biomass target is probably of little consequence. In contrast under achievement of the employment target may have significant social consequences.

Goal programming also has considerable scope for sensitivity analysis. The impact of changing goal targets, goal and constraint coefficients, and goal rankings can be assessed in a relatively straightforward manner. In many respects the results of the sensitivity analysis may yield the information of most use to the decision maker, analyst or stakeholder. Information can be made available on the capability of a particular development strategy to satisfy simultaneously a range of development

Figure 3.6 A Goal Programming Approach to Sustainable Development



Source: Adapted from Cocklin (1989c)

goals, on the nature of goal relationships, and on the implications of uncertainty with respect to system parameters.

Several empirical studies have also demonstrated the practical usefulness of goal programming in the context of resource evaluation and assessment. Dane *et al.* (1977) developed a multiple land use allocation model to assist with planning decisions for the Mount Hood National Forest in Oregon, U.S.A. Lonergan and Cocklin (1988) similarly designed a goal programming model to analyse resource options relating to forest energy plantation development in Eastern Ontario, Canada.

Like the other methods described in this Chapter, goal programming and related MOP methods are not without their limitations. For example, variables and relationships must be expressed at the interval or ratio level even though in some instances preferences can be incorporated ordinally. Other important problems to be considered in the context of modelling sustainable development include the existence of non-linearities, the treatment of uncertainty, and the representation of the dynamics of the systems being modelled.

Most MOP algorithms require that variable relationships be specified in a linear fashion, when the general form of most relationships is nonlinear. The existence of non-linear MOP partly resolves this problem, but non-linear models require a higher level of mathematical abstraction and tend to be less flexible in their range of application (Cocklin 1989a). Uncertainty with respect to the conditions being modelled poses further problems. The development of "fuzzy" programming algorithms has been one response to the problem of uncertainty (Ignizio 1982; Nijkamp 1979), but this approach while recognising the existence of uncertainty cannot change the fact that such uncertainty exists. The application of fuzzy algorithms to planning problems has been limited.

Efforts have also been directed at modelling dynamic system relationships. The addition of dynamic considerations considerable increases the complexity of optimisation models creating formulative and computational difficulties. Lonergan (1981, 1983) in an effort to account for system dynamics, links an optimisation model with a simulation model. The optimisation model is used to generate alternative solutions and the implications of these solutions are examined via the dynamic simulation model. The linkage of simulation and optimisation models has a similar intent to integrated ecological-economic modelling. The use of seperate solution techniques recognises that particular systems may be best represented by appropriate modelling practice.

Given the above limitations, the ability of MOP methods to determine a planning solution that is optimal in the context of sustainable development is doubtful. Mathematical algorithms cannot reflect the complexities of real planning problems and hence their solutions are unlikely to the best available option to society. Consequently, the normative application of MOP models should be limited in public sector planning practice, their analytical power and versatility best serving in a heuristic role rather than in the identification of optimal solutions.

3.7 Discussion and Conclusions

Contemporary research problems in the fields of resource analysis, resource management, and resource evaluation are characterised by a diversity of structures and processes, incommensurable variables, and conflicting objectives. Applied sustainable development research is little different in its need to consider a pluriform of variables, categories, and processes. For example, the dependency of the socioeconomic system on a multi-functional environment, the implications of trade-off's between functions, and the consequences of the loss of some or all of these functions for present and future human welfare, are all important aspects of the problem of sustainable development to be addressed in subsequent research.

The characteristics of the evaluation methods and related processes described in this Chapter and their strengths and weaknesses are summarised in Tables 3.5 and 3.6 respectively. Table 3.5 summarises the evaluation methods with regard to the

Table 3.5 Characteristics of Reviewed Evaluation Methods

	Single Metric			Integrated Ecologic-Economic				Multi-Dimensional		
	CBA	PBS	NEA	IO	NRA -M	NRA-P	ESM	MCA	MOP-G	MOP-P
Planning Role										
Normative	•	•	•					•		•
Descriptive				•		Limited	•		•	•
Heuristic				•	•	•	•	•	•	•
Impact Estimation										
Scientific	•	•	•	•	•	•	•	•	•	•
Judgmental		•						•		
Data Abilities										
Quantitative	•	•	•	•	•	•	•	•	•	•
Qualitative		•						•		Limited
Measurement Unit										
Pecuniary	•				•					
Other Unitary			•				•			
Mixed Unit		•		•		•		•	•	•

Abbreviations:
CBA Cost-benefit analysis
PBS Planning balance sheet
NEA Net energy analysis
IO Input-output analysis
NRA-M Natural resource accounts - monetary
NRA-P Natural resource accounts - physical
ESM Energy systems modelling
MCA Multi-criteria analysis
MOP-G Multiple Objective Programming - Generating
MOP-P Multiple Objective Programming - Preference

requirements for heuristic analysis first discussed in section 3.3.3. Table 3.6 is a more general descriptive comparison of the reviewed evaluation methods with regard to resource assessment and environmental planning. It should be noted that the

Table 3.6 Strengths and Weaknesses of Evaluation Methods and Processes for Resource Assessment and Planning

Evaluation Approach	Strengths	Weaknesses
Single Metric Resource Allocation Methods	Well defined guidelines for the choice of policy objectives, measurement of impacts and weighting factors; widely accepted for project appraisal purposes.	Biased toward economic/energy efficiency criteria; treat ecological systems seriously but in an unproblematic way (except EA); unable to deal with incommensurate data; restricted to quantitative measurement of impacts and evaluation of prior specified alternatives; limited temporal perspective.
Integrated Ecologic-Economic Simulation Frameworks	Powerful methodologies with which to explore, model and measure economic-ecological inter linkages and interdependencies; can provide input to single metric and multi-dimensional methodologies.	Limited prescriptive abilities; highly quantitative and unable to incorporate qualitative considerations; poor representation of social systems; not widely accepted outside of academic research; are data intensive and can be costly and time consuming to construct and calibrate; predictive results have sometimes been disappointing.
Multi-Dimensional Planning Approaches	Can be used for prescriptive, descriptive and exploratory analysis; reflect the diverse characteristics of real-world planning problems including social, economic and ecological dimensions; able to incorporate incommensurate system attributes and different weighting schemes; MOP methods can be used to generate plan alternatives; mixed data MCA procedures can integrate quantitative and qualitative data in a comprehensive manner; can be used in a way consistent with the move to participatory and consensus based planning practices; have considerable scope for sensitivity testing.	Lack a common epistemological basis to guide the choice of objectives, measurement processes, and weighting factors; the failure of MOP procedures to perform well in prescriptive applications has led to some resistance to their use in the public sector; the many different MOP and MCA solution algorithms can be confusing; models can be complex to build; are usually data intensive; may require advanced mathematical and computer skills and resources; can become an end in themselves rather than a means to an end.

analytical requirements for the applied evaluation of sustainable development seem to be little different from the evaluation of other resource and environmental problems. What is different about resource assessment and environmental planning in the context of sustainable development is the greater weighting given to ecological and intergenerational evaluation criteria.

Methodologies that attempt to reduce the the components of sustainable development to a single metric, such as CBA and energy analysis, result in an inadequate representation of the problem of sustainable development. Limiting the scale and scope of the analysis in this manner is likely to reduce the reliability and relevancy
of the results obtained. Such methods also usually require the prior determination of planning strategies which raises additional concerns about the criteria used to select the alternatives. These problems are compounded when the role of analysis in the decision process is normative. As an abstraction of reality, any analytical framework tends to be too different in a functional sense from the actual situation to be relied upon to prescribe management actions. This does not preclude the use of analytical frameworks to lend insight into the nature of the problem, however.

Integrated ecological-economic frameworks such as input-output analysis, energy systems analysis, and resource accounting, represent more appropriate frameworks for assembling the results of systematic data collection regarding the interaction between the ecological and socioeconomic systems. However, they have been used with only limited success in resource evaluation because of their intensive data requirements. The descriptive/simulation orientation of these methods means that they are more severely constrained by data availability and quality than methods with a prescriptive or heuristic orientation. The data required to carry out detailed modelling with these approaches often does not exist, or is available for only a limited set of resource types, such as those related to energy production. Also, while the information generated by integrated ecological-economic models may be of value in the analysis of sustainable development, the frameworks themselves do not constitute comprehensive assessment methodologies. There is no provision for the assessment of trade-off's or for the identification of appropriate management strategies and hence integrated models are, by themselves, inconsistent with the analytical requirements of this research.

The questions raised by sustainable development for resource assessment and environmental planning do not necessarily involve a limited set of pre-specified resource use options. A major objective of sustainable development research may indeed be to identify a possible set of resource allocations given constraints relating to environment, welfare and intergenerational equity. Of the methods reviewed in this Chapter programming models have the greatest potential to generate a set of alternative resource allocation patterns. The evaluation of these alternatives in terms of societal preferences and desires, involving multiple and possibly incommensurate goals, can be best addressed in a relevant manner using a multi-criteria plan evaluation framework, or, from within a preference based MOP model.

Several analytical strategies based on multi-criteria plan evaluation and MOP would appear to have the potential to yield an operational structure for resource evaluation in the context of sustainable development. One approach is to use a multiple objective programming model that incorporates the articulation of preferences for specific objectives. Used in a heuristic manner, a preference based MOP has considerable potential to aid in evaluating the extent to which the biosphere has the capability to meet simultaneously a specified set of development goals. An advantage of this approach is that it does not necessarily entail sophisticated solution procedures. Another advantage is that the sensitivity of the results with respect to parameter shifts can be assessed in a relatively straight forward manner. This approach is limited by its inability to consider qualitative evaluation criteria, however.

A second strategy involves using a combination of an optimisation procedure (multiple or single objective, generating or preference based) and a multi-criteria plan evaluation approach. In this strategy the optimisation framework would be used to establish a set of potential solutions on the basis of environmental and socioeconomic constraints consistent with the biophysical, intergenerational and intragnerational components of sustainable development outlined in Chapter Two. The rationale behind this stage is to reduce the planning problem to a manageable size (van Delft and Nijkamp 1976).

The next stage in the modelling process would then subject the limited number of alternative allocations to a multi-criteria plan evaluation procedure like evamix. This process eliminates the problem of interpreting multiple optima that can sometimes occur with preference based MOP models. Also, decision criteria can now take into consideration the qualitative aspects of the decision making process. Van Delft and Nijkamp (1976) have used a combination of programming and multi-criteria methods in a limited planning context, examining decision strategies regarding a new industrial area. A single objective optimisation model was used to generate series of non-inferior competing alternative plans and a concordance analysis was used with some success to select the most desirable alternative.

Combining an optimisation routine with a multi-criteria plan evaluation model explicitly recognises the sequential nature of the planning process. The resolution of many planning problems may require the use of more than one approach, where each approach is best suited to a particular requirement of the planning process. However, using separate models within a broader framework requires considerably more expenditure in time and modelling effort when compared to the use of a single methodology. Complexity in planning has been described as the policy-makers divider and possible conqueror and where possible should be avoided (Wyatt 1980). If the complexity of the problem is perceived to be too great, a third analytical strategy using a multi-criteria evaluation approach alone to assess prior specified alternative resource allocations could be implemented.

Irrespective of final form, the heuristic evaluation approach used for applied sustainable development research should satisfy certain prerequisites:

- The framework should incorporate an appropriate degree of disagregation, so that the ecological, intragenerational, and intergenerational dimensions of sustainable development maintain their identity.
- Within the framework, the interactions within and between the ecological, intragenerational, and intergenerational components of sustainable development should be articulated in a manner such that the relevant relationships remain explicit.
- An empirical application of the analysis should be possible, at least in principle.
- Subsequent application of the framework should provide information to the decision maker that is relevant to the resource assessment or planning problem at hand.

In the following Chapter specific attention will be paid to the information requirements necessary to integrate the individual components of sustainable development articulated in Chapter Two with the multi-dimensional methods discussed in this Chapter. As well as examining appropriate social and ecological indicators, the role of indicators in resource assessment and environmental planning is examined in detail. Measurement, application, and integration issues are also addressed. Chapter Five then applies the ecological, intragenerational, and intergenerational components of sustainable development to a real-world planning problem by using selected ecological and social welfare indicators in a combined optimisation and multi-criteria plan evaluation framework.

Chapter Four

Indicators for Assessing Sustainable Development

4.1 Introduction

Sustainable development has different meaning for different people. To an agro-ecosystem specialist, it might be defined by the ability of an agricultural region to maintain productivity while experiencing stress or shock. A neoclassical economist may consider sustainability to be a constant real price of natural resources. To an ecologist, managing for sustainable development may require that the composition, structure and function of regional ecosystems remains intact over time. An energy systems approach to the development of urban system could suggest that sustainability is more likely if energy throughput is maximised and energy dissipation minimised. In each instance, researchers would look to a different data or information set to establish whether or not human development activity was sustainable. Such a diversity of contexts makes it unlikely that an uncomplicated, comprehensive, and operational indicator or set of indicators of sustainable development will be found.

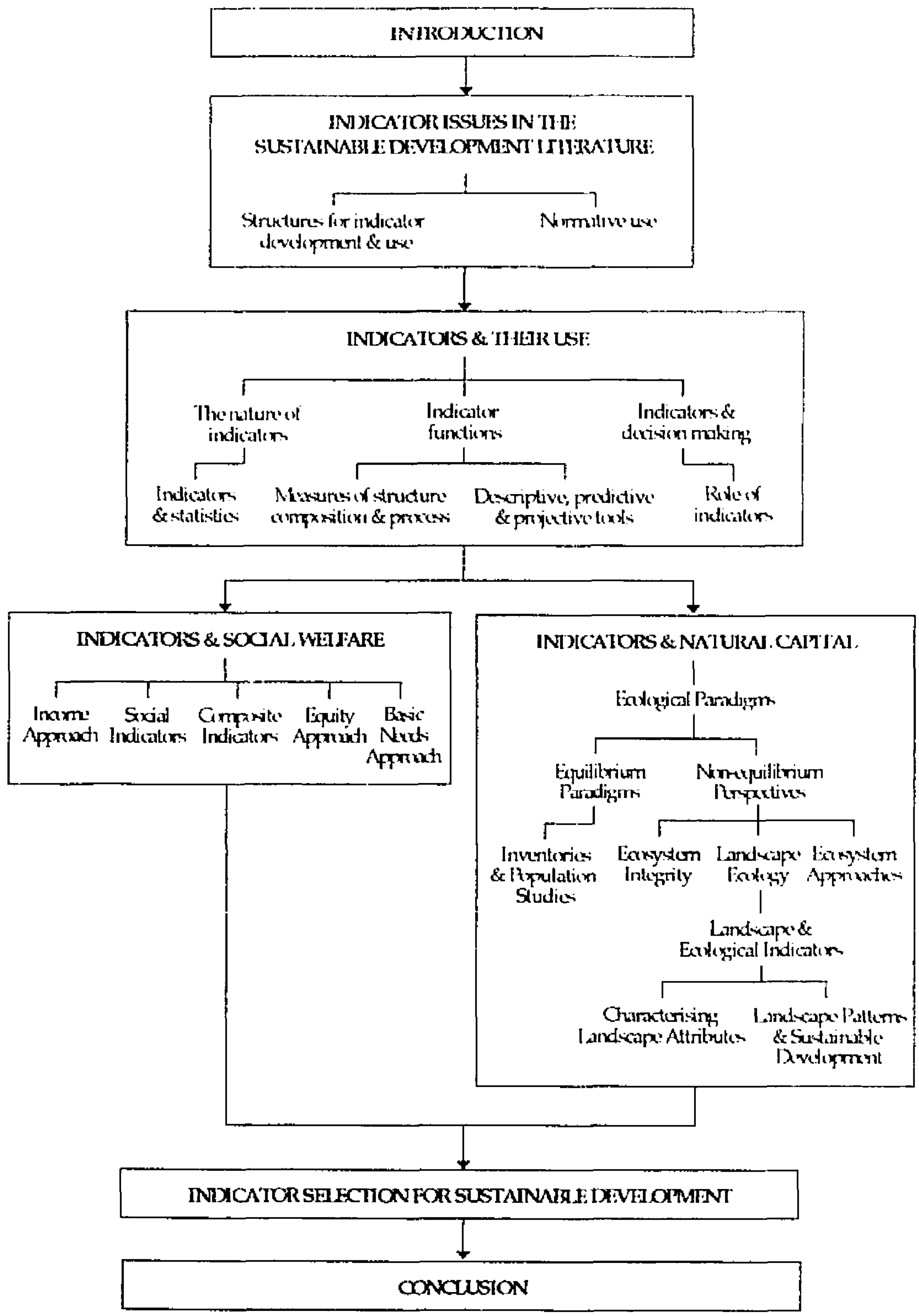
Within individual contexts the need for an expanded approach to resource analysis and environmental management implied by sustainable development further complicates the development and/or adoption of appropriate indicators. The necessary consideration of extended vertical, cross-sectoral, and horizontal system components while implying a more holistic analytical perspective, at the same time requires more detailed social, economic, and ecological information. Traditionally this information has been supplied in a fragmentary, discipline by discipline fashion by reductionist research paradigms. Meeting the challenge of sustainable development requires a broader, more integrated approach to the development and use of appropriate indicators for sustainable development.

The purpose of this Chapter is to build on the discussion of sustainable development concepts and appropriate resource assessment/evaluation methodologies and processes contained in Chapters Two and Three. It examines the more substantive issue of indicators for sustainable development. To date, research dealing with indicators for sustainable development has been slow to appear. Consequently, some effort is required of the sustainable development community before "useful" indicators for sustainable development research achieve the level of maturation required for acceptance by contemporary environmental and planning institutions.

It is beyond the scope of the present Chapter to explore in detail all the dimensions of the indicator problem. Nevertheless, an attempt is made to sketch a broad outline of its scope and to suggest possible solutions to some of the more immediate problems it poses for applied sustainable development research. The rest of this Chapter will examine several different aspects of the indicator problem (Figure 4.1).

First, a brief review is presented of the sustainable development literature dealing explicitly with the issue of indicators. Second, a general characterisation of indicators and their application to resource assessment and environmental planning is presented. Topics addressed in this section include the nature of indicators, indicator functions, and indicators and decision making. Third, measures of social system attributes are examined in regard to the social welfare component of sustainable development

Figure 4.1 The Structure of Chapter Four



articulated in Chapter Two. Fourth ecological indicators of sustainable development are reviewed.

The intent of the ecological indicator section is to address indicators of natural capital, a fundamental concept in the sustainable development literature. However, the discussion is broader in scope than in preceding sections. This is because the ecological dimension of sustainable development has so far received little explicit attention in this research. Examined are the wider implications of different ecological paradigms for indicator development. It is argued that an integration of social and ecological perspectives that goes beyond most linkings of economic and ecological systems is required. Examined are ecological paradigms that may offer this integration. It is suggested that the landscape level of ecological analysis is particularly appropriate for integrating the social and ecological dimensions of sustainable development. Potential indicators of natural capital derived from these approaches are then suggested.

The Chapter concludes with the articulation of a structure for categorising the diverse indicators required for sustainable development research. The ideas underlying this structure, while consistent with the sustainable development concepts presented in Chapter Two and the multi-dimensional planning approach advocated in Chapter Three, are intended to be applicable to human development and ecological research that follows other avenues of inquiry.

4.2 Indicator Issues in the Sustainable Development Literature

Notwithstanding the diverse and plentiful literature that exists regarding sustainable development and related concepts, there is little consensus as to what would comprise a representative set of indicators for sustainable development. Indeed, a search of the sustainable development literature reveals few papers that explicitly deal with the issue of indicators for sustainable development. The neglect of indicators for sustainable development represents a major obstacle to giving sustainable development research greater applied relevancy[1].

Research concerning indicators for sustainable development can be divided into two main avenues of enquiry. Most commonly, researchers have attempted to find normative indicators of sustainable development. Attention is focused on indicators that reveal how far from, or close, global, national, and regional social systems are to sustainable development. A second, less evident area of research focuses on the articulation of theoretical and methodological bases for the creation and use of indicators of sustainable development. While cognizant of the normative/descriptive role of indicators, this approach also explicitly recognises the wider simulative and predictive role that indicators can play in resource assessment and environmental planning.

4.2.1 Normative Indicator Use

The work of Clark (1986), Brown (1987) and Daly and Cobb (1989) is representative of the normative approach to sustainable development indicators. Clark utilizes various density measures in his discussion of the sustainable development of the biosphere. Indicators of population density (population per unit area), agricultural

[1] This is not to say that considerable research has not gone into indicator research for specific sustainability related research applications. For example, natural resource accounting frameworks attempt to develop meaningful physical and monetary indicators of resource stocks and flows. However, such efforts have been largely absent from the more general sustainable development literature.

production density (value added per hectare per year) and energy consumption density (oil equivalents per hectare per year) are used to compare the sustainable development of regions and nations. Areas with the lowest densities are assumed to be more sustainable relative to areas with higher densities. Presented in this manner, however, such density indicators ignore differences in the quality of the resource base between regions.

Brown (1987) implicitly incorporates resource quality considerations when he suggests that there may be important threshold values to economic growth, beyond which development is non-sustainable. Two indicators of economic growth, per capita gross world output and per capita fuel consumption are used to measure development trends. When the costs of development in terms of climate change, forest damage, and soil erosion exceed the benefits of growth, society is on a non-sustainable development path. In order to back up these two primary indicators, measures of carrying capacity developed by the United Nations Food and Agriculture Organisation and the World Bank are also used. The studies cited attempt to estimate the potential population that can be supported by agricultural land and forests in different ecological zones. If current populations exceed the supportable population then an indicator of a non-sustainable society exists. Similarly, the IUCN (1980) uses measure of deforestation, fisheries pollution and depletion, topsoil and arable land loss, malnourishment, and water supply disruption to indicate non-sustainable resource use.

Liverman *et al.* (1988) suggest a set of guidelines that can be used to assess the value of sustainable development indicators such as those above, and also to develop new indicators that have uses beyond simple description and comparison of existing states. These guidelines, which can be seen as a bridge between normative indicators and more complex indicator applications, can be summarised thus: (i) Be temporally sensitive, thereby able to separate normal system cycles from trends away from sustainable development. (ii) Be spatially and distributionally sensitive, therefore able to reveal spatial and distributional inequalities in development. (iii) Be predictive, to be of use to managers. (iv) Have meaning in regard to reference or threshold values. (v) Be unbiased in that ethnocentric influences are minimised. (vi) Reveal reversible or controllable changes. (vii) Be amenable to appropriate data transformations, thus enabling appropriate temporal and spatial comparisons. (viii) Be able to be integrated into composite measures of development, or alternatively, act alone as representative indicators. (ix) Remain relatively easy to collect and use while having regard for the appropriateness of scale and the nature of measured variables.

The index of sustainable economic welfare[2] (ISEW) proposed by Daly and Cobb (1989) comes close to fulfilling these requirements. The ISEW is a monetary measure of economic welfare. The form of the ISEW is an additive index made up of some 20 variables. It represents an attempt to develop a measure of the economy "...that will give better guidance than the GNP to those interested in promoting economic welfare." (Daly and Cobb 1989, p. 401). Its purpose is to show how a nation is fairing in terms of sustainable welfare and to reveal the kinds of policies that would help improve levels of welfare.

4.2.2 Structures for Indicator Use and Development

A second school of research suggests that the development and productive use of indicators is dependent on the economic and ecological paradigms, and the cultural

[2] The ISEW is discussed in more detail in a subsequent section on income based approaches to welfare indicators.

constructs to which their creators and users subscribe. A feature of this research is its proactive approach to the information needs of the users who will subsequently use the frameworks for sustainable development-related planning. Walter (1992) suggests that this approach reflects concerns that indicators incorporate social goals, are pertinent to information creation and use, be legitimised by experts, and convey appropriate meanings.

The complex issues surrounding indicators for sustainable development are the focus of several reports published by the Canadian Environmental Advisory Council (CEAC)[3]. These reports describe the implications of major economic (Victor 1991) and ecological (Kay 1991) theories for both the development of a sustainable development policy agenda and for preparing indicators of sustainable development. Ruitenbeek (1991a) similarly examines various decision making processes and the implications of these for creating sustainable development indicators. In conjunction with the publication of these reports, a workshop was held. The published proceedings of this conference (Potvin 1991) examine the wide range of opinions that surround the issue of how the conceptual foundations of economics and ecological analysis shape subsequent policy relating to sustainable development. Although stopping short of developing explicit indicators, these reports demonstrate the potential efficacy of the structured approach, as opposed to the normative approach, for developing relevant and operational indicators for sustainable development.

Further indicator research is required in this area by the sustainable development research community. Differing social and ecological contexts have major implications for the way in which human development is expressed in any one place (Redclift 1987).

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[3] See, for example, Victor *et al.* (1991) and Ruitenbeek (1991).

The literature dealing with development indicators and their use has ignored or treated this issue superficially, resulting in the adoption of potentially inappropriate measures of sustainable development. More emphasis must be placed on: (i) identifying relevant measures of the physical, biological and social processes that underlie the sustainable development of social systems in given contexts and (ii) developing indicator frameworks that recognise the existence of differing social and environmental contexts.

4.3 Indicators and their Use

Indicator development and use poses a number of methodological problems. Within the context of general empirical research these problems are usually solved in an intuitive way by researchers with little support from theoretical research (Shogren and Nowell 1992). Some of the more immediate problems faced by those who need to use indicators are: What is an indicator? What exactly is to be indicated? What is the appropriate role of indicators in analysis and decision making? How are indicators related to one another and other information?

While there is always cause for a pragmatic attitude to indicator development because of the immediacy of many important environmental, social and economic issues, there is also need for indicator research to have theoretical foundations. Without such a component it is difficult to meld disparate measures within a cohesive analytical framework that has regard for the multi-dimensional character of real world problems.

This section will highlight some of the analytical considerations behind the development and use of indicators for sustainable development. First, the nature of indicators is commented on. The relationship between statistics and indicators is briefly discussed. Two ways of characterising the functions of indicator use are also articulated, one based on the indication of system attributes, the other on the analytical role of indicators. Second, the issue of indicator use is elaborated on following an objective-input-constraint trilogy proposed by Ruitenbeek (1991a, 1991b).

4.3.1 The Nature of Indicators

Put simply, indicators point out the state of system components and processes and their change over time. More significantly, indicators help conceptualise these states. Indicators are therefore not only a tool of measurement but also a way of defining what is measured (Horn 1980).

Indicators and Statistics

The construction and interpretation of indicators relies on statistical information. There are two steps in the preparation of statistics that are particularly relevant to the creation of indicators. First, mathematical methods are applied to the measurement of observable phenomena. Second, following measurement, the resulting data are subject to selection, processing and presentation. The measurement process is usually described as objective, but the selection of data, the choice of methodology, and the presentation of results is largely subjective, depending on individual or disciplinary preferences.

After collection, analysis, and presentation, statistics are open to various interpretations. For example, time series data on the area of coastal old growth forest logged per year in British Columbia can be interpreted as showing the size of the logging industry, or as representing a potential loss of temperate rainforest biodiversity. Both interpretations represent a valid use of the same statistics. However, when the relationship between data and a particular situation or context is made explicit, statistics become indicators. Indicators thus show information that is ordered to demonstrate a particular situation, or change of situation in relation to something else:

> "...indicators are not simply statistics, and statistics are not *ipso facto* indicators - unless some theory or assumption makes them so by relating the indicator variable to a phenomenon that is not what it is directly and fully measures." (McGranahan 1972, p. 91 in Horn 1980).

4.3.2 Indicator Functions

The broad functions of indicators can be characterised in two overlapping ways. First, indicators can be used to reveal the various attributes of systems. Second, indicators of these attributes can function as simple descriptive devices or as more complex predictive and projective tools.

Indicators as Measures of Composition, Structure and Process

Three fundamental attributes of ecological systems have been identified. Noss (1990) labels these attributes composition, structure, and function. It should also be possible to characterise the attributes of social and economic systems in a similar way. Composition refers to the identity and variety of elements in the system(s) being studied. The organisation or pattern of a system forms its structure. Function alludes to the processes and interactions that occur within and between economic, ecological and social systems. It also refers to their evolutionary development.

Noss (1990) suggests that the composition of an ecosystem can be measured using indicators of identity, relative abundance, richness and diversity of species. Alternatively, the relative proportions of endangered, threatened, and indigenous or exotic species could be measured. Habitat complexity, age structures, distribution of physical features, and biogeoclimatic characteristics help describe the organisation of ecological systems. Energy flows, biomass and resource productivity, succession rates, nutrient cycling and hydrological processes are given as examples of functional ecosystem elements.

Measures of the composition of an economic system could include absolute or relative measures of types of economic activity and of the various economic agents involved in these activities. Its structural elements might be indicated by measures of economic diversification, spatial linkages, availability of natural resources etc. The magnitude of flows between economic agents, rates of change, and changes in natural resource exploitation, exchange and interest rate mechanisms, commodity markets, and inflationary and recessionary cycles are examples of economic functions and processes.

Indicators as Descriptive, Predictive and Projective Tools

Indicators can serve a number of different analytical roles (Horn 1980; Ruitenbeek 1991b). At their simplest, indicators act as descriptors, characterising current or past conditions. This role can be extended somewhat to provide an analytical description of past changes. For example, it may be shown that for every one per cent increase in newsprint demand, timber volumes harvested have increased by 0.02 per cent. If the relationship between cause and effect is made more explicit, indicators can also be used in a projective or predictive manner.

Projective indicators are used to forecast future states on the basis of explicitly stated scenarios, while predictive indicators provide more unconditional predictions of future states (Ruitenbeek 1991b). A projective indicator will for a given set of conditions (e.g., initial timber supply, factor prices, technology, and newsprint demand) forecast future conditions (e.g., timber harvests). A predictive indicator will place less emphasis on initial conditions and therefore generate predictions of future conditions that are more arbitrary. For instance, given current newsprint prices, it may be forecast that timber harvesting will increase at two per cent per annum over the next five years. Indicators used in either a predictive or projective manner form much of the basis for subsequent normative, simulation and heuristic applications.

The intent of projective and predictive indicators is to make explicit information available to the decision maker regarding matters such as appropriate policy targets, welfare impacts, interactions between social, ecological and economic systems, and interactions within these systems. Used for these purposes, indicators are not objective measures, and users of indicators must remain cognizant of this. Indicators are created with inherent subjectivity and they are seldom used without bias.

4.3.3 Indicators and Decision Making

Two questions are fundamental to the issue of indicator use: (i) What role can individual indicators play in resource analysis and environmental planning? (ii) How can individual indicators be related to other indicators?

The Role of Indicators

Ruitenbeek (1991a, 1991b) suggests that individual indicators can be used in one of three decision making roles. These roles can be characterised as an "objective-input-constraint trilogy" (Ruitenbeek 1991b, p.9). Indicators used as objectives represent some given endpoint of the planning process such as a target level of social welfare or environmental quality. For example, population densities or food production per hectare can be monitored over time to see whether the trend toward self-sufficiency in food production is increasing or decreasing. Using indicators as objectives is consistent with the normative or prescriptive approach to environmental planning discussed in Chapter Three. In this context indicators are used to assess how close a policy or action is to achieving an indicated goal.

As an input to the assessment process an indicator acts as one possible factor to be considered. Relevant inputs to the analysis and assessment of sustainable development could include such indicators as rates of deforestation, population growth and industrialisation. As inputs, indicators may be complementary to one another or substitutes. Ideally, in any assessment exercise, the use of complimentary indicators should be maximised and the use of substitute indicators minimised.

As constraints, indicators place boundaries on the extent to which trade-offs can take place between input indicators. As an input to the decision making exercise it does not matter at what rate an indicator changes over time and there may well be trade-offs between indicators. In contrast, if used as constraints, there will be absolute limits to the magnitude of indicator change and to the extent of trade-offs between indicator variables. This limit might be based on ecological criteria designed to maintain the viability of an ecosystem, on economic criteria that denote minimum levels of welfare, or on ethical criteria that prevent future generations from inheriting a stock of natural resources that is of a lesser quantity and quality than that inherited by the present generation.

Indicator Relationships

The use of indicators for decision making purposes has two important implications for indicator research. First, there is a need for disparate indicators to be linked so that they can be integrated within a research framework. This means that indicators cannot be developed in isolation from one another. Not only must each indicator have a valid theoretical basis, there must also be some underlying rationale for linking different indicators. Second, since considerable information will be required at some stage to establish these linkages there will have to be some framework that reduces the complexity involved, while retaining information that is relevant to real world management and policy issues.

The amount of information required to establish indicator linkages and the uncertainty surrounding these linkages makes it unlikely that a sustainable development indicator can be defined in a comprehensive manner. To make the indicator/information problem manageable, indicator use must necessarily be restricted in some manner. An appropriate basis for this restriction is not immediately obvious or easily determined, however. One possibility, often used in decision theory, is to limit the selection of objective, input, and constraint variables to those indicators over which humans have direct control (Nijkamp 1982). A significant limitation to this approach is that it may result in the neglect of system attributes that have linkages with, and hence a major effect on, decision variables. Alternatively, it may be possible to examine indicators in terms of a hierarchy. In this manner indicators are chosen according to their relevance to the immediate problem and on the basis of whether or not they incorporate other system attributes. Determining this hierarchy in a given context requires an appreciation of the cross-sectoral dimensions of the problem and of the vertical linkages between systems.

For example, if the maintenance of regional biodiversity is a constraint on economic activity there is little point from an applied viewpoint in modelling biodiversity at the genetic or species level. The linkages between human activity and biodiversity at these levels are too numerous, complex and uncertain to be adequately represented. But maintaining ecosystem diversity at a higher level of system organisation will more or less ensure that regional biodiversity is also preserved. Similarly, while indicators of the compositional and structural elements of ecological systems can be created, it is at the functional level that human resource use has the most impact. Hence, disturbance processes (characterised by areal extent, return interval, intensity, rotation period etc.) created by humans will for the most part incorporate anthropogenic impacts on structural or compositional ecosystem attributes.

Such a hierarchical determination is not easily made, however. In the following sections an attempt will be made to link the determinants of sustainable development with contemporary development and ecological theory. This will help establish an appropriate perspective for applying indicators to the problem of sustainable development.

4.4 Indicators and the Determinants of Social Welfare

A major theme of sustainable development discussed in Chapter One is that many different objectives, inputs, and constraints must be considered in the attempt to bring it about. Ecological constraints on the scope of human development, intragenerational equity, and equity between generations are three potentially conflicting conditions that are, for the purpose of this research, considered integral components sustainable development. In any particular context there will, however, be little agreement as to appropriate indicators of these conditions.

An operationally useful indicator in a variety of development contexts is a variable that is specific enough to allow measurement in order to develop goals, objectives and constraints that are relevant to sustainable development. Social welfare, resource stocks, and intergenerational equity are not sufficiently specific concepts to be used operationally, although they serve adequately at the conceptual level. General concepts often need to be further subdivided into several subcategories. For example, measuring resource stocks may require objectives for quantity (e.g. biomass) and quality (e.g. biodiversity). Operational usefulness is determined by a number of factors including the ease with which a particular indicator can be incorporated into an analytical framework, and the extent to which a particular statement of an objective is meaningful to decision makers. It is also possible that there may be alternative formulations of the same indicator.

4.5 Indicators and Social Welfare

The sustainable development literature considers the purpose of development activities to be the improvement of human wellbeing. Human wellbeing is conventionally measured by some aggregation of individual welfare (Sen 1984). In Chapter Two it was stated that welfare is assumed to be some function of individual aggregate utility. In general utility is considered dependent on the ability to consume, and of the quality of the environment in which the individual lives. In other words, an individuals wellbeing is affected by the quantity and quality of their consumption. This wellbeing is also directly and indirectly influenced by the quality of the environment: directly in that the environment provides non-market utility yielding services; and indirectly in the sense that the environment affects the magnitude and quality of matter and energy available for consumption. For development to be sustainable one of two welfare conditions must exist. Either welfare (however measured) must always exceed some minimum level, for example a given level of subsistence, or any change in welfare must be non-decreasing overtime.

Social welfare can be conveniently characterised as a multidimensional profile[4]. The actual elements of a welfare profile will depend on the context in which development is to be measured. One important component of the multidimensional welfare profile associated with the concept of sustainable development is the principle of equity, both within a generation and between generations. The notion of intergenerational equity has been discussed previously. It is assumed for the purposes of the proposed research that it can be achieved by constraining the intergenerational

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[4] In this research the term social welfare is used generally to refer to human wellbeing. This general treatment is in contrast to the rigorous treatment given to concept in the social choice literature. For an introduction to this literature see Sen (1979, 1982, 1984, 1987).

transfer of natural capital. The issue of measuring natural capital will be dealt with more fully in a subsequent section of this Chapter.

Equity between individuals, ethnic groups, cultures, regions and nations is a more difficult issue to address within the proposed research. As suggested in Chapter Two, human social systems may be sustainable, but the development of that system may not be equitable. The desirability of an equitable distribution of resources and the implications of this for levels of welfare is an ethical issue. The choice of an appropriate ethic will have a fundamental influence on the resolution of social and allocative problems. However, the literature concerned with the normative aspects of sustainable development (described in Chapter Two) suggests that sustainable development is more likely if there are an equal distribution of productive assets, better opportunities for minority groups and the dispossessed within nations, and a reduction of the gap between the rich and poor.

The problem of selecting appropriate welfare or development indicators to form the welfare profile is not only germane to the sustainable development debate. As previously suggested, the notion of indicators for sustainable development has only recently been addressed in the sustainable development literature. For a more complete discussion of indicators it is necessary to turn to the contemporary social and economic development literature.

The welfare indicators selection problem is highlighted in the development literature by what might be termed the "measurement debate". One school of current research is attempting to reformulate traditional indicators of welfare such as GNP so that they better capture the welfare component of development over time and space. A second avenue of research adopts a multidimensional approach, arguing that development involves the evolution of the whole social system, and as such an appropriate measurement of this progress should incorporate a wide range of social and economic indicators. These approaches can be labelled the "income approach" and the "social indicators approach" respectively (Bunge 1981; Horn 1980; Khan 1991).

There is similar debate regarding the question of equity. The suggested solutions to this problem tend to be more normative in nature (Bunge 1981). Again two approaches dominate the literature (Khan 1991). These are the "equity orientated approach", placing its emphasis on redistributive justice and relative poverty and the "basic needs approach" which is concerned with reducing absolute poverty by concentrating on fundamental human needs. Ultimately, the most appropriate indicator of social welfare (or human wellbeing) will depend on the political economy of the problem being studied.

Besides the general measurement debate described above and elaborated on in subsequent sections, there is also a more fundamental, and conceptually rigorous, debate in the social welfare/social choice literature. This discourse concerns the appropriate basis for the social welfare function. Sen (1979, 1982, 1984, 1987), for example, argues against the use of aggregate utility as a basic measure of welfare (c.f., Pigou 1952; Arrow 1963). Instead of a utilitarian/welfarist/consequentialist approach[5], and its attendant problems (e.g., Arrow's Impossibility Theorem), Sen (1984) describes an approach to social welfare based on capability theory.

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[5] Sen (1984) equates utilitarianism with the sum ranking of individual utilities to reflect the goodness of a state of affairs. Welfarism refers to the assumption that utilities are adequate information for judging states of affairs. Consequentialism states that social choices can only be judged in terms of utility information.

Capabilities are notions of freedom and provide opportunities for the type of life an individual lives. For example, the utilitarian will be concerned with the fact that owning a car creates utility (satisfaction) through its use. However, owning a car also gives a person the capability of meeting some of their needs for personal movement. Sen (1984, p.316) writes:

> "The capability to function is the thing that comes closest to the notion of positive freedom, and if freedom is valued then capability itself can serve as an object if value and moral importance."

An individuals wellbeing is thus determined by the opportunity set of basic capabilities to function that a person has available. This capability set in turn is determined by goods, environmental factors and personal characteristics[6].

4.5.1 The Income Approach

The income approach to the development of welfare indicators is based on the notion of utility acquired through market exchange. Simply put, income acts as a measure of an individuals utility. Income is therefore an indicator of the means to derive utility (e.g., pleasure, desire fulfilment, and choice (Sen 1987)) and is not a measure of utility (the end) in itself. As an indicator of wellbeing and therefore development, it implicitly assumes that higher levels of per capita income result in a greater ability to consume, and hence increased welfare and social development.

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[6] Elements of this theoretical debate are incorporated in the following discussion of social welfare indicators, especially in regard to means versus ends issues. However, the applied orientation of the current research means it is beyond its scope to describe the theoretical aspects social choice theory and welfare economics in any great detail. Nevertheless, this does not mean that this body of literature is considered unimportant to the problem of sustainable development.

The income approach to development indicators is best exemplified by the widespread acceptance of Gross National Product (GNP) per capita (or its sub-national equivalent) as a measure of a country's or region's development and hence of the wellbeing of its population. The popularity of GNP as a welfare indicator arises due to a well defined methodology for its calculation, and because the statistics needed for this calculation are collected as a matter of course by most countries. GNP is an economic indicator that is derived from transaction statistics recorded in the internationally accepted system of national accounts (SNA). It represents three elements: value of production, income derived from that production, and the disposal of that income (Horn 1980). Each of these elements can be disaggregated to further represent the composition, structure and functions of a region or country's economic system.

For example, production can be shown by sector and expenditures by type of disposal. Economic flows and their distribution can be divided into production, investment, rest of the world, government and household. Despite the wide spread use of GNP as the principal indicator of development, however, its deficiencies and those of other national and sub-national income figures have long been recognised (Hicks and Streeten 1979; Horn 1980; Khan 1991; Sen 1987).

Horn (1980, p. 443) describes GNP as "... synthetic rather than authentic." Criticism can be levelled at GNPs' adequacy as a measure of development and at its ability to represent distributive changes over time. As a measure of economic wellbeing it is generally restricted to market and government transactions and it omits other closely related activity such as unpaid work in the home or community. Investment in areas such as education is not regarded as a market related expenditure. Production itself is considered neutral irrespective of the purpose it serves, giving rise to the defensive expenditure problem discussed in Chapter Three. Also, GNP disregards significant interactions between market and non-market sectors, and structural changes in these relationships.

GNP per capita is particularly weak when valuing and tracing the evolution of subsistence activity and non-monetary economies. Its focus on the market and monetary exchange means that no account is made of the time and effort required to acquire goods for final use as transactions are recorded at the point of sale, or at the point of expenditure for public goods. GNP also neglects the positive and negative impacts of the natural and social environments on human welfare. These impacts tend to form a more significant component of needs satisfaction in developing countries than in developed countries (Redclift 1987; Sen 1987).

As with the monetary approach to natural resource accounting, discussed in Chapter Three, several attempts have been made to adjust GNP to account for its shortcomings as a measure of welfare. Nordhaus and Tobin (1973) were among the first researchers to initiate debate about restructuring GNP so that it better reflects the wellbeing of a society. They suggested a better "Measure of Economic Welfare" (MEW). This approach added an estimated value of non-market expenditures, values for leisure time, and capital services to GNP. Deductions from GNP were made for disamenities (urbanisation, crime, pollution etc.) and market expenditures that are not a direct source of utility (cost of police, military spending etc.). When calculated, the MEW of the United States was found to twice that of its GNP due to the high value of labour and other non-market activities. Even more significant was the finding that per capita GNP grew six times as fast as per capita MEW in the period 1947 to 1965.

As a measure of social wellbeing, however, MEW still neglects the distribution of wealth. Ahluwalia and Chernery (1974) suggested that GNP per capita is a poor measure of development since it is heavily weighted by the income share of the rich. They suggested two ways to overcome this problem. Each decile of income recipients could receive equal weighting, or alternatively poverty weights could be used which place more importance on the growth of incomes for the lower 40 per cent. Changes in income may still fail to reflect changes in living standards, especially if essential goods and services are lacking (Khan 1991). No measure of income or poverty, no matter how carefully derived, will serve as an adequate indicator of basic need fulfilment without knowledge of the economic and social structure of a country or region (Hicks and Streeten 1979).

A more recent proposal for an income based measure of welfare is the Index of the Economic Aspects of Welfare (EAW) proposed by Zolotas (1981). The EAW differs from MEW by focusing on the current flow of goods and services and by largely ignoring capital accumulation and sustainable development issues. Like MEW it includes the value of personal consumption, unpaid household labour, and leisure. Despite differences in make up, EAW provides similar results to MEW when applied to the United States. In the period 1947 to 1965 per capita MEW increased by seven per cent. Between 1950 and 1965, per capita EAW rose by nine per cent.

Significantly, EAW is the first index to include resource depletion in its calculation of welfare. Zolotas (1981) assumes that the price of non-renewable resources should rise at a rate equal to the long term interest rate, plus a premium for risk and user cost. Since resource prices have not risen at this rate, the market is assumed to have failed in setting an optimal depletion rate for resources. Therefore, Zolotas deducts the difference between actual resource prices and imputed resource prices derived from the long term discount rate and a risk premium.

The development of the ISEW by Daly and Cobb (1989) represents a major advancement in the income approach. Significant differences between MEW and EAW, and the ISEW include allowances for income inequalities, explicit consideration of the sustainability of economic welfare , recognition of non-renewable resource depletion (compared to MEW), and exclusion of allowances for leisure. The motivation for developing the ISEW is also different. Nordhaus and Tobin wanted to show that GNP correlates sufficiently well with economic welfare, making other measures like MEW unnecessary. Daly and Cobb intend to develop a replacement for GNP. They state:

> "We believe that it is urgent to replace the GNP with a measure that does not discourage the growing gap between the rich and poor and that discourages unsustainable economic practices." (p.373).

The ISEW, like MEW and EAW, has been used to measure the health of the United States economy, this time for the period 1950 to 1986.

The ISEW has as its basis personal consumption. This feature is shared by all income approaches to economic welfare, including GNP, MEW, and EAW. But unlike these measures, the ISEW is an estimate of sustainable consumption. To account for the sustainability of welfare, a number of adjustment are made to personal consumption. First, the value of personal consumption is adjusted for distributional inequalities in income. It is assumed that an extra dollar of income adds more to the welfare of a poor family than it does to a rich family.

Second, values from the services of consumer capital, unpaid household labour and some government expenditures (e.g., streets and highways) are inputed. Third, consumer expenditures that are considered regrettable necessities rather than contributions to welfare are corrected for. These expenditures include: defensive private expenditures on health and education; expenditures on national advertising (creates demand but does not add to welfare); costs of commuting and automobile accidents; and the cost of urbanisation. The cost of urbanisation is based on the assumption that increasing population densities result in increased land prices and property rents that are uncompensated for by increases in welfare.

Fourth, the undiscounted value of pollution and other environmental damages is deducted from the calculation of welfare. Estimates are made for the cost of water, air, and noise pollution. Also included is an estimate of long term environmental damages, especially from climate modification.

Fifth, the loss of natural capital is accounted for. Deducted from the ISEW is an estimate of the amount that should be set aside in a perpetual income stream to compensate future generations for the loss of services from non-renewable resources. An additional amount is also subtracted for the loss of wetlands and arable land. Finally, adjustments are made for net capital growth (changes in reproducible capital, excluding land and human capital) and changes in net international capital position (the amount Americans invest overseas minus the amount foreigners invest in the United States).

ISEW statistics produced for the United States from 1951 to 1986 show that per capita ISEW increased by 20 per cent during this period. Most of this growth occurred in the period 1950 to 1975. An improvement in income distribution, especially during the 1960s, was a major factor contributing to this increase. Since 1975 the ISEW has generally declined. Daly and Cobb (1989) suggest that this is largely a result of growing income inequalities, the exhaustion of natural resources, and the failure to invest enough to sustain the economy in the future. In contrast, during this period per capita GNP continued to rise by around 1.8 per cent per year (Daly and Cobb 1989).

Daly and Cobb (1989) also recognise that the ISEW is far from perfect. They suggest a number of important limitations to the ISEW as calculated for the United States. For example, it relies for its base on personal consumption, which though a more appropriate measure of welfare than production, still has deficiencies. It cannot account for diminishing marginal increases in welfare associated with increasing consumption, and the fact that happiness seems to be correlated with relative rather than absolute wellbeing.

The ISEW is also restricted to measures derived from the formal sector of the economy. This means that welfare derived from "underground" economic activities (unreported income from part time work, sale of crafts and home produce etc.) goes unrecorded. Finally, some very broad assumptions have been made in order to calculate the value of some of the components of the ISEW. Variables such as the costs imposed on future generations by resource depletion and the value of long term environmental damage are inherently unmeasurable. In these circumstances, Daly and Cobb (1989) make what they regard as "moderate conjectures, ones that do not overwhelm the index, but which play a substantial role in its outcome." (p. 416).

As a final alternative to GNP, Hicks and Streeten (1979) suggest combining social indicators with GNP. For example, life expectancy could be allowed for by using expected lifetime earnings rather than GNP per capita per annum. The benefits of literacy could be accounted for by calculating the value of educational services as a durable consumer good. Income distribution could be adjusted for by taking the median or modal income rather than the mean, or by adjusting mean income by some measure of income distribution such as the Gini coefficient. Horn (1980) suggests, however, that MEW and similar income derived proposals are still based on market transaction statistics without regard for the effect of these transactions on human wellbeing. He writes:

> "This makes the combined measure a conceptual hybrid that does not represent a welfare measure, while undiluted GNP remains important as a major economic indicator on its own terms and as an ancillary to social analysis." (Horn 1980, p. 443).

The shortcomings of the GNP as an indicator of human wellbeing reflect the limitations of the income based approach for developing welfare indicators. A reliance on market exchange data, assumptions of neutral production and a concern with means rather than ends, make such indicators almost meaningless in some development contexts. At best, where market exchange does dominate social, economic and environmental interactions, income indicators form a limited part of the multi-dimensional information set that is required to examine and represent social welfare. Income indicators have however, helped researchers clarify some of the required elements of more representative indicators of social welfare.

4.5.2 Social Indicators Approach

An alternative way of developing indicators of human wellbeing is the social indicator approach. Social indicators attempt to cover aspects of welfare that cannot be represented by most income based indicators. Such aspects include health, nutrition, wealth distribution, and other attributes of economic, social and environmental systems that contribute to human wellbeing. This approach is distinguished from the income approach by its focus on the determinants of wellbeing, rather than just the means to achieve them.

Social indicators may also include economic performance indicators and few researchers concern themselves with the technical difference between economic and social indicators. The term "development indicators" is sometimes used to avoid confusion between social and economic indicators (Hicks and Streeten 1979; Bunge 1981). It is claimed that the combination of social and economic indicators results in more meaningful development indicators (Khan 1991). At the same time, an *ad hoc* assembledge of social indicators describing system composition and structure is of little use for planning purposes if the functional relationships between variables are not articulated as part of indicator development.

Intensive research in the area of social indicators is a relatively recent phenomenon, beginning in the early 1970s[7]. Today there are many international and national agencies publishing social statistics and indicator compendia. Khan (1991) reports finding 365 such items in a recent literature survey. Although there is some variation in these compendia, most correspond to the list of social concerns of the OECD Social Indicator Project (Horn 1980; Khan 1991). This list, which is constantly being updated and revised includes: Health and health care; education and learning; employment and workplace quality; time and leisure; income, wealth, and control over goods and services; physical environment, including living standards and measures of

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[7] Early social indicator contributions were made by a number of international organisations. See, for example, UNESCO (1974, 1976); UN (1975); UNRISD (1978, 1979); OECD (1973, 1974).

environmental quality; social interrelationships; personal safety; human rights; social opportunity and participation.

The focus of social indicators on the less tangible aspects of human wellbeing presents a number of problems. Data availability is often restricted to the public and market sectors. Thus reliable information on the various dimensions of human wellbeing is generally restricted to formal sectors and their interactions. Health care, education, communications, and employment usually receive adequate coverage. Less well represented are areas such as social relationships, family structures, gender equity, and culture. Data regarding participation in informal economic, social and environmental activities is usually absent from such compendia. Unlike income indicators that use market information to combine heterogeneous elements, there is also no obvious way to combine social indicators. This makes general conclusions regarding overall development and the direction of development difficult.

Some research has been done regarding the development of a general accounting framework for integrating social indicators. This would provide a theoretical basis for linking social indicators with planning action. One example of this approach is the United Nation's (1975) Framework of Social and Demographic Statistics (FSDS). The United Nations has taken the SNA and extended it to the socio-demographic sphere to provide a wider description of an individuals living conditions. An input-output matrix forms the basis for a series of demographic accounts which show annual flows by appropriate characteristics and their linkages with respect to various aspects of living conditions and associated social services (Horn 1980).

Included in the FSDS are data referring to demographic structure, learning, income, income distribution, health, housing, use of time, social mobility etc. The data are arranged as a stock-flow transition matrix by way of four general categories: economic, socioeconomic, distribution, and time budget. The major limitations of the FSDS are its theoretical structure and its assumptions of scientifically collected value free inputs. The data required to put a framework of this complexity and magnitude into practice are unavailable in most countries and little recent progress has been made in implementing the FSDS (Khan 1991).

Used for indicator purposes, social statistics compendia and the FSDS contain inherent biases. The OECD, UNESCO, and other international agencies are generally concerned with identifying the attributes of social systems that best represent implicitly or explicitly held notions of what constitutes development. These attributes may or may not coincide with what the subjects of analyses see as contributing most to their wellbeing. For example, is a person who is illiterate according to OECD definitions but able to function, communicate and survive in their chosen environment, really illiterate in terms of what is necessary for their wellbeing? Increasing literacy rates in some cultures may represent an erosion of wellbeing, representing the degree of integration into the "formal" socioeconomic system. Interactions between formal and informal systems can, and often do, lead to a loss of self determination and cultural identity for the participants who previously existed outside formal socioeconomic structures.

4.5.3 Composite Indicators of Development

Composite indices of development attempt to generate a single measure, similar in nature to GDP per capita, by combining multiple measures of social and economic development (Hicks and Streeten 1979; Khan 1991). Such a measure could be used to supplement or replace GNP as an indicator of social, economic, or overall development. As a composite index, the ability to make international, regional and intertemporal comparisons of development would be greatly facilitated.

A number of composite indicators have been developed since the 1970s. Among the more notable of these are the "Development Index" established by the United Nations Research Institute for Social Development and the Overseas Development Councils' "Physical Quality of Life Index" (PQLI). To create the Development Index, McGranahan *et al.* (1972) examined 73 indicators of social and economic attributes and found a high degree of correlation between these indicators. Through a process of elimination, 18 "core indicators", nine social and nine economic, were selected. The resulting index was highly correlated with GNP per capita ($r^2 = 0.89$)[8]. Hicks and Streeten (1979) question the sensitivity of the index to changes in its composition, suggesting that country rankings remain unchanged when different indicators are used or the number of input indicators changed.

The PQLI combines three indicators: life expectancy; infant mortality; and literacy (ODC 1977). The combination of these three variables allows the measurement of a countrys' fulfilment of minimum human needs. However, these three factors measure the quantity of life rather than the quality of life, however (Hicks and Streeten 1979). Further, each variable is given an arbitrary equal weighting in the calculation of the PQLI but there is no theoretical basis for doing this. Larson and Wilford (1979)

[8] A number of studies have shown high correlation coefficients between GNP per capita and various composite and other social indicators (see, for example, Hicks and Streeten 1979, Khan 1991). Although researchers caution against suggesting a causal relationship (Khan 1991), it may be possible to infer that a shared development ideology identical in both approaches to measuring social wellbeing may explain in part the observed correlations.

examined the correlation between GNP per capita and PQLI and found that a high degree of association existed between the two indicators. This caused them to conclude that the PQLI is not a significant alternative indicator of human welfare.

Silber (1983) propose an alternative measure to the PQLI called the Equivalent Length of Life (ELL) which has an improved theoretical basis. The ELL assumes that people derive utility from the number of years lived and that there exists a separate, additive and symmetric social welfare function of individual lengths of life. This welfare function is used to calculate the ELL by applying inequality measures to data on the length of life.

Different multivariate statistical methods have also been used to create composite indices of welfare and development. Principal component analysis, factor analysis, discriminant analysis, canonical correlation, and multidimensional scaling have all been used as dimension reducing techniques in order to capture the variance displayed by large sets of economic and social variables. Some researchers have criticised the use of dimension reducing methods to aggregate economic and social data.

McGranahan (1985) suggests that many of the attributes of development correlate with one another, but no one variable can be treated as functionally dependent or independent. Khan (1991) similarly comments that current theories of development are designed to reveal the interrelationships between economic and social progress and that composite indices of reduced dimensions do little to help understand these relationships.

4.5.4 The Equity Approach

The income and social indicator approaches to welfare measurement tend to assume that development or progress at the national level will trickle down through all economic, social and environmental systems ensuring equitable development. However, the "trickle down" theory of equitable development has not been substantiated by empirical observation (Bunge 1981; Hicks and Streeten 1979; Kahn 1991). This has created a call for indicators of welfare that are more sensitive to income inequality and that can be linked to appropriate policy responses.

A wide range of income based inequality and poverty measures exist, but most tend to lack a theoretical basis to explain their determinants as well as their interrelationships (Bunge 1981). There is a normative belief, however, that improved income distribution will reduce poverty by raising the welfare of low income people. Khan (1991) reports a short term trade off between income distribution and economic growth. The long run existence of this relationship is disputed between neoclassical and marxist development specialists. Although economic growth may lead to improved individual wellbeing, it may also lead to a strengthening of existing social and economic inequalities.

Welfare enhancement policies consistent with the equity approach have tended to suggest that income should be redistributed to the impoverished through the fiscal system or through the direct allocation of consumer goods. These policies, while theoretically sound, do little to help groups in society who are marginalised from the institutions and constructs of the formal economy. Measuring wellbeing among these groups requires a more fundamental approach than the use of income criterion for the measurement of inequality and poverty. Only in socioeconomic systems dominated by formal institutional arrangements are income based measures of welfare and its distribution adequate indicators of individual wellbeing.

4.5.5 Basic Needs Approach

The basic needs approach advocates the elimination of poverty by meeting the basic needs of people. Unlike the redistributive orientation of the equity approach it focuses on the various combinations of growth, redistribution, and restructuring required to provide adequate levels of nutrition, basic education, health, sanitation, water supply and shelter (Hicks and Streeten 1979; Khan 1991). Emphasis is thus placed on the constituents of wellbeing rather than an arbitrary measure of the means of achieving these ends. Hicks and Streeten (1979, p. 577) comment:

> "Such a focus supplements attention to how much is being produced, by attention to what is being produced, in what ways, for whom and with what impact." and;
>
> " The basic needs approach, therefore, can be the instrument for giving the necessary focus to work on social indicators."

In an attempt to discover the determinants of basic needs development Hicks (1979) examined the relationship between basic needs indicators, growth, and income distribution. It was found that countries that did well in meeting basic needs in the 1960s also had above average economic growth rates in the period 1960 to 1973. However, Hicks suggested that it was impossible to establish whether the improvement in meeting basic needs was a cause or an effect of growing economic output.

In a similar study, Goldstein (1985) concluded that basic needs fulfilment follows a non-linear curve relative to per capita income, approaching a limiting threshold in an asymptotic manner. Some developing countries were found to be more efficient than others in improving basic needs at lower per capita income levels. These countries were characterised by higher existing levels of formalised economic structures including export organisation, education networks and commodity distribution systems.

The findings of Leipziger and Lewis (1980) suggested that income levels are more important than income redistribution for improving basic needs performance in low income per capita countries. In middle income developing economies, wealth distribution was found to be more important in determining basic needs performance. In contrast to these findings, Ram (1985) found that for most basic needs indicators, income is more important than redistribution at all levels of economic development examined. This study was conducted using multiple regression and seven basic needs indicators, one income distribution indicator, and real national income per capita.

Table 4.1 summarises the strengths and weaknesses of the various approaches to welfare and development indicators discussed above. Welfare and development indicators are simply statistics that attempt to reflect the human condition. Their usefulness in sustainable development research depends on a proper understanding of the purpose they serve and on the way they are applied. Researchers must be careful when transposing welfare indicators from one social context to another since the requirements for wellbeing are structurally determined. This means that the way in that wellbeing is expressed depends on its context. The human condition at any one time or place is determined by such things as culture, environment, economy, and prevailing power relationships. Greater emphasis must therefore be placed on understanding the structural determinants of human wellbeing. The measurement of wellbeing has little

Table 4.1 Welfare/Development Indicator Approaches

Approach	Typical Variables	Advantages	Disadvantages
Income	GNP[1]/GDP[2] per capita; family income; Measure of Economic Welfare; EAW[3]; ISEW[4]; Debt per capita.	Well defined measurement methodology; established data sources; standardised at the international level.	Restricted to market and government transactions; concerned with means rather than ends; ideological bias towards capitalist processes.
Social/ Development Indicator	Health (life expectancy, population per doctor, population per hospital bed); education (literacy rate, school enrolment); demographics (birth rates, death rates).	Cover many aspects of welfare not represented by income approaches; focus on determinants of wellbeing, not just means to achieve them.	Data often restricted to those populations integrated into the formal economy; no obvious way to combine measures to examine overall direction of development; descriptive; often based on first world development ideologies.
Composite Indicator	Development Index; PQLI[5]; ELL[6].	Combine multiple measures of social and economic development; facilitate temporal and regional comparisons .	Arbitrary; indices of reduced dimension do little to aid the understanding of the link between welfare and development.
Equity	Income distribution; per cent of population below poverty line.	Sensitive to income and wealth inequalities; can be linked to economic policy mechanisms.	Normative belief that income redistribution will alleviate poverty; rely on income measures; often neglects most marginalised members of society because not part of formal economy.
Basic Needs	Measures of health, housing, nutrition, sanitation, education; water supply, arable land.	Defines wellbeing and welfare in terms of needs satisfaction; Provides focus for the development of social indicators.	Basic needs fulfilment indicators tend to be insensitive to cultural contexts; tend to ignore structural and functional system attributes in favour of composition; difficulty in defining basic needs.

Notes:

[1] GNP Gross National Product
[2] GDP Gross Domestic Product
[3] EAW Economic Aspects of Welfare
[4] ISEW Index of Sustainable Economic Welfare
[5] PQLI Physical Quality of Life Index
[6] ELL Equivalent Length of Life

practical relevance unless it can be related to the actual expression of human wellbeing at a particular time and place.

4.6 Indicators and Natural Capital

The determination and measurement of the constituents of natural capital presents a problem in that the multiplicity of its determining factors presents computational and analytical complexity. Resource stocks can be represented as a multidimensional profile encompassing relevant environmental indicators as elements (Nijkamp 1980). Traditionally, this vector has included quantities of commercially valuable resources such as cubic meters of timber, barrels of oil, or populations of fur bearing mammals. The quality of stocks has usually been considered in terms of the return on harvesting or extraction effort. With the advent of a more holistic environmental perspective, the idea that the resource profile may contain a broader set of environmental variables is becoming part of the conventional wisdom. For example, regenerative capacity, assimilative capacity, and biodiversity, as well as quantities of renewable and non-renewable resources are now recognised as components of natural capital.

Selecting indicators as elements of the multidimensional environmental profile poses a considerable dilemma. Not only must metrics be defined and interrelationships specified, but the relevant elements of the profile will, like indicators of welfare, change from one context to another. Irrespective of context, however, ecological indicators of natural capital need to incorporate both quantity and quality considerations. In the short term there are often trade-offs between stock quantity and quality. Increased exploitation of low quality resource stocks and flows will yield the same levels of welfare as lower rates of exploitation of higher quality resources. Over longer time periods, the nature of the relationship between quality and quantity is less certain. The ability of the resource stock to provide material and energy inputs for productive systems, to assimilate waste, and provide other utility yielding services may be impaired by decreasing environmental quality even if stock size is constant or increasing. Maintaining a constant resource stock as a condition for sustainable development requires that its indicators not decline beyond a level that compromises the provision of these services.

Normative and methodological approaches to sustainable development have tended to turn to economic literature for ideas on how to address the trade-off between the quantity and quality of the resource stock and the wider issue of the trade-off between human wellbeing and the resource stock. Economics provides for several measures of a constant resource stock. First, the value (market price multiplied by physical quantity) of a stock could remain constant. Second, the price (unit value) of natural resources could be kept constant. Finally, the value of the resource flows from the natural stock can be kept constant. In each of these instances however, it is the aggregate utility of the stock being measured, not the inherent attributes of the stock that contribute to sustainable development.

Developing effective environmental indicators for the resource profile requires consideration of fundamental ecological principles. To date, the wider sustainable development literature, with the notable exception of Norgaard's coevolutionary work, has been remiss in this regard. Attempts to apply the concept of sustainable development to resource assessment and environmental planning are unlikely to be successful if the dominant research perspective continues to regard resource-economy interactions as proxies for social system-ecosystem interactions. While the former may prove to be an adequate indicator of the latter in some system contexts, this condition cannot be taken for granted.

In the following discussion, attention is first given to two different ecological paradigms. Each has very different implications for the understanding of ecosystems, and hence for ecological and environmental indicators. It is subsequently suggested that ecological indicators only gain relevance to the present research if they can be inculcated with human preferences in some manner. Possible avenues for integrating the physical expression of human preferences within the wider ecosystem perspective are thus explored. The field of landscape ecology receives particular emphasis.

4.7 Ecological Paradigms: Implications for Sustainable Development

4.7.1 The Dominant or "Equilibrium" Paradigm

The "equilibrium" ecological paradigm focuses on the stable equilibrium of ecological systems (Pickett *et al* 1992; Hobbs and Huenneke 1992). At its simplest, the equilibrium paradigm suggests that ecological systems can be conceptualised as functionally and structurally complete, maintaining themselves in their original state in the absence of catastrophic change (Pickett *et al.* 1992). The widespread adoption of the equilibrium paradigm, despite significant shortcomings, has important implications for the direction of ecological research.

For example, if natural systems tend toward stability it follows that the degree of system stability represents a benchmark state variable for the comparison of ecosystems. Stability, in this context, easily becomes a measure of ecosystem health. Those systems that are farthest from equilibrium are those which are the most degraded and hence in the "poorest health" (Walker 1992). Moreover, if systems are self-regulating ecological research need only be concerned with the outcome of ecological processes and interactions rather than the inherent characteristics of the interactions and processes themselves (Kay 1991a, 1991b; Pickett *et al.* 1992).

The influence of the equilibrium paradigm has caused numerous articles both for and against the notion of ecological stability to be written[9]. The extensive range of indicators that has been developed to empirically validate the principle of stability reflects its importance to the conduct of ecology research. Indices based on genetic variability, species richness and diversity, functional diversity (abundance of functionally different kinds of populations), ecosystem biomass, community diversity (number, size, and spatial distribution of communities), and the resistance of populations, communities and ecosystems to change, among others have been used to measure ecological stability (Hobbs and Huenneke 1992; Kay 1991a, 1991b; Pickett *et al.* 1992; Walker 1992).

However, a lack of empirical evidence supporting the equilibrium paradigm has caused the ontological assumptions behind stability research in ecology to be questioned in recent times (Kay 1991a, 1991b; Pickett *et al.* 1992; Walker 1992). This means that while the indices developed to measure ecological stability remain valid as statistics, their status as comprehensive indicators of ecosystem wellbeing is now uncertain. Nevertheless, stability measures as indicators of ecological wellbeing are still extensively

[9] For a detailed summary of this work see Kay (1991a, 1991b).

used to guide environmental management practice (Kay 1991a, 1991b; Noss 1990; Picket *et al.* 1992).

The influence of the equilibrium paradigm is also evident in the various dimensions of sustainable development research. In particular, two equilibrium related themes seem to underlie both normative and methodological approaches to sustainable development. First, there is the assumption that any landscape unit of reasonable size has the potential to be managed for sustainable development since it is implicitly assumed that the systems within it are functionally and structurally complete. Second, it is assumed that these landscapes will continue to maintain themselves if human development remains within the constraints imposed by the biosphere. Similarly, if existing development exceeds these constraints then reducing the magnitude of human disruption will once again enable ecological systems to return to their previous states. Sustainable development from this perspective is articulated as an anthropocentric problem to be resolved by the management of the resource-economy interrelationship.

Inventories and Population Studies as Management Tools

Inventories and population studies are two common sources of information used to guide environmental management practice grounded in the equilibrium paradigm (Kay 1991a). Inventories of ecosystem composition reflect the first stage of understanding any ecological context and are crucial to the provision of baseline data for subsequent indicator development. However, the implicit acceptance of the equilibrium perspective by resource managers means that inventories often represent the beginning and end of indicator development and use. Management practice is designed to maintain these inventories at a given level. Often this is at a level calculated to maintain resource yields at economic levels.

The resource accounting frameworks described in Chapter Three can be considered to be one type of advanced resource inventory designed to provide information both on resource stocks and flows. Inventories are inherently descriptive and do little on their own to help evaluate sustainable development in the wider context of ecosystem-social system interactions. By focusing on the composition of ecosystems, inventories will often fail to reveal important changes, and the reasons for these changes, in structure and function. Significant deterioration in the resource stock is often unavoidable once changes in composition large enough to be detected by the inventory process have occurred.

Population studies represent a higher level of analysis than inventories. Underlying the use of population studies for monitoring environmental change is the assumption that ecosystems are made up of populations and that by understanding population dynamics, general system dynamics can also be understood. Population studies begin with inventories but continue on to model population dynamics so that the impact of environmental change on the number of individuals within a population can be predicted. Therefore, the appropriateness of management actions is often judged in terms of changes in species numbers and the stability of populations (Kay 1991a; Magurran 1988; Noss 1990; Pickett *et al.* 1992; Walker 1992).

In this way the notion that species diversity is intimately linked to ecological stability continues to pervade the practice of environmental management (Kay 1991a; Noss 1990). While retaining diversity at the species level is part of evaluating sustainable development it is an inadequate indicator of overall resource quality at the ecosystem level (Noss 1990). The functional and structural attributes of ecosystems are neglected because of an overriding concern with ecosystem composition. While many prevailing management indices based on stability and equilibrium represent valid measurement of some ecosystem attributes, their broad application as comprehensive environmental indicators for sustainable development is questionable because of their unsubstantiated ontological precepts.

4.7.2 Nonequilibrium Perspectives

The lack of empirical support for ecological equilibrium has caused researchers to shift their research focus from system states to system processes (Kay 1991a, 1991b; Pickett *et al.* 1992; Walker 1992). Natural systems have accordingly been found to be inherently dynamic, exhibiting multiple pathways of change (Kay 1991a, 1991b). At any given point in time, systems reflect to varying degrees their initial state, prevailing and changing boundary conditions, the sequence of intra-system events, and the influence of near and far systems (Pickett *et al.* 1992).

In response to the findings of applied ecological research, new "nonequilibrium" perspectives on natural systems have emerged that attempt to overcome the ontological weaknesses of the equilibrium paradigm. The idea of equilibrium is not rejected by these paradigms, it is simply recognised as one, albeit uncommon, result of system dynamics. Also recognised by these perspectives is the open nature of natural systems. This suggests that studies of ecosystem attributes must be cognizant of the wider context of which the ecosystem is part. Perhaps more importantly, system processes, interactions and overall ecological context are emphasised rather than the final state produced by these processes.

Managing for sustainable development on the basis of nonequilibrium theory implies a need for greater emphasis on ecological processes and contexts than is traditionally acknowledged in the sustainable development literature. For example, fulfilling ethical obligations to future generations through a bequest of natural capital means that it is the processes that have created and sustained the attributes of ecological systems, and the spatial context and functional interrelationships within that context that must be conserved. In other words, the idea that ecosystems interact together to form a constantly evolving system must be implicit in the development of ecological indicators for sustainable development. Traditional approaches using techniques grounded in inventories and population studies can be a basis for indicator use in sustainable development research, but only if the relationship between data and sustainable development is made in a wider context.

Picket *et al.* (1992) conclude their paper on the implications of the nonequilibrium paradigm for conservation and management by suggesting that researchers and policy makers must be aware of: (i) Controlling system processes; (ii) the context of the system processes; (iii) the historical range of system perturbations; (iv) the evolutionary and physiological limits of system components; and (v) the characteristics and effects of short and long term phenomena.

Nonequilibrium perspectives have given rise to, or allowed, the emergence of new approaches to understanding and resolving pervasive environmental problems. Indicative of these new approaches is the use of energy systems analysis and the theory of dissipative structures to explore the problem of ecological integrity and its implications for sustainable development. The application of ecosystem approaches and landscape ecology to environmental issues also represents a major change in the direction of environmental management. The acceptance of the openness of ecosystems reflected in these developments allows for the inclusion of humans within the purview of ecological study. Anthropogenic disturbances and influences now warrant study both in their own right and as components of the structure and function of ecological systems.

Dissipative Structures and Ecological Integrity

Kay (1991a, 1991b)) draws on Prigogine's work on dissipative structures (discussed in Chapter Three, Section 3.5.3) to examine how ecosystems respond to change, and to explore the implications of ecological integrity as a concept central to indicators for sustainable development. In this context, the term "ecosystem integrity" is used to refer to the ability of a system to maintain its organisation and to continue its process of self organisation in the face of changing environmental conditions[10]. A system loses integrity only if it loses its ability to be self-organising. The compositional, structural and functional attributes of a system with integrity can change over time but its identity as a dissipative structure remains intact. Kay (1991a, p. 24) elaborates:

> "Ecosystems are not static. Their organisation is often changing, both in the short-term and in an evolutionary sense. Furthermore any loss in organisation is often gradual. Thus it is not possible to identify a single organisational state of the system that corresponds to integrity. Instead there is a range of states for which the ecosystem is considered to have integrity."

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[10] The concept of ecological integrity is becoming a subject of much discussion in the ecological literature. Other approaches to the concept do exist. For more detailed discussions of the methodological and ethical dimensions of the subject see Grumbine (1994), Karr (1993), Woodley *et al.* (1993), and Westra (1994).

According to Kay there are four major points to note in regard to ecosystem integrity and its implications for indicators for sustainable development. First, ecosystems may respond to perturbations in qualitatively different ways. They may:

- Operate as before, even though operations may be initially unsettled.
- Operate at a different level using the same dissipative structures as before (for example, with fewer species or with greater populations within species).
- Develop new structures to replace or add to existing structures (for example, new plant communities, or new paths in the food web).
- Change completely, becoming a new dissipative structure (for example, change from a forest ecosystem to a grassland system, or from grassland to desert).

Second, to be useful in the development of indicators for sustainable development, the notion of integrity must have an anthropocentric component which incorporates the preferences of society regarding ecosystem changes. Without this anthropocentric element, integrity (or sustainability) would be necessarily restricted to the ability of ecosystems to absorb environmental change without any loss of self-organisation. The inclusion of this component extends the definition of loss of integrity to include undesirable changes in ecosystems.

Third, and related to two, a new ecosystem "operating point" exhibiting wanted compositional, structural and compositional attributes may be preferred by society to a prior operating point. Under some circumstances society may be willing to accept some degradation (i.e., loss of integrity) of ecosystems to allow others to expand (for example, the conversion of forest lands to grasslands). Finally, environmental change may influence an ecosystems' response to future environmental change, even though the present change has no immediate effect on the ecosystem.

Characterising the sustainability of systems in this way has several implications for the creation and use of indicators for sustainable development. For example, if sustainability is defined in terms of the ability of a system to be self-organising thereby allowing for potentially different orders of system composition, structure and function, the meaning of which can then be ascribed to measures of these attributes is limited. Similarly, using energy flows to examine the thermodynamic state of a dissipative structure is of little evaluative importance in this context if systems can move freely between different thermodynamic equilibria and still maintain their integrity. Moreover, the ecological justification for maintaining a constant resource stock as a condition for sustainable development is also diminished.

It is only with the addition of human preferences that such measures gain relevance as indicators for sustainable development, and then only in terms of the "evaluation" of one system state over another. It is therefore likely that collective social preferences regarding desirable system attributes and their contribution to human wellbeing will constrain the nature and magnitude of development before more fundamental ecosystem integrity (defined in terms of dissipative structures) becomes an issue. This may be especially apparent at moderate to large spatial scales.

This explicit anthropocentric dimension of sustainable development suggests the need for an integration of social and ecological perspectives that goes beyond the simple linkage of economic and ecological systems. In the context of sustainable development, human value systems must be inculcated within the study of ecological systems. Researchers within mainstream disciplines are therefore often ill equipped for the task of developing indicators for sustainable development. The ontological inflexibility of both traditional ecology and neoclassical economics hinders the crossover of concepts required for this integration.

This means that the solution to finding both appropriate environmental indicators for sustainable development, and to integrating these with social indicators, may have to be found within alternative paradigms. Ecosystem approaches and landscape ecology are two ecologically based disciplines that have the potential to provide the necessary ontological basis for this task. Geography's spatial perspective provides a means to synthesise this basis with more traditional ecological and economic perspectives.

Ecosystem Approaches

"An ecosystem approach adopts a holistic, systems perspective, focused on interactions, through an ecological approach to patterns of structure and change" Slocombe (1992b, p.1). Ecosystem approaches differ from mainstream ecological science in that they seek to place the system of interest in a larger systemic context. They do this in two ways. First, they define the ecosystem as the unit of study and second, they apply ecological principles and analysis beyond the boundaries of mainstream ecology. Thus, rather than restricting the concept of an ecosystem to the community level[11] they conceptualise the ecosystem more holistically (Grumbine 1994). Commonly, this involves consideration of regional landscapes such as bio-regions or water sheds. At this level of spatial complexity the study of interacting ecological and human systems is also facilitated.

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11 Ecological science has tended to focus on studying communities of organisms and their interactions with one another and the physical environment (Slocombe 1992a). Studies of structure and function have also tended to be carried out at the community level of system organisation (Noss 1990).

Such is the appeal of ecosystem approaches, a number of disciplines have research traditions which adopt to a varying degree the idea of studying systems within the wider ecosystemic context as part of their ontology. Slocombe (1992a) points out that human ecology, anthropology, and psychology, with their main emphases on cultural and socioeconomic factors, all contain research schools that adopt ecosystem approaches as modes of enquiry. Each variant seeks to explain the structure and functioning of society and individuals in terms of their wider surroundings.

Ecosystem approaches do not appear to offer any significant advantages over traditional ecosystem science with regard to the development of actual environmental indicators for sustainable development. However, a number of characteristics of ecosystem approaches appear favourable for providing a potential ontological basis for linking ecological and social indicators. First, they offer a pluralistic perspective which is complementary to the task of integrating the ecological and socioeconomic dimensions of sustainable development. Second, compared with the reductionist ontologies of ecological science and economics, their broader conceptualisation of the ecosystem gives rise to a temporal and spatial scale better suited to the empirical study of ecosystem-socioeconomic system interactions. Third, they explicitly seek to understand the structure, functions and dynamics of interacting systems. Finally, they have the potential to provide an integrated framework for research, analysis, and planning fulfilling both a descriptive and heuristic role.

Nevertheless, ecosystem approaches are not without their problems (Slocombe 1992a, 1992b; Kay 1991a). Some research traditions do not consider the systems approach to the study of ecosystems to be valid research. Kay (1991a) reports that most granting agencies such as the Natural Sciences and Engineering Research Council do not fund ecosystem studies and that many scientific journals will not publish the results of such studies. There are a number of reasons for this widespread rejection. First, ecosystem approaches are seen as too general, overlapping the research carried out by other disciplines. Second, they can resemble environmental determinism when used as a basis for social theory. Third, they generalise from ecological systems to socioeconomic systems, thereby minimising the importance of the power and social relationships in determining the magnitude and nature of social-environmental interrelationships. Also, they are often regarded as overly qualitative, relying on analogy and comparison. Thus, although conceptually interesting, these approaches appear to have little empirical application.

Despite these limitations, ecosystem approaches represent an alternative conceptualisation of human-environment interaction. They build on the strength and experience of past research. For example, existing disciplines already provide for an understanding of the organisation and functioning of ecological systems, and also contribute methods for the collection and analysis of environmental data. At the same time, ecosystem approaches promote a more appropriate context for the use and integration of this information for the assessment of sustainable development. Slocombe (1992a) comments:

> "Ecosystem approaches can facilitate studies which integrate knowledge from a range of disciplines about an area or society or person, they encourage recognition of complexity, change and the need to adapt to and anticipate it. They promote an appreciation of people's place within rather than separate from nature, and they promote involvement of people in surveys, analysis and plans."

Landscape Ecology

The term "landscape" refers to "a mosaic of heterogeneous landforms, vegetation types, and land uses" (Noss 1990, p. 358). Landscape ecology has been characterised as a "dynamic integrative field of environmental science" (Naveh 1991, p.66). It represents a juncture of related disciplines that centres on the spatial and temporal patterns of landscape (Risser 1987). The subject of study of landscape ecology has been variously described as the variability of ecosystems (Pickett *et al.* 1992; Turner 1989), the vertical and horizontal heterogeneity within landscapes (Risser *et al.* 1984), or as the study of land and landscape, its form, function and genesis (Zonneveld 1988). Despite such a diversity of perspectives, landscape ecology can be seen to centre on a fundamental idea: the holistic view of landscape as an ecosystem (Zonneveld 1988).

The origin of landscape ecology can be traced back to work of Troll, a German geographer active from the late 1930s to the early 1970s (Rowe 1988; Turner 1989; Zonneveld 1988). Zonneveld (1988) suggests that Troll was impressed by the emerging concept of the ecosystem, and by the comprehensive view of landscape as revealed in the new field of airphoto interpretation. The foundations of landscape ecology are therefore considered to be a blend of the European tradition of regional geography and vegetation science, and more recent ecosystem approaches (Zonneveld 1988).

More recently, landscape ecology has benefited from the input of many disciplines (Turner 1989). Economists and geographers have provided many of the methodological tools necessary to link pattern and process at various spatial scales (e.g., Costanza 1991; Isard 1975; Nijkamp 1977a, 1979, 1980, 1991). Ecologists have provided information regarding ecosystem interactions (e.g., Hobbs and Huenneke 1992;

Middleton 1988; Noss 1983, 1989, 1992; Pickett *et al.* 1992; Stenseth 1992), while planners have integrated landscape ecology into land use planning and decision making (e.g., Naveh and Liberman 1990; Turner 1989).

Contemporary landscape ecology exhibits a philosophical dimension and an applied dimension that are often difficult to separate. Both stem from the supposition that a specific landscape is a holistic entity, including all its heterogeneous components (Zonneveld 1988; Naveh 1991). The philosophical dimension perceives:

> "...land as a holistic entity that must be considered, studied and treated (managed) as a system and which cannot, without danger to humans themselves, be treated or studied in pieces." (Zonneveld 1988, p.9).

Naveh (1991, p.66.) also writes in regard to the position of humans within the landscape:

> "...man (sic) cannot be merely be treated as an external disturbance factor of natural ecosystems. He is to be recognised as an interacting and co-evolutionary ecosystem component who has added... newly emerging structural and functional qualities to these natural ecosystems. ...these non-summative qualities are not derived from the biosphere, but from the 'noosphere'- the sphere of human mind and consciousness."

However, as Zonneveld (1988 p. 9) suggests, it is just a small step from general philosophy to ideology and religious fervour, and that practitioners "should carefully exclude such an approach when discussing methodological problems in landscape ecology."

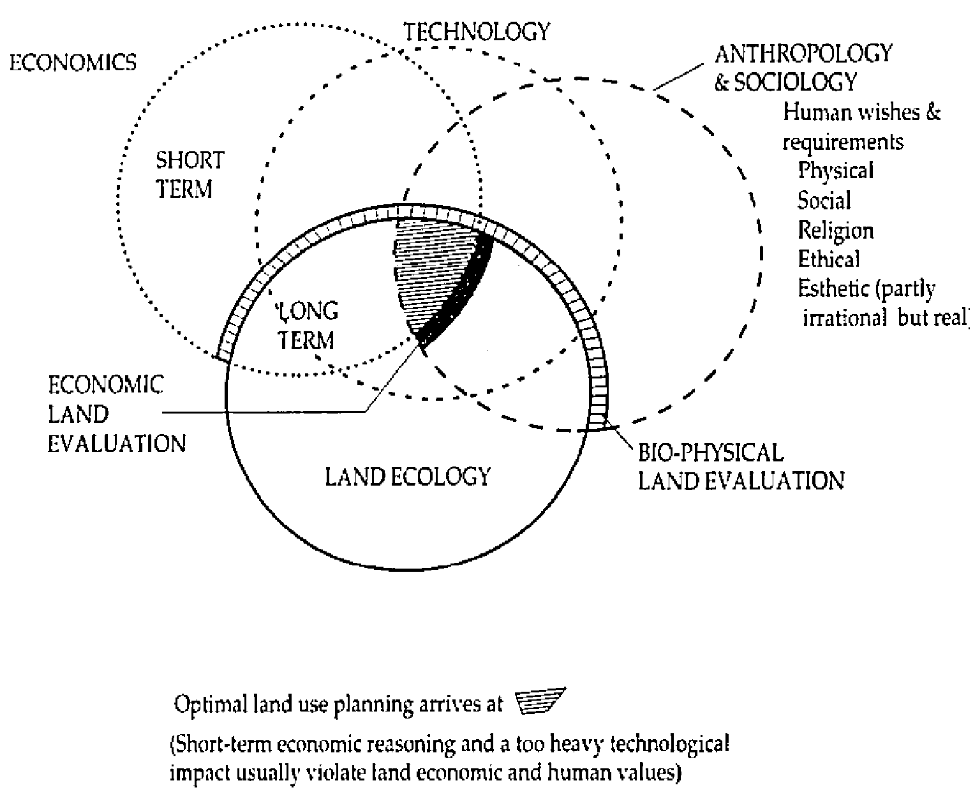
Three main research avenues characterise the methodological dimension of landscape ecology (Naveh 1988, 1991; Rowe 1988; Zonneveld 1988). The first is the study of the visual aspect of the landscape, combining an aesthetic tradition with landscape interpretation. The second approach is the study of the horizontal heterogeneity (chorologic aspect) of landscapes. This involves the study of the spatial heterogeneity of landscape mosaics including the nature, distribution and abundance of patches, dynamics of patches, and the near and far interaction of patches (Forman and Godron 1986). The third research strategy focuses on the vertical heterogeneity (topologic aspect) of landscapes and combines elements of the preceding research areas.

The topologic aspect of landscape can be viewed as a four dimensional phenomena incorporating all the physical, biological, and human factors acting on the earths surface and their change over time. It includes both a horizontal pattern of mutually related land elements and a vertical strata of interrelated land attributes. These attributes include atmosphere and climate, landforms, soil, water, fauna, vegetation, and the noospheric aspects of humans (Zonneveld 1983, 1988). It differs from other ecological studies in that biology is not the dominant discipline but is of equal importance with each of the others.

Significantly, the topologic approach addresses the same spatial and temporal aspects of landscape that are fundamental to resource analysis, management, and evaluation. Figure 4.2 shows the interplay of different disciplines involved in topological analysis. It addresses the structures, functions and changes that characterise the co-evolutionary development of landscapes, and provides a methodological basis for the measurement of these attributes (Forman and Godron 1986; Risser *et al.* 1984; Turner 1989).

Structural analysis attempts to measure the extent of relationships between ecosystems, incorporating such elements as the distribution of energy, materials, and species in relation to the size, shapes, numbers, kinds and configurations of components.

Figure 4.2 The Interplay of Disciplines Involved in Landscape Assessment for Environmental Planning



Source: Adapted from Zonneveld (1988, p.12)

The measurement of function involves estimating the nature and magnitude of interactions between the spatial elements of the landscape including energy, material and organism flows. Estimations of change attempt to record the transformation of landscape through time (Turner 1989).

More so than general ecosystem approaches, landscape ecology has the potential as a perspective from which to develop ecological indicators for sustainable development. It allows for the explicit recognition of interrelationships between and within ecological and socioeconomic systems and also of the extended time horizons implied by sustainable development. There are also methodologies in place for measuring the relevant attributes of these systems. Moreover, the spatial dimension provides an effective avenue for the integration of the diverse ecological and socioeconomic information needed to carry out sustainable development-related analysis.

4.7.3 Landscapes and Ecological Indicators for Sustainable Development Research

The Issue of Scale

Landscapes can be characterised and analysed at different spatial and temporal scales. As such, the measurement of landscape attributes like composition, structure, and function and their change over time is inherently scale dependent (Turner 1990). Significantly, an analysis of landscape structure and function may produce contrasting results at different spatial and temporal scales. A landscape may exhibit equilibrium properties at one particular spatial and temporal scale but show nonequilibrium properties at another combination of time and space.

Human observation of landscape attributes is similarly dependent on scale. The spatial and temporal scales at which researchers perceive landscape composition may have little relevance to actual landscape structure and function (King 1993). Also, processes and constraints on development at one scale may not be as important or indicative of sustainable development at another scale. For instance, local level variations in environmental quality might be explained by the degree of human exploitation of the environment, whereas at a regional or global scale, wider climatic, ecological and geophysical variables may explain variations in environmental quality. Indicators of structure and function must therefore be used with an acute awareness of spatial and temporal scale. This is even more important in sustainable development research because effectively addressing multiple objectives, inputs and constraints requires consideration of varying spatial and temporal scales.

Characterising Landscape Attributes

The spatial patterns of landscapes reflect complex interactions between physical, biological and social processes (Forman and Godron 1986). This spatial patterning is a unique phenomenon that only emerges at the landscape level (Turner 1989). In some cases the landscape pattern is dominated by natural processes. In others, human land use practices predominate so that the resulting landscape is a result of interactions between the social, political, and economic processes controlling land use and management practices, and underlying physical and biological processes. Since most landscapes have been influenced by human use, an observed regional landscape mosaic can be interpreted in terms of a mixture of natural and human made structures that vary in size, shape, arrangement and function.

Identifying and quantifying the spatial characteristics of landscape may provide a possible basis for developing environmental indicators that are appropriate for sustainable development research. Such measures will be an abstraction of the spatial manifestation of the interactions between social and ecological processes. They will tend to be responsive to differing environmental contexts and reflect both a resource quantity and quality component. Also, analysis at the regional level represents a logical mechanism for linking physical, biological and social variables used as objectives, inputs, and constraints in resource assessment for sustainable development.

Various methods have been developed to quantify landscape patterns[12]. Measures associated these methods can be used to compare landscapes across regions and through time, identify change, and relate landscape patterns to ecological and social functions (Turner 1989; Turner and Gardner 1990). Table 4.2 contains several measures that have been used in empirical research relating to landscape structure and function.

For example, a study of the fire history of the subalpine zone in Yellowstone National Park used several indices to examine fire induced changes in landscape structure and diversity (Romme and Knight 1982). An examination of time sequenced landscape richness and patchiness indexes suggested that the park ecosystem is a dynamic system characterised by long term cyclic changes in landscape composition and diversity. The study concluded that fire induced changes in landscape diversity had beneficial effects on species diversity, habitat variety and nutrient cycling processes.

The complexity of landscapes has been examined using fractal geometry (Milne 1990; O'Neill *et al.* 1988; Turner 1989; Turner and Ruscher 1988). Fractal geometry examines shapes that are partially correlated over many scales (Turner 1989). Quantifying shapes and boundaries in the landscape provides a measure of spatial complexity. It has been suggested that landscapes influenced by humans exhibit simpler

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[12] For a detailed review of these measures see among others, Turner (1989) and Turner and Gardner (1990).

Table 4.2 Landscape Level Measures of Spatial Pattern

Measure	Equation	Conditions
Relative Richness (R)	$R = \frac{s}{s_{max}} \times 100$	s = number of different habitats present. s_{max} = maximum number of habitats possible.
Relative Patchiness (P)	$P = \frac{\sum_{i=1}^{N} D_i}{N} \times 100$	N = number of boudaries between adjacent cells. D_i = disimilarity value for the i^{th} boundary between adjacent cells.
Diversity (H)	$H = -\sum_{k=1}^{s} (P_k)\ln(P_k)$	P_k = the proportion of the landscape in habitat k. s = the number of habitats observed.
Dominance (D_o)	$D_o = H_{max} + \sum_{k=1}^{s} (P_k)\ln(P_k)$	s = the number of habitats observed P_k = the proportion of the landscape in habitat k. H_{max} = In (s), the maximum diversity when habitats occur in equal proportions.
Fractal dimension (d)	$\log(A) \sim d \log(P)$	A = area of a two dimensional patch. P = perimeter of the patch at a particular length-scale. d = the fractal dimension.
Nearest neighbour probabilities (q)	$q_{ij} = n_{ij} / n_i$	n_{ij} = the number of cells of type i adjacent to type j. n_i = the number of cells of type i
Contagion (C)	$C = 2\ s\ \log s + \sum_{i=1}^{m} \sum_{j=1}^{n} q_{ij} \log q_{ij}$	q_{ij} = the probability of habitat i being adjacent to habitat j. s = the number of habitat observed.
Edges (E)	$E_{ij} = \sum e_{ij} \times l$	e_{ij} = the number of horizontal and vertical interfaces between cells of types i and j l = the length of the edge of a cell

Source: Turner (1989, p. 176)

patterns than natural landscapes, as measured by fractal dimension (O'Neill *et al.* 1988; Turner and Ruscher 1988). It is further argued that landscapes influenced by natural rather than human disturbances tend to exhibit greater spatial and temporal complexity (Turner and Ruscher 1988).

O'Neill *et al.* (1988) employed three complementary landscape indexes (dominance, contagion, and fractal dimension) to discriminate between major landscape types in the eastern United States. Using complementary indexes enabled information at different spatial scales to be collected. Indexes of dominance and fractal dimension reflected broad scale patterns, while the contagion index reflected fine scale landscape attributes incorporating the adjacency of different habitats. Turner (1989) suggests that this type of scale sensitivity may prove useful in selecting measures of pattern that can be measured through time and that can be related to different processes. Other measures of landscape structure listed in Table 4.2 include measures of edge and adjacency that reflect the degree of landscape fragmentation. These indices can also be used to link pattern with process.

Relating Landscape Patterns to Sustainable Development

Measures of landscape structure have limited use as indicators unless they are given predictive powers through the linkage of system structure to system process. A substantial amount of ecological research on landscapes is therefore concerned with determining the relationship between landscape pattern and ecological process. A range of different models have been developed to relate pattern to process and vice-versa (Turner and Gardner 1990).

"Neutral" models[13] have been used to test the relationship between landscape patterns and ecological processes (Gardner *et al* 1987; Gardner and O'Neill 1990). Neutral models attempt to reduce the analytical complexity associated with linking fine scale processes to broad scale patterns. They do this by evaluating the usefulness of fine scale detail in explaining broad scale patterns. If broad scale patterns can be predicted adequately with a minimum of fine scale detail, there is little reason to postulate additional complexity (Gardner and O'Neill 1990). Neutral models can thus be used as baseline from which to measure improvements in predicting landscape patterns when additional ecological processes are included (Turner 1989). It is also possible to predict expected patterns of other ecological occurrences, such as the spatial distribution of wildlife using a neutral model approach (Milne *et al.* 1989).

Biocybernetic principles and related isomorphic models have also been used extensively in landscape ecology. One of their main uses has been to link ecological process with land use and ecological planning (Naveh 1988, 1991; Naveh and Liberman 1990). An extension of information theory, biocybernetics is a theory of regulation and organisation in biological and ecological systems. Systems are considered to be self-organising because of the presence of positive and negative feedback loops. Positive deviations are amplified and negative deviations are reduced within systems. The advantage of using cybernetic rules and models stems from their capacity to explicitly address complex interrelated physical, biological, and economic processes that are governed by mutually and causally related negative and positive feedback loops (Naveh 1988). Cybernetics has many elements in common with the coevolutionary perspective discussed in Chapter Two and energy systems analysis outlined in Chapter Three.

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[13] An expected pattern in the absence of process is termed a neutral model (Gardner *et al* 1987; Turner 1989).

Both neutral models and cybernetic theory represent an attempt to create a unified theoretical and methodological framework for a transdisciplinary science that is orientated to both problem inquiry and problem solving (Naveh 1991). Such an approach is intended to overcome many of the disciplinary barriers that prevent the linkage of formal quantitative approaches with informal qualitative approaches (Naveh 1988). But, as with ecosystem approaches in general, landscape measures neglect several fundamental determinants of the nature and evolution of social system-ecosystem interactions.

Landscape ecology minimises the role of human agency and social structure in determining the political process through which the environment is managed. It ignores issues such as the relationship between knowledge and power, which is fundamental to the determination of dominant world views regarding environment and resources. There is also little scope to examine the trade-offs between socioeconomic and ecological constraints on human development unless there exists an identifiable spatial component to the trade-offs. Moreover, the search for a metatheory of landscape structure and process may be contrary to the pluralistic and holistic perspective required to effectively deal with sustainable development issues.

These limitations suggest that the methodologies of landscape ecology are incomplete mechanisms for linking the social and environmental components of sustainable development. Instead, it is the landscape level of analysis inherent to landscape ecology and attendant measures of landscape structure, that has considerable potential as a basis for developing environmental indicators relevant to sustainable development. The landscape level of analysis provides an appropriate scale at which to integrate the multiple and often conflicting determinants of sustainable development, that occur at different levels of social and ecological organisation.

Hierarchy theory suggests that higher levels of ecological and social organisation incorporate and constrain the behaviour of lower levels (King 1993; Noss 1990; 1992; O'Neill *et al.* 1988; Sklar and Costanza 1990). If development practices alter landscape structure, processes and structures at lower levels of system organisation (e.g., community-ecosystem and population-species) will also be affected. Hence, regional level processes such as resource over-exploitation and degradation can be seen to impose fundamental constraints on efforts to achieve sustainable development.

The importance attributable to higher order constraints does not mean however that lower order processes can be ignored by sustainable development research. Lower levels of ecological and socioeconomic organisation contain many elements basic to sustainability. They are also the level at which the processes that give rise to higher level structures operate. Nevertheless, for the purposes of resource assessment and environmental decision making, indicators developed at the landscape level may prove to be more widely applicable than indicators developed at lower levels of organisation. Where landscape level indicators prove inappropriate or are not relevant to a particular social or ecological context, indicators developed at lower levels of social and ecological organisation can be substituted.

Thus, landscape level measures can fulfill three potential roles as environmental indicators for sustainable development resource assessment and environmental planning. First, measures of landscape attributes can be used as indicators of resource stocks. The interactions of co-evolving social and ecological systems will give rise to identifiable and measurable landscape structures. Measurement of these structures using relevant landscape indices can subsequently be used as indicators of resource stocks and natural capital.

For instance, the landscape diversity measure presented in Table 4.2 could be used as an aggregate indicator of a regions resource stock. It represents both the proportion of the landscape in a particular habitat (e.g., virgin coastal forest) and the total number of habitats in the region (e.g., coastal, montane, alpine, etc.). It should also prove possible to modify such measures to explicitly account for other resource use and land use practices. For example, the diversity index could be adapted to include other resource stocks not traditionally included within ecologically orientated landscape measures. Non-renewable resources are an additional stock of special interest to sustainability-related analysis. Such a resource diversity index would make the landscape elements that contribute directly to human wellbeing more explicit (through consumptive and non-consumptive resource flows), as well as the larger set of inherent landscape elements that contribute to a regions potential for sustainable development.

Second, the integration of environmental indicators and indicators of human development is facilitated by using landscape level measures. Activities which provide basic human needs, income, and/or contribute in some other manner to wellbeing can be directly and indirectly linked to landscape measures of resource stocks. In this way landscape level indicators can act as inputs to, constraints on, and objectives for sustainability-related resource assessment and environmental planning. Maintaining self-sufficiency in food production for a rural third world community may require a planning objective that establishes the spatial extent of land to be used for agriculture. At the same time, constraints may be imposed on the extent of agricultural land by the need to maintain fuel-wood supplies, and by the need to preserve remaining forest land in accordance with international protocols. Cultural preferences regarding food types, land ownership arrangements, and the extent of contact with other regions can serve as inputs to the assessment and planning process, helping to refine objectives and constraints.

Third, the spatial dimension provides a means to inculcate human values with the study of ecological systems. Without the incorporation of human preferences regarding different system states, the notion of sustainability is necessarily restricted to the maintenance of system self-organisation. The expression of human preferences in terms of the choice of one system state over another (e.g., old growth versus managed forest) is fundamental to the analysis of sustainable development. This choice, involving various trade-offs between welfare, natural capital, and intergenerational equity is based on an evaluation of the consumptive and contributory flows provided by different system states.

Employment generation, timber volumes, aesthetic values, wildlife habitat, and recreational potential are among the contributory and consumptive flows that can be ascribed to forested landscapes of the Pacific Northwest. Monetary values or preference based weights, reflecting societal preferences, can be assigned to these landscape attributes. Preferred system states and their spatial manifestation can then be evaluated in the wider context of the ecological and socioeconomic constraints implied by sustainable development. For example, development that reduces landscape diversity for the next generation may violate the sustainable development constraint of intergenerational equity. Significant reductions in landscape diversity may also lead to the violation of ecological constraints on human development.

4.8 Indicator Selection for Sustainable Development

Table 4.3 is a compilation of some potential measures of physical, biological and social system attributes arranged in a three level hierarchy. These measures indicate the range of indicators that could be used either individually or collectively in the creation of context specific welfare and environmental profiles for the purpose of resource assessment and environmental planning. The categories in the table are not mutually exclusive and the distinctions between them are somewhat arbitrary. The Table is intended to be illustrative of the way in which diverse measures of multiple system attributes can be assembled together in a reasonably coherent manner. The structure of the Table is useful both as a framework for selecting indicators relevant to sustainable development, and more fundamentally as a list of attributes and measurement levels to consider in evaluating different indicator choices.

The selection of specific indicators to represent the different components of sustainable development is a problem not easily resolved. Developing a list of widely applicable indicators for sustainable development is not feasible because of the varying ecological and socioeconomic contexts of human development. Attempts to develop universal indicators tend to rely on reductionist ontologies (e.g., neoclassical economics, equilibrium ecology) that over simplify the problem at hand, or on broad spatial scales (e.g., loss of atmospheric ozone, global extinction rates, or tropical deforestation) that have global rather than regional significance. The opportunities to apply such indicators to real world development issues is limited because of their ontological limitations and lack of spatial specificity. The choice of appropriate indicators will therefore be a compromise based on a number of factors including ecological and socioeconomic context, ontological perspective, the ease with which a variable can be incorporated into a particular assessment methodology, and the degree of relevancy to the conditions required for sustainable development.

Table 4.3 A Hierarchical Structure[14] for Developing Indicators for Sustainable Development

Level	System Attributes		
	Composition	Structure	Function
Landscape/ Land use	Landscape identity, distribution, and proportions of landscape types; collective patterns of landscape distribution.	Landscape heterogeneity; spatial linkages; fragmentation; perimeter-area ratios.	Natural and human disturbance processes (areal extent; frequency, rotation, intensity)*; consumptive flows; non-consumptive flows; energy flows; nutrient cycling; hydrologic processes.
Community/ Ecosystem/ Economy	Identity, relative abundance, frequency and diversity of physical, biological and economic system components; ambient levels of environmental quality.	Slope and aspect; vegetation biomass; abundance, density, and distribution of key landscape physical features and structural elements; water resource availability; identity and distribution of key economic sectors (employment, output, wages)* and social structures (justice, health, education, government); participation rates in formal and informal economic sectors; self sufficiency.	Biomass, resource and economic productivity*; fine scale ecological dynamics; wilderness to managed and rural to urban land conversion rates; inter and intra-sectoral economic-ecological flows; PQLI; ELL.
Species/ Population	Information regarding the absolute and relative frequencies of human populations and other species.	Population structure (age and gender ratios, life expectancy, urban rural growth differentials); access to shelter, food, and freshwater; basic needs attainment (education, health sanitation); self sufficiency.	Demographic processes (birth rates, death rates, causes of death; infant mortality; migration); population growth and decline.

* These or similar indicators are used in the case study contained in Chapter Five.

[14] The variables in this table are indicative of the types of physical, biological, and social attributes occurring at particular levels in the suggested indicator hierarchy.

Three points regarding the choice of actual indicators for sustainable development deserve emphasis. First, the question of what is being indicated and why, is fundamental to selecting appropriate variables. For example, as part of the present research, selected measures of ecological and socioeconomic system attributes are intended to be used as objectives, constraints and inputs to a multi-dimensional planning framework. The purpose of this approach is to examine the relationship between the ecological and social requirements for sustainable development and their implications for resource assessment and environmental planning. The selection criteria associated with indicator choice for this purpose will be very different from those associated with the sustainability-related study of the thermodynamic implications of self-organising systems.

Second, the selection of indicators requires the determination of relevant policy and management questions. These questions can only be formulated within specific development contexts. For example, the expression of ecological constraints on development, non-declining welfare, and intergenerational equity will be very different in a developed region with a high degree of social integration with the formal economy, compared with a developing region where a substantial amount of production and consumption is subsistence based. In the former case the income approach to welfare indicators may be appropriate, whereas in the latter case a social indicator/basic needs approach may be warranted.

Third, an approach to the integration of diverse social and environmental indicators must be found. This issue is especially important if the trade-offs between these measures are to be examined. Lists of environmental and social variables are of little use in meaningful (socially relevant) sustainability research and analysis if the linkages between them cannot be articulated. This requires that the functional relationships between and within society, economy, and environment that determine the sustainability of human social systems be made explicit before indicator selection begins. More immediately, it involves consideration of the appropriate level of system organisation and spatial scale at which the measurement of system attributes is to occur.

4.9 Conclusion

Success in applying the concept of sustainable development to real world policy and regulatory issues will depend to a large extent on the selection of appropriate environmental and social indicators. The issue of selecting appropriate indicators is not only germane to sustainable development research. It is, however, complicated by the need to both measure the diverse attributes of ecological and socioeconomic systems, and to integrate them in a meaningful way. Exploring the dilemma that this creates has been the focus of this Chapter.

No single approach to developing indicators for sustainable development appears to yield appropriate measures in all ecological and socioeconomic contexts. It is therefore important to explore a broad spectrum of approaches to indicator development. It is necessary for researchers to understand how indicators can be used, and to realise that development related social and ecological processes operate at multiple scales and levels of organisation. Increased understanding of the way in which systems operate has removed the justification for over-simplistic treatment. Experience suggests that a narrow ontological focus grounded within individual paradigms has had unfortunate consequences for the outcome of socioeconomic system-ecosystem interactions. However, it may prove impossible to resolve all the problems associated with developing social and environmental indicators for sustainable development.

Nevertheless, it is still possible to focus on the development of indicator frameworks that accommodate rather than arbitrarily resolve difficult measurement issues. For example, it was argued in parts of this Chapter that despite the importance of the ecological dimension of sustainable development, it is still fundamentally an anthropocentric concept. Hence, for sustainable development research, human values and preferences have to be inculcated within the study of ecological systems. The necessary integration of social and ecological dimensions in different development contexts is aided by adopting a hierarchical spatial perspective based on landscape level measurements of ecological and development/social attributes. Measures of landscape attributes can be used as indicators of resource stocks. The necessary integration of environmental indicators and indicators of human development is also facilitated by using landscape level measures. Moreover, the spatial dimension provides a means with which to inculcate human values with the study of ecological systems.

Chapter Five

Resource Assessment for Sustainable Development: The Case of Clayoquot Sound

5.1 Introduction

In this Chapter a sustainable development planning case study will be presented for Clayoquot Sound, Vancouver Island, British Columbia. The purpose of the case study is twofold. Its primary intent is to act as vehicle to draw together the concepts, methods, and measurement procedures described in the previous Chapters and demonstrate how they can be applied to a real-world sustainable development planning problem. its secondary purpose is to generate information on the regional implications of sustainable development and several regional land use plans for Clayoquot Sound.

Clayoquot Sound is a region where resource extraction industries, especially forestry, can dramatically change a landscape. Development planning for Clayoquot Sound is characterised by both environmental problems and economic and social concerns. Its timber resources are extensive and their exploitation is a significant component of the regional economy. However, the regional landscape also provides for substantial non-consumptive opportunities including tourism, hiking, boating and other recreational activities. The region has considerable ecological significance, and its resources are essential to the cultural and economic prosperity of its indigenous peoples.

Much attention has been paid to the problem of utilising the Clayoquot Sound landscape in a sustainable manner. Two steering committees have succeeded in generating much socioeconomic and some ecological data, but have been largely unsuccessful in resolving the issue of sustainable resource use. A compromise land use plan for the region, developed by the Province of British Columbia after consensus based planning initiatives failed, is surrounded by controversy. These planning efforts serve to demonstrate the unsatisfactory outcome of intervention and policy which is partial and opportunistic and lacking in substantive conceptual and methodological underpinnings.

Needed is a more systematic approach to environmental and development planning in general, and sustainable development in particular. Such an approach should provide direction in selecting appropriate concepts to delimit the scope of analysis, provide for methods of analysis that, as far is possible, allow for the assessment of alternative courses of action, and finally, guide the selection of appropriate variables to act as inputs, objectives, and constraints to the analysis. The preceding chapters of this dissertation provide the basis for such a framework.

The way in which applied sustainable development research is carried out will depend on prevailing ecological, social, economic and institutional contexts. Moreover, it will be constrained by the quantity and quality of data available to the researcher. For these reasons it is unlikely that any single case study will contain all of the conceptual and methodological elements described in previous chapters. The methodologies and conceptual components adopted in the Clayoquot Sound case study are thus intended to be indicative of the type of multi-dimensional approach that may have utility for a number of sustainable development planning initiatives.

Figure 5.1 The Structure of Chapter Five

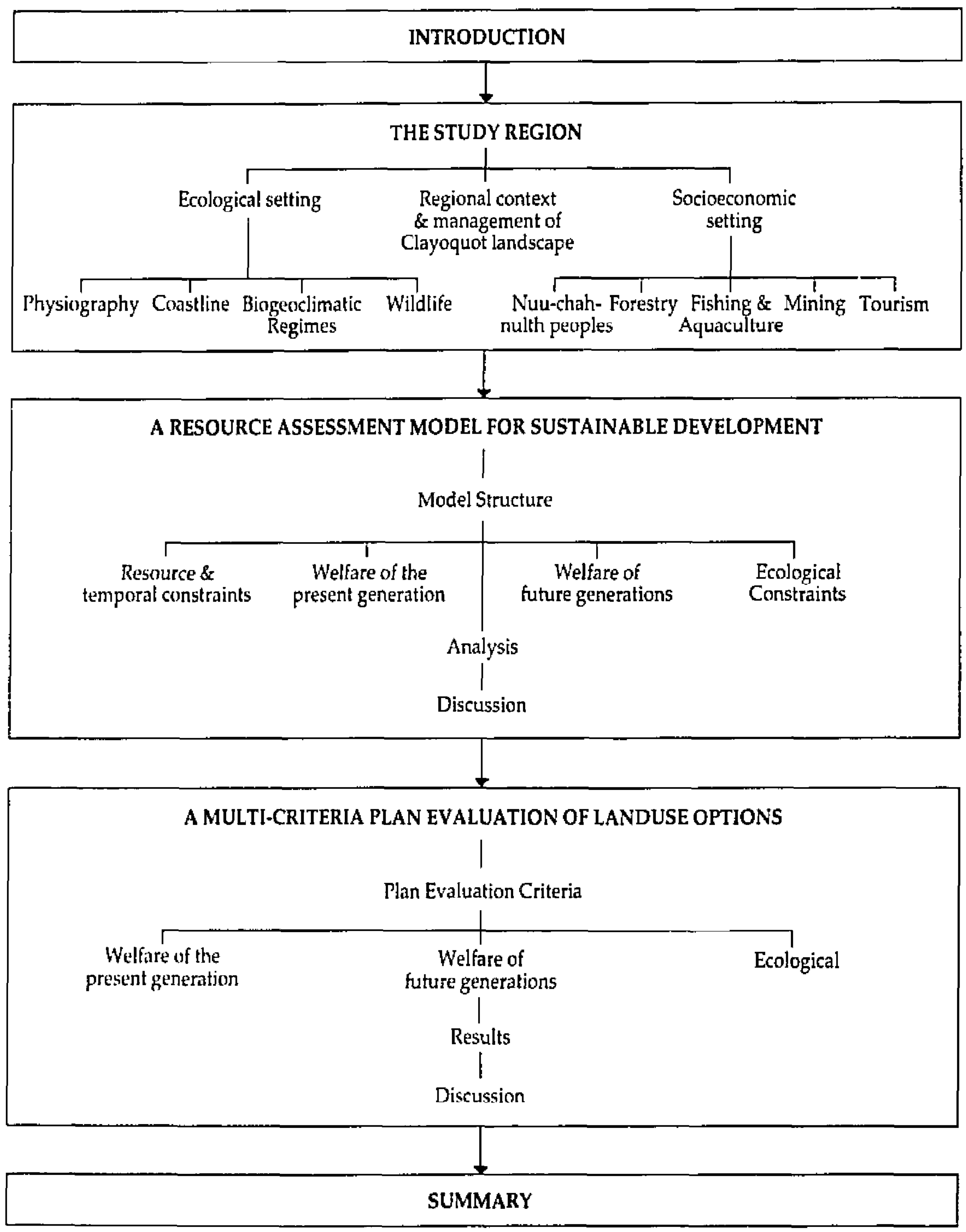

Figure 5.1 outlines the Chapter's structure. The next section describes the general ecological and socioeconomic characteristics of the study region. These characteristics are explored in some detail for two reasons: First, the current land use plan for Clayoquot Sound is one of the foremost environmental issues in British Columbia at the present time. Second, although only indicative, the case study needs to adequately reflect the environmental, social, and economic issues involved. This can only achieved through a review of the region's ecological, social and economic structure.

A simple dynamic optimisation model is presented in Section 5.3. The model is intended to determine what potential allocations of Clayoquot Sound resources conform to a set of objectives and constraints consistent with the concept of sustainable development. The objective function of the model is to maximise the wellbeing of the present generation (intragenerational concept) subject to biophysical and intergenerational welfare constraints. Relaxing or changing the constraint set allows a series of what if questions relating to levels of resource use and intergenerational wellbeing to be explored.

Within the programming model the landscape level of analysis is used to facilitate integration of the social and ecological dimensions of the planning problem. Human disturbance processes at the landscape level (logging) generate resource flows that create measures of human wellbeing (employment) at the community and population level. In turn, the decisions by the present generation as to the nature and quantity of current landscape/resource uses impacts future levels of community and population wellbeing as well as environmental potentials.

A multi-criteria analysis of various land use options proposed for Clayoquot Sound is presented in Section 5.4. The multi-criteria analysis is based on the evamix solution algorithm described in Chapter Three. A form of the simple dynamic optimisation model described in Section 5.3 is used to simulate the resource implications of the land use options. Within the evamix analysis this information is combined with additional qualitative information to determine the best land use options for alternative sets of criteria weights. The ability of the evamix routine to incorporate additional qualitative criteria consistent with the intergenerational, intragenerational, and ecological dimensions of sustainable development, combined with the continuous nature of the programming model, results in the creation of a powerful heuristic tool for sustainable development related resource assessment and environmental planning.

5.2 The Region

The Clayoquot Sound study area extends along the west coast of Vancouver Island between Escalante Point in the north and Quisitis Point in the south (Figure 5.2). The area covers some 350,000 hectares, of which 78 per cent is land, and 22 per cent is water (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Its resources are diverse and include: significant concentrations of metals (gold, copper, zinc) and industrial (limestone, sand, gravel) materials, important fisheries for both Native and non-native peoples, large tracts of virgin forest, areas of high scenic quality and very high recreational potential, and areas of outstanding conservation value consisting of diverse marine, freshwater, and terrestrial ecosystems. Administratively, Clayoquot Sound is part of the Regional District of Alberni-Clayoquot.

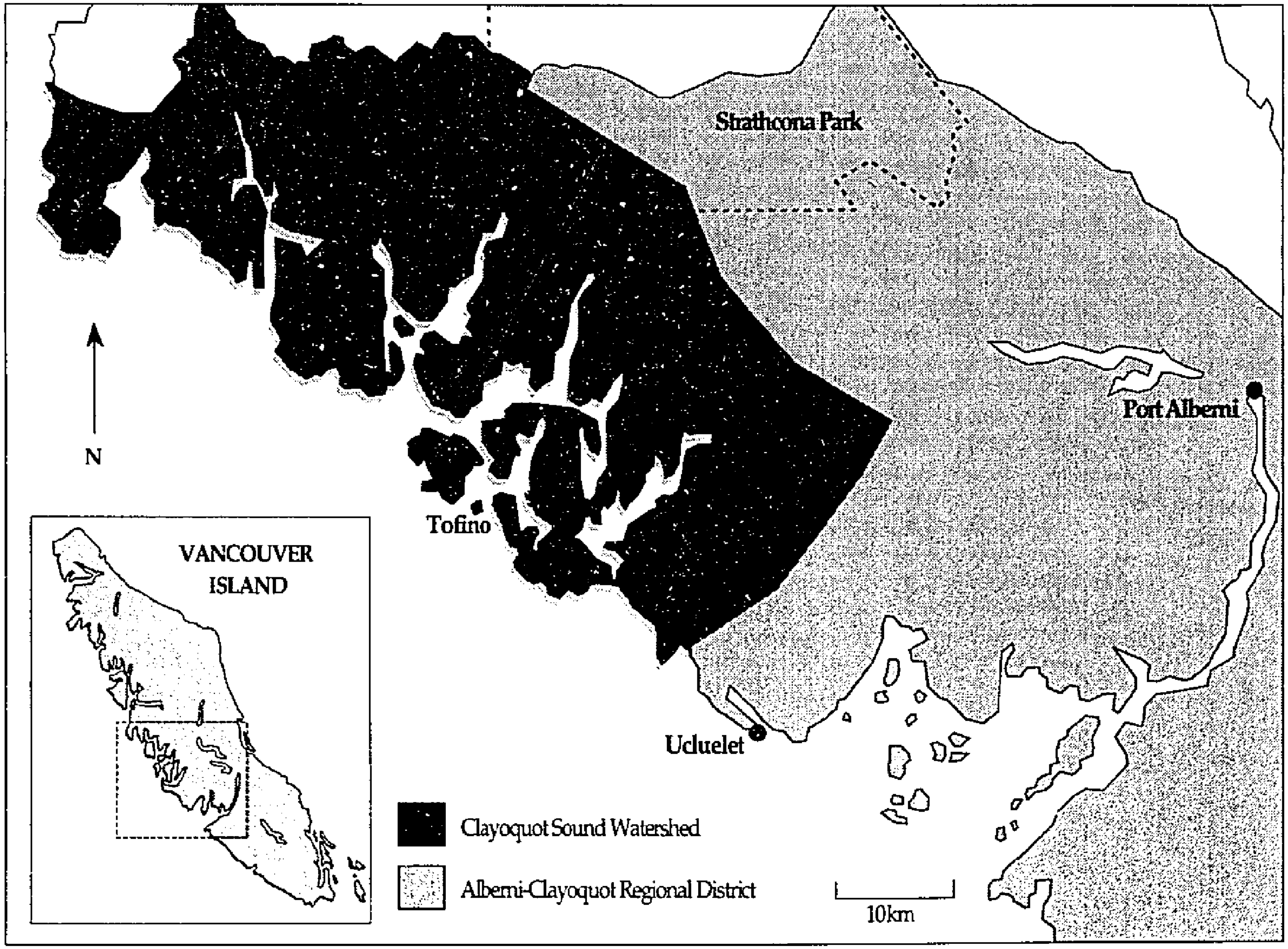

Figure 5.2 Clayoquot Sound Study Area

5.2.1 The Ecological Setting

Physiography

Clayoquot Sound is dominated by two physiographic areas. The boundaries of the Estevan Coastal Plain are approximated by the Hesquiat Peninsula, Vargas Island and Esowista Peninsula. The plain consists of young (under 200 million years) marine deposits which have been uplifted by approximately 30 to 50 meters following the last glacial retreat (Madrone Consultants 1991). Fluvial materials have been deposited over the plain by both past fluvioglacial processes and contemporary fluvial processes (Carter 1991).

Adjacent to the narrow coastal plain are the older (up to 350 million years old) rocks of the insular mountains, rising to approximately 1850 meters. The mountains are composed of a heterogeneous group of sedimentary and volcanic rocks with numerous granite batholiths. Most of the mineral deposits in the region are associated with these volcanic and granite formations. On the lower valley slopes and in valley bottoms, a mixture of morainal, fluvioglacial, and fluvial deposits are present (Carter 1991).

Coastline

The coastline of Clayoquot Sound is heavily dissected, consisting of sounds, inlets, channels and islands. It is unique among the five sounds on the west coast of Vancouver Island[1] due to the large expanses of mud flats and shallow banks, and the

[1] Two of the five sounds are in the Alberni-Clayoquot Regional District (Clayoquot and Barkley) and the rest are to the north (Quatsino, Kyuquot, and Nootka).

number of narrow passages and associated fast tidal currents (Madrone Consultants 1991). The linear distance between the north-south study area boundaries (Escalante Point and Quisitis Point respectively) is some 92 kilometers. However, the sounds, inlets, channels and islands together constitute a coastline that is 930 kilometers long. This coastline is made up of diverse components (Madrone Consultants 1991) as shown in Table 5.1.

Table 5.1 Components of the Clayoquot Coastline

Marine Environment	Extent
Exposed rocky shorelines.	119 km
Wave exposed sandstone.	40 km
Exposed sand beaches.	54 km
Semi-protected channels islands and bays.	350 km
Fjords.	192 km
Fast tidal narrows.	27 km
Large estuaries.	29 km (356 ha)
Mud flats/mixed sediment flats.	105 km (2304 ha)
Small features (stream mouths and lagoons).	14 km
Large banks and shallows.	2070 ha.
Artificial marine environments.	Unknown

Source: Adapted from Madrone Consultants (1991)

Biogeoclimatic Regime

The climate of the area is characterised by moderate temperatures, seasonal fog, and high annual rainfall. The biogeoclimatic regimes of the area are summarised in Table 5.2. Biogeoclimatic mapping of Clayoquot Sound has been carried out by the Ministry of Forests, British Columbia, and the results of this mapping are summarised by Madrone Consultants (1991). Three zones are present in the study area. Low to mid elevations are within the coastal western hemlock (CWH) biogeoclimatic zone. Between the CWH zone and the high elevation alpine tundra (AT) zone is the sub alpine mountain hemlock (MH) zone.

Table 5.2 Mean Climatic Data for Biogeoclimatic Units in the Clayoquot Area

Biogeoclimatic Unit	At[1]	MH[2]	CWHvm[3]	CWHvh[4]
Precipitation of driest month (mm)	40	107	74.5	95.8
Precipitation of wettest month (mm)	84.1	434.8	436.1	431
Mean annual precipitation	756	2954	2787	2952
Mean Temperature of the coldest month (°c)	- 11.1	- 2.3	0.3	3
Mean temperature of the coldest month (°c)	9.5	13.2	16	13.9
Mean annual temperature (°c)	- 1.8	5	8.2	8.2
Number of months with temperature < 0 °c	7	2	0.7	0
Number of months with temperature > 0 °c	0	3	4.8	4.8
Area (ha)	677 (0.2 %)	30725 (11.3 %)	167900 (62 %)	63290 (23.3 %)

Source: Adapted from Madrone Consultants (1991) & Clayoquot Sound Sustainable Development Strategy Steering Committee (1992)

Notes:

1 Alpine Tundra
2 Mountain Hemlock
3 Sub montane very wet maritime coastal western hemlock
4 Southern very wet hyper maritime coastal western hemlock

The CWH zone can be divided into two subzones. At low elevations, from sea level to 150 meters, corresponding to the Estevan Coastal Plain and low elevations of the major fjords is the southern very wet hyper maritime CWH (CWHvh1) zone. Its climate is typically mild oceanic, very wet, with little snow. Approximately 23 per cent of the study area is classified as CWHvh1. The second sub zone, very wet maritime CWH (CWHvm1), has two variants within the study area. From sea level, or the upper boundary of the CWHvh1, to about 600 meters, the sub montane very wet maritime CWH (CWHvm1) zone dominates. The middle and lower slopes of Clayoquot Sound fall into this variant which comprises 50 per cent of the study area. Much smaller in extent (10 per cent of area) is the montane very wet maritime CWH (CWHvm2) zone, occurring in an elevation range from 600 to 900 meters.

The MH zone can also be divided into two subzones. At elevations between 950 and 1,300 meters is the windward moist maritime MH (MHmm1) zone. Within this zone tree cover is continuous. The zone is widespread at higher elevations, though the outer coast and coastal islands are not high enough for MH. Its climate is characterised by high precipitation, cold winters, and deep and long-lasting snow packs. It covers some seven percent of the study area. Above 1,500 meters the MHmm1 zone grades into the windward moist maritime park land MH (MHmmp1) zone. Vegetation in this zone is a mosaic of tree islands, shrub patches, wetlands and rock outcrops. The distribution of MHmmp1 is limited to two per cent of the study area, since only three peaks are high enough to support it. The AT zone is restricted to one per cent of the study area and consists of non-forested ecosystems above 1,500 meters in elevation. Its climate is characterised by high precipitation, cold winters, and a long lasting snow pack.

Wildlife

The characteristics of the regions fauna are harder to describe. Information about the terrestrial fauna for Clayoquot Sound consists largely of species lists. Madrone Consultants (1991) provide a full list of species known to be in the region. A total of 303 terrestrial vertebrates have been identified. This listing includes 9 amphibians, 3 reptiles, 261 birds (including accidentals and pelagics), and 30 terrestrial mammals. These species represent 75, 75, 79 and 56 per cent respectively of the provincial CWH vertebrate fauna. Overall, despite a reduced mammal fauna, the biogeoclimatic zones of Clayoquot Sound support a very high proportion of the provincial vertebrate diversity represented by coastal forests. Twenty seven marine mammals and two marine reptiles have also been recorded in the region. Information on genetic diversity at the subspecies level, distribution and range of populations, size of populations, and general trends in population numbers is generally unavailable (Madrone Consultants 1991). Data are sparse for large mammals such as bear, cougar, and wolf. The quality of information available deteriorates further for other classes of vertebrates and is almost non-existent for invertebrates.

Information on freshwater ecosystems is also deficient and where it does exist it is limited to fish species. Non-salmonoid information is limited to a few isolated studies. As economically significant fish, data on salmonids has been collected for many years on major spawning rivers. It is only in recent years that small systems have been noted as containing salmonids. All streams indicated on a 1:50,000 topographic map probably have some of the pacific salmon and trout species (Madrone Consultants 1991). All five species of pacific salmon are present in the region as well as steelhead, resident rainbow, and sea run and resident cutthroat trout. Coho and chum salmon occur in many of the rivers as do coastal cutthroat trout. The other salmon species are less well distributed. Sockeye salmon occur only in stream systems with lakes and chinook salmon are only present in small numbers in large river systems. Madrone Consultants (1991) suggest that a number of studies indicate considerable differences in sub-stock characteristics for Clayoquot Sound salmon stocks, much of which appears to be genetically based. Escapement information presented in the aquaculture and fisheries background study (Entech 1991) and in the draft strategy document (Clayoquot Sound

Sustainable Development Strategy Steering Committee 1992) indicates significant downward trends in salmonoid numbers since 1950 (Table 5.3).

Table 5.3 Average Annual Escapement for Four Salmon Species: Clayoquot Sound - Selected Years

Year	Chum	Sockeye	Coho	Chinook
1950-54	86,375	47,565	16,195	5,360
1960-64	35,390	46,820	16404	2,557
1970-74	58,290	24,985	11,210	605
1980-84	61,883	30,481	2,422	297
1990-91	23,450	28,438	3,036	165

Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992)

The marine life along the west coast of Vancouver Island can be characterised as cold north temperate (Madrone Consultants 1991). Known as the Oregonian Province, the marine region extends from central California to Kodiak Island in Alaska. The varied coastline of Clayoquot Sound gives rise to a diverse marine biota. This biota, including marine plants, invertebrates and fish populations is described in more detail by Madrone Consultants (1991). Marine mammal populations include 21 whales and dolphins, five hair seals and seals, and the sea otter. Grey whales are among the most studied marine mammals in the region. Some individuals appear to halt their northward migration in spring and stay within the region to feed throughout the summer. The grey whales have been a significant tourist attraction in recent years.

5.2.2 The Regional Context and Management of the Clayoquot Landscape

In the wider regional context, Clayoquot Sound has the largest continuous block of unmodified primary watersheds on Vancouver Island (the Megin, Moyeha, Watta, Sydney, Ice, and Cecilia). Of 90 primary watersheds greater than 5,000 ha on Vancouver Island only eight are undeveloped (Moore 1991). Three, the Moyeha, the Megin, and the Sydney are in Clayoquot Sound. Using less rigorous criteria, nine primary watersheds of greater than 1,000 ha in the study region are essentially natural, less than two per cent of their area having been affected by logging, mining and other similar activities (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Table 5.4 and Figure 5.3 show the area of each terrestrial ecosystem type in Clayoquot Sound and the proportions that are classified as "natural", "modified", or built[2]. Of the unmodified watersheds the Moyeha (18,050 ha), the Megan (24,530 ha) and its tributary, the Talbot (7,797 ha) are protected.

In total, some 89,000 ha of land falls within areas protected by federal or provincial legislation. Thirty-six per cent of this land is within the boundaries of Strathcona Provincial Park. The remaining protected areas fall within the boundaries of the Long Beach Unit of Pacific Rim National Park (eight per cent) and numerous small Provincial Parks and Ecological Reserves (66 per cent). Included in this latter figure is

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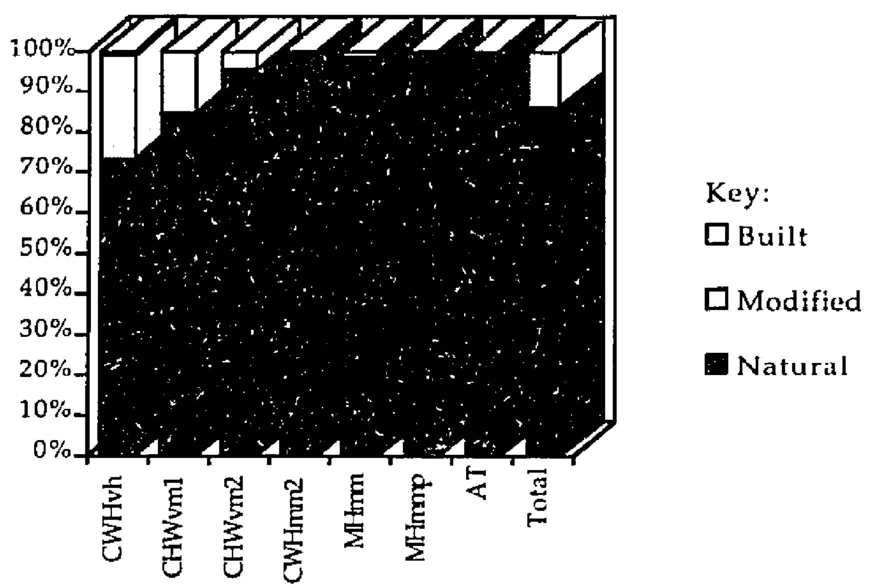
[2] The CSSDSSC (1992) uses the following terms when classifying the condition of Clayoquot ecosystems: Natural ecoystems are defined as systems where the impact of humans has been no greater than the impact of other native organisms, and has not altered the ecosystems structures. Modified ecosystems are ecosystems where the impact of human is greater than any other species. Built ecosytems are dominated by human structures. In future cultivated ecosystems will becom a major element of the landscape. Cultivated ecosystems are stocked with non-native species, or are stocked with native species under intensive management.

Table 5.4 The State of Clayoquot Ecosystems by Area

Ecosystem Type	Ecosystem Condition			Total
	Natural	Modified	Built	
	(ha)	(ha)	(ha)	(ha)
CWHvh	46,423	16,553	314	63,290
CHWvm1	99,167	17,804	0	116,971
CHWvm2	48,549	2,219	0	50,768
CWHmm2	162	0	0	162
MHmm	28,440	324	0	28,764
MHmmp	1,957	3	0	1,960
AT	677	0	0	677
Lakes				8,521
Total	225,375	36,903	314	271,113

Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992, p. 6-10)

Figure 5.3 The State of Clayoquot Ecosystems by Proportion



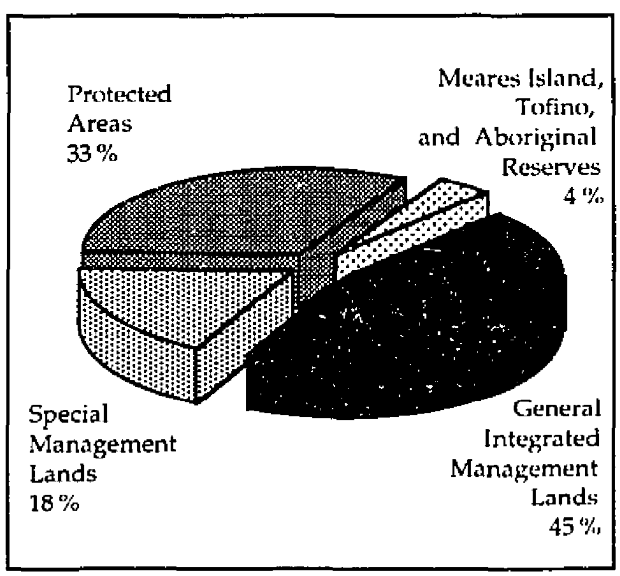
Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992, p. 6-10) some 48,000 hectares of newly protected land. The type of protected status for this land has yet to be decided.

It is the combination of large tracts of forest and varied marine habitats that provides much of the resource base on which the peoples of Clayoquot Sound depend for their livelihood. Increased exploitation of the resource base in the past century has given rise to a number of existing and potential resource conflicts (e.g., forestry versus tourism, conservation versus development, aboriginal versus European interests etc.). In May of 1989, with the intent of resolving these conflicts, the Steering Committee of the District of Tofino tabled a strategy for the sustainable development of Clayoquot Sound. Concerned that the strategy did not fairly represent the interests of all stakeholders the Provincial Government of British Columbia established a second task force in late 1989. Called the Clayoquot Sound Sustainable Development Strategy Steering Committee, it was composed of representatives from communities, interest groups, and provincial and federal governments.

The purpose of the Steering Committee was to develop a strategy that would achieve sustainable development in Clayoquot Sound. The strategy was to be generated through the use of dispute resolution mechanisms, thereby bringing about consensus between all involved parties. Once there was an agreed on strategy, it was to be implemented by the Provincial Government in coordination with other parties. A first draft of the proposed strategy was released in January 1992. A second draft was released in August 1992 (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). In late 1992 the task force was effectively disbanded after failing to achieve consensus. A final report was never made public.

In April 1993, the Province of British Columbia released its *Clayoquot Sound Land Use Decision*. This document contains many recommendations from the second Steering Committee draft. The main components of the decision included a doubling of protected areas (from 14.9 per cent to 33.4 per cent), a commitment to maintaining general integrated resource management (forestry) in 45 per cent (down from 81 per cent) of the Sound, and the creation of special management areas that will be managed primarily for recreation, wildlife and scenic values. In these areas forestry will be considered a secondary use. Figure 5.4 shows the proportions of the Clayoquot Sound landscape under different provincial management designations.

Figure 5.4 Provincial Government Management Designations for the Clayoquot Landscape



Source: Adapted from Province of British Columbia (1993)

Although the land use strategy extends formal protection to a substantial area of Clayoquot Sound, and effectively halves the area of land available for forestry, future land use practices will occur over an area substantially larger than that affected in the past. At the time of the 1993 decision, only about 14 per cent of the Clayoquot landscape had been modified by human activity. Further timber harvesting, though "restricted" to 1,000 ha per year (Province of British Columbia 1993), is virtually unchanged in magnitude from the previous rate of timber harvest. Other forestry activities (burning, planting, fertilising and spacing etc.) will affect more than the one half of one per cent of the landscape allowed to be harvested. These harvesting rates, combined with increasing recreational and other non-extractive uses (e.g., aquaculture), suggest that the rate of landscape modification will likely continue unabated. The implications of this growth in terms of sustainable development remain uncertain.

5.2.3 The Socioeconomic Setting

Four communities live in the Clayoquot Sound study area (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Most non-indigenous people live in the District of Tofino, which at the time of the 1991 census had a population of 1,103. The population of the three Nuu-chah-nulth bands, Ahousaht, Tla-o-qui-aht, and Hesquiaht numbered some 845 in 1991. More members of the Nuu-chah-nulth bands live off-reserve than on-reserve, however (Archeo Tech Associates 1991). To the south, there are three other communities which have economic, social and cultural ties to the study area. The Village of Ucluelet had a 1991 population of 1,595. The Nuu-chah-nulth Ucluelet and Toquaht bands had on-reserve populations of 218 and 24 respectively. To a lesser extent, the entire Regional District of Alberni-Clayoquot has economic linkages to Clayoquot Sound. The largest population center in the District is Port Alberni with a population of some 18,403. The entire District, including the study area, had a population of 31,224 in 1991.

The nature of the socioeconomic linkages with the Clayoquot Sound environment varies markedly for the different communities in the Regional District of Alberni-Clayoquot. The communities have in common that they depend to a considerable extent on the resources of the study area. These resources support timber, tourism, fishery, and aquaculture industries. Mining is a potential major industry, though activity is presently limited to exploration.

Table 5.5 shows the relative importance of these industries in the Alberni-Clayoquot Regional District. The report on which Table 5.5 is based warns that the data are incomplete, cover different years, and have been arrived at by different methods (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). It is, however, the best available estimate of the economic importance of Clayoquot Sound to the regional economy. Tourism and seafood processing are the most important economic sectors for the Nuu-chah-nulth bands and Tofino. Significantly, the employment generated by these sectors is highly seasonal. For the remainder of the Regional District, timber, followed by tourism are the most important sectors. While few people in Clayoquot Sound are involved in the timber sector, Clayoquot Sound timber supports a third of the jobs in the Regional District.

Resource Use by the Nuu-chah-nulth Bands[3]

Each of the five Nuu-chah-nulth bands that rely on the resources of Clayoquot Sound has its own economic structure and philosophy toward future resource development. Past resource development and infrastructure creation in the region has profoundly influenced both attitudes and lifestyles. The resource base upon which the

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[3] The following discussion is based on information contained in the report "The Nuu-chah-nulth Sustainable Development Interest in Clayoquot Sound" by Archeo Tech Associates (1991).

Table 5.5 The Relative Importance of Resource Sectors to the Alberni-Clayoquot Regional District

	Alberni-Clayoquot Regional District			Contribution of Clayoquot Resources to : Alberni-Clayoquot Regional District			Clayoquot Sound		
Sector	Gross Value[1]	Labour Income[1]	Jobs[2]	Gross Value[1]	Labour Income[1]	Jobs[2]	Gross Value[1]	Labour Income[1]	Jobs[2]
	($ million)	($ million)	(FTE)	($ million)	($ million)	(FTE)	($ million)	($ million)	(FTE)
Timber[3]	486.8	185.6	3638	162.3	61.9	1404	N.A.	0.9	22
Tourism	176.8	52.1	2736	37.6	15.1	839	37.6	N.A.	N.A.
Fisheries	35.3	N.A.	424	15.5	N.A.	N.A.	15.5	5.2	148
Aquaculture	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	11.1	2.3	120
Seafood	N.A.	>5.0	N.A.	N.A.	N.A.	N.A.	N.A.	1.0	75
Mining	N.A.	N.A.	N.A.	3.8	N.A.	N.A.	N.A.	N.A.	N.A.

Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992)

Notes:

N.A. = Not available.

1. 1991 dollars.
2. Full time equivalent employment
3. Employment in the sector has declined steadily since 1982. Further job losses are likely.

non-monetary economy of the Toquaht and Ucluelet bands depended was degraded early in the development of the region. Subsequent declines in the native food fishery have further reduced the self-sufficiency of the bands. Consequently, they are having to abandon their traditional lifestyles and look towards the tourism and forestry sectors for their economic livelihood. The territories of the bands within Clayoquot Sound are more geographically remote and, hence, have suffered less environmental degradation. The Ahousaht and Tla-o-qui-aht bands are concerned with preserving their remaining resource base. Attempts are being made to diversify their economies, especially into the tourism sector, while keeping a close relationship with the land. The Hesquiaht is the most isolated of the three Clayoquot bands, living primarily at Hot Springs Cove. They oppose the commercialisation of their forests and waters and want to maintain a mostly non-monetary economy.

Only 30 per cent of Nuu-chah-nulth people aged between 15 and 65 participate in the wage economy of Clayoquot Sound. Whether or not this translates to a 70 per cent unemployment rate is uncertain since many band members may opt to remain part of the non-monetary economy. Discussions with the bands by Archeo Tech Associates (1991) would suggest, however, that the majority of band members would wish to earn some income from the wage economy if jobs were available. Approximately 206 Nuu-chah-nulth people from the study area were employed by the Clayoquot economy in 1990. Of these people, 73 per cent worked in the fishery, 20.4 per cent in tourism, 3.4 per cent in aquaculture, 1.4 per cent in forestry, and 1.4 per cent in mineral exploration. Most jobs in the fishing and tourism sectors are seasonal, and year round employment for band members is rare. A further 106 Ucluelet and Toquaht band members were employed in the Clayoquot economy in 1990. According to the five bands, employment used to be higher and the 1990 figures are part of a continued downward trend.

In terms of lifestyle, employment, and income, the marine resource is the most significant to the Nuu-chah-nulth. This is in keeping with their traditions, the commercial aspect of fishing being more easily integrated with their lifestyle . However, fishing regulations, rising license and boat costs, and declining fish stocks are forcing them out of the commercial fishery. Declining fish stocks also threaten the traditional native food fishery.

The bands are therefore attempting to diversify their economies into tourism. The Toquaht are the only band without a planned tourism venture. Financing for these ventures is apparently difficult to secure. The forestry sector used to be an important source of jobs during the winter when the fishery was closed, the two sectors thus providing year round employment. Currently, forestry is a minimal employer of band members, although both the Ahousaht and Toquaht are developing logging plans for part of their lands. Given the choice, fishing is the preferred option for the bands. With sufficient rehabilitation, they see the commercial fishery and the food fishery as sustaining their lifestyle.

The Nuu-chah-nulth Tribal Council is currently pursuing a comprehensive land claim on behalf of all the bands. The bands contend that their ownership of the tribal territories and resources therein have never been purchased or extinguished. The settlement of the Nuu-chah-nulth land claim is probably many years off. A separate court action by the Ahousaht and Tla-o-qui-aht also claims Meares Island. In the meantime the bands desire equal involvement in the decision making process for resource developments within their territories. To this end the bands are seeking policy and regulatory changes by the provincial Forest Services and the federal Department of Fisheries and Oceans since current resource extraction practices threaten the sustainability of the bands way of life and jeopardise future development opportunities.

The Forest Sector

Prior to the April 1993 land use strategy, Clayoquot Sound had an estimated 144,000 ha of productive forest land[4] containing approximately 79 million cubic meters of timber outside of then existing protected areas (Clayoquot Sound Sustainable

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[4] Productive (or contributing) forest land is land that is available for growing an economic crop of timber. It is a "net" area that recognises the non-contribution of environmentally sensitive land, inaccessible area and inoperable forest land that may support healthy stands of timber but are not realistically avialble (CSSDSSC 1992; Sterling Wood Group 1991).

Development Strategy Steering Committee 1992; Sterling Wood Group 1991). Non-productive forest land covered an additional 76,500 ha. About 82 per cent of this productive forest is older than 120 years. The remaining areas of second growth will not be available for harvest within the next 50 years. The quality of productive forest land is classified according to growth capacity. Some two per cent of productive forest land is classified as good quality, 24 per cent as medium quality, and 64 per cent as low quality (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Following, the 1993 land use decision, between 75 to 80 per cent of former productive forest land, containing some 56 to 58 million cubic meters of old growth timber, remains available for harvest (estimated from Clayoquot Sound Sustainable Development Strategy Steering Committee 1992 and Province of British Columbia 1993).

In the period 1985 to 1989, the timber harvest in Clayoquot Sound averaged 895,469 cubic meters per year, and was 770,032 cubic meters in 1990 and 1991. Based on a rotation period of 75 to 120 years, Sterling Wood Group (1991) calculatesthe long run sustainable yield (LRSY) of forest land in Clayoquot Sound to be 570,000 cubic meters per year. For the next fifty years, an allowable annual cut (AAC) of about 700,000 cubic meters per year is possible. Between the years 2040 and 2060 this would decline to the estimated LRSY. An AAC set at this rate would remove virgin forest from general integrated management lands by the end of the next century. At this time, second growth forest 1-80 years old would constitute 75 per cent of timber stocks and the remaining 25 per cent of the stock would be 81-140 years old.

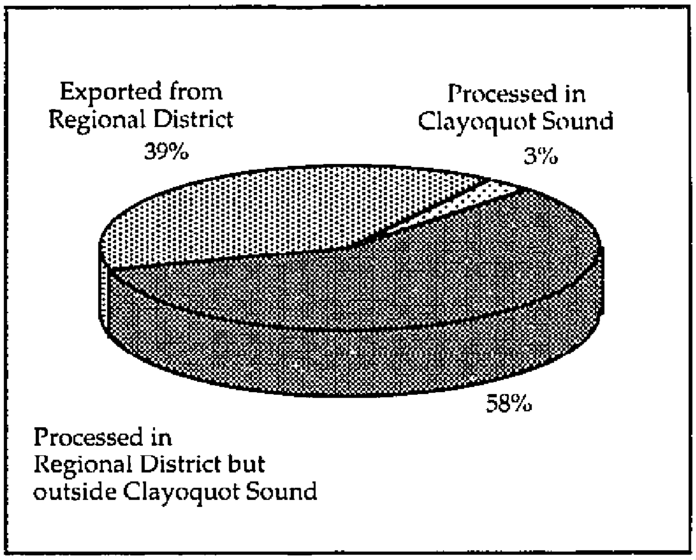
The study area falls within two Tree Farm Licenses (TFL). MacMillan Bloedel operates in TFL 44 which prior to the 1993 land use decision contained 75 per cent of the areas total timber. Fletcher Challenge Canada operates in TFL 46 which contained

23 per cent of the total. The remaining two per cent is harvested under Timber Sales awarded by the British Columbia Forest Service.

Timber harvested by Fletcher Challenge Canada is processed outside the Alberni-Clayoquot Regional District. MacMillan Bloedel processes most of the timber harvested in the region in Port Alberni. In the period 1987-1991 MacMillan Bloedel processed 92.4 per cent of its TFL 44 harvest within the Alberni-Clayoquot Regional district and exported 7.6 per cent. On this basis, an average of 38,000 cubic meters of timber harvested by Macmillan Bloedel in Clayoquot Sound left the region per year in 1990 and 1991. Combined with the exports of other producers, 300,000 cubic meters (39 per cent of the harvest) of timber were sent outside the Alberni-Clayoquot region each year in 1990 and 1991. Only about 20,000 cubic meters of timber (three per cent) of the harvest was processed in Clayoquot Sound (Figure 5.5).

A third of the 4,272 workers employed in timber related occupations in the Regional District were estimated to depend on timber harvested in Clayoquot Sound in 1991 (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Of these workers, 584 were in wood operations, 480 were in pulp and paper manufacture, and 376 were employed in wood processing. Since 1991 substantial reductions have occurred in timber employment in the region. Latest figures suggest the timber related work force has fallen to 3,638 FTEs (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). Wood operations (-189 FTEs) and pulp and paper processing (-460 FTEs) have been especially affected by a range of factors including escalating costs and reduced product prices. Long term prospects for

Figure 5.5 Processing of Clayoquot Sound Timber Harvest 1990-91



Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992)

the industry are at best uncertain. An estimated 153 people will be laid off from pulp operations during 1993[5].

The impact of industry restructuring on harvesting levels is undetermined at the present time. Company Working Plans for the TFLs are apparently unchanged at the present time. The 1993 land use strategy sets harvesting levels at 1000 ha per year, equating to about 600,000 cubic meters of timber (Province of British Columbia 1993).

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5 *Times-Colonist*, April 11 edition, 1993, Victoria, British Columbia

Fisheries and Aquaculture[6]

The Clayoquot Sound study area is more or less coincident with the federal Department of Fisheries and Oceans Area 24. Area 23 makes up the rest of the Alberni-Clayoquot Regional District. The value of the commercial fishery, including outside fisheries, in 1990 was 15.5 million[7]. The estimated landed value of the catch that originated within Clayoquot Sound in 1990 was approximately $5.9 million. This estimate encompasses the inside fishery, including shellfish, and the contribution to the outside fishery that originates in Clayoquot Sound. It was calculated that 277 Clayoquot Sound residents were employed on fishing vessels and 32 were employed in shellfish harvesting activities. With an average fishing season of 24 weeks, minimum full time equivalent employment was calculated at 128 and 15 respectively. Summary income and employment data for the fisheries and aquaculture sectors is contained in Tables 5.6 and 5.7.

Table 5.6 Income Summary for Clayoquot Fisheries, Aquaculture, and Processing in 1990[1]

Sector	Gross Income
Fishing (Area 24)	$15,500,000
Aquaculture (finfish)	$11,000,000
Aquaculture (shellfish)	$76,000
Processing (value added)	$1,000,000
Native fishing (not elsewhere included)	$900,000
Total	$28,476,000

Source: Adapted from Entech (1991)

Notes:

[6] Unless otherwise indicated the data pertaining to the Clayoquot Sound fishing and aquaculture sector is from a report on the sector by Entech Environmental Consultants (1991)

[7] Data on the contribution of the fisheries and aquaculture sector to the Clayoquot Sound economy is not readily available. Consequently data are restricted to the landed and/or "farmgate" value of products, and employment information.

[1] Adjusted to 1991 dollars

Table 5.7 Employment Summary for Clayoquot Fisheries, Aquaculture, and Processing in 1990

Sector	FTEs
Fishing	128
Harvesting	15
Aquaculture (finfish)	117
Aquaculture (shellfish)	3
Processing	75
Native fishing (not elsewhere included)	5
Total	343

Source: Adapted from Entech (1991)

The income derived from the fishery activities of Clayoquot Sound native bands was estimated to be $3.4 million in 1990. The commercial catch of the inside fisheries consisting of sea urchins, sea cucumbers, claims and goosenecks, ling cod and rock fish, was estimated to be worth $1.4 million. The value of the outside commercial Native salmon fishery was calculated to be $2.0 million. Band members occupy 61 FTE positions in combined shellfish/finfish harvesting and processing. The total excludes Native people working in processing off reserve.

Aquaculture in Clayoquot Sound consists of both finfish (salmon) and shellfish farming. Salmon farming in the area has seen a rapid rise in production since it began in 1986. The value of production rose from $4.8 million in 1989 to $11 million in 1990. In 1991 the value of production is expected to be some $25 million, and rise to $30 million in 1992. In terms of tonnage (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992), 742 tonnes were produced in 1988, 2,220 tonnes in 1990, and 4,841 tonnes for 1991. The maximum licensed production is currently 6,547 tonnes per year. Chinook salmon account for nearly all of the production. Atlantic salmon and steelhead trout (one per cent of 1991 production) are also farmed. There are 22 fish farms licensed in Clayoquot Sound, 18 of which are in production. Tenures have been approved for eight more sites that are not presently licensed.

Shellfish production is estimated to be worth under $1 million annually. Some 67 tonnes of pacific oysters were produced by 13 oysters tenures in 1989. Two farms raised scallops. In 1990, about 18 fish farming operations employed 117 FTEs. The corresponding figure for shellfish operations was three FTEs. The Clayoquot Sound Sustainable Development Strategy Steering Committee (1992) suggests there is considerable potential for further aquaculture development in the study area. Over the next few years an additional 100 full time and part time employees are expected to be needed to harvest and process farmed finfish and shellfish in Clayoquot Sound.

There are ten licensed fish handling businesses in the study area, two are in Ahousat and eight are based in Tofino. Aquaculture supplies two businesses, while the others act as buying stations for commercially harvested products. The fish processing sector employs some 75 FTEs, of which 56 per cent can be attributed to aquaculture. Workers employed in wild fish processing plants typically have employment for four months of the year. More regular hours are worked in the plants which process farmed fish. The fish processing industry in Clayoquot sound is estimated to have paid out approximately $1 million in wages in 1990.

Mining

Within the Clayoquot Sound study area there are some 150 known mineral deposits (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). In February 1991, 25 per cent of the area was covered by 400 mineral claims.

Only the Estevan Coastal Plain has little or no mineral potential. Mining and exploration activity has occurred since late last century and 15 prospects have yielded mineral production since 1900. Currently, no metal mines are operating in Clayoquot Sound although some industrial materials such as sand and gravel are mined for local use. Mineral exploration projects in Clayoquot Sound incurred expenditures of $5.5 million in the five years prior to 1991 (Carter 1991). Future mining would most likely involve small underground operations, but there also exists potential for large open pit mines. Carter (1991) estimates that potential development of three known Clayoquot mineral deposits could involve capital expenditures of $250 million, create 325 person years of construction work and 385 jobs during actual mining operations. Annual wages would amount to approximately $21 million.

Tourism

Clayoquot Sound is a significant tourism resource, its natural environment attracting approximately 222,000 people for a total of 600,000 visitor nights in 1990 (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992). The two biggest tourist attractions appear to be the Long Beach Section of Pacific Rim National Park and the twice yearly grey whale migration. Estimates of tourist expenditure vary considerably. The Clayoquot Sound Sustainable Development Strategy Steering Committee (1992) gives estimates of total tourist expenditures ranging from $14 million (1988) to $38 million (1990).

Estimates of employment generated by tourism also vary. In a 1988 study, tourism activities generated an estimated 249 FTE positions in the Clayoquot Sound area (Careless 1988). A 1991 study suggests that tourism may generate up to 804 FTE positions in Tofino alone (Maclaren Plansearch 1991). Growth scenarios contained in the latter study suggest an additional 300 to 500 FTEs could be generated by tourism growth by the year 2000. These estimates assume a four to six per cent annual increase in tourism, and an increase in nights stayed per visitor. Despite the deficiencies in tourism related data, it is evident that it is a major contributor to the local economy. It is the second most important industry in the Alberni-Clayoquot Regional District after timber and is also second in importance in Clayoquot Sound after seafood production (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992).

5.3 A Resource Assessment Model for Sustainable Development

The purpose of the Clayoquot Sound Sustainable Development Programming Model (CSSDPM) described in this section is to demonstrate the application of a methodology that can be used to identify the extent to which the resources of a region can be used to satisfy a set of land use constraints that are consistent with the concepts of sustainable development. The CSSDPM is heuristic[8] (exploratory) in nature and takes a long-term (two-hundred year) view point by way of a multiperiod or "dynamic" formulation. Within a simple optimisation framework it has a stock-flow structure and includes material balance considerations. Constraints on the size of stocks and flows between periods are used to establish present day development possibilities. To aid comparison with other recent Clayoquot Sound planning studies, common data has been used where possible. Any augmentation of these data is noted where appropriate.

Consistent with the discussion of indicators for sustainable development contained in Chapter Four analysis within the CSSDPM is carried out at the landscape

[8] See Chapter Three, Section 3.3, for a discussion of prescriptive, predictive, and heuristic approaches to resource assessment.

level. It is assumed that development practices that alter the structure of the landscape also alter processes and structures at lower levels of system organisation. Also, the landscape level of analysis facilitates the measurement of resource stocks and provides a means to integrate ecological and human development indicators. It is reemphasised that the CSSDPM is not a comprehensive representation of the conditions for sustainable development in Clayoquot Sound. Rather, it is structuredto be representative of the sustainable development concepts and methods outlined in Chapters One, Two, Three, and Four.

The CSSDPM is depicted in detail in the following sections. The objective function, constraints and results of the model are discussed under the following headings:

- The objective function and the welfare of the present generation;
- Technical and resource constraints;
- Equity between generations;
- Biophysical requirements;
- Analysis; and
- Discussion

In each section, a general discussion regarding the construction of the constraint(s) is presented, as are their mathematical forms. Relevant data for Clayoquot Sound is also included. A complete specification of the model is presented in Table 5.8.

5.3.1 The Objective Function and the Welfare of the Present Generation

As discussed in Chapter Two and Four, the purpose of development is assumed to be the improvement of human wellbeing. This wellbeing is can be measured in a

Table 5.8 Specification of the Clayoquot Sound Sustainable Development Programming Model[1,2]

Maximise	$\sum_j w_j a_{1j}$	(1)
subject to	$\sum_j w_j a_{1j} \geq W_{min}$	(2)
	$\sum_j a_{ij} \leq A_i$	(3)
	$L_i^s \leq \sum_i L_{i-2}^g$	(4)
	$P_i = P_{i-1} - L_i$	(5)
	$\sum_j w_j a_{ij} \geq \sum_j w_j a_{i-1j}$	(6)
	$\sum_i l_{ij} \leq l_j^{max}$	(7)
	$a_{ij} \geq 0$	(8)

Where:

w_j	is the welfare generated per unit area of land use j
a_{1j}	is the area of land devoted in period 1 to land use j
a_{ij}	is the area of land devoted in period i to land use j
A_i	is the total area of land available in period i
L_i^s	is the area of second growth harvesting in period i
L_{i-2}^g	is the area logged in period i - 2
P_i	is the area of pristine land remaining at the end of period i
L_i	is the area of land modified by human activity during period i
W_{min}	is some arbitrary minimum level of welfare required for the present generation
l_{ij}	is some measure of landscape attributes modified by activity j during period i
l_j^{max}	is some maximum allowable level of attribute modification by activity j.

[1] The general form of the programming model is based on recursive optimisation techniques associated with dynamic programming. The model is solved using a variant of the "branch and bound" method. An involved discussion of dynamic programming is beyond the scope of this research. The interested reader is refered to Bertsekas (1987), Hastings (1973), Stokey *et al.* (1989) among others for more information.

[2] For simplicity linear relationships between variables are assumed. Specification of nonlinear relationships is possible within the models structure, however. This specification would require data about variable relationships in Clayoquot Sound that are unavailable at present. A good general discussion of nonlinear programming is contained in Hartley (1985).

number of ways. No matter how it is measured the conditions imposed by sustainable development on the level of welfare can be expressed by requiring either that welfare always exceeds some minimum level, or by requiring a non-decreasing change in welfare over time. Various approaches to developing appropriate welfare indicators were examined in Chapter 4, Section 4.4. No single variable, or group of variables can be clearly said to be superior indicators of wellbeing. Income or equity based measures of welfare may be appropriate in developed regions with highly integrated economic and social systems. Where the formal economy and informal modes of production are less integrated, a social indicator or basic needs approach may provide a more basic measure of wellbeing. The appropriateness of particular indicators of wellbeing must be judged in terms of the prevailing cultural, environmental, and economic contexts as well as prevailing power relationships.

The characteristics of the economic and social structure of the Clayoquot Sound have been outlined in some detail in Section 5.2. The Native and non-native populations form two distinct social groups. Both groups rely on the regions resources. The Native populations have strong cultural and productive ties with the landscape, and less formal links with the regional economy. In contrast, the non-native population uses the regions resources as a means to participate in the formal (capitalist) economy. The cultural ties of the non-native population are not with the landscape, but with the resources that the landscape provides. These resources become commodities for exchange in the market based economic system.

The non-native population of the Alberni-Clayoquot Regional District can be further divided into two subgroups: Those who live within, or in proximity, to the Clayoquot Sound watershed and those who do not. The former category includes the populations of Tofino and Ucluelet, and the latter includes the population of Port Alberni. The relationship between Clayoquot Sound and these two groups is fundamentally different. This dichotomy can be explored with respect to the earlier statement that individual wellbeing depends on the ability to consume, and the quality of the environment in which the individual lives. Under current production relationships the non-resident population gains most from consumptive land uses and loses little in terms of the associated decline in environmental quality. The resident population gains little from current consumptive activities, but loses the most in terms of the decline in environmental quality (excluding for the moment the Native population).

Native populations stand to lose the most from both consumptive and non-consumptive uses of the Clayoquot Sound landscape. Already marginalised from the formal socioeconomic structure, having outstanding land claims with the provincial and federal governments, and facing an uncertain future for the west coast fishery, Native groups were until recently largely excluded from planning deliberations. Continuation of present productive relations will likely see continued high unemployment rates among the Clayoquot bands. The alternative, formal protection of large areas of Clayoquot Sound further excludes consumptive Native uses of traditional resources. Intensive logging in areas outside protected areas will contribute further to the degradation of traditional native lands.

A two-year interim agreement reached in December 1993 between the Native bands and the Province of British Columbia may alleviate some of the aforementioned disparities. The agreement gives Native people exclusive logging rights in some areas of the region, and appoints Native leaders to a joint management advisory board that has an advisory role in determining logging activities in the Sound (Times-Colonist, December 11, 1993). While this development may represent an improvement over the prior absence of Native participation, the Bands have been encouraged to "buy in" to an existing land use plan, rather than given the opportunity to develop their own plan with equal or greater standing than other stakeholders.

Finding or developing an appropriate indicator of welfare in Clayoquot Sound, is a difficult task. Consideration must be given to the political economy of the region. Moreover, this task is constrained by the availability and reliability of data. The CSSDPM analysis addresses this problem by using employment as a surrogate measure of wellbeing, by integrating welfare related environmental quality consideration within the ecological constraints, and by neglecting the equity question at this stage of the Clayoquot Sound analysis. Equity implications can be deduced from the model output but are not explicitly part of the CSSDPM. Equity considerations form a fundamental aspect of the subsequent multi-criteria analysis.

Within the context of the Clayoquot Sound analysis, employment provides a direct measure of the landscapes contribution to wellbeing. It is suggested that high levels of employment created as a consequence of a regions resource base will be reflected in enhanced standards of living[9]. Further, employment may be sensitive to distributional changes in wellbeing. For example, a increase in logging revenues brought about by a higher cut rate may or may not accrue to the regional population. In contrast, the increased employment and associated benefits created by the higher cut rate will almost certainly enhance the short-term welfare of the regional population. Using regional employment as a welfare indicator is also broadly consistent with the intent of

[9] The use of employment as an indicator of welfare in this study is somewhat similar to Sen's (1985, 1987) notion of capabilities (discussed briefly in Chapter Four, section 4.5). Increased employment gives more individuals the capability to enhance wellbeing.

a Rawlsian utility function since the unemployed are often one of the worst-off groups in society. The employment impact of a sustainable development planning strategy is also the major welfare related concern of the regional population (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992)[10].

Direct employment data for the various sectors of the Clayoquot Sound economy were presented in Table 5.5. The CSSDPM assumes that this employment is generated by both consumptive and non-consumptive land uses. Consumptive uses, (forestry) generate some 1,404 direct jobs. Tourism is assumed to be a consequence of non-consumptive use and generates 839 direct jobs. The model makes the assumption that all forest jobs are a consequence of the area logged per year, and that all tourism jobs are generated by visitors attracted by the area of unmodified land remaining in the Sound. This results in a welfare trade-off between consumptive and non-consumptive uses.

Table 5.9 presents baseline employment data for the CSSDPM. Included are employment coefficients for forestry and preservation land use alternatives. Also included are the employment multipliers used to calculate indirect and induced employment levels. All employment data are reported in terms of full time employment equivalents and were current as of July 1993. It is assumed that labour coefficients remain unchanged over the modelling period.[11]

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[10] It is recognised that employment is generally regarded as an economic cost rather than benefit. However, at the regional level increased employment is often considered a benefit by the local population. Moreover, an economic case can also be made for considering employment a benefit if its increase results in a reduction in regional unemployment or underemployment, i.e., labour was previously earning less than its opportunity cost elsewhere.

[11] Factor substitution over the course of two hundred years is inevitable. Modelling its form and evolution for predictive purposes is problematic, however. Since the purpose of the CSSDPM is heuristic and this type of model is intended to be run frequently with new data to aid the decision making process, factor substitution may be less of problem in practice than in theory.

Table 5.9 Baseline Employment Data for the CSSDPM

Direct forest employment	1,404 FTEs
Average annual harvest[1]	1,306 hectares/year
Forest-related employment per ha[2, 8]	1.07 FTEs/hectares
Forest employment multiplier[3]	1.93
Total forest related employment[4]	2,710 FTEs
Direct tourism employment	839 FTEs
Tourism-related employment per ha[5, 8]	0.0031 FTEs/hectare
Tourism employment multiplier[6]	1.52
Total tourism related employment[7]	1,275 FTEs

Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992)

Notes:

1 Averaged over the period 1985-1991.

2 Direct forest employment divided by the average annual harvest.

3 Economic base multiplier estimated by Sterling Wood Group (1991).

4 Direct + indirect + induced employment.

5 Direct tourism employment divided by area of pristine land.

6 Economic base multiplier estimated by Clayoquot Sound Sustainable Development Strategy Steering Committee (1992).

7 Direct + indirect + induced employment.

8 For simplicity these employment coefficients are assumed to be constant.

The constraint on welfare for period one can be specified thus:

$$\sum_j w_j a_{1j} \geq W_{\min} \tag{5.1}$$

Where a_{1j} is the area of land devoted in planning period 1 to land use j,

w_j is the welfare generated per unit area land use j and

$W_{\min}$ is some arbitrary minimum level of welfare required for the present generation.

For simplicity the CSSDPM assumes that one generation is equivalent to 50 years. This is slightly longer than the usually accepted 35 years, but is close to the current length of time spent by an individual in the work force (40-60 years).

As discussed previously, W_{min} can be interpreted in one of two ways. If set at the current level of employment, it reflects a non-declining constraint on present welfare. However, if the present level of welfare is greater than the sustainable level of welfare W_{min} defined in this way will be unachievable. This situation will require setting a level of welfare lower than that obtained from current land use practices.

In Chapter One sustainable development was defined as an anthropogenic term. Its intent is to ensure the continued ability of humanity to meet its needs and fulfill its aspirations within the constraints imposed by environment, society, and technology. Since future generations do not exist yet, and this generation cannot know their desires, a pragmatic overall planning objective would seem to be the maximisation of present welfare subject to constraints to safeguard, as far as possible, the wellbeing of future generations. To this end the CSSDPM adopts the following objective function:

$$\text{Max} \ \sum_j w_j a_{1j} \qquad (5.2)$$

With this objective function, equation 5.1 can be left out of the CSSDPM if its inclusion precludes the achievement of a feasible solution. In this situation the model will report the maximum level of present welfare possible while meeting intergenerational and ecological constraints on the size of potential resource flows. The magnitude to which the maximum achievable level of welfare fall shorts of the current level provides a guide to those seeking alternative methods of improving the level of sustainable welfare.

For example, changing the present welfare constraint specification to reflect strategies designed to improve land use employment coefficients could substantially improve the welfare contribution of the regions resource base, as modeled by the CSSDPM. Selective logging techniques and intensified silviculture practices, coupled with increased value-added timber operations in the region, are examples of possible improvements. Substantially increased visitation in Clayoquot Sound could also improve tourism's contribution to regional welfare. Alternatively, increased marine harvesting (wild and farmed) and mining activity could provide opportunities to achieve any needed increases in regional employment levels.

5.3.2 Resource and Temporal Constraints

Resource Constraints

The first resource constraint specifies that the total area of land devoted to a particular land use must be less than or equal to the total amount of land available for that use.

$$\sum_{j} a_{ij} \leq A_i \qquad (5.3)$$

Where a_{ij} is the area of land devoted in period i to land use j. and

A_i is the total area of land available in period i.

Despite the apparent political complexities that surround the Province of British Columbia's (1993) land use decision, actual land use considerations are relatively straightforward. Only two large scale land use practices are possible in the region:

forestry and preservation. Compared to these two land uses, secondary land uses such as mining and aquaculture tend to be confined in spatial extent[12]. Moreover, to a greater or lesser degree - that is depending on institutional arrangements - mining and aquaculture are possible whether the Clayoquot landscape is subject to consumptive or non-consumptive use.

The largest resource base for consumptive land uses are the forested regions of Clayoquot Sound. Two categories of potential consumptive forest use can be identified:

1. Old growth logging, involving the extraction of timber from land identified by the British Columbia Ministry of Forests (1993b) as previously unmodified.
2. Second growth harvesting, involving the extraction of timber from land identified as previously modified. The second growth timber harvested can be consequence of natural regeneration or silviculture practice.

Old growth logging involves the consumption the pristine landscape of Clayoquot Sound. For all practical purposes this is a non-renewable resource[13]. Norse (1990) in his book *Ancient Forests of the Pacific Northwest* presents data to suggest that the structural and compositional attributes of a naturally regenerating forest approach those of an old growth forest after 200 to 250 years. Functional attributes may require 500 years or more to return. He also suggests that the original level of system organisation may never be achieved because of the nature of the original perturbation, and the ongoing modification of the surrounding landscape. It is thus implicitly assumed that old-growth forest is a higher quality resource stock than second growth

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12 For example, one mining operation may disturb 500 hectares of landscape on a one time basis. In contrast, forestry practices involve harvesting large areas of forest year after year.

13 For the purposes of this study non-renewable resources are defined as those resources which have a regenerative capacity of zero or close to zero. Regenerative capacity is defined as the length of time it takes one resource unit to reproduce itself.

forest. It is assumed to yield higher volumes of timber than second growth, and as an unmodified landscape have higher intrinsic and instrumental ecological values.(Norse 1990; Karr 1992). Trade-off's between consumptive resource extraction and environmental quality can be modelled by the CSSDPM. Indeed this type of analysis is implicit in Table 5.12 and Table 5.13 (section 5.3.5 of this Chapter).

Other definitions of old growth forest do exist. For example, Sterling Wood Group (1991) in an unpublished background study prepared for the Clayoquot Sound Sustainable Development Strategy Steering Committee, define old growth as timber older than 120 years. There is little evidence to suggest that a 120 year old forested landscape provides the same contributory services as an unmodified forest landscape (Norse 1990).

Second growth logging involves the extraction of timber, a renewable resource, from modified forest lands. The British Columbia Ministry of Forests (1993a) suggests that on average second growth timber in Clayoquot Sound can be expected to take 100 years to reach maturity and provide two-thirds the volume of timber of the original old growth forest. This estimate assumes current silviculture practices are followed. These assumptions regarding regeneration are built into the CSSDPM. They can, however, be easily changed if more appropriate information is forthcoming.

Unlike many other regional landscapes, Clayoquot Sound has very little agricultural or urban potential. Its considerable mineral potential is unlikely to be exploited unless current mining regulations are relaxed, and/or there is a significant rise in mineral and metal prices, especially copper (Ministry of Energy, Mines and Petroleum Resources 1993). Therefore, the only significant alternative land use to forestry is some form of non-consumptive use. This can involve active preservation that sets land aside for non-consumptive purposes including national and provincial parks, recreational areas and ecological reserve designations. Alternatively, it may be appropriate to designate land for general use, but a choice may be made not to undertake consumptive use within the time frame under consideration.

The amount of potential land available at the beginning of period one for each of the land uses is given in Table 5.10. The areas available for preservation, old growth logging, and second growth logging form the right-hand-sides of equation 5.1. The base line logging data in Table 5.10 may differ from those previously presented in Section 5.2.2 because of differing methods of calculation.

Table 5.10 Baseline Resource Data for the CSSDPM

Total land available for preservation[1]	271,114 hectares
Total contributing timber area	166,433 hectares
Total contributing old growth	135,828 hectares
Total contributing second growth[2]	0 hectares

Source: Adapted from Clayoquot Sound Sustainable Development Strategy Steering Committee (1992) and B.C. Ministry of Forests (1993b)

Notes:
[1] Equals the total land area of Clayoquot Sound
[2] No contributing second growth will be available for 100 years.

The data in Table 5.10 are calculated irrespective of institutional arrangements by cross referencing unpublished Ministry of Forests (1993b) ecosystem inventory data with data supplied in Clayoquot Sound Sustainable Development Strategy Steering Committee (1992). Previously available data has been calculated net of land in

Provincial and National parks, ecological reserves, Native reserves, and the District of Tofino. Since the purpose of the model is to estimate the sustainable development potential of a regions resources, it is more appropriate to consider this potential irrespective of existing land use designations. The inclusion of this extra land area increases the amount of contributing timber land from 144,017 hectares (Clayoquot Sound Sustainable Development Strategy Steering Committee 1992) to 166,433 hectares, an increase of 15.5 per cent.

In addition to making adjustments for institutional arrangements, the area of contributing timber available was calculated at the individual watershed level and then aggregated in an attempt to account for variability in the contributing timber area. The aggregated form of the present CSSDPM only makes a distinction between resource qualities in terms of old growth and second growth timber, however. In other words the input to the CSSDPM is somewhat sensitive to resource quality, and the output of the model only generally so.

Consistent with equation 5.3, the constraint on second growth logging can be expressed more specifically as:

$$L_i^s \leq \sum_i L_{i-2}^g \qquad (5.4)$$

Where L_i^s is the area of second growth harvesting in period i, and

L_{i-2}^g is the area logged in period $i - 2$.

The expression $i - 2$ refers to the availability of second growth timber. Assuming a 100 year rotation for second growth timber and a 50 year planning period, land harvested two planning periods ago will now be yielding mature second growth timber.

Temporal Considerations

Perhaps the most fundamental aspect of modeling sustainable development is that it requires the consideration of extended temporal horizons. This is because the wellbeing of future generations is an explicit consideration of sustainable development. Moreover, consideration of intergenerational equity from Rawlsian type perspective[14] tends to exclude discounting as a way of dealing with policy implications for future generations since they can neither express individual time preferences or play a role in determining the opportunity cost of capital. Strict adherence to the concept of sustainability would require the modeling of human development activities over an indefinite time period. More realistically, it means modeling the consequences of development over at least several generations, rather than several decades. To this end the CSSDPM is run over four, fifty year time periods, giving a total time span of two-hundred years.

The periodicity and the overall time horizon of the model are somewhat arbitrary choices. Their selection will be influenced by nature of the assessment problem at hand, the extent to which the model is designed to represent reality, the reliability and cost of data, and available computing power. Complex models consisting of many variables run over long time horizons with many planning periods can be difficult to construct, incur considerable time and costs in assembling data, and require large amounts of computing power. The human and financial resources required to develop complex models may be beyond the means of many groups and organizations. However, Ignizio (1982) suggests that it is often best to begin with a simplified model that contains a

[14] See the subsection *The Ethical Dimension of a Constant Resource Stock* in Chapter 2, Section 2.3.3 for a discussion of the implications of various ethical perspectives.

minimum of variables. Even in large complex systems only a few variables have a significant impact on a systems output. If this is the case, programming models deserve wider attention than has been traditionally given to them because of their perceived complexity.

Although the current model is run over two-hundred years, it is not intended that the results of the analysis be used predict future levels of wellbeing or to establish policy for that length of time. Dynamic models are suited to use in a rolling or sliding format. In this way the model is run at the beginning of time period one and the results are used to aid in the allocation of resources for an established period of time. After this period has elapsed, or as required by a change in circumstances, the model can be rerun with new and/or better information and forecasts. The results of this analysis are then used to help allocate resources for the next planning period. What is significant is not the length of the time period being modeled, but that present resource allocations are constrained by future outcomes, given a set of initial development considerations. This is consistent with the ethical nature of the intergenerational dimension of sustainable development.

As the name suggests multiperiod programming models partitions time into a number of separate periods. These single period or static models are linked in two ways (Schrage 1986):

1. By a linking or inventory decision variable for each resource and time period. In the context of the current model the inventory variable represents the amount of a resource transferred from one period to the next.

2. By a "material balance" constraint for each resource and period. The simplest form of this constraint is beginning resource inventory + resource regeneration - ending inventory = consumptive resource use.

The second general constraint in the CSSDPM thus specifies the material balance conditions necessary to link the four planning periods:

$$P_i = P_{i-1} - L_i \qquad (5.5)$$

Where P_i is the area of pristine land remaining at the end of period i, and

L_i is the area of land modified by human activity during period i.

5.3.3 The Wellbeing of Future Generations

Chapter Two stated that the second development goal served by the concept of sustainable development is equity between generations. This requires the construction of a constraint that ensures that the activities of the present generation do not preclude the attainment of the needs and aspirations of future generations. The CSSDPM assumes that to have equity between generations, future generations must have access to a resource base that is of equal, or enhanced, quantity and quality as that exploited by the present generation. It is considered unethical for the present generation to either: (i) endow future generations with a lesser level of natural capital than it inherited, and/or (ii) to leave a stock of natural resources to future generations which makes sustainable development unlikely.

The constraint of equity between generations thus becomes a temporal restriction on the magnitude and nature of the interactions between the ecological and socioeconomic systems. This constraint can be functionally expressed as requiring some condition be imposed on the intergenerational transfer of natural capital. Pearce (1988), Pearce and Turner (1990), Pearce *et al.* (1989), and Victor (1991) among others have argued that intergenerational equity requires a constant stock of natural capital. This same literature gives little consideration to the operational definition of such a constraint however.

From a landscape perspective, maintaining a constant stock of natural capital requires that the compositional, structural, and functional attributes of the landscape remain constant over time. Realistically this goal is unachievable. Norgaard's (1985, 1988) co-evolutionary perspective discussed in Chapter Two suggests that changes in each subsystem of the landscape, arising as a consequence of random events (both large and small), chance discoveries, and purposeful intent, change both the quality and distribution of system attributes. Moreover, in regions where the landscape is largely unmodified by human activity, any consumptive utilisation of the resource base will reduce the stock of natural capital.

It was further suggested in Chapter Four that an ecosystem, or landscape, may respond to perturbation in qualitatively different ways. Any of the resulting states may be sustainable in terms of a systems continued ability to be self-organising. Sustainable development, however, requires the valuation of one set of system attributes over another in terms of their contribution to human wellbeing. What is important in terms of intergenerational equity is that the resource flows provided by the attributes of the most valued landscape remain available to future generations. Later generations may decide to maintain these flows or move to some different system state.

The CSSDPM constrains the intergenerational transfer of natural capital by requiring that the natural resources transferred between planning periods be capable of yielding an equivalent level of welfare. In its present form this means equivalent employment levels:

$$\sum_j w_j a_{ij} \geq \sum_j w_j a_{i-1j} \tag{5.6}$$

It is not expected that the modelled level of welfare will be that achieved by future generations, it may well be higher or lower. What is required in terms of intergenerational equity is that the transferred resources be capable of yielding at least the same level of wellbeing. Because the labour intensities of future land uses are unknown, current labour intensities are used as a starting point for analysis. Labour intensities can be adjusted within the CSSDPM to reflect alternative intensity assumptions, or a new model developed to model dynamic relationships.

Other intergenerational constraints may also be appropriate. By definition the consumption of non-renewable resources precludes their use by future generations. Consistent with the quasi-sustainability principle[15] suggested by Daly (1990) and Daly and Costanza (1992), the replacement of old-growth timber by a compensating renewable substitute (second growth timber) addresses this issue to some extent. However, second growth timber in not a direct substitute for the loss of old growth forest. The composition and structural and functional attributes of the two landscapes

[15] See Chapter Two, Section 2.5.1 for a more detailed discussion of this principle.

are fundamentally different. Consequently, future generations may have lost some "freedom of action"[16] in that some of their land use options have been diminished. This could be considered a loss of potential welfare. Constraints reflecting such planning criteria as adaptivity, robustness, flexibility, and resiliency (Lonergan 1985b) could be built into the evaluation of sustainable development possibilities. This type of constraint is absent from the CSSDPM, but receive consideration in the subsequent multi-criteria plan evaluation analysis.

5.3.4 Biophysical Constraints

When characterising sustainable development it is easiest to envisage the biosphere as imposing dynamic constraints on the scale and scope of human development. Development within these constraints is sustainable and development which violates the constraints is non-sustainable. There is no intrinsic reason, however, for development to be sustainable. It is conceivable a society may to decide that the short term costs of sustainability and immediate welfare gains of resource exploitation out weigh the possible long term benefits of sustainable development and any moral obligations to future generations.

Chapter Two suggested that environmental constraints on human activity can be expressed in terms of the biosphere's capacity to: (i) provide inputs to production processes; (ii) assimilate waste material from consumption and production; and (iii) provide other contributory services essential to human wellbeing including life support services. To be sustainable human exploitation of the environment should not exceed

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16 Lonergan (1985b) discusses eight related regional planning criteria in an assessment of Canada's National Energy Plan. These criteria could be applied to sustainability-related planning. They include: Adaptivity; flexibility; freedom of action; reliability; resiliency; robustness; stability; and inertia.

the capacity of ecosystems to provide these services. As discussed in Chapter Four, individually estimating these services and then estimating the impact of various welfare generating activities on them is extremely difficult. If regenerative and assimilative capacities and the ability of ecosystems to provide other contributory functions are considered components of natural capital, finding an appropriate indicator(s) becomes a little easier. It is then possible to use landscape level measures of resource stocks.

To model the biosphere's capacity to provide sustainable development possibilities the CSSDPM requires an estimation of the degree to which landscape attributes can be modified before any one component of their welfare yielding services becomes unavailable. In a comprehensive model of Clayoquot Sound, different land uses could be constrained separately. For example, the amount of effluent generated per hectare of built land could become a constraint on urban development. Similarly, the area of old growth forest harvested could be constrained by a limit on the degree to which a landscape diversity index can change. Such a constraint(s) can be expressed thus:

$$\sum_i l_{ij} \leq l_j^{max} \tag{5.7}$$

Where: l_{ij} is some measure of landscape attributes modified by activity *j* during period *i*.

l_j^{max} is some maximum allowable level of attribute modification by activity *j*.

In the CSSDPM equation 5.7 is specified in terms of the total amount of the Clayoquot Sound landscape allowed to be modified by human activity. This implicitly assumes that each ecosystem in the watershed provides an equal contribution to the regions ecological integrity. In other words, if to maintain the integrity of the desired landscape one-half must remain unmodified, it does not matter if the one-half modified is all coastal western hemlock, or one-quarter coastal western hemlock and one-quarter mountain hemlock. This assumption is flawed if it can be shown that one ecosystem contributes more to ecological integrity. Unfortunately, the information to create more realistic ecological constraints reflecting these conditions does not exist for the Clayoquot Sound ecosystem.

How ecosystem changes are measured at the landscape level is also extremely important. Needed is are indicators that will reflect the impact of various land use practices on the various attributes of the landscape. The CSSDPM uses the total area modified by direct human activity as a gross indicator of landscape modification. This measure is consistent with current clear cutting forestry practices. It may not be appropriate if other logging practices such as selective-logging or small-scale patch clear cutting were implemented in the region. These practices would still result in landscape modification but their impact on the landscape would be very different. Similarly, a gross measure of modification will not be appropriate in situations where land use practices are more subtle. An example of these latter practices would be the fire suppression policies in place in Yellowstone National Park, as discussed in Chapter Four. In these instances other indicators of spatial pattern such as those in Table 4.2 may prove better indicators of landscape alteration.

Despite the large amounts of information generated by the activities of the Clayoquot Sound Sustainable Development Strategy Steering Committee and in particular Madrone Consultants (1991) report *Clayoquot Sound: Life Support Services and Natural Diversity* insufficient information is available to establish an appropriate right-hand-side value for equation 5.7. If the major role of the CSSDPM was normative in nature, this absence of data would severely limit the applicability of the model. However, since the intent of the model is heuristic, much information regarding potential welfare flows can be gained from varying l_j^{max}. Further study is required to find representative values of l_j^{max} for Clayoquot Sound and other similar ecosystems in the Pacific Northwest (Norse 1990).

5.3.5 Analysis

In this section the CSSDPM will be used to demonstrate how a heuristic programming model can be used to investigate three related aspects of Clayoquot Sound's potential to support sustainable development[17]. The first question to be addressed is:

- Can Clayoquot Sound's contribution to the welfare of the Alberni-Clayoquot Regional District be sustained?

Questions two and three follow from section 5.3.4 and their form reflects the lack of data regarding ecological limits to development in Clayoquot Sound:

- For any potential value of l_j^{max} what is the corresponding level of sustainable welfare? and;
- For any potential value of l_j^{max} what resource stock will future generations inherit if the welfare of the present generation is maintained at its present level?

Although the model is intended to be representative rather than comprehensive, its structure still reflects a set of conditions for general-system sustainability which are

[17] The CSSDPM analysis was carried out on an Apple Macintosh 040 based computer using Microsoft Excel's optimization add-in. Microsoft Excel Solver can solve or optimize spreadsheets that involve both linear and non-linear equations and inequalities. It uses a generalised reduced gradiant algorithm for non-linear problems. Linear and integer problems utilise the simplex method with bounds on the variables and the branch and bound method (Microsoft 1993).

based on data relating to the ecological and socioeconomic subsystems of Clayoquot Sound. This information is no less limited than that used in by the Province of British Columbia (1993) to formulate its *Clayoquot Sound Land Use Decision*. Even in a limited form the CSSDPM may prove useful in providing information relating to the conditions for sustainable development in the region. The overall approach is consistent with the role of resource evaluation outlined in Chapter Three, Section 3.2.3 and with the prerequisites for an operational methodology described in the conclusion of Chapter Three.

The first question regarding the sustainability of the present contribution of Clayoquot Sound to regional welfare can be examined by setting the right-hand-side of equation 5.1 at current employment levels. From Table 5.9 total Clayoquot forestry and tourism related employment is estimated at 3,991 FTEs. Even with the complete depletion of all contributing old growth forest the CSSDPM could not find a feasible solution with this constraint included. From this it can be concluded that, with regard to the models initial assumptions, the contribution of Clayoquot Sound to regional employment cannot be sustained for 200 years. Table 5.11 presents the results of this analysis:

Table 5.11 Maximum Sustainable Employment by Clayoquot Resources

Maximum sustainable employment	3,063 FTEs
Employment shortfall	928 FTEs
Maximum sustainable timber yield[1]	787,842 m^3
Depletion of contributing old growth	100%
Pristine landscape remaining	42%
Remaining old growth forest	34 %

Notes:
[1] Includes second growth logging in Periods 3 and 4

Even if all 207,000 hectares of old growth forest could be harvested, the level of sustainable employment would be two per cent below existing levels. This level of harvesting would leave only 11 per cent of the landscape in its pristine state. If the validity of these results were substantiated following a more comprehensive empirical research programme the apparent discrepancy between sustainable employment levels and present employment levels would suggest that the relationship between the ecological and socioeconomic systems must undergo a substantial change if sustainability is to be achieved. Moreover, most of the benefits from present land use practices accrue to those outside Clayoquot Sound. The residents of Clayoquot Sound will see a continuing loss of pristine landscape and a possible associated loss of tourism induced employment[18].

Given its initial assumptions regarding the interactions between the ecological and socioeconomic systems in Clayoquot Sound, the CSSDPM indicates that the regions natural capital cannot continue to support existing levels of employment and consumption. It would seem logical to next examine what levels of employment can be sustained by the regions resource stock. Since the right-hand-side of equation 5.7 cannot be specified with any certainty the CSSDPM is best used in an exploratory fashion to generate sustainable employment levels over a range of landscape values. The present welfare constraint (equation 5.1) is removed from the model run since its inclusion results in an infeasible solution. The results of this analysis are presented in Table 5.12.

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[18] Corresponding to Table 5.10, the CSSDPM indicates a 45% decline in tourism jobs over the 200 years due to the loss of pristine landscape. This assumes that there is no increase in the propensity to visit Clayoquot Sound to offset a decline in visitors due to the degradation of the landscape.

Table 5.12 Sustainable Employment Levels - Clayoquot Sound

Depletion of Contributing Old Growth	Pristine Land Remaining	Sustainable Employment
	(hectares)	(FTEs)
0%	233,896	1,102
10%	220,313	1,298
20%	206,730	1,491
30%	193,148	1,690
40%	179,565	1,886
50%	165,982	2,082
60%	152,400	2,278
70%	138,876	2,475
80%	125,234	2,671
90%	111,651	2,867
100%	98,068	3,063

For each additional 10 per cent of old growth timber harvested Table 5.12 shows the level of sustainable employment achievable and the area of pristine land remaining after 200 years. This type of information can aid the decision maker in two important ways. First, it can used to indicate the nature of the trade-off between sustainable consumption and ecological constraints on resource use. For example, if an endangered species needs 165,000 hectares of pristine land to maintain its population, the corresponding level of sustainable employment is between 2,000 and 2,200 FTEs. Second, this information can be used to establish trade-offs within welfare functions by revealing possible utility maximising combinations of environmental quality (amount of pristine land remaining) and consumption (sustainable employment). In this way it might be determined that British Columbia's current welfare preferences are for 100,000 hectares of pristine land and 2,500 sustainable FTEs.

As suggested previously it is possible that the present generation may place lesser value on the wellbeing of future generations. This is especially likely if this ethical obligation has significant opportunity costs for the present generation. Also, there exists the possibility that future generations may decide to follow non-sustainable development paths even if this generation meets its ethical obligation in this regard.

If for the above or other reasons the concept of intergenerational equity is rejected by the present generation it is still important from the perspective of sustainable development to know what the intergenerational impact of this decision is. The CSSDPM framework can also be used to explore this problem by searching for future levels of consumptive and non consumptive land use that result in the maintenance of current employment levels.

The future welfare implications of maintaining current employment levels for the next 50 years are shown in Table 5.13. The table first indicates that present welfare levels cannot be sustained for 50 years unless approximately 60 per cent of available old growth timber is harvested. If a 60 per cent old growth harvest is consistent with probable ecological constraints and societal preferences, then available resource flows will be able to sustain 3,991 FTEs over the first 50 years and 800 FTEs over the remaining 150 years. This latter level of employment is some 1,500 jobs below the sustainable level of employment. If 100 per cent of available old growth is harvested future employment increases to 2,300 FTEs. This is some 800 FTEs below the sustainable employment level.

Table 5.13 Intergenerational Impacts of Maintaining the Welfare of the Present Generation

Depletion of Contributing Old Growth	Pristine Land Remaining	Future Employment
	(Hectares)	(FTEs)
0%	233,896	---
10%	220,313	---
20%	206,730	---
30%	193,148	---
40%	179,565	---
50%	165,982	---
60%	152,400	798
70%	138,876	1,179
80%	125,234	1,542
90%	111,651	1,906
100%	98,068	2,270

5.3.6 Discussion

The CSSDPM demonstrates how the general ideal of sustainable development can be given a "logically consistent and operational content" (Daly 1990, p2). Though limited in its consideration of system interrelationships, the structure of the analysis is consistent with the concepts of sustainable development outlined in Chapter Two, a multi-dimensional heuristic planning approach as discussed in Chapter Three, and is developed around an indicator framework for sustainable development that follows from Chapter Four. While it is premature to present any conclusive results without developing a more comprehensive model for Clayoquot Sound, the analysis indicates that present development may be non-sustainable.

Two additional spatial elements not included in the CSSDPM, but which are very important for the study of sustainable development in the regional context deserve consideration. First, there is the issue of cross-boundary flows[19]. The preceding analysis does not include consideration of the sustainability of goods and services imported into the region, or of the processing of resource flows from the Clayoquot watershed (e.g., air emissions and effluent discharges from timber processing in Port Alberni).

If it is assumed that sustainability will be pursued at the planning-unit level and that all regions will achieve this goal, then boundary issues need not be a problem since all regions will move to use indigenous resources and imported resources in a sustainable way. This is an unrealistic assumption in anything but the long-term. The alternative is to develop an inter regional model of sustainable development. Regional economic-ecologic input-output models and/or regional resource accounting frameworks could form the basis for such an approach. In many instances data is not available to create such models and our understanding of system interrelationships is also restricted, however. The resolution of this problem is problematic and requires further research.

The second spatial consideration concerns the scale of analysis. While the economic consequences of resource extraction can be measured at the level of the watershed, many ecological impacts and amenity values arise at very small scales. For example, some ecosystem types may be more important to the integrity of landscape than others. Similarly, some areas may have greater amenity value than others. For example, it can be suggested that most visitors come to Clayoquot Sound for one of

[19] See Cocklin (1989c) for a detailed methodological discussion and Chapter 2, Section 2.4 of this dissertation for a more general discussion of this issue.

three reasons: Long Beach/Pacific Rim National Park; whale watching; and to visit Hot Springs Cove.

One possible solution to the problem of scale would be to integrate a CSSDPM type approach with a geographic information system[20]. In this way the integration of small-scale spatial data and non-spatial data could be facilitated. Alternatively, and more realistically in the context of Clayoquot Sound, the CSSDPM can be used as a general guide to regional requirements for sustainable development. Having established the general direction and order of magnitude of sustainable development related system interrelationships and trade-offs, local-area plans can be implemented that better reflect local system attributes but are broadly consistent with the meso-scale analysis of CSSDPM type models.

Finally, mention should be made of the CSSDPM's simple optimisation framework. Chapter Three extensively discussed the use of multiple objective programming models for resource evaluation. In the current single objective specification of the CSSDPM the wellbeing of the present generation forms the basis of the objective function. If specified as a multiobjective model intergenerational equity and ecological considerations could also be included in the objective function. This would require the additional specification of preferences for the achievement of these new objectives. This is also an avenue for further research (see, for example, Cocklin 1989c).

For the purposes of this illustrative exercise a simple optimization algorithm has proved adequate. There is some merit to the suggestion that maximising the wellbeing of the present generation is also the most appropriate form of the objective function. It is

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[20] See, for example, Giaoutzi and Nijkamp (1993).

arelatively simple matter to explore other trade-off's between ecological and intergenerational considerations. Determining preferences for a multiple objective specification can also be difficult. Significantly, a single or multiple objective programming model cannot easily take into consideration qualitative data. All variables and constraints must be cardinal. Often variables cannot be measured at the cardinal level either because of a lack of data or lack of understanding of the processes involved. In the current framework, it would prove difficult to specify meaningful biodiversity and equity related constraints at the cardinal level of measurement. Criteria preferences and qualitative data can, however, be integrated into a multi-criteria plan evaluation framework[21].

As discussed in Chapter Three a multi-criteria analysis is used to choose the best plan or policy from a set of alternatives. Combining an optimisation routine with a multi-criteria plan evaluation explicitly recognises the sequential nature of many planning processes. This type of approach is particularly suited to situations where a range of solutions need to be found to a particular problem and the best of these solutions selected, or, where the consequences of alternative plans need further examination before the best plan is selected. The current Clayoquot Sound land use planning exercise is an example of the latter situation.

The CSSDPM is clearly only a pilot model for resource assessment and sustainable development and further research is required to improve the empirical robustness of the model. Some equations require more reliable data to enable a realistic specification (e.g., tourism visits per hectare of Clayoquot wilderness). Other assumptions or questions relating to sustainable development may also be studied with

[21] Chapter 3, Section 3.6 discusses the application of muli-dimensional planning frameworks to resource assessment and environmental evaluation in some detail.

extended versions of the model, such as including aquaculture and mining. The results of the CSSDPM are for the time being illustrative of a sustainable development planning application. Nevertheless, they have clearly demonstrated the applicability of the framework for sustainable development planning and resource assessment. The utility of this approach may be further enhanced when combined with other planning methodologies such as a multi-criteria plan evaluation routine. This is demonstrated in the next section.

5.4 A Multi-Criteria Plan Evaluation of Land Use Options for Clayoquot Sound

The potential use of multi-criteria analysis for the evaluation of alternative sustainable development resource use plans can also be demonstrated in the context of the Clayoquot Sound case study. The five land use alternatives evaluated are based on two options considered by the Clayoquot Sound Sustainable Development Strategy Steering Committee (1992), the land use plan adopted by the Province of British Columbia (1993) and two hypothetical options created for this study. The CSSDPM is first used to simulate the impact of the options on the landscape, present generations, and future generations. Additional qualitative ecological and equity considerations are then added to better reflect other sustainable development evaluation criteria. Ordinal weights reflecting hypothetical societal rankings for each of the criteria are also incorporated.

As both quantitative and qualitative data are involved, a mixed data multi-criteria analysis based on the evamix routine described in Chapter Three and specified mathematically in Appendix One is used. Briefly, this method involves constructing two dominance scores, one for the quantitative data and one for the qualitative data. After standardization, overall dominance scores of alternatives are determined and a ranking created.

The multi-criteria plan evaluation is described in three sections. The first section describes the land use plans to be evaluated. The second section describes the construction of the plan impact matrix, and the third presents the results of the multi-criteria analysis. Again, the research and results presented are indicative rather than comprehensive in nature. Further empirical study is required to improve the robustness of the analysis.

5.4.1 The Land Use Options

The case study refers to the evaluation of five land use plans for the Clayoquot watershed. None of the five are comprehensive land use plans. They are meso-level plans designed to place restrictions on the magnitude of consumptive uses within the watershed. Small-scale land use practices are expected to be consistent with these plans, but there is considerable scope for variation in specific practices. This structure is consistent with the current trend toward bottom-up, community based participatory planning whereby stakeholders are involved in a consensus oriented planning process (Priscoli and Homenuck 1986; Thorburn 1987; Walter 1992). It is assumed that the main objective of the five land use plans is to bring about sustainable development in the region.

Option A is based on the proposal by the Western Canada Wilderness Committee (1990) that tracts of land in Clayoquot Sound be designated as "wilderness reserves" and that sustainable timber production be permitted in the rest of the

Clayoquot Sound watershed, except for Strathcona Park and Pacific Rim National Park. Option B was the status quo option before the announcement of the *Clayoquot Land Use Decision* by the Province of British Columbia (1993). It involves timber production throughout the watershed except for existing parks. Option C is the Province of British Columbia's present land use plan. Options B and C are discussed in some detail in Section 5.2.2 of this Chapter. Option D is similar to option A but restricts logging to the eastern part of the watershed (except for existing parks) and gives a commitment to timber processing in or adjacent to the Clayoquot watershed. Option E is a complete preservation option with all land in Clayoquot Sound off limits to consumptive uses. The land use implications of each of the options are presented in Table 5.14. These data form the basis of the CSSDPM simulation analysis.

Table 5.14 Land Use Implications of Five Plans

Option	Contributing Old Growth Forest[1]	Depletion of Non-Renewable Resources
A	74,887 hectares	32%
B	146,311 hectares	63%
C	100,147 hectares	43%
D	68,649 hectares	29%
E	0 hectares	0%

Source: Options A, B, and C adapted from Sterling Wood Group (1991) and Province of British Columbia (1993).

[1] Aggregated from individual watershed data

5.4.2 Plan Evaluation Criteria

The eight criteria used to evaluate the land use alternatives are grouped in three categories:

- Wellbeing of the present generation;

- Wellbeing future generations; and
- Biophysical criteria.

These categories are intended to be consistent with preceding discussion and analyses. The categories, and criteria within these categories are designed to be mutually exclusive of one another. This helps limit possible "double counting" when preference based weights are assigned to each criteria.

In a comprehensive sustainable development planning study, criteria, criteria scores and criteria weights would be determined in consultation with experts in relevant fields and other stakeholder groups. This would improve the empirical robustness and relevancy of the methodology. However, this is beyond the scope and resources of the current research and is unnecessary to demonstrate the validity of the approach. The simple model is structured so as to enable changes to be made with relative ease to criteria, criteria scores, and criteria weights. This allows the analyst, decision maker, or stakeholder to explore the implications of different assumptions and values sets on the outcome of the evaluation exercise.

Wellbeing of the Present Generation

Two cardinal and two qualitative data based criteria make up this evaluation category (Table 5.15). The two cardinal criteria, "employment loss" and "pristine land remaining" (after 50 years) are generated by the CSSDPM for each land use option. Respectively, they represent the consumption and environmental quality components of the welfare function. Consistent with the findings of the resource assessment analysis in Section 5.3, no land use option allows for sustainable employment at current levels.

The inclusion of two qualitative criteria reflects the fact that existing information does not allow for a quantitative assessment of all the components of human welfare. These two criteria relate to equity considerations. "Equity: Clayoquot watershed" recognises that consumptive activities tend to benefit individuals living outside the watershed and disadvantage those living in the watershed. The reverse is true for non-consumptive activities "Equity: aboriginal" recognises that the Nuu-Chah-Nulth people may have a different set of development priorities compared to the remainder of the population.

For example, the Nuu-Chah-Nulth people prefer land use options that do not preclude the use (consumptive and non-consumptive) of land they consider to be theirs (Archeo Tech Associates 1991). Options A and E would to a greater or lesser extent preclude Native use. Option B has very limited Native involvement but allows for the logging of large areas of old growth forest. Options C and D allow for varying degrees of joint management of the Clayoquot landscape. The ranking of options with regard to these two categories is also shown in Table 5.15. The greater the number of positive signs the more preferred the alternative is for that criteria[22].

Table 5.15 Criterion Scores: Wellbeing Present Generation

Criteria	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*
Employment Loss (FTEs)	-2,010	-1,171	-1,713	-2,083	-2,889
Pristine Land Remaining (hectares)	210,036	187,277	201,985	212,022	233,896
Equity: Clayoquot Watershed	+++	+	++	++++	+++
Equity: Aboriginal	++	+	++++	+++	++

[22] Negative signs and neutral signs (0's) could also be assigned to options for individual criteria. This would indicate whether the impact is negative, neutral, or positive. However, since the purpose of these scores is to enable the pairwise comparison of alternatives this is unneccessary for subsequent mathematical operations.

The Wellbeing of Future Generations

The wellbeing of future generations category consists of three criteria (Table 5.16). The impact scores for the criteria "sustainable employment" and "non-renewable resource depletion" are generated by the CSSDPM. They are indicators of the consumption and environmental quality components of the future generations welfare functions. The third criteria "plan adaptivity" is measured qualitatively.

Plan adaptivity attempts to address the limitations of the quasi-sustainability compensating principle of Daly (1990) and Daly and Costanza (1992). As suggested previously selection of one planning option often forecloses other options. The term adaptivity implies that these options are preserved (Lonergan 1985b). For example, option B cuts large areas of old growth forest which although replaced with a renewable substitute (second growth timber) still results in the loss of many landscape attributes. Options A and E also preclude future options because they call for formal protection of land. From a practical standpoint once a landscape is protected it can be procedurally difficult to reverse such designations. Lonergan (1985b) measures policy elements such as plan adaptivity, flexibility, robustness etc., quantitatively. This is an area for further research if qualitative consideration of such criteria proves inadequate.

Table 5.16 Criterion Scores: Wellbeing Future Generations

Criteria	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*
Sustainable Employment (FTEs)	1,981	2,819	2,278	1,908	1,102
Non-Renewable Resource Depletion	-32%	-63%	-43%	-29%	0%
Plan Flexibility	+++	+	++	++++	+

Ecological Criteria

The specification of ecological constraints and criteria for resource assessment and plan evaluation has proved problematic for this research. Available data is simply inadequate for this task. This is troublesome because, as stated in Chapter Two, sustainable development is best characterised in terms of the biosphere imposing dynamic constraints on the scale and scope of human development. Despite considerable expenditure of money and effort on the study of Clayoquot related social systems and social perceptions, the Clayoquot Sound Sustainable Development Strategy Steering Committee (1992) and Province of British Columbia (1993) generated little information about the ecological consequences of development in the region. This suggests a fundamentally different perspective, or lack of perspective, regarding the basis of sustainable development.

The heuristic design and adoption of landscape level indicators by the CSSDPM partly overcomes the lack of ecological information. The use of a mixed data multi-criteria plan evaluation routine also has the potential to help overcome the absence of quantitative ecological data. For example, in a more comprehensive study expert judgment can be used to assess the impact of each land use option on any number of indicators of ecosystem health. In the present study one qualitative criteria for ecological impacts is used. The land use options are ranked in terms of their disruption to the integrity of the structural attributes of the landscape.

This ranking is somewhat arbitrary and is for illustrative purposes only. Option E involves complete preservation of the landscape and is judged to have the least impact on structural integrity. Option B modifies the largest area of the Clayoquot landscape and is therefore judged to have the greatest impact. Options C and D are considered to have similar impacts although D alters a smaller percentage of the landscape. Option D results in the complete harvest of forest in one area. Under option C logging is spread out over a much wider area of the watershed. The relative rankings of the land use options are given in Table 5.17. The final impact matrix used to evaluate the five land use options is shown in Table 5.18.

Table 5.17 Criterion Scores: Biophysical Criteria

Criteria	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*
Structural Integrity	+++	+	++	++	++++

Table 5.18 Clayoquot Sound Plan Impact Matrix

Criteria	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*
Wellbeing Present Generation					
Employment Loss (FTEs)	-2,010	-1,171	-1,713	-2,083	-2,889
Pristine Land Remaining (hectares)	210,036	187,277	201,985	212,022	233,896
Equity: Clayoquot Watershed	+++	+	++	++++	+++
Equity: Aboriginal	++	+	++++	+++	++
Wellbeing Future Generations					
Sustainable Employment (FTEs)	1,981	2,819	2,278	1,908	1,102
Non-Renewable Resource Depletion	-32%	-63%	-43%	-29%	0%
Plan Flexibility	+++	+	++	++++	+
Biophysical					
Structural Integrity	+++	+	++	++	++++

5.4.3 Results of the Multi-Criteria Plan Evaluation Analysis

Before the evamix analysis can be carried out a set of weights has to be assigned to the criteria. These weights reflect the importance assigned to each of the criteria by different stakeholders. Ideally, these weight sets would be assigned during and following public consultation. In the present study three hypothetical weight sets are used (Table 5.19). These weight sets represent general world views reflecting growth (maximise resource extraction), environmental (minimise resource extraction), and egalitarian orientations (minimise differences between peoples and generations). Although there might be some circumstances in which quantitative criterion weights are available, usually only qualitative priority weight sets are available. It is a relatively straightforward task to rank eight criteria from most important to least. It is more complicated to rate criteria on a cardinal scale of some kind.[23]

The evaluation criteria ranked eight are the highest ranked and criteria ranked one are the lowest ranked in Table 5.19. These rankings are arbitrary and are for illustrative purposes only. Equal rankings are also allowed but are excluded from theanalysis for simplicity. These rankings are converted to cardinal information using the expected value method (after Nijkamp *et al.* 1990). The cardinal values corresponding to these rankings are given in Table 5.20. In the multi-criteria analysis an arbitrary scaling factor of one is used in conjunction with the expected value weighting method. This is to ensure that differences between alternatives based in minor criteria will have an influence on the value of the quantitative and qualitative dominance scores (see Appendix One).

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[23] See Nijkamp *et al.* (1990) for a detailed discussion of the assessment of priority weights and preferences.

Table 5.19 Clayoquot Sound Criteria Rankings

Criteria	Criteria Rankings		
	Growth	Environmental	Egalitarian
Employment Loss	8	1	3
Pristine Land Remaining	3	7	2
Equity: Clayoquot Watershed	6	4	7
Equity: Aboriginal	5	3	8
Sustainable Employment	7	2	6
Non-Renewable Resource Depletion	2	6	1
Plan Flexibility	4	5	5
Structural Integrity	1	8	4

Table 5.20 Weights Corresponding to Criteria Rankings

Rank	1	2	3	4	5	6	7	8
Weight	0.02	0.03	0.05	0.08	0.11	0.15	0.21	0.34

Table 5.21 shows the outcome of the evamix analysis for the three weight sets. The highest ranking option has a score of five and the lowest ranking option a score of one. Option A ranks highly only under the environmental world view. Option B, the status quo situation prior to the 1993 land use decision, ranks lowest under the environmental and egalitarian world views and moderately under the development view. Option C ranks second highest under the growth and egalitarian views but poorly under the environment view. Option D ranks highest under the growth and egalitarian views and moderately under the environmental view. Option E is the highest ranked option under the environmental world view but is poorly ranked under the other two. Given the criteria scores and weight sets there is little that is surpassing about the outcome of the evaluation exercise. Option B might have been expected to perform better under the

Table 5.21 Land Use Option Appraisal Rankings

Land Use Options	World View		
	Growth	Environment	Egalitarian
Option A	2	4	3
Option B	3	1	1
Option C	4	2	4
Option D	5	3	5
Option E	1	5	2

growth view, but its poor equity scores prevented it from ranking higher. Options C and D would seem to be the most preferred land use plans.

A sensitivity analysis of criteria relationships based on the combined multi-criteria and programming approaches is an area for further research. This analysis would be similar in intent to the simple sensitivity analysis described in Chapter Three, Section 3.6.1. The computational complexities accompanying this exercise placed it beyond the scope of this research, however. Also, given the limited scope of the case study there would be little empirical utility in carrying out such an analysis.

Required for sensitivity analysis is a linking of the programming model and multi-criteria analysis in a manner such that the impact of changes in the specification of objectives, constraints and right-hand-side values in the programming model are reflected in the criteria impact scores of the multi-criteria impact matrix. This would improve the heuristic abilities of the combined approaches. Project rankings for the various weight sets would be immediately available to an analyst following any change in model assumptions. For example, the changes in the employment coefficients required before project rankings changed could be explored as could the ecological implications of different land use practices. A similar computer algorithm could be developed to model the sensitivity of the results to changes in qualitative impact scores.

5.4.4 Discussion

The multi-criteria plan evaluation study has demonstrated that this approach can be useful for accounting for several types of sustainable development issue including welfare, equity and ecological considerations. It can be used alone or in conjunction with other analytical approaches. It represents a powerful plan evaluation tool explicitly able to take into account quantitative and qualitative information.

More generally, its framework reflects the diversity of structures and processes, incommensurable variables, and conflicting objectives that characterise problems in resource and environmental planning. Analysts, decision makers, and stakeholders need to consider a pluriform of variables, categories, and processes. For example, the dependency of society on a multi-functional environment, the implications of trade-offs between development options, and the consequences of the loss of some or all of these functions for present and future human welfare, are all important aspects of public policy planning. Moreover, the need to incorporate appropriate weights that reflect different values held by members of society puts increasing pressure on planners to use methods that are amenable to stakeholder involvement.

It is not suggested that such an analysis be used normatively to select the best land use plan. Rather it is suggested that the technique be used heuristically. For example, in the above example options C and D consistently rank high consistently for the given weight sets. This suggests that these options, for the selected criteria, have favorable attributes. These attributes include a moderate or high level of potential consumption and environmental quality, and an equitable distribution of resources. Instead of selecting the best option at this stage of analysis it may be beneficial to reformulate options so that any favorable elements are enhanced. The CSSDPM analysis also showed that there may be a need for a fundamental alteration to the nature of socioeconomic-ecological linkages in Clayoquot Sound.

From a technical perspective there remains much research to be done regarding the applicability and robustness of multi-criteria plan evaluation procedures. Several studies have indicated that the particular multi-criteria method adopted has a bearing on final plan rankings (Nijkamp *et al.* 1990). This problem can be partly overcome by using a number of different solution methods and assessing the sensitivity of the results to the method being used. Within individual methods, including evamix, results also show varying degrees of sensitivity to criteria scores and weights. Once again this can be partly overcome by sensitivity analysis. However, these potential shortcomings should not detract from what is a potentially flexible and widely usable evaluation tool. Its advantages make it particularly suited to regions where data bases are weak, economic and social systems are dependent on natural resources, and there are substantial distributional concerns.

5.5 Summary

The purpose of the case study in the overall context of this research was to show that the concepts and methods discussed in previous Chapters could be applied to real-world sustainable development planning problems. Research succeeding in this regard would provide for a more substantive approach to sustainable development than has been forthcoming in the relevant literature. The articulated methodology uses a spatial perspective to draw insights from economics, ecology, landscape ecology, environmental planning, and other disciplines to present a flexible multi-dimensional framework. Notwithstanding the methodological and data limitations of the approaches used the research demonstrated the utility of using programming and multi-criteria algorithms both singly and in combination.

The case study, although by no means comprehensive, showed that while the recently adopted land use strategy for Clayoquot Sound (option C) may be an acceptable compromise land use plan for many stakeholders (e.g., the Nuu-chah-nulth First Nation, the logging industry, and the communities of Ucluelet and Port Alberni) neither it or any of the other land use alternatives examined provided for sustained employment at present levels. This suggests that there needs to be a fundamental reorientation of ecological-socioeconomic linkages in the region. Without this reorientation significant irreversible degradation of the resource stock will occur with few long-term benefits to the residents of the region or province.

Since recoverable timber makes up only half of the Clayoquot landscape there is a strong possibility that the integrity of the landscape will not be severely impaired by proposed land use practices. However, significant alterations in landscape composition, structure and function can be expected. These changes make it likely that social preferences regarding desirability of different system attributes and their distribution will determine the nature of development in the region. For example, the defense or rejection of an environmental ethic will influence planning decisions long before the continued ability of the system to be self-organising becomes an issue.

The case study and its background can thus be seen to serve two important purposes. Directly, it provides a heuristic methodology to aid in the resolution of sustainable development planning problems. It has generated information, albeit limited by data availability, on the regional implications of sustainable development and several regional land use plans. Indirectly, it provides a framework with which to characterise the problem of sustainable development. In this way the framework becomes a means to further discussion and stakeholder participation, rather than the end result of an abstracted decision making process.

The situation where the methodology becomes the focus of the planning process should also be avoided. Data requirements regarding ecological and socioeconomic interrelationships and societal values may guide the information gathering exercise, but the methodology itself should not become the sole determinant of subsequent action. For planning purposes much can be learned from the direction of change and relative order of magnitude of change. Precise prediction of parameter and variable changes is often little more than spurious precision. Nevertheless, there is still a need for fundamental ecological and economic research that recognises the fundamental interdependency of socioeconomic and ecological systems. Without this research present planning mechanisms will continue to treat ecosystems as a subset of the human system and therefore the many unsatisfactory relationships between environment, economy and society will remain unchanged.

Chapter Six

Summary and Prospects

6.1 Introduction

This concluding Chapter summarises the findings of this research and discusses prospects for future sustainable development research. A brief Chapter overview is presented in the next section. This is followed by a more detailed summary of, and conclusions relating to, the concepts of sustainable development, multi-dimensional approaches, appropriate indicators, and the case study. A section on future research prospects concludes the Chapter.

6.2 Chapter Overview

This research makes a contribution to the areas of resource decision making and sustainable development research in several regards. First, it represents a comprehensive review and synthesis of the sustainable development literature, environmental evaluation processes and indicator issues. Second, it articulates a framework which can apply sustainable development concepts to real-world resource assessment and environmental planning problems. This latter contribution is especially important since sustainable development has been, and remains, largely a normative concept with little empirical content. Without the development of empirical frameworks there is no way to demonstrate whether or not sustainable development is a realistic or achievable state for human society and economy. Moreover, it is difficult to explore the empirical relevance of sustainable development as a planning objective. Third, it makes a theoretical contribution to both the sustainable development literature and to the broader field of resource analysis by articulating and applying concepts derived from non-equilibrium theory. This perspective allows for a better understanding of the tradeoffs between the intergenerational, intragenerational and ecological dimensions of sustainable development.

Geography played a major role in the conduct of this research. Its ontology grounded in the traditions of spatial, ecological, and regional analysis provided both a guide to the research programme and contributed to a pluralism that enabled information from diverse and often competing disciplines and research paradigms to be synthesised. Methodologically, the spatial dimension provided a means to integrate the complex interrelations within and between ecological and socioeconomic systems and the extended time horizons that are necessarily part of sustainable development research.

In Chapter Two, normative and methodological approaches to sustainable development were examined. Methodological approaches were found to have the greatest potential to move the notion of sustainable development from programmatic statement to the substantive research concept. They provide for rules and procedures that indicate how sustainability research is to be conducted. Central to the development of an applied framework capable of modelling sustainable development is the establishment of a general relationship between society, economy, and environment. It was argued that this could be expressed in terms of the biosphere imposing dynamic constraints of the scale and scope of human development. This notion contained two key elements, a set of ecological constraints which act on expression of social systems, and a series of development goals relating to the condition and evolution of socioeconomic system.

In Chapter Three, environmental evaluation methods and related processes were examined in terms of their ability to act as an analytical basis for an applied sustainbility-related resource assessment framework. The Chapter began with a discussion of the role of resource analysis, resource management, and resource evaluation in sustainable development research. Resource analysis was highlighted as an important bridging discipline between the analytical qualities of resource analysis and the planning oriented nature of environmental management. The relative strengths and weaknesses of single metric resource allocation methods, integrated ecologic-economic simulation frameworks, and multidimensional approaches were then examined.

All too frequently, research methods have been applied to questions for which they are unsuited. All the methods reviewed in Chapter Three had inherent weaknesses. Single metric resource allocation methods and integrated ecologic-economic simulation frameworks were not so much rejected because of these weaknesses, but because they were unsuited to the type of analysis implied by resource assessment. Cost-benefit analysis may, for example, be unsuited to resource assessment, but it is suited to other forms of efficiency analysis. Similarly, while multi-dimensional planning approaches seem to have the greatest utility for resource assessment, there are many questions relating to resource decision making for which they may not be appropriate.

Chapter Four dealt with the issue of indicators for sustainable development. It Reviewed the limited literature dealing with sustainability development indicators.

Following this review, the nature of indicators and their application to resource assessment and environmental planning was discussed. This led to an examination of appropriate measures of welfare and ecological attributes to act as sustainable development related objectives, constraints and inputs for the planning methodologies discussed in Chapter Three. It was concluded that no single approach to developing indicators for sustainable development yielded appropriate measures in all ecological and socioeconomic contexts. Instead, a pluralistic approach cognizant of the appropriate level of ecological and socioeconomic system organisation and the spatial scale at which the measurement of system attributes is required.

The concepts and methods described in Chapters Two, Three, and Four were assembled in an empirical application in Chapter Five. The case study contained two related components. The first was a partial analysis (using a simple multi-period programming model) of the potential of Clayoquot Sound's resources to support sustained development activities. This aspect of the case study is timely because the future development of Clayoquot Sound is subject to much political and public debate. The second part of the case study integrated the results of the programming model with a multi-criteria plan evaluation model. This allowed for the evaluation of prior specified development alternatives involving quantitative and qualitative criteria scores and ordinal criteria weights.

Although both analyses were indicative rather than comprehensive in form, they still demonstrated the potential of the approach for applied sustainable development resource analysis and environmental planning. They indicated a conflict between present land uses and the objective of sustainable development. The new land use options appeared to represent an improvement over the existing situation, but the potential still exists for conflict between short-term welfare considerations and the long term structural adjustments necessary for sustainable development.

6.3 Sustainable Development

Sustainable development can be considered to mean the continued ability of humanity to meet its needs and fulfill its aspirations within the constraints imposed by environment society and technology. It has been argued by others that sustainable development should be made a concise, systematic and rigorous concept. This may be a self defeating exercise, however, for sustainable development is ultimately a normative concept made empirically vague by its extreme sensitivity to ecological, social and economic context. It is best considered a general social ideal, but a lack of a precise definition need not hinder the empirical investigation of its implications for individual development situations. To succeed in this task, however, researchers most develop empirically relevant conceptual and methodological frameworks that are consistent with the intent of sustainable development. To date, this effort has been lacking from the sustainable development literature.

One aim of this research was to describe a set of concepts consistent with the ideal of sustainable development. The purpose of these concepts was to define the nature of the research problem thereby identifying its parts and their relationships. As mentioned in the previous section the idea of sustainable development can be considered to contain two key elements: a set of ecological constraints which act on the expression of social systems, and a series of development goals relating to the condition and evolution of socioeconomic systems.

The ecological economic literature typically expresses ecological constraints on human development in terms of the constancy of environmental-ecological stocks. This expression derives from an ontology that treats the heterogeneity and complementarity of environmental systems seriously but simplistically. While an interesting theoretical notion, maintaining a constant resource stock is an unrealistic empirical constraint. Two major problems exist. First, any use of non-renewable resources violates the constraint. It is highly unlikely that any two resources provide identical contributions to the biosphere, and therefore to human wellbeing. Thus, any use of a non-renewable resource will see a depletion of natural capital, no matter how much is invested in a "renewable" substitute. Moreover, any use of a renewable resources may create changes in an ecosystem's structure, function, and/or composition that are permanent, regardless of the rate of renewal of the harvested resource.

Second, it can be argued that there is no ecological basis for the maintenance of a constant resource stock. If the term sustainability is used to refer to the ability of a given system to maintain its self-organising ability (integrity), a systems composition, structure, and function (i.e., the resource stock) can change through time. What is important in ecological terms is that human activities do not compromise the integrity of the biosphere. Defined in this way it is possible that some components of the resource stock may be significantly degraded without any impact on sustainability. Moreover, maintaining a constant resource stock, especially one defined in terms of resource prices or even the ISEW is no guarantee of biosphere integrity.

Dismissing the ecological rationale for a constant resource stock does not mean that the concept need be rejected in its entirety, nor does it mean that there are not ecological limits to human development. What it does mean is that a constant resource stock only has relevance for human development if it is inculcated with human preferences for different ecosystem states. Different environmental possibilities are valued in terms of an environment's potential contribution to human wellbeing. These preferences are formed within the context of prevailing social, economic and cultural constructs. Ethical considerations regarding the wellbeing of future generations are also associated with these preferences.

What becomes important is the degree to which the resource attributes that constitute a preferred environment can be degraded while maintaining the environment in its preferred state. It is likely that human preferences for different environmental states will acts as constraints on the quantity and quality of resource stocks long before ecological integrity become an issue. This is especially true at micro and meso-level spatial scales (e.g., individual ecosystems and bioregions). At the macro (i.e., global) scale, the cumulative impact of human development may require that limitations be imposed on material and energy throughput at smaller scales irrespective of regional sustainable development constraints.

The second component of sustainable development concerns two development goals relating to the condition and evolution of socioeconomic systems. The first goal suggests that the welfare of the present generation should always exceeds some arbitrary minimum level. It has also been expressed in terms of a non-decreasing change in welfare over time. The second development goal requires that the activities of the present generation do not preclude the attainment of the needs and aspirations of future generations. Both constraints assume that welfare is a function of the level of consumption and environmental quality.

Adherence to the concept of sustainable development means that it is unethical for the present generation to endow future generations with a lesser level of natural capital than it inherited, and/or to leave a stock if natural resources to future generations that makes sustainable development unlikely. There is, however, nothing to prevent the present generation from trading off the wellbeing of future generations for improvements in its own welfare. In such instances development occurs but it is not sustainable.

The intergenerational equity concept is thus a temporal restriction on the magnitude and nature of the interactions between the ecological and socioeconomic systems. Rather than requiring a constant level of natural capital, a more flexible interpretation of this constraint requires that the welfare contribution of natural capital be non-decreasing over time. The actual mix of resources in the stock of natural capital will depend on societal preferences regarding the desirability of different environmental states. Ecological parameters constrain the range of feasible environmental states from which a society may choose at one level, and at another set the ecological limits to all development possibilities.

The motivation behind the academic and institutional call for sustainable development can thus be characterised as an attempt to move towards a more stable, ecologically-based society. A serious commitment to this ideal would challenge the kind of utilitarian thought that has previously dominated discussions about natural resources and the environment. A Rawlsian philosophy suggests that the wellbeing of an individual living now or in the future should not be sacrificed in order increase aggregate or even average welfare. Conceptual frameworks that recognise the ecological and ethical consequences of this position, such as that attempted in this research, are needed to guide empirical research capable of revealing the implications of this development perspective for environment, society, and economy.

6.4 An Applied Planning and Assessment Framework

A major contribution of the present work was its development of an applied framework capable of applying hitherto programmatic statements about the concepts of sustainable development to real-world resource assessment and environmental planning problems. Several types of evaluation approach were examined in terms of their potential to provide the methodological foundations of the framework. It was necessary that any method used be able to represent the diverse determinants of sustainable development and reveal something of the potential trade-off's between them. Furthermore, the approach needed to be amenable to varying degrees of prescriptive, descriptive and predictive use as dictated by the nature of the problem at hand. Any method selected also had to be sensitive to spatial scale and ecological, economic, and social context.

No one methodology or class of methods was found to meet all of the above requirements. However multi-criteria plan evaluation approaches and programming models came closest because of their ability to incorporate the ecological, social and economic dimensions of resource analysis. Moreover, these methodologies have robust data handling capabilities allowing, to a varying degree depending on the actual method used, the integration of quantitative and qualitative information. Their flexibility also makes them particularly relevant tools in today's climate of participatory and consensus based planning.

Multi-dimensional methodologies and modelling in general fulfills a useful role in thinking about sustainable development and in resolving resource allocation problems. First, models facilitate communication between different disciplines such as geography, economics, and ecology. This enables the integration of diverse knowledge with a reduction in methodological conflicts. Second, models provide a focal point for dialogue between decision makers, resource analysts and other stakeholder groups. Different model assumptions, resource allocations and preferences can be tested and the relevancy of the results debated. This heuristic capability is often missing from decision making processes which rely on less rigorous methods to define the planning problem and options for its resolution.

Third, models can aid in understanding complex, interrelated system processes in the context of long term socioeconomic-ecological co-evolution and also reveal something of the implications of the relationship for human wellbeing. Fourth, models allow common sustainability concepts and ideas to be tested under different social, economic and environmental conditions. This is the only way to adequately demonstrate whether or not sustainable development is a realistic or achievable state for human society and economy. An even more fundamental question that may also be answered in this way is whether or not the concept of sustainable development has any relevance for applied resource evaluation and environmental planning.

Chapter Four discussed the issue of indicators for sustainable development. This is an important aspect of applying sustainable development concepts that has received inadequate attention in the literature. Even if a set of sustainable development concepts can be adequately articulated and appropriate methods to model them found, empirical research cannot continue without indicators to act as operational constraints, inputs and planning objectives. Significantly, indicators act not only as a tool for measurement but also as a way of defining what is measured.

In the review of social and ecological indicators carried out in Chapter Four, no single approach to developing indicators for sustainable development appeared to yield appropriate measures in all ecological and socioeconomic contexts. It is therefore important to explore a broad spectrum of approaches to indicator development. It is also necessary for researchers to understand how indicators can be used, and to realise that sustainable development related social and ecological processes operate at multiple scales and levels of organisation.

Three points regarding the choice of actual indicators for sustainable development research were emphasised. First, the question of what is being indicated and why, is fundamental to selecting appropriate variables. Second, the selection of indicators requires the determination of relevant policy and management questions. These questions can only be formulated within specific development contexts. Third, an approach to the integration of diverse social and environmental indicators must be found. This issue is especially important if the trade-off's between measures are to be examined. It is required that the functional relationships between and within society, economy, and environment that determine the sustainability of development be made explicit.

This research resolved some of these problems by adopting a spatial perspective based on landscape level measurements of ecological and socioeconomic system attributes. Landscape level measures were found to fulfill several potential roles as sustainable development indicators. It was suggested that measures of landscape attributes can be used as indicators of resource stocks. The necessary integration of environmental indicators and indicators of human development is also facilitated by using landscape level measures. Also, the spatial dimension was found to provide a means with which to inculcate human values with the study of ecological systems.

The main disadvantages of the approach to sustainable development described above are associated with the potential complexity of operational methods, the mathematical restrictions of the techniques, and the difficulty associated with defining and adequately specifying ecological, economic and social system interactions. The use of multi-criteria analysis overcomes part of the evaluative aspect of these problems, but researchers still often lack a basic understanding of the ecological implications, and hence impacts on future wellbeing, of human development activities. Two conclusions can be drawn from this. First no single methodology or framework should be used to determine the outcome of the planning process. Their structures are useful in defining the nature and general implications of the problem, but at best their results can only indicate the general direction of system changes and their relative order of magnitude. Second, much interdisciplinary research is required to overcome some of the above weaknesses that are common to all methods intended for application to environmental and resource planning problems.

6.5 The Case Study

In order to test some of the concepts and approaches developed in Chapters Two, Three, and Four, a case study centered on Clayoquot Sound, British Columbia, was carried out. This is a region where there are potential resource use conflicts. The first component of the case study was a simple programming model. It was exploratory in nature and took a long-term view point by way of a multiperiod formulation. Within a simple optimisation framework it had a stock-flow structure and included simple material balance considerations. Constraints on the size of stocks and flows between periods were used to establish feasible development possibilities. This part of the study concluded that Clayoquot Sound's current contribution to human wellbeing could not be sustained without a restructuring of the present ecosystem-socioeconomic interrelationship. These results have to be interpreted with caution because of the partial nature of the case study.

The potential use of multi-criteria analysis for the evaluation of alternative sustainable development resource use plans was demonstrated in the second part of the case study. Five land use alternatives were evaluated, one of which was based on an land use plan proposed, but yet to be implemented, by the Province of British Columbia. A variant of the programming model was first used to simulate the impact of the options on the landscape, present generations, and future generations. Additional qualitative ecological and equity considerations were then added to better reflect other sustainable development evaluation criteria. Ordinal weights reflecting hypothetical societal rankings for each of the criteria were also incorporated.

The case study and its background served several important purposes. Directly, it provided a heuristic methodology to aid in the resolution of sustainable development planning problems. It also generated information, albeit limited by data availability, on the regional implications of sustainable development and several regional land use plans. Indirectly, it provided a framework with which to characterise the problem of regional sustainable development. In this way the framework may become a means to further discussion and stakeholder participation. Finally, it demonstrated the potential of the suggested concepts and methods to formally incorporate sustainable development criteria into applied resource assessment and environmental planning.

6.6 Prospects

Several areas for future sustainable development research, building on and supplementing the present work, can be distinguished. The first area of research is to expand the conceptual framework discussed in Chapter Two. There is no urgent need to refine the concept of sustainable development itself. Rather, research should be directed at its component parts. For example, the area of ecological limits to human development needs further conceptual refinement. Notions of environmental determinism and limits to growth seem to have been excised from the environmental-resource lexicon, perhaps with some justification. However, this research indicates that at any one time the range of feasible development possibilities is still constrained by both regional and global ecological imperatives.

Similarly, there remains much work to be done examining the implications of different ethical positions for both current and intertemporal resource allocations. For example, Rawl's principles of equal liberty and difference could be refined to involve explicit environmental recognition. In a democratic society, however, resource allocations will be ultimately decided by the collective preferences of the present generation. The wellbeing of future generations and the environment will be protected only if these preferences incorporate an intergenerational and/or ecological ethic.

The second type of research prospect relates to the refinement of methods and processes for sustainable development related resource assessment and environmental planning. At the broadest level this involves developing more robust analytical methodologies and synthesising existing diverse solution methods within a common framework. This exercise would make the range of applications to which the routines are suited obvious to the researcher or planning practitioner.

Similarly, there is much work to be done in the area of extending the our knowledge about appropriate environmental and development indicators. Exploration of their role in expanding the ontological basis of resource analysis and environmental planning may also prove useful. At least three research avenues can be followed. First, the search for a comprehensive indicator of sustainable development can be continued. While this may be useful in individual development contexts, it is unlikely a universal indicator of this type can be developed. Second, separate indicators approaches (e.g., the social indicators approach, biodiversity indicators etc.) can be pursued within individual disciplines. This work may provide useful indicators for sustainable development research, but their relevancy could be restricted by the lack of a theoretical basis with which to link the disparate indicators. Third, a broader perspective can be adopted that considers not only the issue of measurement but also the issue of how such indicators can be integrated with one another and applied in a range of contexts. This means that indicators must be the an explicit part of any methodology adopted and not a secondary consideration. This has been the philosophy behind the applied aspects of this research.

Also on an operational level there is a pressing need to integrate micro, meso, and macro-level sustainable development issues in some manner (e.g., geographic information systems, inter regional simulation models etc.). Without this integration there is no easy way to determine the implications of global sustainability for regional sustainable development planning and vice-versa. Any attempt at the integration of spatial scales will be faced with a number of data collection problems. The type of obstacles to be met including the non-existence of data, costly fieldwork to obtain them, and transforming and processing data to formats useful for the purpose of the individual study.

Almost all types of sustainable development research need better ecological data. This requires more empirical work on system processes and interrelationships and also increased dialogue between the ecological and social sciences. In any ecological context sustainable development research has to incorporate information and data relating to controlling system processes, the historical range of system perturbations, the evolutionary and physiological limits of system components, and the characteristics and effects of short and long term ecological phenomena. In contrast to this type of ecological information, economic and social data is generally readily accessible. This situation creates an imbalance in favour of short-term gains in human welfare at the expense of future generations and the environment.

Most decision problems, especially in an environmental context, are multi-dimensional in nature and involve a pluriform of variables and interrelationships. It may therefore prove impossible to resolve all the problems associated with developing a comprehensive approach for applied sustainable development related resource assessment and environmental planning. A more productive route may be to focus on the development of flexible approaches and perspectives that can accommodate as many of these issues as possible. This requires as much a shift in research philosophy as an improvement in method. Sustainable development's strength is its holism. Attempts to reduce the concept to its component parts have to be balanced with an attendant diffusion of meaning and the potential demise of a conceptually and methodologically provocative, and widely supported social goal.

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Appendix One

The Evamix Multi-Criteria Plan Evaluation Methodology

In this Appendix the evamix methodology discussed in Chapter Three and applied in Chapter Five is specified mathematically. The specification is based on Nijkamp *et al.* (1990) and Voogd (1982). Readers interested in a detailed explanation of the methodology will find Voogd (1982) more instructive than Nijkamp *et al.* (1990).

The evamix methodology begins with an impact matrix E with elements e_{ji}, where i ($i = 1, \ldots, I$) represents an alternative plan and j ($j = 1, \ldots, J$) an evaluation criterion. Two subsets of criteria denoted O and C are created, where:

$$O = \{j \mid j \text{ takes ordinal values}\} \quad (1)$$

and

$$C = \{j \mid j \text{ takes cardinal values}\} \quad (2)$$

It is assumed that the differences between alternatives can be expressed by means of a dominance score $\alpha_{ij'}$ for the ordinal criteria, and a dominance score $a_{ij'}$ for the cardinal criteria. The **dominance scores** have the following structure:

$$\alpha_{ij'} = f(e_{ji}, e_{ji'}, w_j), \text{ for all } j \in O, \quad (3)$$

$$a_{ij'} = g(e_{ji}, e_{ji'}, w_j), \text{ for all } j \in C, \quad (4)$$

where e_{ji} represents the criterion score of criterion j and alternative i, and w_j the weight attached to criterion j. The functions of expressions 3 and 4 differ because in 3 only the ordinal characteristics of the e_{ji} variables have to be taken into consideration, whereas in expression 4 their metric properties have to be used as well. Expression 3 can be more fully specified as:

$$\alpha_{ii'} = \left(\sum_{j \in O} \left\{ w_j \operatorname{sgn} \left(e_{ji} - e_{ji'} \right) \right\}^c \right)^{1/c} , \quad c = 1,3,5,..., \tag{5}$$

Where:

$$\begin{aligned} \operatorname{sgn} \left(e_{ji} - e_{ji'} \right) &= \{1 \text{ if } e_{ji} > e_{ji'} \\ \operatorname{sgn} \left(e_{ji} - e_{ji'} \right) &= \{0 \text{ if } e_{ji} = e_{ji'} \\ \operatorname{sgn} \left(e_{ji} - e_{ji'} \right) &= \{-1 \text{ if } e_{ji} < e_{ji'} \end{aligned} \tag{6}$$

The symbol c in equation 5 is an arbitrary scaling factor. Any odd value for c may be chosen. Evan values would distort the various signs. The larger c is the less influence differences between the alternatives based on minor (low ranked) criterion will have on the value of the dominance scores (both ordinal and cardinal). To ensure consistency c should be the same for all expressions. Sensitivity testing shows that when using the expected value weighting method as in the case study c is best set at one. This retains the significance of low ranked criterion.

The quantitative dominance measure (expression 4) can be expressed in a similar way to equation 5 but for some minor differences:

$$a_{ii'} = \left(\sum_{j \in C} \left\{ w_j \left(e_{ji} - e_{ji'} \right) \right\}^c \right)^{1/c} \tag{7}$$

Before the operation implied by equation 7 can be performed the cardinal criterion scores have to have been standardised ($0 \le e_{ji} \le 1$). All standardised cardinal scores (and ordinal scores) should be in the same direction. This also applies to the ordinal scores in equation 6. A higher score should reflect a better score. There are various ways to achieve this standardisation. Two common approaches can be expressed thus:

$$\alpha_j = \frac{x_j}{\max x_j} \quad (8)$$

$$\beta_j = \frac{(x_j - \min x_j)}{(\max x_j - \min x_j)} \quad (9)$$

Where max x_j and min x_j indicate the maximum and minimum value observed for criterion j among all alternatives. Equation 8 will yield results where the lowest level may be different from 0. Equation 9 yields results where the highest score is equal to 1 and the lowest score equal to 0. The method of standardisation will have some effect on the results of the evaluation exercise. This effect is often small, but a sensitivity test of the final results should be carried out. The method of standardisation was found to make no difference to the final land use option rankings in the case study.

The next step in the evamix methodology is a standardisation of α_{ij}' and a_{ij}' into the same measurement unit. Without this standardisation a comparison cannot be made between equations 5 and 7. Following Voogd (1982) equation 9 was used to standardise cardinal scores in the case study. The **standardised dominance measures** can be written as:

$$\delta_{ii'} = h(\alpha_{ij'}) \tag{10}$$

and

$$d_{ii'} = h(a_{ij'}) \tag{11}$$

Where h represents the standardisation function. The standardised dominance measures are then combined with information regarding criterion weights to produce an **overall dominance measure** $m_{ii'}$. The weight of the qualitative criterion set O can be expressed as:

$$w_o = \sum_{j \in O} w_j \tag{12}$$

Similarly for the cardinal weight:

$$w_c = \sum_{j \in C} w_j \tag{13}$$

The degree to which alternative i dominates alternative i' (this includes option A versus option A as well as AB, AC etc.) for the given set of criteria and criterion weights is given by:

$$m_{ii'} = w_o \delta_{ii'} + w_c d_{ii'} \tag{14}$$

The last step in the evamix methodology is to determine an **appraisal score** s_i for each alternative. The measure $m_{ii'}$ is considered a function of the appraisal scores s_i, $s_{i'}$:

$$m_{ii'} = k(s_i, s_{i'}) \tag{15}$$

The way in which the final appraisal score is calculated depends on the way function k is made explicit. At least three solution techniques can be distinguished based on different definitions of expressions 10, 11 and 15. These are the subtractive summation technique, the subtractive shifted interval technique, and the additive interval technique. Equations 1 to 9 and 12 to 14 are common to all three solution techniques.

The Subtractive Summation Technique

This solution technique is based on the assumption that expression 15 has the following form:

$$m_{ii} = s_i - s_i' \tag{16}$$

This implies that the form of expressions 10 and 11 should be such that $m_{ii}', = -m_i'_i$. The following standardisation's are therefore appropriate:

$$\delta_{ii'} = \alpha_{ii'}\left(\sum_i \sum_{i'} |\alpha_{ii'}|\right)^{-1} \tag{17}$$

$$d_{ii'} = a_{ii'}\left(\sum_i \sum_{i'} |a_{ii'}|\right)^{-1} \tag{18}$$

Assuming that the mean of the appraisal scores s_i is zero, the following expression can be found:

$$s_i = \frac{1}{I}\sum_{i'} m_{ii'} \tag{19}$$

Where I is the number of alternatives under consideration. The higher the score for s_i, the better alternative i will for the weight set w_j.

The Subtractive Shifted Interval Technique

This technique differs from the previous technique by its standardisation which is now defined as:

$$\delta_{ii'} = \left(\frac{\alpha_{ii'} - \alpha^-}{\alpha^+ - \alpha^-} \right) - 0.5 \tag{20}$$

and

$$d_{ii'} = \left(\frac{a_{ii'} - a^-}{a^+ - a^-} \right) - 0.5 \tag{21}$$

Where:

α^- is the lowest qualitative dominance score of any pair of alternatives (i, i')

a^- is the lowest quantitative dominance score of any pair of alternatives (i, i')

α^+ is the highest qualitative dominance score of any pair of alternatives (i, i')

a^+ is the highest quantitative dominance score of any pair of alternatives (i, i').

The appraisal score can now be calculated using equation 19.

The Additive Interval Technique

This technique differs from the additive summation technique in its specification of expression 15. Expression 15 is now defined as:

$$m_{ii'} = \frac{s_i}{s_{i'} + s_i} \tag{22}$$

which implies that $m_{ii'} + -m_{i'i} = 1$. This additive expression can be arrived at using the following standardisation's:

$$\delta_{ii'} = \left(\frac{\alpha_{ii'} - \alpha^-}{\alpha^+ - \alpha^-} \right) \quad (23)$$

and

$$d_{ii'} = \left(\frac{a_{ii'} - a^-}{a^+ - a^-} \right) \quad (24)$$

The corresponding appraisal score is:

$$s_i = \left(\sum_{i'} \frac{m_{i'i}}{m_{ii'}} \right)^{-1} \quad (25)$$

This expression means that the appraisal scores should add up to unity, i.e., $\sum_i s_i = 1$.

The three solution procedures are best applied simultaneously in order to account for the differences in the techniques. This is somewhat akin to using a combination of cost-benefit ratio, present value, and internal rate of return criteria to select the best plan alternative using a cost-benefit framework. If land use option rankings were not consistent across all solution techniques in the Clayoquot Sound case study, rankings were assessed on the basis of the number of shared rankings. For example, if for a given weight set an alternative ranked second under the subtractive summation technique and also under the shifted interval technique, and first under the additive interval technique it would be assigned a rank of second overall. Voogd (1982) provides a discussion of appropriate techniques to resolve this problem when greater conflict exist.