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Workshop on Natural Capital

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1.0 Introduction

The November 1988 Canadian · Environmental Assessment Research Council (CEARC) workshop on environmental and economic analysis examined the role and relationship of analytical tools and bargaining procedures in support of decision making for sustainable development. Participants at this workshop identified "natural capital" as an important concept for organizing a more integrated approach to macro (policy) and micro (project) analysis.

This concept, which treats ecological resources as capital stocks, is central to developing a better accounting of the costs and benefits from development. The concept of natural capital is inextricably linked to sustainable development. Considerable theoretical and applied research has been undertaken to develop tools (i.e. the methods and procedures) that will facilitate decision making for sustainable development. Part of this effort has been directed toward estimating the economic contribution that ecological capital makes to the economy. Specifically, this research is focused around the following:

1. ensuring that national accounting systems make explicit the tradeoffs and value judgements regarding impacts on biological resources that may not be measured in monetary terms;

2. developing methods for assessing the cross-sectoral impacts of resource utilization;

3. collecting information on the physical properties of resources in specific environments and for specific uses;

4. developing methods for assigning values to non-marketed ecological resources; and

5. estimating the economic productivity of various ecosystems.

CEARC is interested in furthering research into the application of analyses based on the natural capital with a view to ensuring that natural capital analysis becomes an integral part of environmental and economic assessment and decision making. To move towards it research objectives, CEARC convened a two-day workshop in Vancouver, B.C. on March 15 and 16, 1990 to review the concept of natural capital and recommend the research. Based upon the issues raised and the recommendations suggested at this workshop, CEARC intends to undertake a case study demonstration project of natural capital in cooperation with other interested institutions, notably those that may be interested in adapting and testing the recommended approach and procedures in ongoing project assessment and regional planning activities.

This report describes the workshop, and recounts the issues and recommendations that emerged.

2.0 Objectives of the Workshop

The purposes of the workshop were to 1) review the concept of natural capital, and 2) recommend to CEARC a research approach to translating natural capital into operational terms= It was necessary, however, to ensure that the workshop participants were working from a common notion of the concept of natural capital. The workshop was therefore designed to meet three primary objectives:

1. develop a generic conceptual framework for natural capital;
2. test this conceptual framework against two case studies - agricultural soils, and wetlands; and
3. identify important research initiatives.

3.0 Emerging Issues

The workshop opened with a welcoming address and an overview of the objectives by Barry Sadler of CEARC. Robert Costanza, of the University of Maryland Center for Environmental and Estuarine Studies, then began the morning plenary session by presenting a paper in which he and Herman Daly of the World Bank explore the concept of natural capital, and try to put it into perspective with respect to sustainable development. The participants were then asked for their ideas on the key issues concerning the concept and utility of natural capital. During the ensuing dialogue many issues emerged concerning the definition, measurement, valuation and regulation of natural capital, and they are listed below under seven general headings.

3.1 Alternate Perspectives

- alternative paradigms based on ecodevelopment or ecoredevelopment
- general principles that need to be considered:

  1. intergenerational equity,
  2. self-reliance, and
  3. ecological diversity

- environment as a potential base for development.
- need to look at "ecological productivity"; also cultural productivity, ecotechnological productivity - ultimately looking for more rational approach to managing resources and community development
- most Latin American countries have lost development potential
- maximum output of commodities to satisfy people's needs outside the context of the market economy

3.2 Methods

- what to measure, and in what units
- how to measure/detect thresholds
- we are approaching thresholds (e.g. acidity of soils)
- necessity of incorporating pricing externalities (e.g. Japanese tastes with respect to shrimp)
- Caribbean Islands using sustainable development simulation modelling (development planning applied to ecological systems); some problems with lack of data for model

- natural capital concept must **not** be restricted **only to** market values
- **complementarity is important** but is a limiting concept
- **need to get the** relationship between natural capital and methods for environmental assessment and **decision-making**
- natural capital broadens the scope of economics
- need to consider heterogeneity
- measurement problem in "isolating" natural capital
- need to integrate natural capital into existing methods
- need physical stock taking
- need monitoring programs
- need to consider how land uses are changing to evaluate the gross "ecological productivity" of a region
- are ecosystem factors related to each other? mutually exclusive?
- can a hierarchy of functions be defined, so that it is **sufficient** to measure key functions and assume that others are implicitly accounted for?
- Conway's Methodology for Agroecosystems - criteria include: 1) increase in productivity (**kg/$**), 2) sustainable production over extended period of time, 3) stability and resilience, and 4) equity

3.2.1 Valuation

- focus groups may be useful alternatives to man-in-the-street, need people to take into account **future** generations
- biases in valuation result from common property resources and subsidies (e.g. for fossil energy use)
- valuing resources in the Caribbean is difficult because resources are not traditional ones (e.g. forests, mines); **difficult** to apply traditional cost benefit analysis (e.g. beaches)
- valuation is problematic, but unavoidable
- how do you break up nature into resources or valued ecological functions?

3.2.2 Natural Resource Accounts

- case study of Indonesia by World Resources Institute; attempted to account for natural capital in forestry and oil sector; depletion was a large component of National Income Accounts

- natural capital was converted into other forms - transportation networks and education

- techniques and measurement have to be consistent with SNA methods; SNA exclude other aspects besides natural capital; one approach is development of satellite accounts

- method needs to be consistent with neoclassical economic framework

- does not account for resources crossing international boundaries

3.2.3 Energy Analysis

- for regional analysis use macro-scale measurements (e.g. energy analysis); necessary to consider renewable energy flows and uses

- need to consider relationship between total energy flow and economies

3.3 Relationships Among Forms of Capital

- difficulty in differentiating between Natural and Manmade Capital creates problems (e.g. national parks in Britain)

- describing each factor of production as a form of capital gives them equal standing

- environmental problems (e.g. loss of soil productivity) can be hidden by extra inputs

- as fossil fuels resources are depleted, wetlands may have to be uses as sewage treatment plants

- extent of substitution/complementarity among forms of capital

- preferred development includes the mutual enhancement of the three different forms of capital

3.4 Data and Databases

- large amount of detailed resource accounting taking place without regard to how it would be used (e.g. France, Norway, Sweden)

- fundamental limitations exist for data from developing countries
- global inventory of natural capital needs to be compiled (what should be included?) will we miss things? (things falling through the cracks)
- large global data collection programs (e.g. GEMS), need a model to guide data collection
- legal and extralegal use of natural resources must be considered (what parts get incorporated into accounting)

3.5 Spatial and Temporal Issues

- questions of scale
- national accounts versus regional studies
- for some cases, a regional (extensive geographical) approach may be appropriate (e.g. the area around the Baltic Sea); many resources are shared by a number of nations
- how shall we combine community with regional and national planning, and promote decision-making at the regional and local level?
- natural capital is not static, but dynamic; natural capital changes as a result of technological change and human intervention
- there may be important interactions between ecosystems within regions (i.e. a diversity of systems); emergent properties of interactions between different systems

3.6 Participation in Decision-Making/Evaluation

- who values natural capital, and what is relationship to beneficiary?
- who ought to determine option values; man-in-the-street vase experts - contrary to welfare economics
- is the analogy to pricing works-of-art appropriate?
- economic gradient between subsistence and post-subsistence economies
- in post-subsistence economy, profit motive provides rationality; in subsistence economy, issue is minimization of risk
- future generations and natural systems ought to have voting rights
- some native American groups have representatives who speak for the next seven generations

- **conferring rights** on the beneficiary of **capital stocks may** lead to improved representation of those values
- involve beneficiary groups in defining and managing natural capital stock8
- often no relation between people working on management of natural resources and the budgeting/planning process
- in developing countries, people depleting resources may not **suffer** the consequences of such depletion
- burden of proof for negative changes in natural capital should he with those who benefit
- if local people are not included, there may be a shift of capital to the urban elite (e.g. luxury houses)

3.7 Relationship to Sustainability

- irreversible and non-substitutable changes should be the focus of concern (e.g. loss of species, loss of wetlands)
- is constancy of natural capital stocks **sufficient** for sustainable development?
- constancy of natural capital as necessary condition for sustainability has **difficulties** in application; if it is the focus of attention, then it promotes sustainability as only sustaining natural capital stocks
- a policy for sustainability must consider Man-made, Human Capital as well as natural capital
- Stokoe paper provides more general definition of sustainability
- people participation is necessary condition for sustainability
- local customs may involve prohibition from harvesting resources during critical times (e.g. festivals during spawning periods)
- **conflicting** government policies with respect to fisheries stocks may prevent the -development-of a sustainable fishery
- trade-offs between capacity, efficiency and equity
- sustainability is linked to the optimal mix of Man-made and natural capital

- for prudence sake, should limit resource **degradation at or** below current **levels**
- link between non-renewable resource depletion and enhancement of renewable resources
- let's not worry about how fast it's decreasing, but instead **try to** reverse it

4.0 Forestry Case Study

To provide some focus for the discussion of natural capital, a forestry case study was then presented in the afternoon plenary session (see Appendix 1). The presentation outlined a number of possible forest ecosystem functions, criteria for considering those functions, measurement units, inventory methods, and characteristics that might be used for economic valuation. The workshop participants were asked to consider natural capital in the context of this particular case study, and to identify any issues missing from those brought forward during the morning session (Section 3.0). The ensuing discussion brought out the following points:

- degradation of the environment due to smog, acid rain, etc. should be considered in forest inventories
- distant beneficiaries should perhaps pay for the maintenance of ecosystem quality (e.g. India and Bangladesh might pay Nepal to not cut its forests, because they reap the benefits of flood control)
- ecological function ought to be the stock that is preserved, to avoid foreclosing options for differing strategies for resource use (i.e. maintaining the process that results in ecological production, or the "ability to produce")
- is natural capital a yardstick for sustainable development, or is sustainable development the basis for natural capital?
- it is important to identify the actors who will make decisions on, and those who will benefit from, natural capital
- scientific uncertainty and risk have not yet been mentioned
- the link between economic and ecologic values is crucial
- a great deal of information already exists, but it is not being shared (may be individual-to-individual information transfer, but rarely is it government-to-government)
- empirical constraints to measuring ecosystem function are too overwhelming, and they may actually be immeasurable; but this is the challenge to ecologists - can we measure it, and if not, are there surrogates for some of the functions we can't really measure
- the definition of capital in this context needs to be clear (i.e. determine the services it can deliver into the future, and then amortize it)

- regarding **natural capital stock: "stock" is** quantitative, but it is **the structure that is important;** there may be a large **physical** stock, but it may provide only short **term benefits**

5.0 Subgroup Discussions

Next, participants were divided up into two groups, to further discuss an operational strategy for natural capital while focusing on agricultural soils and wetlands as specific case studies. Both subgroups were charged with exploring the following questions with respect to their case study:

1. Methods for determining the structural/operational characteristics of ecosystems;

2. Strategies for linking characteristics with measurement units;

3. Methods for quantifying the amount of natural capital;

4. Methods for economic valuation of natural capital; and

5. Research needs.

5.1 Agricultural Soils **Subgroup**

This subgroup was to discuss the five issues listed above in the context of agricultural soils as natural capital. To prepare subgroup participants for this discussion, the group had been earlier provided with a case study description of soil productivity on the Canadian prairies (see Appendix 2). As well, John Pierce, of Simon Fraser University's Department of Geography, presented a second case study (see Appendix 4). His suggestion that natural soil productivity be measured in terms of above ground net production (ANP), and the idea of using native grasslands as a standard or bench mark against which to evaluate the productivity of agricultural soils, elicited a number of valuable comments from the subgroup participants.

Comments regarding the use of ANP as a measurement:

- ANP on its own does not measure parameters such as the loss of soil organic matter if this loss is masked by the input of nitrogen fertilizer

- ANP is not what a "natural" ecosystem would maximize; it would be above <u>and</u> below ground productivity, and animals, etc....

- a problem with using ANP emerges from the fact that many native plants have a high root:shoot ratio, whereas crops tend to have a low root:shoot ratio - why not measure soil organic matter instead?

- a relative measurement of the decline in natural capital can be obtained by measuring ANP of grasslands on un-subsidized soil, and comparing this to the growth of the same grasslands on subsidized soil

Comments regarding the use of comparisons between sites:

- causality assumptions from this type of measurement can be misleading
- soils are now man-made, and *we* now have no "original" soil from which to base our comparisons; does this matter, or is simply a current bench mark with which to compare future degradation sufficient?
- absolute change from a pristine state or bench mark may not matter, if the lower state is stable and can be maintained
- once you show people that there is a discontinuity of the system, they want to know how close they are to the threshold

General comments:

- natural capital is the sum of a number of components, not just one; therefore, how do you chose what to measure?
- however, if you measure many components, how do you deal with the results on an operational scale (i.e. how to integrate the information)?
- how do you chose the area over which the information will be averaged? (i.e. size *matters...)*

The subgroup participants then addressed the five issues they were charged to explore.

1. Methods for determining ecosystem characteristics:

- watershed input/output (energy and materials)
- primary productivity --> ecological productivity
- process structure model (includes identifying processes and linkages, and performing uncertainty analyses; intentionally provoke error to see how these processes and linkages change)
  - problems: natural capital is a transitional resource, not a classic steady-state; how do you get a model to characterize this?
- need spatial and temporal compatibility with the feature that is being characterized
- need to focus on a small subset of natural capital - we won't get anywhere trying to deal with natural capital as a whole

- use the ecological "law of the minimum" principle (the factor in least supply governs the rate of growth Of the whole); define the necessary and limiting factor for the ecosystem

- remote sensing and modelling to capture the variability and diversity of the landscape

- terrestrial system - measure water; aquatic system - measure food chains

- longevity of soils; need to look at how environmental degradation has occurred in the past, and future impacts

2. Measurement units:

- measure output in physical units, but also measure multiple uses of resources (man-made services)

- use an experimental approach:
  1. establish a bench mark for natural capital
  2. get a measure of departure from (1)
  3. get a measure of recovery, when stresses relax

- another experimental approach: use some measure' of biomass as the standard or bench mark for natural capital (this precludes other ecological functions, but this is less crucial for agroecosystems which are somewhere between a natural and a manmade state)

  - plant grassland on farm soil and measure the difference in soil productivity, or hold inputs constant and measure yield responses over time to get a rate of change

- gross primary productivity (GPP), rather then net primary productivity (NPP) (i.e. the ability to fix solar energy)

- must consider cultural utility, in addition to ecological, economic exploitability and soil productivity components
- the link between ecological and soil productivity information exists, but it is in unusable form

3. Methods for quantification:

- how do you measure the conditions necessary to provide basic ecological productivity? incorporate risk of collapse, perhaps (easier to visualize)

- need simple indicators of measurement units that can be extrapolated to a larger natural capital feature (if adopting the experimental approach suggested under 2.)

- incorporate different regions, and fine spatial grid
- must deal with aggregation and multiplication problems
- must include qualitative aspects.

4. Methods for valuation:

- *there* can be a large difference between ecological and economic valuation (e.g. the ecological cost of the extraction of a particular oil reserve may be quite different from the economic cost of extraction); we need to know, therefore, if natural capital is an ecologic *or* an economic concept
- use current methods for valuing resource stocks (assuming an efficient market mechanism>:
  1. present value of all future net revenues
  2. site-transaction costs
  3. net price method
- cost-benefit analysis
  1. loss of productivity
  2. replacement cost of a resource
  - problems. with this: we cannot currently deal with irreversibility, or the long-term intergenerational trade-offs
- need to be able to transform qualitative differences into dollar losses
- need to be able to determine the value of maintaining the ecosystem
- economic valuations have biases built in, because the market is inefficient with respect to common property resources; market imperfections undervalue certain resource8
  - but dollar value is important for comparison purposes (i.e. for evaluating trade-offs)
- need to figure out how to link environmental and economic valuation methods

5. Research needs:

- need conceptual research into operational measures (past research has been too theoretical)
- need pilot studies on the basic conditions of ecological productivity, for specific ecosystems

- need to maintain reserves of ecosystems
- if economics drives the search for natural capital, we'll fail
- the experimental approaches mentioned above should be implemented
- need to look carefully at the existing information in the literature (e.g. a UN/FAO agroecosystems zones project is currently measuring biomass potential)
- need to investigate the relationship between total energy flow and gross economic output (efficiency), and how this changes over time
- need to learn how to increase natural capital in the future
- conceptual understanding of multiple uses of ecosystems
- economic and ecological linkages in valuation
- develop GIS to handle the spatial and temporal aspects of natural capital
- apply "best practicable option" (BPO) method beyond just pollution problems to natural capital

The subgroup concluded by identifying a number of issues which will' require further attention:

- thresholds
- longevity
- degradation, and the implications of
- irreversibility
- link to other approaches (EIA?)
- cultural utility/accessibility

5.2 Wetlands Subgroup

This subgroup was to discuss the five issues listed under Section 5.0 in the context of wetlands as natural capital. To prepare subgroup participants for this discussion, the group had been earlier provided with a case study description of wetlands (see Appendix 3). The group broadened their discussion to include other ecosystems; and although the subgroup session was not focused on the five issues they were charged to explore, these were indirectly addressed and the subgroup discussions were categorically summarized by the facilitator.

1. Methods for determining ecosystem characteristics:

- need to involve both scientists and users (and therefore must define the scale, which is context-dependent)

- use unique biological properties (e.g. endemic species, biodiversity, endangered species)

2. Measurement units:

- use existing methods, identified by scientists who determine ecosystem characteristics (above)
- multiple passes may need to be done; "quick and dirty" (using existing data) versus a detailed evaluation, or both

3. Methods for quantification:

- for most functions, there are already existing methods
- need to measure ecological function in a systems context (i.e. economists want to know "what if we lose this function?")
- market for function (i.e. who, or what, are the beneficiaries of the product or output from this function?)

4. Methods for valuation:

- use standard methods at the local, national, global level
- apply these methods over a broader scale and time frame than is currently done in EIA or economic analysis
- using discount rates, create scenarios to offer options to decision makers (i.e. the value of the natural capital stock will vary with the discount rate
- be open to new ideas; analogy of museums measuring wear on the floor to locate popular displays

The subgroup agreed that a framework that incorporates natural capital is a better decision making tool than one that does not. To summarize the above information, this subgroup outlined a set of tasks that would be followed in creating this tool:

1. Identify the asset of interest (on-site, off-site functions).
2. Bound the area and time-frame of interest.
3. List the functions in hierarchical order (global, national, local).
4. Evaluate these functions (private/proponent CBA as a first requirement, opportunity cost, visual valuation of landscape (current methodologies exits), replacement cost (e.g. of air filtering)).

5. Draw a matrix, with functions across the top and scale along the side,

	F_1	F_2	F_3	F_n
global				
national				
local				

and fill each of the cells with 1) an analysis of that function, 2) a valuation of the function, and 3) an estimate of the uncertainty; the sum of these tabular values would provide a comprehensive picture of the natural capital for any particular ecosystem.

5. Research needs:

- compile a checklist of functions, by ecosystem
- prepare a synthesis of methods for evaluating each of these functions (nationally and globally), and of the results of applying these evaluation methods in specific cases; this could be in a literature syntheses, handbook or expert system format
- biodiversity, and how it relates to stability, species richness, genetic richness
- need "systems economists", or a systems approach to economics (i.e. cannot take micro-economic conclusions and apply them to the much wider spatial and temporal scale of natural capital)
    - traditional cost-benefit analysis assumptions of constant market price would not be made
    - consideration of non-equilibrium, non-linearities
    - determine markets for ecosystem functions
    - examine the relationship between dynamic preferences and human welfare
- is there a "natural" discount rate (which would probably differ between functions)?
    - how are human preferences formed?
    - how do they change over time?)

- intergenerational equity
- social **considerations** (patrimony of natural resources)
- thresholds

The results from the two subgroup deliberations were presented in a subsequent plenary session. General points from plenary discussion follow:

- function versus output versus use:
  - **all** uses are derived **from** functions, but not all **functions** are uses
  - function is derived **from** stock
  - some **functions** are valued for the output, and some functions are themselves valued (therefore what is preserved and valued is important
- natural capital is simply **EIA** done right, but with **different** functions and a larger spatial and temporal scale
- EA **<--->** NATURAL CAPITAL **<--->** ECONOMIC ANALYSIS or

[ENVIRONMENT **<--->** **NATURAL** CAPITAL **<--->** ECONOMY] **--->** EA

6.0 Research

The definition of natural capital provided by Costanza and Daly (1990) (see Appendix 4), in a paper prepared for the workshop, provides an insight to needed research. They define natural capital as " a stock that yields a flow of valuable goods and services into the future". By accepting this definition, it becomes clear that we need to identify the to identify these "flows" and to then determine those stocks on which the flow depend. While this definition appears to neglect the fact the ecosystems may undergo structural change it helps us begin to answer the research question "*What* is *natural capital?"*

The case studies (Kurz, Bernard, and Sutherland) (see Appendices 1, 2, 3) identified the many important ecological functions provided by the ecosystems. These functions are the flows of goods and services. The case studies pointed the analytical difficulty in judging the importance of any specific functions and the additional difficulty of choosing appropriate physical units of measurement. Perhaps the must critical area of research will be directed towards answering the question *"Why is natural capital important?"*.

There was much discussion in the workshop on the difficulties of aggregating estimates of natural capital over larger spatial scales. The problems range from it simply being too costly to aggregate because of the spatial heterogeneity of natural capital to the fact the appropriate measurement units may change as one moves from one scale to another.

Everyone agrees that we are depleting our natural capital at rates that are not sustainable. It was agreed that one must establish some initial baseline against which to compare changes to date and to forecast changes in the future. We must be able to answer the question *"How is the natural capital changing over time?"*

The tight agenda at the workshop precluded any. meaningful discussion on what measures are required to prevent further depletion of natural capital. However, the was strong feeling that any research that is undertaken must be ultimately directed to the question *"What can be done?"*

Costanza and Daly convincing argued that natural capital is normally greatly undervalued. Discussion of various valuation methods lead to the conclusion the methods could not incorporate "irreversibility" and "non - substitutability" concepts. In spite of the limitations of existing methods, it was felt that one must build on these methods.

6.1 Case Study Approach

The **workshop quickly** realized that the most profitable way to make progress would be to use a case study approach. The objective of a demonstration project would be to show that natural capital is a viable notion; that it can be defined, measured, and valued, and that natural capital data can be used in the management of natural resources. The project would address the following five questions:

1. What is natural capital?
2. Why is natural capital important?
3. **How is natural** capital changing/decreasing?
4. Why is natural capital changing/decreasing?
5. What can be done about cases where natural capital is declining?

The case study would involve systems modelling, and experimental approach for determining baseline estimates of stocks and flows, and the need statistical analysis to determine how to aggregate to large spatial scales. The participants in the workshop proposed the forestry be considered and/or the wetlands and agriculture be considered. It seems that it would be possible to look forestry and fisheries interactions.

There is considerable work being done on environmental problems in Canada around the world and the question becomes "What *will* be ***different about analysis that is based on the concept of natural capital?***" It quite possible to halt the decline of natural capital without introducing the concept into the consciousness of the academics, industry, and government. Where is the value added?

Surely the value added will be in the analytical framework that emerges and in any new methods that arise to represent the value of the capital in economic terms. It seems prudent to piggy back on existing programs by undertaking a parallel natural capital analysis. To be compatible with a natural capital analysis, an existing ecological research program would have to involve systematic collection of spatial data on natural capital stocks; have defined some logical relationship between those stocks and important ecological functions; have established criteria for selection of those functions and by extension the stocks; have determined a method be which to assess changes in natural capital over time; and directed towards determining appropriate ways of preventing further depletion of natural capital.

6.2 Research **Questions**

Research needs were addressed throughout the workshop. These questions should be considered for incorporation into any future research programs.

- What are the basic conditions of ecological productivity, for specific ecosystems?

- Can comparisons with contemporary bench marks be used to measure future changes in natural capital?
- What information already exists in the literature?
- What is the relationship between total energy flow and gross economic output (efficiency), and how does this changes over time?
- How can natural capital be increased in the future?
- How can we gain a conceptual understanding of multiple uses of ecosystems?
- What are possible economic and ecological linkages in valuation?
- How can we develop GIS to handle the spatial and temporal aspects of natural capital?
- Can we apply the "best practicable option" (BPO) method beyond just pollution problems to natural capital?
- How can we include consideration of thresholds, longevity, degradation and its implications, irreversibility, possible links to other approaches (e.g. EIA), and cultural utility/accessibility?
- What are the functions of each ecosystem?
- What methods currently exist for evaluating each of these functions (nationally and globally)?
- What have been the results of applying these evaluation methods in specific cases?
- How can biodiversity, and its relation to stability, species richness, and genetic richness be considered?
- What are the markets for ecosystem functions?
- What is the relationship between dynamic preferences and human welfare?
- Is there a "natural" discount rate?
- How are human preferences formed? How do they change over time?
- How can intergenerational equity be considered?
- Kow can social considerations be included?

6.3 The Policy Context

The imperative for further research is based on the belief that review and formation of national development policies must:

1. treat ecological resources as capital resources and invest accordingly to prevent their depletion;
2. estimate the relevant benefits which ecological resources produce;
3. ensure that the objectives of sustainable utilization are met; and
4. address the basic needs of local people who depend on ecological resources for their continued prosperity.

Ultimately, any analysis of environmental problems must confront the political reality of economic costs and benefits. Natural capital is a viable concept because its potential fit into the current economic thinking (on which decisions are presently based). We need to communicate this to policy makers; failure to include considerations of changes in natural capital in decisions will lead to the continued degradation of the environment. Natural capital is decreasing because of things we are or are not doing, and because our current evaluation system doesn't include natural capital in its calculus.

7.0 References

Pearce, D., E. Barbier, and A. Markandya. 1988. Sustainable development and **cost benefit analysis. Paper** for **CEARC, workshop on** Integrating economic and **environmental assessment,** Vancouver, B.C., Canada November **17-18, 1988.**

Appendix 1

Natural Capital: Forestry Case Study

Werner A. Kurz

NATURAL CAPITAL: FORESTRY CASE STUDY

Werner A. Kun

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1. INTRODUCTION

The recent interest in sustainable development originates from the growing awareness that 'world economies are depleting **stocks** of ecological capital faster than the stocks can be replenished' (MacNeill 1989). This depletion of ecological stocks has often gone unnoticed because traditional national accounting systems do not include changes in natural resource capital. Many economies have maintained growth at the expense of diminishing natural resources.

A prerequisite for sustainable development therefore is a system which is capable of accounting and monitoring the change in natural capital. The following discussion highlights some of the major problems and challenges which must be overcome when developing a natural capital accounting system. Forestry has been chosen as a case study because forests are both a valuable economic and ecological resource.

2. NATURAL FOREST CAPITAL: TIMBER RESOURCES

Trees in forest ecosystems are both the 'commodity' and the 'production facility'. The productive capacity of trees changes with age: it is initially low, increases sharply in the first few decades, culminates, and declines at greater ages. To ensure sustainable supply of timber, annual withdrawals and depletions should not exceed annual growth. The total area, the productivity, and the age-class distributions of forests must be recognized when **calculating annual growth** estimates.

In those parts of the world where forest management is practised (as opposed to forest mining), forest planners have long recognized these relationships. The principle of sustainability was applied in a forestry context as early as the last century. Traditional forest inventories are accounting for changes in forest area, forest volume, and forest age class distributions with the objective to monitor change and to guide management towards sustainability.

In Canada, forest inventories are maintained at different levels of spatial resolution and for different entities ranging from forests (defined as a collection of stands) to Timber Supply Areas (TSA), to Provinces, or the entire Nation. An example of national forest inventories is Canada's Forest Inventory 1986 (Forestry Canada **1989).** Honer and Bickerstaff (1985) developed an account of the wood volume and forest area changes in Canada for the years 1977 to 1981. In their account, Honer and Bickerstaff use the economic analogues of capital, annual accruals, and annual withdrawals. Table 1 shows that over the 5 year period, wood volume in Canada increased by 50.51 million cubic meters annually. The balance sheet of forest areas (Table 2) shows that annually 0.45 million ha were lost from the forest land base.

Such inventories provide an important first step towards assessing natural capital in forest resources and, had they been available for those (tropical) countries in which forests are rapidly eliminated, could have provided the much needed early warning system for non-sustainable developments. Inventories of this type furnish useful information but fall short in many regards. An economic assessment of the results obtained from either Table is difficult because important information is missing. For example, timber values depend strongly on species, location (distance to mills), accessibility, and piece sizes. For example, the conversion of old-growth forests to second growth stands in BC cannot be identified from either Table. Yet, the dwindling old-growth resources will have significant economic and technological implications for the Forest Industry in that Province. Current or anticipated future stumpage values could added to the inventories to add an economic component.

At present, these timber inventories are not tied into the economic accounts of nations. Depletions of the natural forest capital do not show up in the annual GNP statistics.

Table 1: **Canada's volume** of forest **growing stock** consolidated statement of **capital and annual change** 1977-1981. (**from** Honer and **Bickerstaff** 1985).

		Millions m³
Growing **Stock Capital 1981:**		
Regeneration		288.21
Immature		7 181.44
Available for Harvest		14 066.66
TOTAL GROWING STOCK		21 536.31
Annual Accruals to Growing Stock *Volume:*		
Stocked Forest		334.80
Natural Regeneration		2.74
Artificial Regeneration		0.32
Silvicultural Treatment		0.12
TOTAL ANNUAL ACCRUALS		337.98
Annual Withdrawals from Growing Stock Volume:		
Planned Operations		
Harvest	(143.68)	
Land Alienation	(No Data)	
Total		(143.68)
Depletion		
Fire	(79.98)	
Pests	(63.81)	
Total		(143.79)
TOTAL ANNUAL WITHDRAWALS		(287.47)
Annual **Average Balance**		
Net *Increase* **(Decrease)** in Growing Stock		50.51

Table 2: **Canada's area of** productive forest land consolidated statement of **capital and annual** change 19774981. (from Honer and **Bickerstaff** 1985).

		Millions ha
Land Capital 1981:		
Not determined		0.76
Not Satisfactorily Restocked		21.91
Stocked land		
Regeneration	20.14	
Immature	91.08	
Available for Harvest	87.14	
Total		198.36
TOTAL PRODUCTIVE LAND		tt1.03
Annual Accruals to Stocked Land:		
Natural Regeneration		
Cutovers	0.407	
Burns	0.669	
Pest-Killed	0.400	
Old NSR	0.122	
Total		1.60
Artificial Regeneration		
Planting	0.129	
Seeding	0.037	
Total		0. I?
TOTAL ANNUAL ACCRUALS		1.77
Annual Withdrawals from Stocked Land:		
Planned Operations		
Harvest	(0.759)	
Land Alienation	(No Data)	
Total		(0.76)
Depiction		
Fire	(0.956)	
Pests	(0.501)	
Total		(1.46)
TOTAL ANNUAL WITHDRAWALS		(2.22)
Annual Average Balance:		
Net Increase (Decrease) in Stocked Land		(0.45)

3. NATURAL FOREST CAPITAL: ECOLOGICAL FUNCTIONS

-Traditional forest inventory systems, established to meet the needs of forest managers, are accounting for changes in total forest area and wood volume. Forest ecosystems, however, are more than merely a production facility for timber. They provide many important functions which may also have to be considered in natural resource accounts. For example:

1. hydrology: forest ecosystems are important regulators of water flow rates. Intact forests can retain much water which they release slowly, thereby regulating minimum and maximum flow rates.

2. hydrology: water flowing out of forest ecosystems has gone through a filtering process and is therefore of improved quality.

3. erosion: forests reduce erosion from soils surfaces which maintains soil productivity and reduces siltation.

4. slope stability: tree roots contribute to slope stability: mass wasting and slope failure often follow logging in sensitive areas.

5. protection: trees reduce the risk of avalanches in areas of high snowfall and steep slopes. Communities in the European Alps introduced the death penalty centuries ago for people logging in protection forests upslope of their villages.

6. wildlife habitat: forest ecosystems provide important habitat for many wildlife species.

7. fisheries: streams in forests are spawning grounds for many (commercially important) fish species.

8. biodiversity: forests provide the habitat for many endangered animal and plant species.

9. landscape design: forests are an important visual component of many landscapes.

10. recreation: forests, accessible or in wilderness areas, have high recreational value for many people.

11. spiritual: forests play an important spiritual role in many societies and religions.

12. air quality: forests, especially coniferous forests have very high surface areas and are effective air filters for pollutants and particulate matter.

13. air temperature: forest stands tend to be cooler during the day and warmer during the night compared with surrounding open areas. Near urban centres, they can reduce temperature extremes in the adjacent city.

14. regional climate: forests affect regional water cycles by intercepting precipitation and regulating evapotranspiration.

15. global climate: forests influence the albedo of the earth's surface.

16. carbon. cycles: forest are both sources and sinks of carbon. They play an important role in the global carbon cycle and can potentially mitigate some of the increases in atmospheric carbon dioxide.

This is a partial list of the major functions and services provided by forest ecosystems. Many of these functions and services are important for the sustainability of environmental quality, others are significant only in special circumstances.

Criteria will have to be developed by which to decide whether an ecological function of a forest ecosystem is considered part of natural capital and should therefore be accounted. Appropriate units of measurements have to be provided which can be used to assess natural capital stocks and changes in the stock. If naturai capital is to be tied in with traditional national accounting systems, these measurement units will have to translated into monetary equivalents. Each of these points will be discussed below.

4. CRITERIA FOR CONSIDERING ECOLOGICAL RESOURCES

Any forest ecosystem generally provides several of the ecological functions in above partial list of examples. Not every possible ecological function which might be provided by a forest ecosystem can be accounted for when assessing natural capital. But which criteria should be used to consider an ecological function part of or outside of a natural capital accounting system?

Ecological resources are traditionally not included in natural resource accounts because monetary values of their 'services' cannot be established without involving some (highly speculative) assumptions (Repetto et al. 1989). This assumption is too restrictive for the present discussion, and other criteria need to be defined by which to include or exclude ecological resources.

Criteria which might be used to make such decisions could include:

Spatial criteria: What is the spatial extend for which the function is provided? Ecosystem, watershed, regional. or global. An example in which the ecological function is provided 'at -the ecosystem level would include micro-climate. Most hydrological functions should be considered at the watershed level. Questions of wildlife habitat, species diversity, regional climate, landscape design, and so forth should be considered at the regional scale, and functions such as carbon storage, albedo, and climate influences should perhaps be considered at the global scale.

Temporal criteria: What is the timeframe over which ecological functions can be provided. Can the function be provided indefinitely? Ecosystems such as forests are often subject to cyclical natural disturbances followed by stages of succession. For example, carbon stored in the tree and biomass component may be released periodically due to fire or other natural disturbances.

Irreversibility: If the ecological function is lost, can it be replaced or does natural succession or forest management reconstitute an ecosystem which can provide similar functions?

Quantifiability: The degree of effort required to quantify ecological functions differs greatly, and some may not be quantifiable at all because our scientific understanding is limited. Furthermore, the provision of the same ecological function varies between different ecosystem types and it may be difficult to generalize the results obtained in some ecosystems.

Beneficiary: Who benefits from the fact that the ecosystem provides a particular function? This question raises the issue of how anthropocentric natural capital accounting should be? Is the provision of clean water by some remote boreal forest of equal 'value' as' that by a watershed used for urban water supply? What about beneficiaries who live outside national boundaries? Regulation of water flow rates by a forest stand in Nepal's Himalayas may not be of relevance to Nepal but is of great significance to the flood-prone deltas of India and Bangladesh.

5. MEASUREMENT UNITS

Some of the functions listed above could be quantified using some form of physical measure such as amount of water cleaned, net uptake of carbon, number of species for which habitat is provided, etc. Other functions could be measured indirectly, i.e. the number of hours people spend hiking through a wilderness area, temperature differences in cities with and without adjacent forest stands, number of fish spawning in forest streams, etc. Perhaps the biggest difficulties are encountered when attempting to quantify functions which involve non-physical components (spirituality) or global scales. How does one measure the importance of a forest to the spiritual well being of indigenous people? How does one measure the contribution of a forested area to global albedo or climate circulation patterns?

Many, but not all, of the functions could perhaps be quantified by establishing some relationships to some other measure which is more easily quantified. Carbon storage is roughly proportional to wood volume, many hydrological functions are related to the area of the forest, and other examples can be listed. For many ecological functions, forest ecologists will be hard pressed to provide quantitative data between an ecological function and some more easily determined measure, such as area or wood value. Moreover,, most of these relationships are likely to change with factors outside the relationship, such as stand age, ecosystem type, elevation, and other biophysical characteristics.

What to do about those functions which are not easily related to traditional measures? Habitat for endangered species is related to the size of the undisturbed forest stand and the type of surrounding habitat. The minimum size requirements for habitat provision are rarely defined, however. Moreover, the relationship between area and wildlife habitat is not linear because the quality of habitat is defined by characteristics such as the degree of fragmentation, and the mixture of forest types and successional stages.

Accounting of ecological capital may also require that measurement units such as area are reconsidered. Forests may have to be defined by the boundaries of watersheds rather then some often arbitrarily defined management boundaries.

In summary, the definition of units by which ecological capital can be determined will require considerable research. There is a high probability that by focusing primarily on some key ecological functions, most aspects of ecological capital can be considered. The challenge will be to define a subset of ecological functions small enough to be manageable and yet comprehensive enough to cover most ecosystem aspects which society may wish to sustain.

6. INVENTORIES OF NATURAL CAPITAL

Direct comparisons of man-made capital and ecological capital have a serious deficiency: the relationship between economic capital and yield is mostly linear while the ecological analog is often non-linear. A certain amount of economic capital invested at a given interest rate will yield a known investment income. Withdrawing 20% of the capital will reduce the investment income by a known amount. Forest ecosystems provide a particular function which may not be at all affected by reducing the area of forest ecosystems by 20%. Withdrawing a second 20%, however, may greatly reduce or totally eliminate the forests' ability to provide the function. It will be very difficult to quantify such non-linear relationships between capital stock (forest area?) and income (forest function).

To establish an inventory of natural capital the issues discussed in the preceding sections have to be resolved first. If a set of ecological functions can be identified for inclusion in the accounting of natural capital and the appropriate measurement units can be defined, the actual inventory is 'merely' a task of collecting the required data and summarizing them.

The information requirement for establishing natural resource accounts will be considerable. The likely success of establishing such an inventory will depend on the types of measurement units which will be required. If most of the ecological functions can be quantified from traditional existing inventory information such as area, age-class distribution, species, soil characteristics, etc., then it will be relatively easy to establish an inventory. If, however, ecological functions can only be quantified by measuring some complex processes, the natural capital inventory will be harder to develop. Moreover, the development of functional relationships between traditionally measured entities (area, wood volume) and ecological functions will require considerable research efforts.

Geographic information systems may be a valuable tool for establishing natural capital inventories because with their use it is possible to quantify areas and spatial relationships between areas. For example, the ecological significance of a particular wildlife habitat may increase with greater distance to an area with similar habitat characteristics.

7. TRENDS IN NATURAL FOREST CAPITAL

Many ecological functions are not linearly related to traditional measures of forest inventories, such as area. Therefore, care must be taken when assessing natural capital trends based solely on such measures. Replacing old-growth natural forest ecosystems with manmade plantation forests may keep. the total forest area constant, but will affect many ecological functions provided by this forest area.

Trends in natural forest capital cannot be generalized because of the large differences between nations in the developmental stage of the forest resource. Many Scandinavian countries have successfully managed to develop sustainable forest management plans. Despite a stable forest area, some ecological functions may still be declining because natural forest ecosystems have been replaced by plantation forests with lower species diversity, a more uniform habitat, and lower carbon storage in forest floors and soils.

In many tropical countries, the net decline in forest area is probably a good indication that ecological functions provided by forests are also declining. In China, large scale afforestation efforts increase the total forest area with the associated increase in some ecological functions provided by these areas.

8. ECONOMIC VALUATION

After establishing criteria for determining importance of ecological capital and units of measurements, the translation into economic units will be required. This is the job of the political economists.

Traditional forest inventories of wood volume and forest area are faced with the same challenge. Wood of different species is priced differently. Old-growth timber is generally more valuable than second growth timber of the same species. The accessibility and transportation costs need to be considered when assessing natural resource capital. Systems for forest accounting which recognize these issues have been developed.

HOW could the ecological functions of forests be evaluated economically? One approach is to consider the costs incurred when trying to substitute the function by other means. Villages in the Swiss Alps had to spend millions of dollars to replace the protective functions provided by forests which died from air pollution by concrete and steel avalanche protection structures. Drinking water not cleaned by forest ecosystems has to be processed at considerable expenses.

Another approach is to evaluate the natural resource function based on the money tourists and users are willing to spent to benefit from this function. In Europe, for example, forest managers seek compensation from communities for the services provided by establishing and maintaining access to and hiking trails in forests. It has been suggested to compute compensation from a measure of user expenditures such as cost of travelling to the resource, cost of equipment used, and other items which all require a set of assumptions.

What should be the timeframe for these evaluations? The annual 'income' generated by a piece of wilderness may be small but could be provided indefinitely.

The largest difficulties will likely be encountered when attempting to put a value to such functions as the prevention of species extinction, the provision of spiritual values, and other non-physical functions. In many of these cases assumptions (future economic significance of an endangered species?) and value judgements may have to made. Value judgements are generally required when assessing the ecological functions of natural resources because the perceived demand for them is often based on the value system of the assessor.

The discussion of economic evaluation of ecological functions brings back the question of the beneficiary of those functions. In the above mentioned case of Nepal and India for example, Nepal's national capital account is unaffected by the flood control provided for countries downstream, but the economic account may be affected by not harvesting the timber resources. Along the same line of argument, why should tropical countries not harvest their rainforests if the effects on global climate are felt by all countries of the world? Or on a more local scale, why should the people of remote communities in BC not log certain watersheds and forego economic growth if the primary beneficiaries of the ecological functions (recreation, wilderness) live in urban centres away from those communities?

Proper accounting for changes in forest ecological capital might provide a means by which to resolve many resource use conflicts by enhancing decision making beyond the jobs vs. environment debate and by perhaps providing a tool by which compensation could be calculated.

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Appendix 2

Natural Capital Case Study: Soil Productivity on the Canadian Prairies

Glenn D. Sutherland

NATURAL CAPITAL CASE STUDY: SOIL PRODUCTIVITY ON THE CANADIAN PRAIRIES

Glenn D. Sutherland

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1. OVERVIEW OF THE PROBLEM

The Canadian Prairies contain over 37.7 million hectares (ha) of developed agricultural land (PFRA 1985), of which over 24 million ha is cropped (Bircham and Bruneau 1985). Prairie agricultural lands produce over half of all agricultural outputs in Canada, and generate nearly $10 billion in farm cash receipts annually (Science Council of Canada 1986). In recent years, changes in farming techniques have raised production efficiency and reduced the level of human involvement. From 1971-81 the number of farmers across Canada declined 11% while the investments in machinery increased four times (Dyer, 1982).

Despite the seemingly large area of prairie cultivated land and its demonstrable economic output, the productivity of these lands is dependent on the top 10 cm of soil. Damages from human impact to this soil base is already significant. In the Prairie region, soil losses due to erosion alone account for 300 million tonnes/yr (Keating, 1989). Organic matter and soil biomass have been reduced by nearly 50% since the land was first broken. About half the original stocks of soil nitrogen in the West has been exported in the form of grain, and soil is being lost 10 times faster than it is being formed (Keating 1989). Current total costs of soil degradation (including off-farm costs) have been estimated at over $1.3 billion annually; cumulative costs may be expected to exceed $40 billion by the year 2005 (Figure 1).

The remainder of this case study will examine some of the components of the soil productivity problem, and illustrate the important considerations and complexities in valuation of soil productivity in natural capital accounting.

2. COMPONENTS OF SOIL PRODUCTIVITY

2.1 Soil Degradation

There are three major types of soil degradation on the Prairies (Bircham and Bruneau 1985):

1) loss of soil materials (including erosion (water, wind), loss of organic material, and loss of organic soW.

2) chemical deterioration including salinization, acidification, contamination;

3) physical deterioration including compaction, mixing and disturbance.

2.1.1 Loss of Soil Materials

Soil loss has received the most research attention of all the contributing factors to soil productivity declines. The quantity of erosion varies dramatically depending on location, climate, topography, soil type, crop rotation, and other factors. Estimates of total soil losses due to water erosion are 117 million tonnes/yr (equivalent to crop reductions of 30,500 tonnes of wheat each succeeding year)(PFRA 1983). Similarly, PFRA (1983) estimates wind erosion to account for 160 million tonnes of topsoil/yr (equivalent to 41,400 tonnes of wheat (or 8% of Prairie crop production) each succeeding year.

Although soil organic matter is lost in part through erosion, other losses occur through cultivation and management actions. Organic matter content of soil and soil nitrogen content are highly correlated (Rennie 1982). Increased activation of soil microbial action through tillage reduces soil's organic matter (especially the most easily decomposed "organic fractions") and the release of mineral nutrients, (mainly N) for crop uptake or leaching. Prairie soils have lost about 40-60% of their original levels of organic matter since the start of cultivation (700 million tonnes) (Figure 2a and b; McGill et al 1981; Rennie 1982).

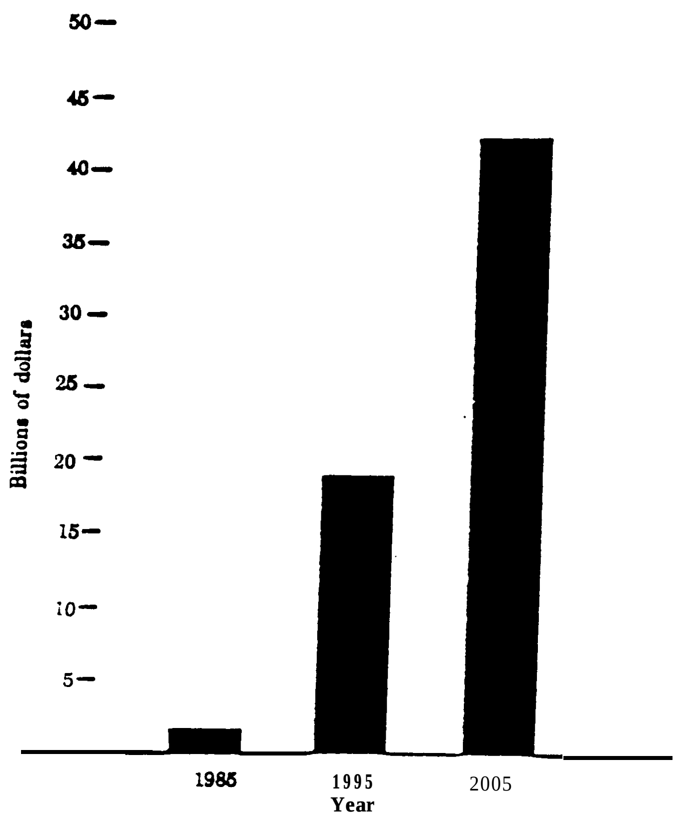

Figure 1: Estimated cumulative total costs (including off-farm costs) of soil degradation in Canada. (Source: Science Council of Canada 1986).

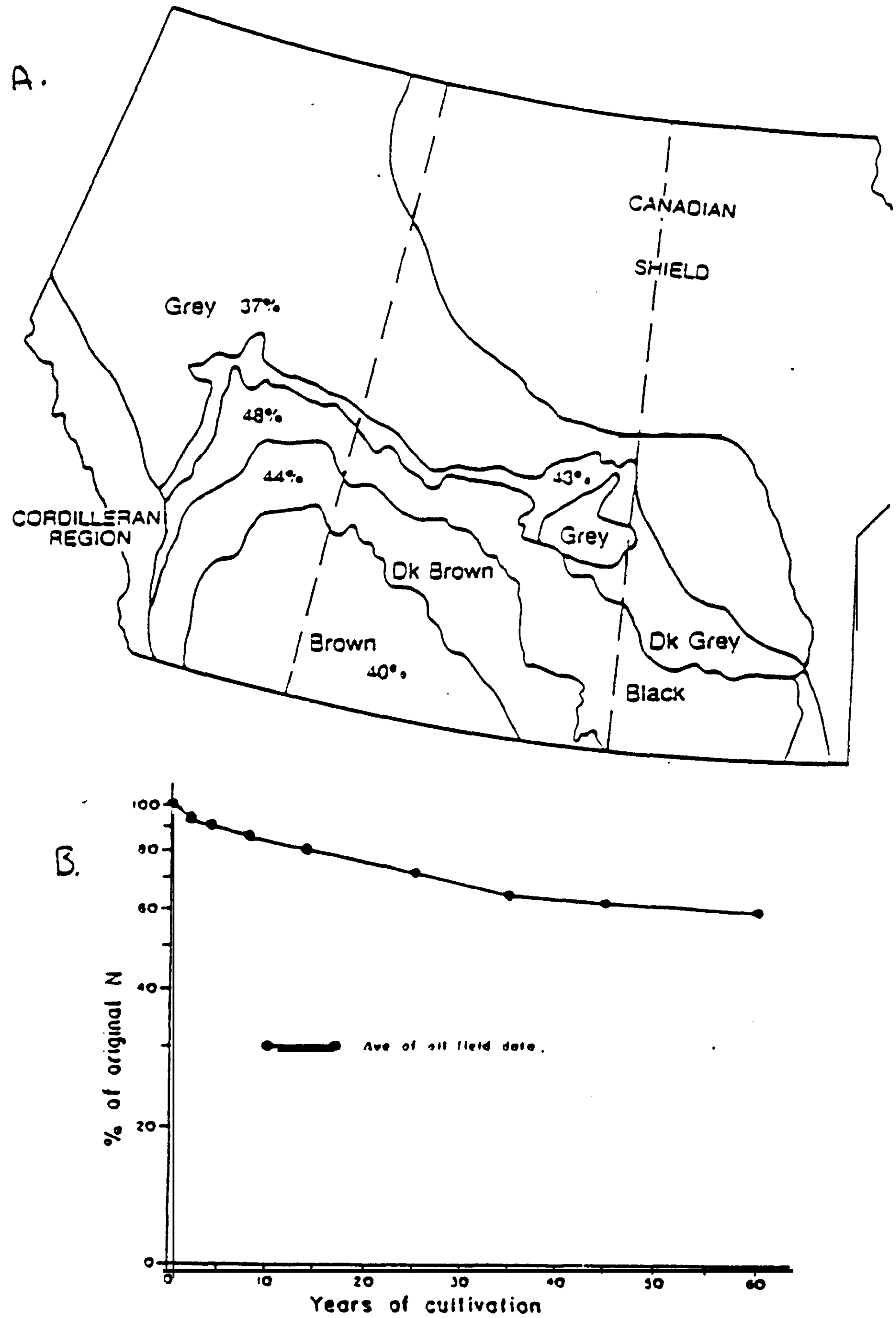

Figure 2: Estimates of declines in soil organic matter and soil nitrogen since the start of cultivation: a) average losses of soil organic matter from **A** horizons by soil zone (Source: McGill et al. 1981); b) average N content of prairie soil since the start of cultivation (Source: Campbell et al. 1976).

2.1.2 Chemical Deterioration

In terms of chemical changes that degrade soil productivity, management-induced soil salinization is the most important because of the high economic cost (Science Council of Canada 1986). Virtually all Prairie soils are at some risk of salinization, principally from Artesian salinity (the bringing up of salts from below the rooting zone through mobilization caused by excess water, and subsequent evaporation), local recharge from sloughs and depressions, and "saline seeps". PFRA (1983) estimates are that 1.5 million hectares of cropland were affected by dryland salinity by the mid-1970's, and that 1982 farm income losses due to productivity reductions reached $257 million in total. Estimates of annual rate of expansion of saline soils range from 1%/yr (Anderson et al 1984) to 10%/yr (PFRA 1983).

Soil acidification may occur via several processes (Bircham and Bruneau 1985): a) use of ammonium or urea-based fertilizers which have strong acidifying actions (considered the most important cause, representing 93%, 100%, 96% of increased acidity in Manitoba, Saskatchewan and Alberta); b) industrial pollution; c) removal of bases through harvesting (PFRA 1983); and d) for soils with acidic sub-soils, deep ploughing tends to increase soil acidity. Acidity is generally considered "low risk" over much of the Prairies. Estimates are 530,000 ha of cultivated land with pH less than 5.5, and 1,825,000 with pH between 5.5 and 6.5 (Bircham and Bruneau 1985). No estimates of the total cost of acidity to productivity were found in the literature.

2.1.3 Physical Deterioration

Compaction (caused by heavy machinery, working soil when wet, shattering of clods by high-speed tillage) interferes with root growth, reduces water movement in soil (confounding drainage and increasing erosion) and increases energy requirements for tillage. In general, soil compaction is not considered a serious problem on the Prairies (PFRA 1983). Scattered areas in the Red River Valley, Saskatchewan and the Peace. River area are at a moderate risk.

2.2 Soil Regeneration

Shallow soils are generally less productive than deep soils, because they store less water and plant nutrients. For annual crops in shallow-moderately deep soils (depth < 100 m), productivity generally decreases as soil depth decreases (Alexander 1988). Soil should therefore not be lost faster than it is formed from the underlying bedrock.

How fast is soil formed? Although little information is available to estimate these rates for the Prairie region, calculated rates of conversion of bedrock or consolidated deposits to soil range from 0.02 tonnes/ha/yr in Zimbabwe to 1.3 tonnes/ha/p (Alexander, 1988). Soil formation rates are positively related to amount of surface runoff, but soil depth is very important (the fastest rates occur at intermediate soil depths) (Alexander, 1988). Few soils are produced faster than 2.24 tonnes/ha/yr (Alexander 1988).

2.3 Effects of Management on Soil Productivity

With the rapid changes in food production technology over the past 30 years, farmers have often been encouraged by researchers, advisory personnel and govemment policies to adopt production changes, many of which have been detrimental to the environment. The degree of soil degradation (especially erosion and salinization) is strongly influenced by farm management practices. In particular, intensive tillage is a major cause of both erosion and salinization (Rennie 1982; Bircham and Bruneau 1985). For example, overworked summerfallow (8-9 tillages/yr) destroys trash cover and loosens soil.

Conservation is discouraged by many factors that include: 1) forgone income associated with wise soil management; b) cost of fertilizers and herbicides; c) productivity declines that are masked by advances in crop varieties, fertilizer use, cultivation techniques (Figure 3); d) leasing arrangements for land which provide no conservation incentives (Bircham and Bruneau 1985); and e) large variations in global pricing for grain that dramatically influence measured farm returns. Conservation practices will not be accepted at the individual producer level unless returns exceed those of degrading practices within a short period. Given that conservation practices frequently require more inputs and/or give lower output over the short term, finding those that will pay within the planning horizon of many farmers is a considerable challenge (Figure 4).

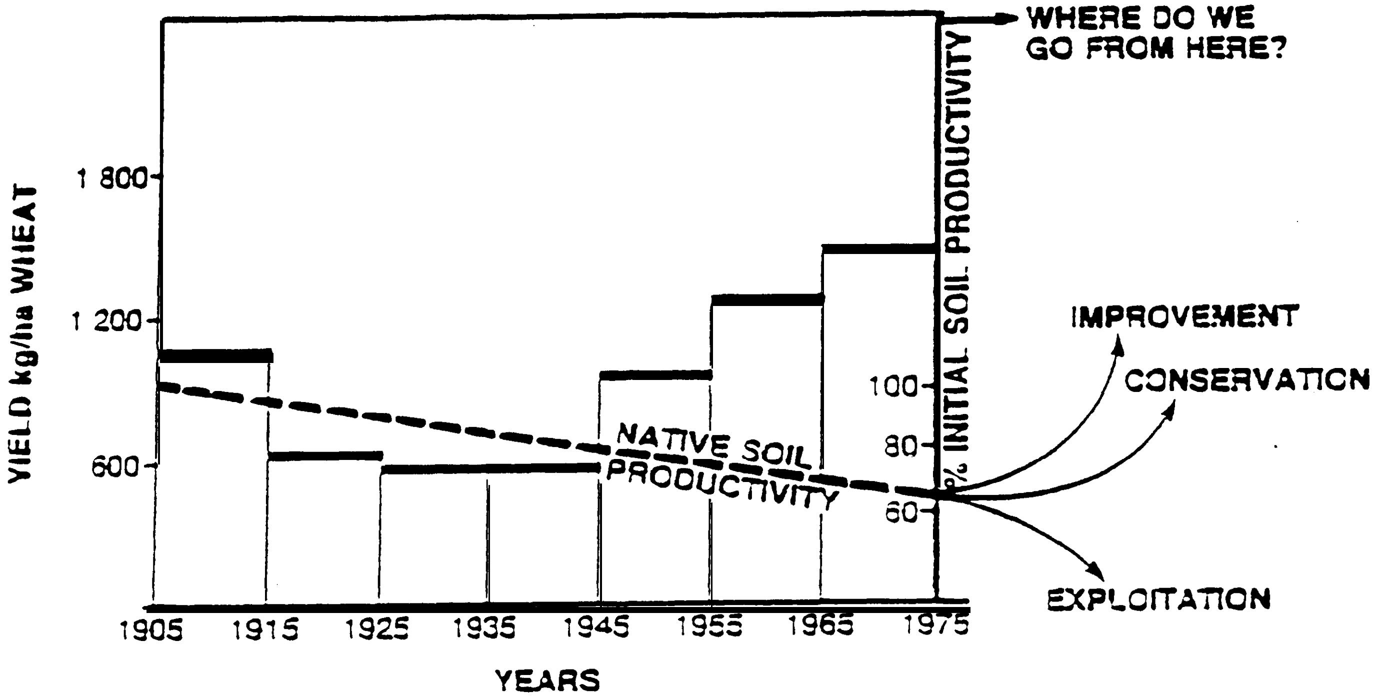

Figure 3: Schematic diagram illustrating how soil productivity declines have been masked by improvements in crop varieties, fertilizer use, tillage and planting techniques. (Source: Bircham and Bruneau (1985). Originally published by Rennie and Ellis (1977)).

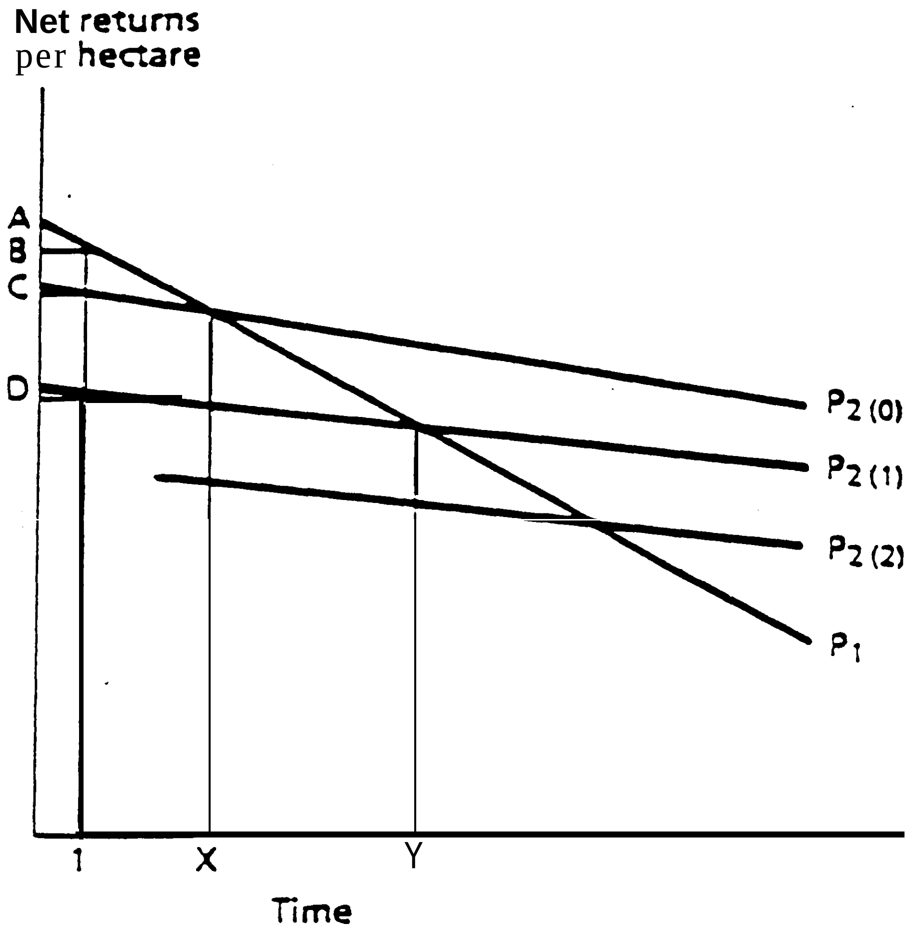

Figure 4: **A** schematic representation of how net returns from a soil degrading production practice (P_1) compare with a series of net return curves for a less degrading practice (P_2). At time 0, a producer will lose earnings by adopting the less degrading practice (represented by $P_{2\,(0)}$. By selecting the degrading practice for year 1 the producer will be facing a decline in earnings of AB. However, practice P_2 (if adopted at this time) lowers income even more (AD), and returns will only succeed those from P_1 by time Y. Had the producer adopted P_2 a year earlier, returns would have surpassed those for P_1 by time X. (Source: Girt 1986).

3. ECONOMIC POLICY CONSEQUENCES

Although some estimates of the economic consequences of particular components of soil degradation were given above, more general studies carried out by Ag. Canada suggest that the on-farm economic impact of soil degradation in 1984 were $472-609 million (Table 1).

Table 1: Estimates of the impact of soil degradation on farm Gross Domestic Product (GDP) in millions of dollars (Source: Girt, **1986).**

Location	Agriculture GDP - 1984 (millions)	Est'd on-farm costs of soil degradation	Est' % reduction in Ag. GDP
Prairies	$4,483	$472-609	9-11
National	$9,752	$698-915	7-9

Agricultural Gross Domestic Product (or value added) for the farm sector consists of net farm income before depreciation, interest payments, rent payments, and wages paid. It measures how much greater the value of the farm output is than the value of the purchased inputs (excluding land). The above table shows the national agricultural GDP was reduced almost 10% by soil degradation (Girt, 1986). Most, if not all of this reduction would have been taken out of farm incomes. Alternatively, it could be argued that avoidance of soil degradation would have increased farm GDP by $1 billion, less the costs of avoidance.

Because degradation costs primarily affect farm incomes (which are about on half of value added from farming), why does soil degradation not generate more concern among farm lobby groups? Part of the answer is that productivity has increased despite soil degradation (see Figure 3; Girt 1986). Profitability or returns have been somewhat diminished on a per-farm basis, but not to the extent suggested by the effects of soil erosion. For the individual farmer, knowledge that degradation is occurring may not be available, or may not be credible, and does not necessarily lead him to adopt more sustainable methods. In many cases, the short-term costs of avoiding degradation exceed the long-term benefits that will accrue.

Equally important (for public policy development) as the difficulty of measuring "real" productivity losses, is the fact that the impacts of soil degradation and declines in productivity on the non-agricultural sector of the economy have not yet been considered in detail. Information on these effects are very weak; one estimate suggests that the total national public and private costs of agricultural soil degradation may approach $1-1.4 billion or 12-13% of agricultural GDP in 1984 (Girt 1986).

4. QUESTIONS

1. Which important ecological resources are to be considered as natural capital?

Land is unique among other means of production as well as other resources because it is a composite of factors influencing crop production rather than a single definable entity. In economic terms, agricultural land derives value within the production process not only because it has a fixed location, and provides an area in which production can take place, but also because it has the ability to capture rainfall and sunlight energy. These external inputs are necessary before the primary production of food from soil can take place.

One potential conceptualization of land and soil productivity that may allow at least a partial definition of soil natural capital was provided by Gaffney (1965). In his definition, agricultural land embodies two components:

i) ***an*** essentially fixed ***component (the*** "enduring matrix" of the soil) which holds and makes available for production processes limiting factors such as water. In this view, the amount of water which can be utilized by crops is dependent upon the physical texture of soil as well as on prevailing climatic conditions.

ii) a ***capital component,*** consisting of the fund of nutrients important to crop production. The most important nutrient to consider is the total nitrogen content of the soil. This capital component can be subject to investment/disinvestment decisions as with any other form of capital.

Using this model, nitrogen exists as both a "stock" (unavailable to crop production) and as a "flow" (available to crop production). The total physical (capital> stock of nitrogen in the organic matter of the soil releases a fixed flow of available nitrogen to crops through the process of mineralization. The nitrogen released by this natural process can be augmented by farmers by the addition of synthetic fertilizers. Unused available nitrogen can be returned to the stock via the organic matter of the resulting crop, or lost to the soil through leaching. Nitrogen may also be added to the stock via the nitrogen-fixing actions of legume crops.

Problems with this definition include:

- other nutrients (including trace elements) are also important for crop growth, and may be limiting depending on the location and soil type;

- other physical factors (such as soil depth, soil salinity, soil acidity) do play an important role in productivity, and thus should also be considered as important components of soil productivity.

- productivity is a composite of many other biophysical factors (including weather, crop variety, soil trash cover, land management, etc.), whose influences are not easily &aggregated from those of soil nitrogen;

These considerations suggest that there is a relatively large set of ecological resources that need to be considered in forming a natural capital budget for soil productivity. These include (but are not limited to):

- nutrient concentrations (in both available and mineralizable forms);
- soil organic matter content
- soil depth (particularly the **A** and B horizons)
- soil structure
- sub-soil type
- water storage capacity
- soil regeneration capacity

These factors will tend to be medium to longer term indicators of potential soil productivity; actual or "realized" soil productivity depends on many other factors (weather, tillage practice, crop type, global pricing patterns, etc). Even so, many of these factors will be subject to change on an annual basis (particularly nutrient concentrations and soil organic matter).

2. What is an appropriate measurement unit of amount of natural capital?

Given the difficulties described above in determining which of several potential ecological resources are critical in assessing amounts of natural capital, defining appropriate measurement units will be tenuous at best. Soil productivity is so dependent on the crop or ecosystem,its management, and external climatic factors that development of general strategies for measurement of soil productivity capital stocks may be impractical.

Three approaches could be considered:

1) direct measurement of each major component of soil productivity (e.g. soil organic matter, soil depth, etc.) as expressed on a per-ha basis. While this is essentially the approach now taken to assess the economic impacts of soil degradation, the sampling effort required to assemble region-wide assessments of these parameters is high, and fails to account for changing management practices and climatic influences.

2) development of a "crop productivity index" based upon productivity experiments or models, and empirical measures of soil bulk density, water capacity and pH (Rijsberman and Wolman, 1985). While empirical models of this sort are closely tied to the indicators of interest- (crop productivity) rather than soil characteristics per se, the experimental estimation of plant productivity is very expensive (requiring long-term

studies) and is likely not to be established for many crop varieties, management regimes, and weather patterns.

3) estimation of "soil-loss tolerance" indices based on soil organic matter and soil depth (Alexander, 1988). soil organic matter is closely correlated with net primary productivity and is much easier and faster to measure than productivity (Alexander 1988), although organic matter alone may not be adequate to characterize saline or acidic soils. This approach has not yet received wide attention; further refinements should include providing better estimates of soil regeneration, verification of the indices with yield data, and development of these indices under different management regimes.

3. How **does one determine the actual amount of natural capital stock available?**

Assuming it was possible to arrive at one (or several) indices of soil productivity capital, there are at least three problems in generating an assessment of current stocks:

1) soil is not homogeneous, and its characteristics vary widely not only regionally, but often between fields on the same farm.

2) many important characteristics of soil productivity (e.g. soil nitrogen), exist in both "pools", and as "flows". Given this dynamic nature of soil productivity, regional assessments will contain considerable uncertainties of the sizes of the component stocks at any point in time.

3) development of a standard interpretation of "productivity" may be difficult, as productivity can only be viewed in the context of non-soil related factors (e.g. grain pricing, crop varieties, farm management constraints).

If relatively simple measures of soil productivity capital stock are appropriate for assessment purposes (e.g. estimates of soil organic matter content), then data already available from individual farmers may be used in the assessment. Many farmers annually submit soil samples to provincial soil labs for nutrient and moisture characterization in preparation for spring and summer operations. Although soil productivity is a resultant of a complex of factors that go beyond soil characteristics, and despite statistical difficulties in using such ad hoc data, approximations of some regional measures of soil productivity capital could perhaps be based on this data.

4. What are the current rates of depletion of natural capital stocks?

As illustrated above in the case study, estimates of native soil productivity declines range from 40% - 60%, and some estimates claim that soil losses exceed regeneration by a factor of 10. However, not all components of soil productivity are being depleted at the same rate, and the causes of depletion may differ at different times. For example, after breakup of Prairie lands, soil organic matter rapidly declines in the first 20 years due to mineralization of the more available fractions of soil N. Subsequent declines are dominated more by the rate of erosion of the soil, than by soil N mineralization (Rennie 1982).

Confounding a more precise estimate of depletion rates of soil productivity are: a) lack of good baseline information on original soil productivity; b) the technological advances (tillage practice, better-yielding varieties); and c) additions of formerly marginal land to the cultivated land base. Developing ways to factor these influences out of the soil productivity equation will be critical early step in proper assessment of capital stock change.

5. What approaches should be undertaken to reduce depletion rates or prevent further depletion?

Two land management factors are important in determining how to develop strategies for reducing soil productivity capital.

1) land is owned and managed by individual producers, with widely differing interests, education, and financial states. Individual farmers must be aware of the extent to which declines on soil productivity affects their income now, and in the future. However, many face other problems, such as high debt and low income that they may perceive as more significant (Culver and Seecharan 1986). In addition, the variety of techniques that they must adopt may be large, even for effective soil conservation on one farm.

2) jurisdiction over land management falls to provincial governments, and is not in the control of the federal government. Thus; development of effective national programs for soil productivity management may be difficult.

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Appendix 3

Natural Capital Case Study: Wetlands

David P. Bernard

NATURAL CAPITAL CASE STUDY: WETLANDS

David P. Bernard

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1. INTRODUCTION

As long as 'world economies are depleting stocks' of ecological capital[1] faster than the stocks can be replenished' (MacNeill 1989), the quest for sustainable development is obviously hopeless. Historically, depletion of natural capital has largely gone unnoticed because traditional national accounting systems do not include changes in natural resource capital (Repetto et al., 1989). With the emergence of new approaches to, and methods for, natural capital accounting (cf. Pearce et al., 1988), we now realize that numerous economies have maintained economic growth at the expense of diminishing stocks of natural capital (Rowe, 1989). A prerequisite for sustainable development, therefore, is a system which is capable of quantifying stocks of natural capital, and monitoring changes in the ecological inventory through time.

[1]For the purpose of thia paper, the terms natural capital and ecological capital are considered to be interchangeable.

To help identify some of the major problems and challenges which must be overcome when developing a functional natural capital accounting system, I have prepared a case study focusing on wetlands. It is not the purpose of this paper to provide a comprehensive treatment of the application of natural capital concepts to wetlands, but rather to raise issues, stimulate questions, and promote discussion during the' upcoming Canadian Environmental Assessment Research Council (CEARC) Workshop on Natural Capital, to be held in Vancouver on 15-16 March 1990.

1.1 Wetland Types

Although comprehensive systems for classifying wetlands have been developed in both the United States (Cowardin, 1978) and Canada (Environment Canada, 1987), for the purposes of this general introduction, only very broad types of wetlands are identified. The three primary factors distinguishing these types of wetlands are (OTA, 1984):

1) location (coastal or inland),
2) salinity (freshwater or saltwater), and
3) dominant vegetation (marsh, swamp, or bog).

The major types of saltwater wetlands are: inland saline marshes, coastal salt marshes, and mangrove swamps. Freshwater wetlands are generally classified into at least five major categories (Tamocai, 1979): bogs, fens, marshes, swamps, and shallow water areas. The predominance of peat deposits in bogs and fens typically distinguishes them from the other three wetland types; together they are commonly referred to as peatlands. Riparian ecosystems are also sometimes classified as floodplain wetlands (USFS, 1979). A schematic illustration of major wetland types, and their relation to deepwater habitats, is provided in Figure 1.

For the purposes of this report, it is important to recognize that not all wetlands are identical in either structure or function. This means that when we prepare a natural capital inventory, it is probably inappropriate to lump all wetland types together, and simply report total acreage. This idea is explored more fully in Section 3.

2. WETLANDS AS A RESOURCE

In former times, wetlands were often viewed as useless, and, worse still, as sources of diseases and pests. In the pursuit of health, food, homes, energy, and sport, North American society looked upon wetlands as a land resource in need of improvement through man's intervention. As described in Section 5, wetlands were altered for agriculture and forestry, for residences, transportation, industry, and recreation. As a result, several wetland dependent species (e.g. American crocodile and alligator, sea cow, whooping crane, Mississippi sandhill crane) are now threatened or endangered. Habitat modification has also resulted in long-term downward trends in several important populations of migratory waterfowl (CWS, 1986).

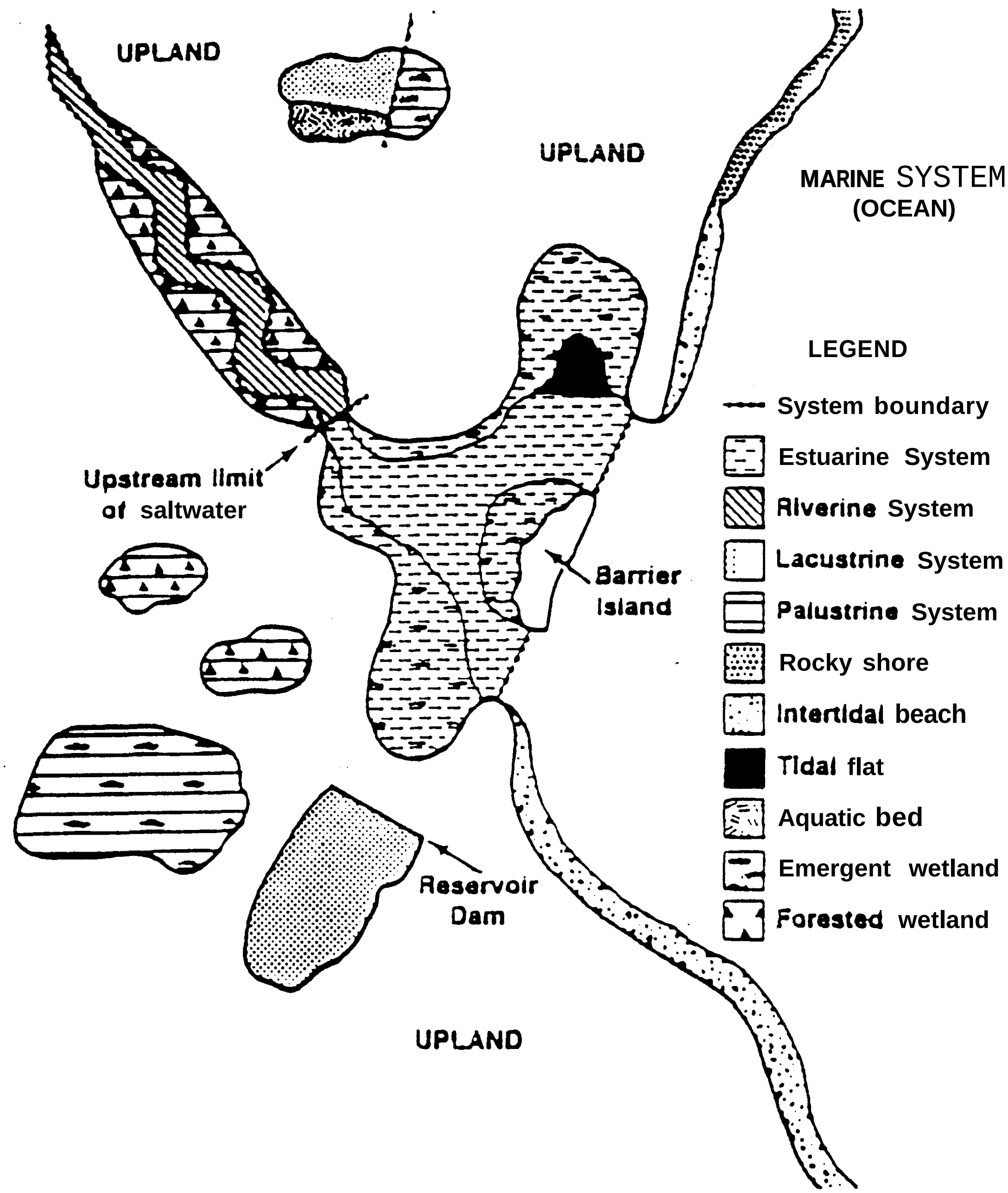


Figure 1: Diagram showing major wetland and deepwater habitat systems. (from Tiner, 1984).

Over the past two decades there has been a growing awareness that ummodified wetlands also have value, *viz.*, wetland values are not simply derived from the uses to which they are put following their condemnation and 'improvement'. In fact, research and assessment during this period has revealed a that natural wetlands exhibit a wide range of both ecological and social values. Those that have been cataloged can be divided into two main groups (1) intrinsic values, and (2) ecological services or resource values.

Wetlands have intrinsic value, independent of man and his needs. Examples of intrinsic values for wetlands include (adapted from OTA, 1984):

1) wetlands as natural areas;
2) wetlands for recreation, education, and research; and
3) other intrinsic values.

Of course, not all wetlands are an equally 'valued' for each of these categories. The first two entail some degree of human recognition, while the third is entirely independent of man's presence. An unusual illustration of how wetlands proved useful for research in a discipline far removed from wetlands (molecular biology and evolution) can be found in (Crawford, 1978). A list of "other intrinsic values" would contain: primary production (cf. Good et al., 1978;Sather and Smith, 1984), decomposition (cf. Good et al., 1978; Sather and Smith, 1984), nutrient cycling (cf. Good et al., 1978) and export (Sather and Smith, 1984), food web, biodiversity, plant communities, animal communities, and habitat for migratory species (e.g. waterfowl: CWS, 1969).

Whether or not society recognizes the fact, wetlands also provide ecological services thereby providing them with a resource value. Here are some of the more notable ecological services provided by wetlands (adapted from OTA, 1984):

1) floodpeak reduction (Sather and Smith, 1984);
2) shoreline erosion control and hurricane protection (Sather and Smith, 1984);
3) ground water recharge (Sather and Smith, 1984);
4) water quality improvement through nutrient assimilation (Sloey et al., 1978; Nichols, 1983; Sather and Smith, 1984) and wastewater treatment (Kadlec and Tilton, 1979; Nichols, 1983; Sather and Smith, 1984);
5) fish and wildlife for non-consumptive uses (e.g. birdwatching, livestock grazing, preservation of rare species) and consumptive uses (e.g. sport and commercial harvesting of waterfowl, fur, fish and marine products);
6) climatic and atmospheric functions (carbon storage);
7) commercial forest products (Abemethy and Turner, 1987);
8) commercial agricultural products (e.g. wild rice); and
9) energy (gas from peat).

In short, wetland ecosystems represent an economic resource whose value to society is only now becoming recognized. Two examples of the economic importance of wetlands to Canada are found in the "Canadian Lake Wild Rice" program sponsored by Agriculture Canada, and the international treaties between the United States, Canada, and Mexico pertaining to the management of North American migratory waterfowl (CWS, 1986).

3. MEASUREMENT UNITS

The most elementary and common measurement unit for preparing a quantitative tally of wetlands is simply to report acreage. Of course, since there are many types of wetlands, comprehensive systems have been developed for classifying them. In the United States, for example, the Fish and Wildlife Service (FWS) has developed a detailed classification system for use in national wetland surveys (Cowardin, 1978; Cowardin et al., 1979). Unfortunately, despite the obvious effort that was devoted to developing the classification scheme, little or no attention was attached to the task of defining how to best quantify the amount of a particular wetland ecosystem found at any given time.

A first derivitive of the data on wetland acreage is the percentage of wetlands lost. Of course, determining this requires not only use of consistent or comparable methods to generate a time series of data, but also some estimate of the 'preanthropogenic' baseline abundance of wetlands on the landscape.

Two more measures of wetlands are the rate of primary production and the rate of decomposition. On an annual basis, each wetland type fixes carbon (t/ha) at a slightly different rate. For example, bogs in the boreal belt extract roughly 3.5 t/ha annually from the atmosphere, compared with 13 t/ha in a swampy, broadleaf forest with small bog areas in the subboreal belt (Rodin et al., 1975). Likewise, the decomposition rates vary with temperature, dissolved oxygen content, and as a function of nutrient content of the dead vegetation. Therefore, if one were to inventory wetlands for the purpose of quantifying the ecological service provided when carbon is extracted from the atmosphere and put into storage, thereby delaying global climate warming, thenthe key measure would be net carbon storage. To derive this value, it would be necessary to have data on not only net carbon storage rates, but also the volume of the ecosystem doing the storage.

Consequently, since not all wetlands are equally suited for providing each type of natural service, to adequately quantify wetland contributions to natural capital, it would be necessary to consider each of the functions independently, to determine what the appropriate measure would be. There are likely to be some clusters of functions that have similar measures (e.g. floodpeak reduction, ground water recharge, and water quality improvement) that are quite different from those in other clusters (e.g. shoreline erosion control and hurricane protection). As well, some measures will require that the ecosystem be intact (e.g. fish and wildlife, commercial forest products, commercial agricultural products) while others are less dependent on a functional ecosystem (e.g. peat mining for energy production).

4. WETLAND INVENTORIES

A number of databases exist containing quantitative estimates of wetland acreage, stratified by wetland type. The major database in the United States is the FWS National Wetland Inventory (Tiner, 1984). This is complemented by data from USFS field-data surveys of forested wetlands (Abernethy and Turner, 1987). Carbon in live vegetation of major wetland types worldwide was estimated by (Olson et al., 1983). In Canada, the Lands Directorate of Environment Canada maintains data on wetland acreages, and changes through time (Lynch-Stewart, 1983). To the best of my knowledge, there are no other significant databases that provide data other than acreage, although the new US Environmental Protection Agency program known as EMAP (Environmental Monitoring and Assessment Program) may provide such data in the future.

6. ACTIVITIES AFFECTING WETLANDS

For convenience, we can arbitrarily divide all activities affecting wetlands into three broad types (1) climate-related, (2) anthropogenic, and (3) government programs.

5.1 Climate-Related

Climate-related actions include hurricanes and rises in sea level. The latter may also be accompanied by saltwater intrusion. An example of how global climate change, with attendant elevation in sea level, could affect a threated species (salt marsh harvest mouse) is provided by Shellhammer (1989). He explains that rising sea levels, coupled with tectonic changes, can be expected to force the mouse to shift from submerged tidal marshes to diked marshes that themselves are threatened by development. Thus, he argues, to protect this species it will be necessary to protect the Bay/Delta marsh ecosystem that supports this endangered mouse population. The salt marsh harvest mouse is, after all, part of the natural capita-in the San Francisco Bay area.

5.2 Anthropogenic

Many of man's activities result in alteration of wetlands. Some of these actions include: flood control, draining and filling, canal dredging, and pollution (e.g. acidic precipitation (Gorham et al., 1984), DDT (Rapaport et al., 1985)). Wetlands have been altered to make way for agriculture, forestry, residences, the transportation system, marinas, vacation homes, parking lots, industrial plants, and businesses. Wetlands have also been used for solid waste disposal sites.

5.3 Government Programs

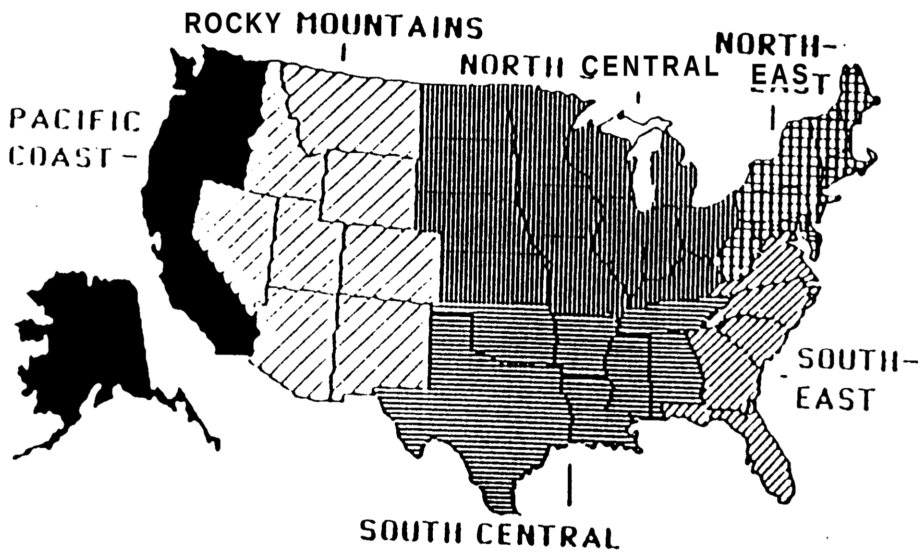
For nearly the entire history of the United States and Canada, the two governments encouraged, and often promoted, projects involving wetland destruction. Now there exist federal, provincial, and state programs specifically designed to protect wetlands. Nevertheless, there are still examples where government programs influence the obliteration of wetlands. An example can be found in the Canada-Alberta Forest Resource Development Agreement (FRDA). Under this program, a "wetland drainage and **improvement** program was instituted... to develop optimal silvicultural regimes for increasing growth of commercial tree species on drained wetlands..." (emphasis added) (Hillman, 1988).

6. WETLAND TRENDS

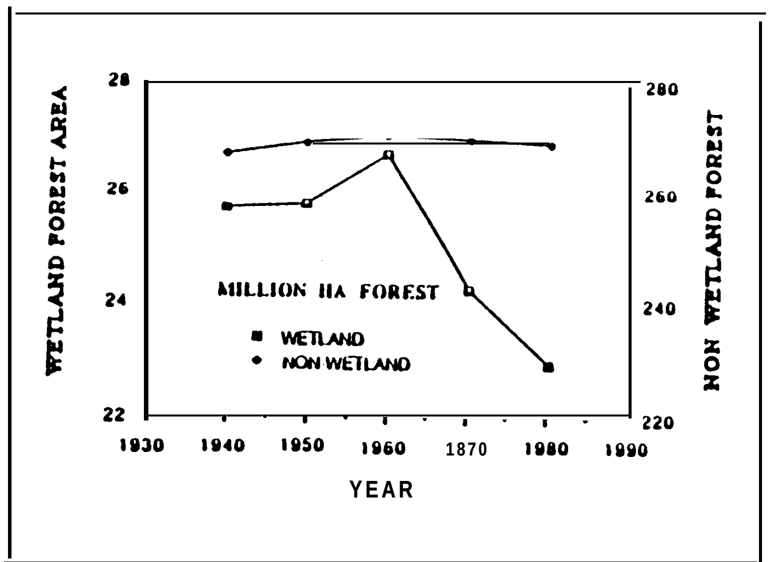
Wetlands in the United States and Canada are being lost at an alarming rate. By the 1950s, perhaps 35% of U.S. wetlands present in colonial times had been lost (Shaw and Fredine, 1956). Between the 1950s and 1970s, additional net losses of U.S. wetlands amounted to an extimated 3.7 million ha (Frayer et al., 1983), and losses of forested wetlands were particularly high (Mitsch and Gosselink, 1986). In general, about 60% of all the U.S. wetland area is classified as forested wetlands. During the 'period 1940-1980, more than five times more forested wetlands were lost than nonwetland forests (Figures 2,3) (Abemethy and Turner, 1987). According to Tiner (1984), between the mid-1950s and the mid-1970s, >85% of the wetland losses were due to agricultural practices. Examples of wetland losses in individual states and regions are provided in Table 1. Table 2 provides examples of wetland loss rates for selected states or regions.

In Canada, the trend is essentially the same as in The U.S., although "an accurate, comprehensive view of the national situation is obscured by information gaps, overlaps, and inconsistencies" (Lynch-Stewart, 1983). Again, in Canada, the major force behind wetland decline has been agricultural 'reclamation'. This is especially true in the prairie pothole region of Alberta, Saskatchewan and Manitoba, and in southwestern Ontario (Lynch-Stewart, 1983). Dredging, draining, and filling activities in wetlands to make room for urban and industrial expansion is a particular problem in the wetlands of the St. Lawrence and the shoreline of the lower Great Lakes, as well as on the shoreline and in the estuaries along the Fraser River delta (Lynch-Stewart, 1983; Pilon and Kerr, 1984).

Recently, there has been considerable effort devoted to the issue of how to quantify and assess cumulative impacts on wetlands (cf. Bedford and Preston, 1988). In part, this depends upon having some form of monitoring program to generate relevant data. This topic was discussed at a workshop in Ottawa in 1985 (Rump and Hillary, 1987). Some of the new methods that are available for assisting with this type of work are remote sensing (Hardiskv et al. 1986), simulation modelling (Costanza et al., 1990), and the use of Geographic Information Systems (GIS) (Crain, 1987).



US Forest Service regions in the United States.



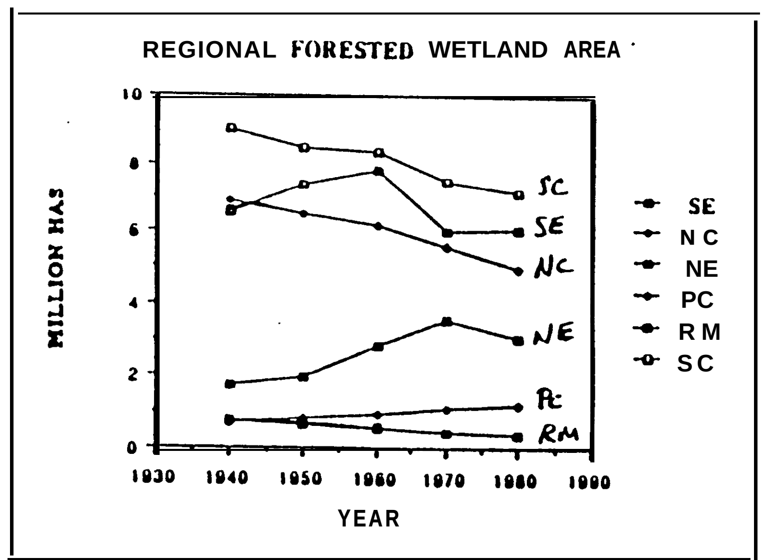


Figure 2: (Left) National inventory estimates of wetland forests and of nonwetland forest area in 1980 (excluding Arizona, Alaska, California, Hawaii, New Mexico, and Puerto Rico). (from Abernathy and Turner, 1987).

Figure 3: (Right) Regional forested wetland area 1940-1980. SE = southeast; NC = North Central; NE = Northeast, PC = Pacific. (from Abernathy and Turner, 1987).

Table 1: Examples of wetland losses in various states. (from Tiner, 1984).

State or Region	*Original Wetlands (acres)*	*Today's Wetlands (acres)*	*% of Wetlands Lost*	source
Iowa's Natural Marshes	2.333.000	26.470	99	Bishop (1981, pen. comm.)
California	5,000,000	450,000	91	U.S. Fish and Wildlife Service (1977)
Nebraska's Rainwater Basin	94,000	8.460	91	Farrar (1982)
Mississippi Alluvial Plain	24 .000.000	5,200,000	78	MacDonald, et al. (1979)
Michigan	11,200,000	3 200.000	71	Michigan Department of Nat. Res. (1982) .
North Dakora	5,000,000	2,000,000	60	Elliott, U.S. FWS, (pers.comm.)
Minnesota	18,400,000	8,700,000	53	Univ. of Minn.(1981)
Louisiana's Forested Wetlands	11.300.000	5,635,000	50	Turner and Craig (1980)
Connecticut's Coastal Mushes	30.000	15,000	SO	Niering (1982)
North Carolina's Pocosins	2.500.000	1,503,000*	40	Richardson, et al. (1981)
South Dakota	2,000,000	1,300,000	35	Elliott, U.S. FWS, . (pers.comm.)
Wisconsin	10,000,000	6,750,000	32	Wisconsin Dept. of Nat. Rts. (1976)

*Only 695,000 acres of pocosins remain undisturbed; the rest are partially drained, developed or planned for development.

Table '2: Examples of recent wetland loss rates. **(from Tiner, 1984).**

State or Region	*Loss Rate (acres/ year)*	*Source*
Lower Mississippi Alluvial Plain	165,000	MacDonald, et al. (1979)
Louisiana's Forested Wetlands	87,200	Turner and Craig (1980)
North Carolina's Pocosins	43,500	Richardson. et al. (1981)
Prairie Pothole Region	33,000	Haddock and DeBates (1969)
Louisiana's Coastal Marshes	25,000	Fruge (1982)
Great Lakes Basin	10,000	Great Lakes River Basin Comm. (1981)
Wisconsin	20,000	Wisconsin Department of Natural Resources (1976)
Michigan	6,500	Weller (1981)
Kentucky	3,600	Kentucky Department of Fish & Wildlife Resources (1983)
New Jersey's Coastal Marshes	3,084 50*	Ferrigno, et 31. (1973) JACA Corpontion (1982)
Palm Beach County, Florida	3.053	U.S. Fish and Wildlife Service (1982)
Maryland's Coastal Wetlands	1,000 20*	Redeifs (1983)
New York's Estuarine Marshes	740	O'Connor and Terry (1972)
Delaware's Coastal Marshes	444 20*	Hardisky and Klemas (1983)

* Loss rate after passage of state coastal wetland protection laws.

7. ECONOMIC VALUATION

It is encouraging to note that there have recently been a number of creative and valiant attempts made to begin translating the wetland values discussed **in Section 2 into** economic terms, specifically dollars. For instance, Hufschmidt et al. (1986) provided a valuation of losses of marine product resources caused by coastal development of Tokyo Bay. Their analysis was based upon changes in productivity of marine resources, and on compensation paid to the fisherman's union in exchange for their fishing rights.

During hurricanes, wind damage is lower at properties protected by coastal wetlands. **A** recent estimate (Farber, 1987) has placed the value of these coastal wetlands for protecting property on the Louisiana gulf coast from hurricane wind damage to be around US $1.1-$3.7 million.

Development-value estimation methods were used to generate economic information on the value of wetlands at Virginia Beach, VA (Shabman and Bertelson, 1979). The data presented by Shabman and Bertelson (1979) are taken directly from land parcel sales prices; transfer prices and land parcel characteristics were obtained from tax and property transfer records.

The value of marsh areas for marine production processes was explored by Lynne et al. (1981). They developed an approach for generating a quantitative relationship between blue crab ecomomic productivity on Florida's gulf coast and marsh availability. One important finding of this study was that marsh availability is a statistically significant factor in the Florida blue crab fishery. Thus, previous studies that viewed 'effort' as the only driving factor may be invalid. The authors suggested that this wetland factor may become even more important as population pressures further reduce available blue crab habitat.

In each of the analyses listed above, the wetland was treated as either present or absent. While the physical loss of a wetland is an obvious endpoint, it is also true that many of man's activities can also result in damage to the structure or function of the wetland, even though the acreage remains the same. During the past decade there has been increased encouragement of efforts to provide "compensation" for lost wetlands by 'creating' artificial wetlands. A thoughtful analysis quickly reveals that, unless the objective is to simply maintain the acreage of wet lands, the created wetland must perform similar functions before it can be included in a natural capital accounting.

Restoring function to a damaged wetland ecosystem is a much more complicated and costly activity. Fisher and Krutilla (1985) have discussed the economics of restoration. They point out the dangers of proceeding to allocate natural environments to urban uses on the assumption that they can eventually be restored. Even if the scientific, technical, economic, and time elements of restoration could be overcome, they argue that, because there is a highly inelastic demand for "originals" (undisturbed natural environments), there is a case for explicitly recognizing the option value associated with preservation of the original state. They then proceed to examine models of irreversibility,

The whole topic of extinction, substitution (incl. ecosystem restoration), and ecosystem services was discussed in some detail by Ehrlich and Mooney (1983). In short, we need an answer to the question posed by Westman (1977) when he asked "How much are nature's services worth?"

Perhaps the most thorough and detailed investigations to date of the value of wetland ecosystems have been performed by Robert Costanza and his associates (Costanza et al., 1989; Costanza et al., 1990; Farber, 1987). Usinb both willingness-to-pay and energy analysis-based methods, they were able to bracket a range of values to society of coastal wetlands. Their estimates are that these wetlands are valued at around (US) $4,900-$24,700/ha, even though their market price is only (US) $490-$990/ha (Costanza et al., 1989). They point out that, even at the lowest value, the current rate of wetland loss in Louisiana is worth about $77 million annually. They conclude that "it now seems clear that no reasonable amount of effort will produce very precise estimates of wetland values...". Therefore, they outline a Wetlands Assurance Bonding system to address the problems of wetland loss and destruction.

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Appendix 4

Submissions Prepared by Workshop Participants

Robert Costanza and Herman Daly
John T. Pierce
AnnMari Jansson
Peter Stokoe
Colin W. Clark
Tor Hundloe

Natural Capital and Sustainable Development

Robert Costanza
Coastal and Environmental Policy Program
Center for Environmental and Estuarine Studies
University of Maryland
Box 38, Solomons, MD 20688-0038
(301) 326-428 1

and

Herman Daly
The World Bank
1818 H. Street, NW
Washington, D.C. 20433
(202) 473-3990

DRAFT 1 as of 3/12/90

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Abstract

This paper explores the concept of natural capital and its relationship to ecosystem services, man-made capital. and sustainable development. A minimum necessary condition for sustainability is taken to be maintainance of the total natural capital (TNC) stock at or above the current level. While a lower stock of natural capital may be sustainable, given our uncertainty and the dire consequences of guessing wrong, it is best to at least provisionally assume that the we are at or below the range of sustainable stock levels and allow no further decline in natural capital. This "constancy of total natural capital" rule can thus be seen as a prudent minimum condition for assuring sustainability, to be abandoned oniy when solid evidence to the contrary can be offered.

We then go on to discuss methodological issues concerning the degree of substitutability of man-made for natural capital. and the problem of quantifying ecosystem services and natural capital, with particular reference to wetland ecosystems. Here we compare willingness-to-pay with energy analysis based approaches, concluding that we need a pluralism of approaches to understand the problem. We also discuss the importance of the discount rate in valuing natural capital and some reasons for choosing a reiatively low discount rate for estimating the size of natural capital stock from natural services.

Next we differentiate between the concepts of growth (material increase in size) and development (improvement in organization without size change). Given these definitions growth cannot be sustainable indefinitely on a finite planet. Development may be sustainable, but even this aspect of change may have some limits. One problem is that current measures of economic well-being at the macro level (GNP) measure mainly growth and not development. This urgently requires revision.

Finally we put forward some operational principles of sustainable development and describe why maintaining natural capital stocks represents a fail-safe policy for insuring sustainable development. There is disagreement between technological optimists (who see technical progress eliminating all resource constraints to growth and development) and technological pessimists (who do not see as much scope for this approach and fear irreversible use of resources and damage to natural capital). By limiting total system natural capital at current levels (preferably by using higher severance and consumption taxes) we can satisfy both the pessimists (since resources will be conserved for future generations) and the optimists (since this will raise the price of natural capital resources and more rapidly induce the technical change they predict). By limiting physical growth, only development is allowed and this may proceed as long as it is able, without endangering sustainability.

What is Natural Capital?

Since "capital" is traditionally defined as produced (man-made) means of production, the term "natural capital " needs explanation. It is based on a more functional definition of capital as "a stock that yields a flow of valuable goods or services into the future". What is functionally important is the relation of a stock yielding a flow-- whether the stock is man-made or natural is in this view a distinction between kinds of capital and not a defining characteristic of capital itself. For example, a stock or population of trees or fish provides a flow or annual yield of new trees or fish, a flow which can be sustainable year after year. The sustainable flow is "natural income", the stock that yields the sustainable flow is "natural capital". Natural capital may also provide services like recycling waste materials or water catchment and erosion control, which are also counted as natural income

We need to differentiate as well between natural capital and income and natural resources. There are at least two possibilities here: (1) natural capital and natural income are simply the stock and flow components, respectively, of natural resources, and (2) natural capital and natural income are aggregates of natural resources in their separate stock and flow dimensions, and forming these aggregates requires some relative valuation of the different types of natural resource stocks and flows. Capital and income, in this view, have distinct evaluative connotations relative to the more physically-based term resources. We prefer this latter definition because it does emphasize the aggregate nature of terms like capital and income, while acknowledging that this aggregation is both a strength and a weakness.

We can differentiate two broad types of natural capital: (1) renewable or active natural capital and (2) nonrenewable or inactive natural capital. Renewable natural capital is active and self maintaining using solar energy. Ecosystems are renewable natural capital. They can be harvested to yield ecosystem goods (like wood) but they also yield a flow of ecosystem services when left in place (like erosion control and recreation). Nonrenewable natural capital is more passive. Fossil fuel and mineral deposits are the best examples. They yield no services until extracted.

Figure 1 elaborates on these concepts and their interconnections. Both man-made capital (MMC) and renewable natural capital (RNC) decay at significant rates by the second law of thermodynamics and must constantly be maintained. Nonrenewable natural capital (NNC) also decays, but the rates are so slow relative to MMC and RNC that this can be neglected. NNC can be viewed as a long term inventory that will sit quietly until extracted and used, but once it is used its gone. RNC produces both ecosystem goods (portions of the RNC itself) and ecosystem services, and renews itself using its own capital stock and solar energy. Excessive harvest of ecosystem goods can reduce RNC's ability to produce services and to maintain itself. MMC, RNC, ecosystem services, and NNC interact with labor and demand to determine the level of "economic" (marketed) goods and services production. The form of this interaction is very important to sustainability, and it is also not well understood. More on this later. Total income in the context of fig. 1 is a combination of traditional marketed economic goods and services, ecosystem goods, and ecosystem services.

The concept of sustainability is implicit in the definition of income (following Hicks), so natural income must be sustainable, i.e. any consumption that requires the running down of natural capital cannot be counted as income. This should at least be true for RNC. Since NNC must run down with use, a logical way to maintain constant income is to maintain constant the total natural capital (TNC = RNC+NNC), which implies some reinvestment of the NNC consumed into RNC (as has been suggested by El Serafy (1989) for national income accounting. More on this later.

Hence constancy of total natural capital (TNC) is the key idea in sustainability of development. It is important for operational purposes to define sustainable development in terms of constant or nondeclining TNC, rather than in terms of nondeclining utility (e.g. Pezzey, 1988). While there are admittedly problems of measuring TNC, utility is beyond all hope of measurement. Aggregated, discounted future utility is what is really needed, and that is even more of a will-o'-th'-wisp. Also, an important motivation behind the sustainable development discussion is that of a just bequest to future generations. Utility cannot be bequeathed, but natural capital can be. Whether future generations use the natural capital we bequeath to them in ways that lead to happiness or to misery is beyond our conuol. We are not responsible for their happiness or utility--only for conserving for them the natural capital that can provide happiness if used wisely.

In the past only manmade stocks were considered as capital because natural capital was superabundant in that mankind's activities were at too small a scale relative to natural processes to interfere with the free provision of natural goods and services. Expansion of manmade capital entailed no opportunity cost in terms of the sacrifice of services of natural capital. Manmade capital was the limiting factor in economic development. Natural capital was a free good. We are now entering an era, thanks to the enormous increase of the human scale, in which natural capital is becoming the limiting factor. Human economic activities can significantly reduce the capacity of natural capital to yieid the flow of ecosystem goods and services and NNC upon which the very productivity of manmade capital depends.

Substitutability Between Natural and Manmade Capital

In addition to the former smallness of the human scale, an additional reason for the neglect of the very category of natural capital has been the tenet of neoclassical economic theory that manmade capital is 3 near perfect substitute for natural resources, and hence for the natural capital that generates the flow of natural resources. This assumption has little support in logic or in fact. It was motivated more by mathematical convenience than anything else, except perhaps the hubris-driven technological dream of being independent of nature. Consider the following list of objections to the tenet of high substitutibility of manmade for natural capital:

(a) If manmade capital were 3 perfect substitute for natural capital, then natural capital would also be 3 perfect substitute for manmade capital. But if the latter were the case there would be no reason to develop and accumulate manmade capital in the first place !! Why does one need manmade capital if one already has an abundance of 3 near perfect substitute?? Historically we developed manmade capital as 3 complement to natural capital, not as a substitute. It should be obvious that the manmade capital of fishing nets, refineries, and saw mills does not substitute for, and would in fact be worthless without, the natural capital of fish populations, petroleum deposits, and forests.

(b) Manmade capital is itself made out of natural resources, and with the help of human labor (which also consumes natural resources). Creation of the "substitute" requires more of the very thing that it is supposed to substitute for! !

(c) A physical analysis of "production" reveals that it is really 3 transformation process--- 3 flow of natural resource inputs is transformed into a flow of product outputs, by two agents of nansformation, the stock of laborers and the stock of manmade capital at their disposal. Natural resources are that which is being transformed into a product (the material cause of production) ; manmade capital is that which is effecting the transformation (the efficient cause of production). The relationship is overwhelmingly one of complement&y , not substitutibility. The overwhelming reason for increasing the stock of manmade capital is to process a larger flow of natural capital, not to make possible 3 reduced flow. It is possible to reduce the waste of materials in process by investing capital in the recycling of prompt scrap, but this is marginal and limited.

The point being made is that the substitution of man-made capital for natural capital in the production of a given good is very limited, and that on the whole natural capital and manmade capital are complements in the production of any given good. There may remain considerable substitutibility between labor and capital (the two agents) , or among various particular forms of natural capital (aluminium for copper, glass for aluminium) or even between NNC and RNC. That is not in dispute. Nor are we disputing the possibility of substituting a technically superior product that requires less energy and materials to render the same human service (eg. cars that get more miles per gallon and light bulbs that give more lumens per watt). The latter is efficiency-increasing technical progress (development) as opposed to throughput-increasing technical progress (growth). But for any given product embodying any given level of technical knowledge, man-made capital and natural capital are, in general, complements, not substitutes.

Valuation of Natural Capital

The issue of valuation of natural capital is problematic- but essential for many purposes, including aggregation and determining the optimal scale of human activities. The valuation of natural capital involves allocation of matter-energy across the boundary separating the economic subsystem from the ecosystem, and could be referred to as *macro-allocation.* By contrast *micro-allocation* is the allocation among competing uses of matter-energy that has already entered the economic subsystem--allocation proper. The logic defining the two optima is the same--MC=MB. But the nature of the cost and benefit functions in the two cases is very different.

The cost and benefit functions relevant to the micro allocation problem are those of individuals bent on maximizing their own private utility both as consumers and producers. The market coordinates and balances these individualistic maximizing efforts and in so doing determines a set of relative prices that measure opportunity cost. Individuals are allowed to appropriate matter-energy from the ecosystem as required for their individualistic purposes. Since the benefits of such expropriation are mostly private while the costs are largely social , there is a tendency to overexpand the scale of the economy--or to "allocate" too much of the matter-energy of the total ecosystem to the economic subsystem. Therefore the macro-allocation or scale problem should be viewed as a social or collective decision rather than an individualistic market decision. This means that the cost and benefit functions of macro-ailocation are at the level of social preferences. A social preference function may give considerable weight to individual utility but is certainly not reducible to that alone. It has a community dimension. The value of community (with other people and other species , both present and future) must be counted in the cost and benefit functions associated with macro-allocation (Daly and Cobb 1989). These community costs and benefits are not captured in micro-allocation market prices.

How then are these nonmarket social costs and benefits measured? One approach is to imagine the valuation to be done by a different ***Homo economicus* than** the neoclassical pure individualist. This broader ***Homo economicus*** (call him ***H-e*** 2 ***to*** differentiate him from the neoclassical ***H-e*** 1) is a person in community rather than a pure individualist. ***H-e*** 2 ***is*** also fully informed about how the economy is related to the ecosystem and is constituted in his very identity by the relations of community with both future generations and other species with whom he shares a place in the sun. ***H-e 2*** would value natural capital according to its relative long term potential for supporting life and wealth in general. This long term potential is closely associated with the low entropy matter-energy embodied in the natural capital. Therefore we offer as one hypothesis for investigation that natural capital could be evaluated in proportion to its embodied energy (Costanza 1980, Cleveland et. al 1984). The willingness to pay of ***H-e*** 2 (person in community) is hypothesized to be in accordance with this long run capacity to support life and wealth.

But it will be objected that this ***H-e*** 2 is not the "real" one. The real one ***(H-e*** 1) is ignorant of ecological relations, short-sighted. and individualistic. The willingness to pay of this more usual ***H-e*** 1 as elicited by questionnaires is the more usual approach to the value of natural capital. Both concepts of ***H-e*** are abstractions from real people. For the micro allocation probiem we think people generally behave like the traditional individualistic ***H-e*** 1. But when confronted with the macro-allocation problem we think most people would behave more like ***H-e 2,*** the person in community. Therefore valuation of natural capital, we submit, should be done by individuals acting in an entirely different mode from that in which they operate in consumer markets. ***H-e*** 1 is different from ***H-e*** 2, but both are equally real as different aspects of real human beings relevant to different purposes. At any rate this is the interpretation we offer for the two methods of valuation we discuss here : the willingness to pay approach and the energy analysis approach.

Because natural capital is not captured in existing markets, special methods must be used to estimate its value. These range from attempts to mimic market behavior using surveys and questionnaires to elicit the preferences of current resource users (ie. willingness-to-pay (WTP) to methods based on energy analysis (EA) of flows in natural *ecosystems* (which do not depend on current human preferences at ail). Below we briefly summarize these methodological issues, using wetland ecosystems as an example. More complete discussions are given in Farber and Costanza 1987 and Costanza et al 1989.

There are also problems common to valuing any kind of capital, including man-made capital. One can generally not value capital directly. The two options in use for MMC are to value the net stream of services produced by the capital, or to value the cost of forming the capital. With reference to fig. 1, for RNC this amounts to valuing the present value of ecosystem goods and services production (with, for example, WTP) or to valuing the cost of RNC production (with, for example, EA). Table 1 summarizes results from a recent study of wetland values in Louisiana (Costanza et al 1989) as an example and point of departure. Some discussion of the methods is given below.

Table 1 Summary of Wetland Value (RNC) Estimates (1983 dollars)

Method		Per Acre Present Value at specified discount rate 8%	3%
WTP based			
	Commercial Fishery	$317	$ 846
	Trapping	151	401
	Recreation	46	181
	Storm Protection	1915	7549
	Total	$2429	S8977
	Option and Existence Values	?	?
EA based			
	GPP conversion	6,400- 10,600	17,000-28,200
"Best Estimate"		$2429-6400	S8977-17000

Willingness to Pay and Extending Existing Markets

For the individual, one estimate of the economic value of an increment in any good or service is the maximum amount that he or she is willing to pay (WTP) for it. Conversely, the value of a decrement is the minimum amount that the individual is willing to accept (WTA) for it. The prices formed in well functioning markets are one source of WTP and WTA estimates of marginal increments or decrements of goods and services. Where markets fail to provide appropriate measures of environmental values, the WTP and WTA concepts of economic value are not invalidated, but alternative "pseudomarkets" must be used to elicit these values from individuals.

The notion that an alternative chosen will be at the expense of the best opportunity foregone is central to economic decision making. For example, the cost of providing a scenic view can be directly derived from the net value of the highest use foregone--perhaps timber harvest and dispersed grazing. This is referred to as the opportunity cost . For scenic view preservation to be economically efficient, the scenic view must be preferred over other uses. In other words, its value must exceed the opportunity cost.

Ecological goods and amenities are valued by individuals for a variety of reasons. Utilitarian (or use) value refers to the value of using an ecosystem's products and amenities to derive both current and future benefits. These benefits include commercial outputs such as timber, outdoor activities and experiences, wildlife, and aesthetics (for examples of raw material evaluation see Bartlett (1984), who discusses valuation assumptions and methods for range forage). Individuals may also be willing to pay now for the option of using a resource in the future. Such an option price includes an amount equivalent to the expected use value plus a premium, similar to a risk premium, which a person would pay over and above the expected use value. This premium is referred to as option value, and is due either to uncertainty surrounding rhe individual's preferences or to uncertainty regarding the price or availability of the resource. This premium may be positive, negative, or zero (as in the case of preference uncertainty) but it will always be positive in the case of supply availability for a risk averse person (see Greenley et al. 1981, Bishop 1982, and Brookshire et al. 1983 for the theory and empirical studies of option value). The passage of time will likely reduce the uncertainty surrounding resource usefulness. When resource use is irreversible, individuals may be willing to sacrifice current irreversible use until uncenainty about its cost has been reduced. They may be willing to pay for increased information. This payment is termed quasi-option value (Arrow and Fisher 1974, Conrad 1980). It is not attributable to risk aversion, like option value, but is due to the value of information. This value arises in the case of resource use decisions that create irreversible damages, such as species extinction or large scale deforestation. A final, pure non-use value is what a person may be willing to pay simply to know that a resource exists even when there is no intention of use. This existence value has nothing to do with preserving options for future use or paying to delay use until more information is available (see Randall and St011 1980 and Brookshire et al. 1983).

In practice, WTP valuation refers to valuing the particular dimensions of benefits of projects by determining society's willingness-to-pay (WTP) for those particular benefits. It requires a listing of the types of benefits and an estimate of the WTP for each one. Our analysis of the WTP for wetlands (Farber and Costanza 1987, Costanza et al 1989) concentrated on four major categories of benefits of wetlands: commercial fishing, commercial trapping, recreation, and storm protection. Waste treatment benefits are partially included in the other benefit estimates to the extent that water quality affects recreation, fishing, and trapping values. We were not able, as part of this analysis, to place values on the existence and option value of wetlands.

The methodology for estimating commercial productivity consisted of estimating the marginal productivity of an acre of wetlands. Our estimates concentrated on the following commercial products: shrimp, menhaden, oysters, blue crab, and furs. The critical problem in estimating the marginal productivity of wetlands was to separate the effect of human effort from the effect of the intrinsic wetland productivity, when we can only observe the total effect as reflected in harvests. Failure to make this separation results in a potentially very large overestimate of the contribution of the wetlands to commercial production. A second problem in this estimation procedure is to distinguish between the average and marginal productivity of the wetlands. This is important if there exist decreasing returns to wetlands productivity (ie. if the productivity of a unit area of wetlands depends on the amount of remaining wetlands). Perhaps average productivity is appropriate for valuing very large wetlands projects, but valuation of small scale projects should use marginal productivity.

The estimation of WTP for recreational value is also complex. Two techniques can be used to make this valuation. First, one can simply ask recreational users what they would be willing to pay to use the wetlands in the project area. The problem with this technique is that respondents may engage in strategic responses. For example, if they think they may have to actually pay what they say they are willing to pay, they may state a value lower than their true value. On the other hand, if they think their response may positively impact the probability of implementing a project, they may state a value higher than their true value. A second technique is to estimate recreational users' WTP based on observations of what it actually costs them to use the project area. This technique is called the travel cost method and was our primary means of assessing the recreational value of wetlands.

The value of the wetlands for hurricane protection was obtained from a methodology which determined the reduction in expected property damages in populated areas along a gradient relative to distance from the coast. In principle, people would be willing to pay for a wetlands project according to the reduction in expected property damages attributable to the project.

Ecosystem Function, Energy Analysis, and Economic Value

In practice, measurement of WTP based value concepts has remained difficult and largely limited to the valuation of environmental commodities and amenities which produce fairly direct benefits to humans, like the ones listed above. An alternative approach is Norton's (1986) concept of contributory value, which assigns value to environmental resources not due to their direct value to humans, but according to their indirect role in maintaining and accentuating the ecosystem processes which support these direct benefits. These include the maintenance of atmospheric and aquatic quality, the amelioration and control of climate, flood control, the maintenance of a genetic library, and the supportive role of food webs and nutrient cycling. Contributory value recognizes both the long time horizons involved in many ecosystem processes and the synergism which can result from the interaction of two or more species creating benefits of which neither is individually capable.

Though empirically elusive, contributory value does provide a useful framework for conceptualizing how natural ecosystems might be evaluated. However, as Randall (1986) contends, human preferences are focussed more on life forms than on life processes. This bias is increased by the fact that humans, in general, will assign higher preferences to species with commercial value, to wild relatives of domesticated species and to those which are most familiar and/or easy to empathize with, such as large mammals (charismatic megafauna, such as the Giant Panda). Lovejoy (1986) refers to this bias against invertebrates as vertebrate chauvinism, while others point to interspecies inequity (Costanza and Daly 1987). If it is accepted that each species, no matter how uninteresting or lacking in direct usefulness, has a role in natural ecosystems (which do provide many direct benefits to humans), it is possible to shift the focus from the imperfect perceptions of individuals to the contributory value of ecosystems as expressed through .their ecological relationships. One might argue that this contributory value is an estimate of the value individuals would place on environmental services if they were fully informed about the functioning of the environment in their behalf, and if they were ignorant of their temporal position.

Assessing the contributory value of ecosystems involves the ability to understand and model the ecosystem's role in an integrated ecological economic system and its response to perturbations. The models must be at a level of detail and resolution that allows the assessment of impacts (marginal products) on economically important ecosystem commodities and amenities. Several types of ecological modeling can be used for this purpose, which we define under the general heading of "ecological-economic" models.

They range from relatively simple, static, linear input-output models (Hannon 1973, 1979, Isard 1972, Costanza and Neill 1984, Costanza and Hannon 1987) to multiple regression models (Farber and Costanza 1987) to more sophisticated nonlinear, dynamic spatial simulation models (Costanza et al. 1990). Braat and van Lierop (1985) provide a summary of ecological-economic models currently in use.

The point that must be stressed is that the economic value of ecosystems is connected to their physical, chemical, and biological role in the overall system, whether the public fully recognizes that role or not. Standard economics has too often operated on the assumption that the only appropriate measures of value are the current public's subjective preferences. This yields appropriate values only if the current public is fully informed (among 3 host of other provisos). The public is most likely far from being fully informed about the ecosystem's true contribution to their own well being, and they may therefore be unable to directly value the ecosystem's services (Costanza 1984). However, scientists may be able to derive estimates of the values that a fully informed public (H-e 2) would produce by analyzing the structure and function of ecosystems. In practice, this has usually involved analysis of energy flows in ecosystems and a direct comparison with energy flows in economic systems in order to translate to economic values. This is not the only conceivable approach to determining ecosystem contributory value, it is only the most popular and easiest.

As applied to wetland valuation, a simplified energy analysis (EA) technique looks at the total biological productivity of wetland vs. adjacent open water ecosystems 3s a measure of their total contributory value. Primary plant production is the basis for the food chain which supports the production of economically valuable products such as fish and wildlife. It is converted to an equivalent economic value based on the cost to society to replace this energy source with fossil fuel as measured by the overall energy efficiency of economic production. This technique is comprehensive and does not require a detailed listing of all the specific benefits of wetlands, but it may overestimate their vaiue if some of the wetland products and services are not usefui (directly or indirectly) to society.

Discounting

Often the present vs. future issue is thought to be objectively decided by discounting. But discounting at best only reflects the subjective valuation of the future to presently existing individual members of human society. Discounting is simply 3 numerical way to operationalize the value judgment that: (3) the near future is worth more than the distant future to the present generation of humans, and (b) beyond some point the worth of the future to the present generation of humans is negligible. Economists tend to treat discounting as rational, optimizing behavior based on people's inherent preferences for current over future consumption.

There is evidence, however, that discounting behavior may be symptomatic of a kind of semi-rational, sub-optimizing behavior known as a "social trap." A social trap is any situation in which the short-run, local reinforcements guiding individual behavior are inconsistent with the long-run, global best interest of the individual or society (Platt 1973, Cross and Guyer 1980, Costanza 1987). We go through life making decisions about which path to take based largely on the "road signs", the short-run, local, reinforcements that we perceive most directly. These short-run reinforcements can include monetary incentives, social acceptance or admonishment, and physical pleasure or pain. Problems arise, however, when the road signs are inaccurate or misleading. In these cases we can be trapped into following a path that is ultimately detrimental because of our reliance on the road signs. Discounting may allow individuals to give too little weight to the future (or other species, other groups or classes of humans, etc.) and thus helps to set the trap. Economists, while recognizing that individual behavior may not always lead to optimal social behavior, generally assume that discounting the future is an appropriate thing to do. The psychological evidence indicates, however, that humans have problems responding to reinforcements that are not immediate (in time and space), and can be led into disastrous situations because they discount too much.

It can therefore be argued that the discount rate used by the government for public policy decisions on common property resources (like wetlands) should be significantly lower than the rate used by individuals for private investment decisions. The government should have greater interest in the future than individuals currently in the market because continued social existence, stability, and harmony are public goods for which the government is responsible, and for which current individuals may not be willing to fully pay (Arrow, 1976). thus willingness to pay evaluation may be biased by a willingness to discount too much.

Discounting future value by the rate of interest also provides a tight link between ecological destruction and macroeconomic policy. Any exploited species whose natural rate of population growth is Iess than the real rate of interest is under threat of extinction, even in the absence of common property problems. While Paul Voelker and the Federal Reserve probably do not worry about the effect of U.S. interest rate policy on deforestation in the Amazon or destruction of Louisiana wetlands, such links really do exist, and they probably should be broken.

In terms of our wetland valuation problem all this merely increases the uncertainty concerning the total present value of wetlands, because the appropriate discount rate is uncertain and it makes a big difference in the results. We have stated estimates for a range of discount rates (3%-8%) in order to demonstrate how much uncertainty is introduced by uncertainty in the discount rate, and have given arguments for why a lower discount rate may be more appropriate for natural capital valuation decisions. Indeed there is a reasonable case to be made for a zero discount rate in decisions taken on behalf of society at large (Page 1977, Georgescu-Roegen 1981), since society, unlike the individual, is quasi-immortal. A zero discount rate gives infinite or very large vaiues for any indefinitely sustainable stream of income. The wants of future generations will be just as immediate to them as ours are to us. And if the fears of many climatologists and ecologists prove correct, productivity growth will be negative in the Iong run, so that equity would even require discounting at a negative rate--i.e. future resources should be valued more highly than present resources.

Another possibility is that the appropriate discount rate for natural capital should be linked to the natural decay rate (see fig. 1). RNC will not produce a stream of benefits into the indefinite future unless it is constantly suppiied with new energy to maintain it aginst enuopic decay. If this energy were not put into the natural capital stock in question it could be used to maintain some other natural capital stock. The "natural" discount rate should therefore be the average natural decay rate (probably somewhere on the order of 1-3% per year). This is an issue for further research.

Growth, Development, and Sustaninability

Improvement in human welfare can come about by pushing more matter-energy through the economy, or by squeezing more human want satisfaction out of each unit of matter-energy that passes through. These two processes are so different in their effect on the environment that we must stop conflating them. Better to refer to throughput increase as growth, and efficiency increase as development.[1] Growth is destructive of natural capital and beyond some point will cost us more than it is worth--i.e. sacrificed natural capital will

[1] This distinction is explicit in the Dictionary's first definition of each term. To grow means literally "to increase naturally in size by the addition of material through assimilation or accretion". To develop means "to expand or realize the potentialities of: bring gradually to a fuller, greater, or better state." (The American Heritage Dictionary of the English Language).

be worth more than the extra manmade capital whose production necessitated sacrifice. At this point growth has become anti-economic, impoverishing rather than enriching. Development, qualitative improvement, is not at the expense of natural capital. There are clear economic limits to growth--but not to development This is not to assert that there are no limits to development, only that they are not so clear as the limits to growth , and consequently there is room for a wide range of opinion on how far we can go in increasing human welfare without increasing resource throughput . How far can development substitute for growth--this is the relevant question, not how far can manmade capital substitute for natural resources, the answer to which , as we have seen, is 'hardly at all".

Some people believe that there are truly enormous possibilities for development without growth. Energy efficiency, they argue, can be vastly increased (Lovins 1977, Lovins and Lovins 1987). Likewise for the efficiency of water. Other materials are not so clear. Others (Costanza 1980, Cleveland et al. 1984, Hail et al. 1986, Gever et al. 1986) believe that the coupling between growth and energy use is not so loose. This issue arises in the Brundtland Commission's Report (WCED, 1987) where on the one hand there is a recognition that the scale of the human economy is already unsustainable in the sense that it requires the consumption of natural capital, and yet on the other hand there is a call for further economic expansion by a factor of 5 to 10 in order to improve the lot of the poor without having to appeal too much to the "politically impossible" alternatives of serious population control and redisuibution of wealth. The big question is , how much of this called for expansion can come from development, and how much must come from growth? This question is not addressed by the Commission. But statements from the leader of the WCED, Jim MacNeil (1990) that "The link between growth and its impact on the environment has also been severed (p.13)", and "the maxim for sustainable development is not 'limits to growth; it is ' the growth of limits", indicate that WCED expects the lion's share of that factor of 5 to 10 to come from development, not growth. They confusingly use the word "growth" to refer to both cases, saying that future growth must be qualitatively very different from past growth. When things are qualitatively different it is best to call them by different names. Hence our distinction between growth and development. Our own view is that WCED is too optimistic--that a factor of 5 to 10 increase cannot come from development alone, and that if it comes mainly from growth it will be devastatingly unsustainable. Therefore the welfare of the poor, and indeed of the rich as well, depends much more on population control, consumption control, and redisuibu don,, than on the technical fix of a 5 to IO-fold increase in total factor productivity .

We acknowledge, however, that there is a vast uncertainty on this critical issue of the scope for economic development from increasing efficiency. We have therefore devised a policy that should be sustainable regardless of who is right in this debate. We save its description for the final section. First some general operational principles of sustainable development.

Operational Principles of Sustainable Development

Weak sustainability is maintaining intact the sum of man-made and total natural capital. Even that is not done currently. Strong sustainability is the maintaining intact of natural capital and manmade capital separately. Weak sustainability would require the pricing of natural capital, which as we have just argued itself requires a given scale, i.e. the holding constant of natural capital at some level, which is to say strong sustainability. So we can concentrate on strong sustainability, maintaining total natural capital intact. What does this mean operationally?

(a) The main principle is to limit the human scale to a level which, if not optimal, is at least within carrying capacity of the remaining natural capital and therefore sustainable. Once carrying capacity has been reached the simultaneous choice of a population level and an average "standard of living" (level of per capita resource consumption) becomes necessary. Sustainable development must deal with sufficiency as well as efficiency, and cannot avoid limiting physical scale.

(b) Technological progress for sustainable development should be efficiency-increasing rather than throughput-increasing. Limiting the scale of resource throughput by high resource taxes would induce this technological shift, as discussed further below.

(c) RNC, in both its source and sink functions, should be exploited on a profit-maximizing sustained yield basis and in general stocks should not be driven to extinction, since they will become ever more important as NNC runs out. Specifically this means that:

   (i) Harvesting rates should not exceed regeneration rates; and

   (ii) Waste emissions should not exceed the renewable assimilative capacity of the environment,

(d) NNC should be exploited, but at a rate equal to the creation of renewable substitutes. Nonrenewable projects should be paired with renewable projects and their joint rate of return should be calculated on the basis of their income component only, since that is what is perpetually available for consumption in each future year. It has been shown (El Serafy, 1989) how this division of receipts into capital to be reinvested and income available for current consumption depends on the discount rate (rate of growth of the renewable substitute) and the life expectancy of the NNC (reserves divided by annual depletion). The faster the growth of the renewable substitute and the longer the life expectancy of the NNC, the greater will be the income component and the less the capita1 set-aside. "Substitute" here should be interpreted broadly to include any systemic adaptation that allows the economy to adjust to the depletion of the nonrenewable resource in a way that maintains future income at present levels (e.g. recycling).

A Fail-Safe Policy Proposal

We end with a simple policy proposal that accomplishes much toward the end of sustainable development. In spite of the disagreement over how much to expect from development without growth, both sides should be able to agree on the foilowing. Strive to hold throughput (consumption of TNC) constant at present levels (or lower truly sustainable leveis) by taxing TNC consumption, especially energy, very heavily. Seek to raise most public revenue from such resource taxes, and compensate by reducing the income tax, especially on the lower end of the income distribution, perhaps even financing a negative income tax at the very Iow end. Optimists who believe that efficiency can increase by a factor of ten should welcome this policy which raises resource prices considerably and would powerfully incentivate just those technological advances in which they have so much faith. Pessimists who lack that technological faith will nevertheless be happy to see the throughput limited since that is their main imperative in order to conserve resources for the future. The pessimists are protected against their worst fears; the optimists are encouraged to pursue their fondest dreams. If the pessimists are proven wrong and the enormous increase in efficiency actually happens, then they will be even happier (unless they are total misanthropists). They got what they wanted, but it just cost less than they expected and were willing to pay. The optimists, for their part, can hardly object to a policy that not only allows but strongly incentivates the very technical progress on which their optimism is based. If they are proved wrong at least they should be glad that the rate of environmental destruction has been stowed.

Agreement on this policy seems politically realistic, and does not hinge upon the solution (assuming it exists) to the difficult question of how to value natural capital. The valuation issue remains relevant in the sense that our policy recommendation is based on the perception that we are at or beyond the optimal scale. The evidence for this perception consists of the greenhouse effect, ozone layer depletion, acid rain and general decline in many dimensions of the quality of life. It would be helpful to have quantitative measures of these perceived costs, just as it would be helpful to carry along an altimeter when we jump out of an airplane. But we would all prefer a parachute to an altimeter if we could take only one thing. The consequences of an unarrested free fall are clear enough without a precise measure of our speed and acceleration. The point, if it needs restating, is that we should not be mesmerized into inaction by fascination with intractable measurements.

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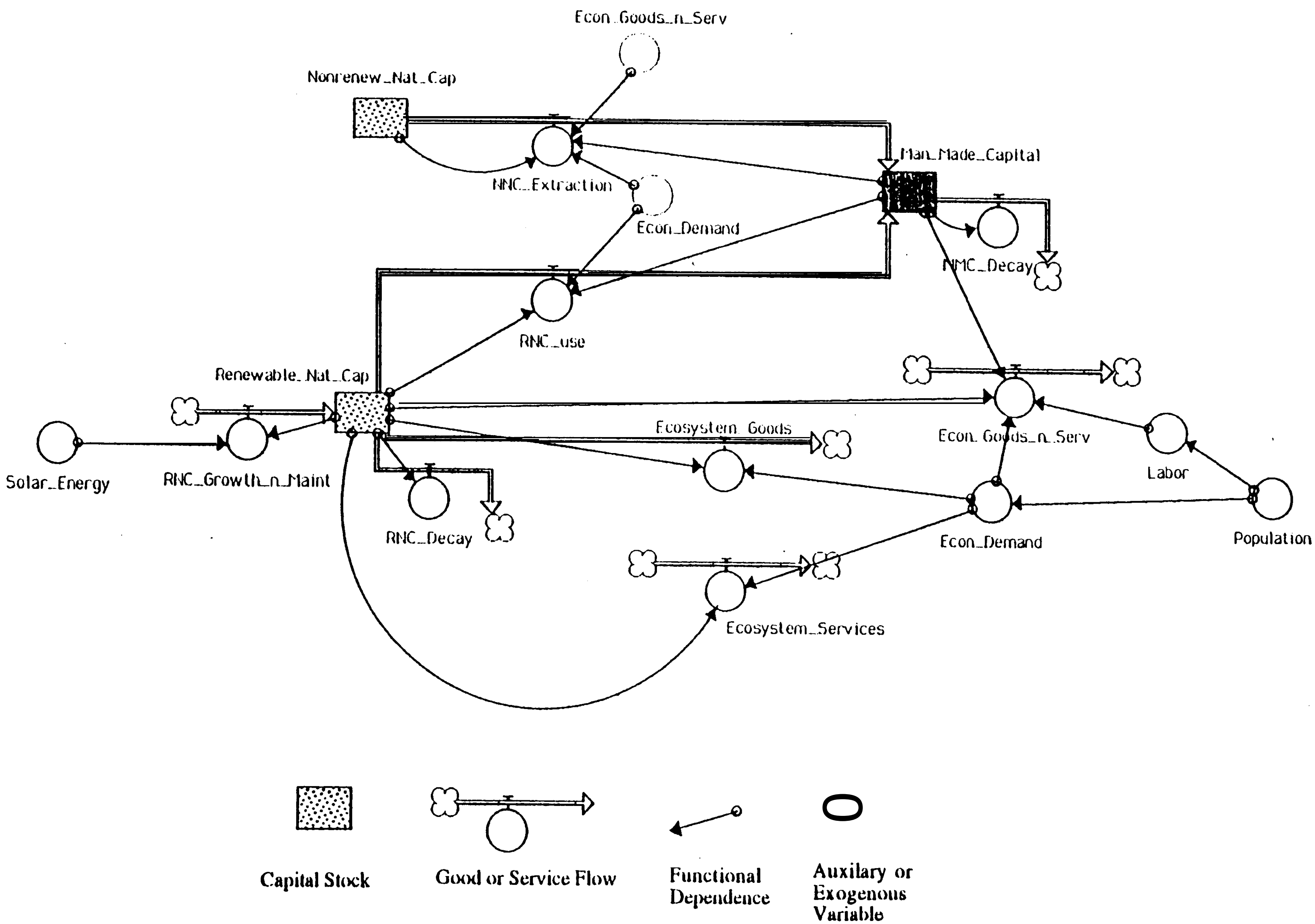

Figure 1. Types of Natural and Man-made capital stocks, good and service flows, and their interdependence

Natural Capital and Soil Productivity in the Canadian Prairies

by

J.T. Pierce
Simon Fraser University

The soils of the Canadian prairies are of recent origin. Following the retreat of the continental glaciers some 10,000 BP, soils began to form in isolated pockets which expanded during the Holocene as the accumulation of glacial meltwaters declined to expose the present drainage system. With gradual warming, the length of growing season increased, microbial activity and nutrient cycling intensified as did biomass growth rates and accumulation. Within a relatively short span of time the region's vegetation had evolved to a climax grassland vegetative system. Although highly productive and rich in complexity the stability of the system was heavily dependent upon an extremely thin mantle of soil and climatic stability.

With the introduction of agriculture in a systematic way to the prairies about 100 years ago the reciprocal bond and balance between grasslands and their soils was severed. Annuals replaced perennials, or more exactly 'herbaceous seed-bearing perennial polyculture', to produce a homogenized landscape that was based upon monoculture operations and large energy subsidies. It has been observed that where the prairie grasslands lives on income and saves, wheat and other commercially grown grains live off capital (Eisenberg 1989). Other cultural practices such as summer fallowing, irrigation, abandonnement of crop rotation, separation of' crop and livestock systems were also at the expense of that storehouse of natural capital.

The recognition of the need for conservation and augmentation of that capital is not new. What is new is that natural capital should be seen as a yardstick for sustainability, as a necessary condition for sustainability. In a similar vein Wes Jackson (Eisenberg 1989) believes that wilderness (i.e. undisturbed native grasslands), should be the standard against which agriculture should be judged. I would like to pursue this idea further within the context of defining natural capital as soil productivity, Assessing Changes to Natural Capital

Attempts to define natural capital have invariably focussed on the matrix of ecological processes and resources that underly soil productivity. The factors influencing soil productivity can be conceptualized first as necessary and limiting (keeping in mind the importance of the principle of the ecological law of the minimum - 'the factor in least supply governs the rate of growth of a system as a whole'). These factors can be further subdivided into endogenous and exogenous. Endogenous factors represent parent material, nutrient concentrations, acidity, organic content, porosity, depth of topsoil; whereas exogenous factors represent climate - length of growing season, moisture supply - energy inputs, pest and animal populations and vegetative cover.

Figure la indicates that these two dimensions define soil productivity under natural conditions. To emphasize the dynamic and evolutionary aspect to soil productivity it is illustrated as becoming successively larger assuming a continuation in favourable conditions.

As a surrogate measure for soil productivity one could propose the use of a measure. of annual change in biomass or biomass yield such as net primary production (NPP). The energy budget for gross production is as follows:

NPP = Growth = Assimilation - Respiration

Although easy to define in the abstract as a measure of the total biological activity of a plant community there are many obstacles to successful measurement. Instead above ground net production (ANP) is more manageable (Mitchell 1984). I would propose that natural soil productivity be measured in terms of ANP. This could provide a standard measure of the inherent productivity of and, in turn, the quality of natural capital in an undisturbed state. ANP can also be converted to energy units (e.g. joules) and provide a measure of energy efficiency through input/output calculations.

Like the concept of efficiency, productivity is not a quantity but a ratio (to paraphrase Mumford). To calculate the quantity of natural capital another dimension must be added - area or space (Figure lb). Production potential or biomass potential and hence the size of the natural capital of a

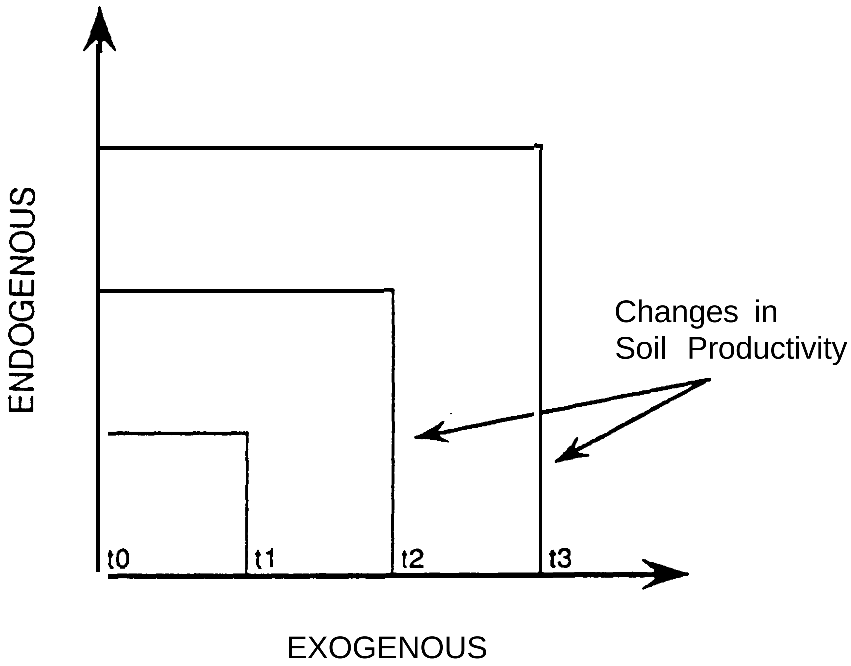

Fig. IA Changes in the quality of natural capital as measured by soil productivity

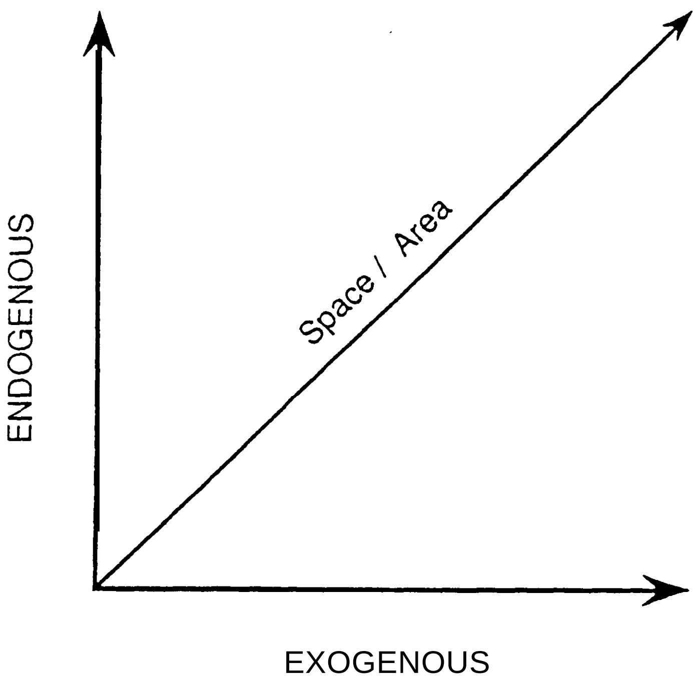

Fig. 1 B Dimensions defining the quantity of natural capital

region becomes the area of region weighted by its ANP. This is analogous to the calculation of annual production (P) as a function of area (A) and yield (Y):

$$P = A \times Y$$

Concerns over the sustainability of agricultural systems are normally expressed in terms of changes to the quality and quantity of the resource base. The natural capital that underlies all agricultural production has undergone significant alterations during the last one-hundred years. Natural capital is now subsidized through factor substitution and the reliance on non-renewable energy to augment the solar budget. The reliance on fossil fuel subsidies has driven a wedge between endogenous and exogenous forces and in the process weakened the complimentary interaction that sustains natural soil fertility. Therefore a distinction must be made between (the quality of) natural capital as defined by native soil productivity measured by ANP and subsidized natural capital as defined by crop productivity measured by yield. Yield can be expressed as ANP if adjustments are made for harvest index. Figure 2 indicates that despite a lowering of native soil productivity crop productivity or yields remain high. The difference between native soil productivity and crop productivity is a measure of energy subsidy.

These comparisons raise questions (worth research attention) regarding whether the differences between crop productivity and soil productivity are due to environmental conditions (disturbing topsoil or artificial energy inputs) or biological differences inherent in plant genotypes. As a first step the native soil productivity of a region defined by ANP could be used as a wilderness standard against which the energy budget of modern agriculture could be judged. A considerable body of evidence already points to environmental factors being responsible for the difference between the two systems (PFRA 1983). Research strategies need to be designed, with the appropriate control conditions, that can isolate the rate of change to natural capital and the additional resource inputs required to sustain the current productivity of the agri-food system under different production methods (e.g. organic vs chemical intensive).

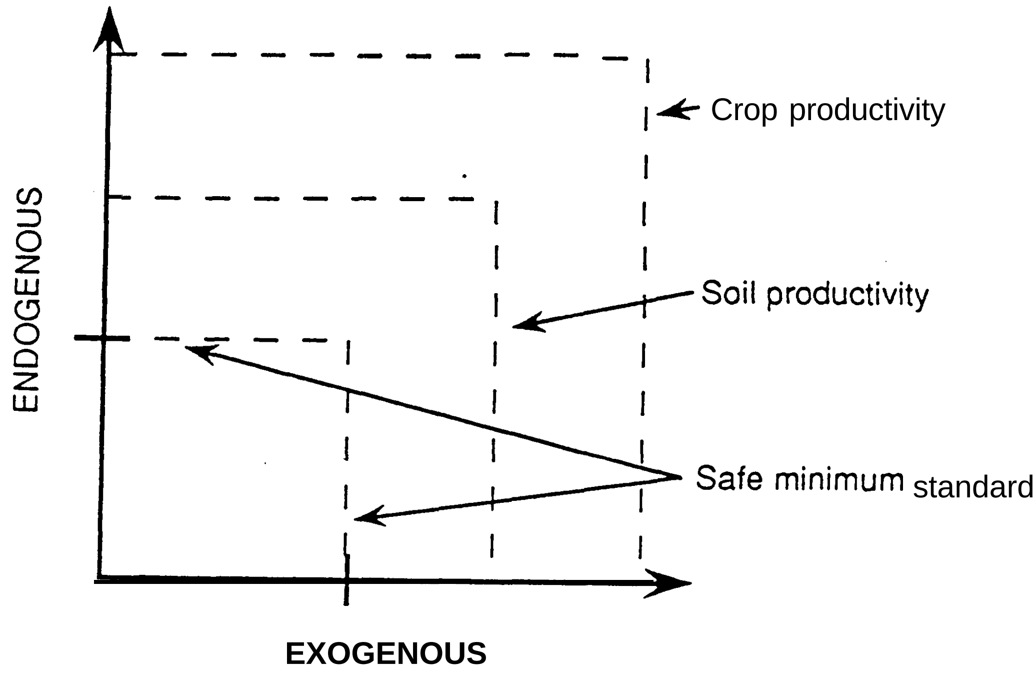

Fig. 2 **Subsidized natural capital**

Are there thresholds in the declines in natural capital with changes to exogenous and endogenous conditions? If there are, consideration must be given to the establishment of safe-minimum standards of conservation.

While there are numerous difficulties in identifying the spatial extent of changes to soil productivity and declines in natural capital, in cases where those changes are irreversible or where productivity is now zero, it is possible to provide a more accurate assessment. The loss of agricultural land to built-up uses or reservoirs, the elimination of topsoil, have been well documented for the prairies. These losses can be expressed in terms of production equivalents or ANP equivalents.

Recent Research

Appendix 1 contains a typology of land degradation/desertification that I prepared for my recently published book The Food Resource. It may help to structure and summarize some of the major issues relating to these processes.

Appendix 2 contains results of a simulation modelling exercise with a twenty-five year time horizon into possible resource and environmental constraints affecting future grain production on the prairies. These constraints include climate change, land degradation (e.g. soil erosion, salinization, loss of organic matter) and loss of agricultural land. It is recognized that technological change and factor substitution have historically played important roles in offsetting productivity effects of degradation. So the study indirectly indicates by how much both climate and technology must change to compensate for the constraints.

Ameliorative Action

How can we better protect the natural capital that sustains the agro-ecology of the prairie food system? I have listed a number of agricultural policy points in no particular order of importance:

1) Restructuring of existing producer subsidies to reduce market distortions and provide a ‘level playing field’ for competing agricultural production methods.

2) Implementation of incentives which bridge the gap between conservation investments and conservation returns.

3) Changing agricultural prices to reflect the true cost to society of the provision of goods and services. Farmers pay the full marginal costs of resources used. Reliance on polluter-pay and cross-compliance principles would move agriculture closer to a convergence of social and private costs of production.

4) Anticipation of economic and environmental effects through the use of benefit/cost analysis and environmental impact research (OECD 1989).

5) Diversification of agricultural research to meet the needs of alternate production strategies.

6) Balancing the major goals associated with sustainable agricultural production (e.g. stewardship, equity, sufficiency).

7) Design of conservation strategies.

8) Integration of environmental and agricultural policy through **new** institutions, organizations and co-ordinating bodies.

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APPENDIX 1

Source: Pierce (1990)

Table 7.1 A typology of land degradation/desertification

Type	*Physical/biological loss*	*Chemical change*	*Structural change*
Form	W–Wind erosion E–Water erosion OM–Oxidization of organic matter	S + A–Alkalization and salinization SC-Soil contamination A-Acidification L–Leaching	C-Conipaction PD–Profile disturbance WL–Water logging
Source/process	E–Sheet and rill erosion; gully erosion; mass movement; flooding inundation OM–Microbiological; artificial fertilizer use	A–Atmospheric and terrestrial sources of sulphur and nitrogen S + A–Changes in water salt balance SC-Heavy metals and organic compounds L–Percolation	C–Heavy machinery PD–Anthropogenic excavation WL–Raised water tables
Critical factors	W–Windspeed and soil moisture; vegetation cover E–Rainfall crosivity and soil erodability; slope; ground cover and crop management; animals; erosion control OM–Temperature; soil moisture; carbon/nitrogen ratio; crop residues; topography; vegetation cover; PH: manuring; artificial nitrogen use	A–Efficiency of ammonium-based fertilizers; presence of sulphates in fertilizers; soil buffering capability (dependent on calcium and magnesium availability); acid rain; low-based low cation exchange capacity S + A–Excessive application of irrigation water; high PET: poor drainage; fallowing; salt in geologic sub-stratum	C-Excessive tillage; humus content; moisture content of soils; soil texture PD–Surface mining and pipelines WL-Excessive application of irrigation water; poor drainage: subsidenco

Table 7.1 A typology of land degradation/desertification (*cont.*)

Type	*Physical/biological loss*	*Chemical change*	*Structural change*
		L-High permeability; fallowing; lack Of vegetative cover SC–Type of pesticide; organochloride vs. organophosphates; climatic conditions; proximity lo airborne contaminants such as PCBs	
Impact	W + E–*Offsite*: siltation and increased turbidity: water pollution; clogged ditches and reduced life of hydroelectric projects; declinc in soil production of sites receiving deposits. *Onsite*: declinc in nutrients and water retention abilities; reduced yields; increased costs of farm production OM–Irreversible declinc in organic matter; loss of water-retention abilities; greater risk of erosion; decline in yields; higher levels of CO_2	A–Increase in toxic levels of manganese and aluminium; reduction in nitrification and nitrogen uptake adversely affects aeration from earthworms and other soil fauna S + A Production loss through impediments to water nutrient uptake: moisture stress; reverse osmosis L-LOSS of organic matter; mineralized nitrogen; declines in productivity SC-Toxic to livestock, humans and microflora	C-Reduction in soil aeration: subsurface water movement and rooting zone depth creates surface ponding and plow pan; requires increased energy expenditure WL-Reduction in soil aeration: declines in productivity PD-Removal of topsoil; declines in organic content and mineral nutrients; loss of productivity

Comments on Natural Capital Case Studies

Tor Hundloe

Comments on Forestry Case Study

Under the heading of "Criteria for Considering Ecological Resources" the question of "how anthropocentric" natural capital accounting should be is raised. The answer must be that it is totally anthropocentric: humans are doing the accounting; their values are what are being counted.

Under this same heading, the question of "who benefits" is raised. In the first example, there is no reason why the provision of clean water by some remote boreal forest should be of equal value as that provided by a watershed used for urban water supply. Water will have different uses in these situations and the value will be reflected accordingly. In the second example, the question is what to do about beneficiaries outside national boundaries. The theoretical answer is that forest protection in one country which provides benefits outside of that country is an export service. In the case of Nepal protecting its forests - presumably for the benefits gained by Nepal - the "externality" which other countries gain (reduced flooding) should be paid for by these other countries.

Under the heading of "Measurement Units" it is suggested that major difficulties are involved in quantifying functions "which involve non-physical components (spirituality) or global scale". It is recognized that to attempt to measure the spiritual value of forests to indigenous people is extremely difficult - particularly if the people involved have little or no understanding of the market system and the notion of utility (satisfaction> and disutility which is fundamental to making trade-offs in developed countries. Of course, the theoretically correct measure is either willingness-to-pay to protect the forest or willingness-to-accept compensation if it is degraded or destroyed. We can put aside here the often-found divergence between these two measures. What is crucial is how we might attempt to gather data to estimate the value. I do not pretend to have an answer to this question. It is analogous to the problem that arose in the 'cost-effectiveness analysis of the proposed third London airport (20 years ago) in which a value needed to be established for an old Norman church which would have had to have been demolished.

The question of how to measure the contribution of a forested area to global albedo or climate circulation patterns would seem to be analogous to the situation of measuring the trans-frontier damage of acid rain, or pollution of the oceans. That is to say, If we can - and we should be able to - measure the damage costs, where-so-ever they occur - we at least get a minimum value of protecting the resource. Of course, we would need to know much more than we presently do about the precise role of forests In determining climate circulation patterns and what changes to these patterns would mean to producers and consumers wherever they happened to be.

Under the heading of "Inventories of Natural Capital" we find the argument that there is a 'serious deficiency" in making direct comparisons between man-made and natural capital. The argument is founded on the notion that there is, mostly (to use the author's terminology), a linear relationship between man-made capital and yield (returns) and that this is not the case with natural capital. The proposition about man-made capital is only necessarily true if (as the author argues) we are considering the lending of money at a given interest rate. Once that money is invested in a factory and machinery we have to operate at the optimal level of production, otherwise returns will not necessarily be linear.

The crucial part of the paper is that headed "Economic Evaluation". This is a very brief section, and for that reason alone does not do justice to the central theme of this gathering.

One suspects the paper was not written by an economist. The quaint, old-fashioned use of the term "political economists" is one clue. There are others; for example, there appears to be an attempt to explain the travel cost method, but if that is what is intended it is wrong. The issue of time (discounting the meaning of sustainability) is presented as a simple question.

Then there is the statement: Value judgements are generally required when assessing the ecological function8 of natural resources because the perceived demand for them is often based on the value system of the assessor.' This would not be the case if the assessor was an economist.

Comments on Soil Case Study

While itisa side issue, one wonders what is Intended by the opening remarks about the number of farmers decreasing and the investment in machinery increasing. If by *farmers" the writer means farm owners, this change probably indicates a realization of economies of scale through farm amalgamation. If farm workers are the subject of comment, the implication is that given the marginal productivities of labourers and machines (capital) and the substitutability between the two, machines are less expensive than labour; that is capital is less expensive than labour.

A very significant point (relevant to all valuations of any good service, at any point In time) is raised In the section titled "Effects of Management on Soil Productivity". It is that there can be "large variations in global pricing for grain that dramatically influence measured farm returns." What this Implies is that the value of a farm - and that includes the natural capital of the soil - will vary from period to period. Should this worry us any more than the fact that the value of any of the goods and services produced by an economy and measured in traditional national accounts can vary - for a whole range of reasons - from period to period? It is certainly clear that the author is relating his/her comments to how product price variability influences - on farm conservation measures. Nevertheless, we can use this example to note the fact that the value of natural capital is as dependent on the forces of the market (and all that that implies) as is the value of anything else.

The paper takes up the important issues under the general heading of "Questions".

The firstissue raised is that, somehow, land is unique among other factors of production. This, it is suggested, is because it is a "composite of factors" influencing crop production: a fixed location, able to capture rainfall and sunlight, energy.

Whether or not land is unique should not worry us unless some telling point is going to be made in terms of valuing land. That would appear to be the author's intention, but he/she does not persevere with it.

The one thing that differentiates land - for all practicable time - from the other factors of production is its fixed location. Some physical embodiments of capital (eg. factories) are fixed in location during their economic life-span, likewise are consumption goods such as private housing, and even, in this day and age, much of labour is fixed in location.

The fact that soil can capture rain fall and sun light energy (physical properties) is no different - one might argue - from the fact that humans "capture" food which allows them to work. Humans also learn and develop skills which, ceterls paribus, increases their value as human capital.

The point of all this is that humans, as much as soil, require "external inputs" before production occurs. There is in fact another point and it is that in the search for a meaning and measurement of natural capital it is too easy to get side-tracked into technical non-economic matters. This is not to argue that we should not understand the various ecological resources (nutrient concentrations, organic matter, structure, etc.) of soils - because they will differ and hence different values will apply - but rather concentrate our efforts on how we should value soils.

As the author of the paper argues, actual or "realized" soil productivity depends not only on soil characteristics but very important factors such as tillage practice, crops grown, prices received, technological advances, all of which are subject to change due to market forces. That is, as the author argues, soil productivity - its value as an input in the production process - "can only be viewed in the context of non-soil related factors".

The issue we face with measuring the value - and the depletion of soils - is different to that of forests and wetlands, at first glance at least. Markets for agricultural/pastural land have existed for a long time. In purchasing a farm, farmers to the best of their abilities take into account the expected value of land as one of the factors of production. On the other hand, wetlands (as the author of that case study argues) are often viewed as useless (valueless) unless converted to some market-oriented use. With regard to forests; while there has been for many decades a market - often distorted as a consequence of institutional factors - for the timber production value of forests, non-wood values have been neglected. In addition, in those situations where forests are not in private ownership, the notion that forests should earn rent (as 'agricultural land does) is not necessarily a consideration.

What is being argued is that the market for agricultural land placesa value on the "natural capital" - "land" as it is termed in economics, while there are not markets for wetland and forestry land. If we assume the market for agriculture land is as perfect as is the market for factories, plant and machinery (man-made capital), changes in market value will indicate the depreciation (or otherwise) of land in the same manner as the market for man-made capital will indicate changes in worth.

There are, of course, various problems with the market oriented approach in valuing soils from the sustainable development perspective - if that concept is taken to imply no net loss of natural capital. For instance, the time horizon of farmers and the private discount rate could lead to mining the soil. This is not just confined to soils, but can apply to fisheries, forests and, in fact, any type of natural capital. It should be recognized that it can also apply to man-made capital. That is to say, there can be economic circumstances which result in a rational decision by the individual owner of capital to run it down, not maintain it indefinitely.

That stated, the question of **maintaining soils,** in particular preventing soil erosion, should be considered in the context of **externalities - the off-site effects. Soil erosion** can result in sedimentation and **siltation downstream.** Such **off-site effects** can damage (reduce) the productive capacity of other producers and consumers. **A** case study, applying extended cost-benefit analysis, by this author which **analyzed** soil conservation in the highlands of Northern Thailand showed very respectable cost-benefit ratios **for soil conservation practices when the off-site effects were** taken into account.

Comments on the Wetlands Case Study

On the heading "Wetlands as a Resource" the author categorises the various values of wetlands. He writes in terms of wetlands having both ecological and social values. A minor, but nevertheless important, pointis that it needs to be recognized that ultimately "ecological" values are only meaningful in economic terms when they are converted into social value.

The author also categorizes wetland values into intrinsic and resource values, where intrinsic values are viewed as being independent of human needs. There is a problem with his example of intrinsic values. He suggests these are: (i) wetlands as natural areas; (ii) wetlands for recreation, education, and research; and (iii) other intrinsic values. He does recognize that the first two "entail some degree of human recognition". Clearly, if wetlands are to be valued (and their depreciation Included) In the national accounts, it is only their use values (which obviously will include option, preservation/existence and bequest values as well as the more commonly understood productive and non-consumptive values which are relevant. The argument actually turns on what is meant by "intrinsic" values. If humans care about the existence of natural ecosystem, that has come to be recognized as a non-consumptive use value - and it can be measured.

All the "other intrinsic" values mentioned by the author can ultimately be traced along a path leading to use values.

The author presents a list of "ecological services" provided by wetlands. They can be used to suggest the method/s which can be applied in economic evaluation of these uses. (He does address the valuation issues later in the paper, but his list is not as comprehensive as the earlier one).

His first ecological service is flood peak reduction. This would normally be measured as the expected value of property damage prevented and lives saved. The next is shoreline erosion control and hurricane protection. Again, the measure is the expected value of damage prevented. The third is ground water recharge. Water as either an input in production (e.g. of agricultural crops) or, as a consumption good has market values, although these are often difficult to estimate due to Institutional factors which, in some cases, suggest to users that water is a "free" good.

Water quality Improvement and wastewater treatment are the next values mentioned. The damage costs prevented by provision of better quality water is an appropriate measure of these values. Next come non-consumptive uses (such as bird watching and preservation of rare species). These can be valued using standard measures of consumer surpluses by utilizing travel cost and/or contingent value techniques. Then there are consumptive (or more appropriately "production Input" uses) for such things as commercial harvesting of fish and waterfowl. In this situation, wetlands are a factor of production, equivalent to land for agricultural production, and - If the Institutional arrangement6 are appropriate - their value is measured as a resource rent. The practical problem is that wetland6 - and too often the associated marine environment - are not subject to property rights and hence subject to open access problems (dissipation of rents).

The next values listed are climatic and atmospheric functions. At this point in time there is probably too little known in terms of cause and effect to trace through these functions to their ultimate effect on production and consumption. The list is completed with three commercial uses (forests, agricultural product6 and energy). All of these can be measured by their market values.

It is clear that we can value the flow of resources provided by wetlands. It is also obvious, that similar to agricultural land, wetlands have a market value, per hectare or whatever other unit, and that market value should represent the capitalized value of the flow of goods/services produced by the wetlands. Furthermore, degradation of wetlands is no different from the depreciation of agricultural land or man-made capital.

Turning to the author's comments on "Economic Valuation", he could have used - as above - a wider range of examples. A minor point of clarification is that his use of "transfer prices" is presumably meant to be "sales prices". Transfer prices has a very different, technical meaning in economics. Of more substance, the author refers to the work of ecologists to ask the pertinent question: "how much are nature's services worth?' What should be recognized is that there has been, recently,' considerable work done on this question by economists. It is that literature which is going to assist us in the pursuance of developing appropriate values for natural resources. In passing - and without laying claim to any innovation in the area - this writer has estimated minimum values for one of Australia's (if not the world's) most important natural assets, the Great Barrier Reef. The economic techniques of travel cost and continent valuation were used.

A final point which the paper's author should clarify is the quote by Contanza et al. It suggests - but this might not be the intention - that devoting more effort to valuing wetlands might not be worth the effort.

Appendix 5

List of Workshop Participants

Dr. Gordon Baskerville
Faculty of Forestry
Bag Service #44555
Fredericton, New Brunswick
E3B 6C2
Tel: (506) 453-4501
Fax: (506) 453-4599

David Bernard
ESSA Ltd.
705 - 808 Nelson Street
Vancouver, B.C.
V6Z 2H2
Tel: (604) 689-2912
Fax: (604) 682-2114

Dr. Brian Clark
Centre for Environmental
Management and Planning
University of Aberdeen
48 college Bounds
Old Aberdeen, Aberdeen
Scotland
AB9 1FX
Tel: 224-272-480
Fax: 44-224-487658

Dr. Colin Clark
Department of Mathematics
University of British Columbia
Vancouver, B.C.
V6T 1Y4
Tel: (604) 228-3262
Fax: (604) 228-6074

Dr. Robert Costanza
Coastal and Environmental Policy
Program
Centre for Environmental and
Estuarine Studies
University of Maryland
Solomons, MD
20688-0038 USA
Tel: (301) 326-4281

Robert R. Everitt
ESSA Ltd.
705 - 808 Nelson Street
Vancouver, B.C.
V6Z 2H2
Tel: (604) 689-2912
Fax: (604) 682-2114

Dr. Tor Hundloe
Institute of Applied Environmental
Research
Griffith University
Nathan, Brisbane
AUSTRALIA
Tel: 61-7-275-7111
Fax: 61-7-875-7459

Dr. AnnMari Jansson
Asko Laboratory
University of Stockholm
S10691 Stockholm, SWEDEN
Tel: 46-8-164254
Fax: 46-8-158417

Dr. Werner AI Kurz
ESSA Ltd.
705 - 808 Nelson Street
Vancouver, B.C.
V6Z 2H2
Tel: (604) 689-2912
Fax: (604) 682-2114

Patrice LeBlanc
CEARC/FEARO
200 Sacré-Coeur Blvd
Fontaine Building
Hull, Quebec
K1A OH3
Tel: (8 19) 997-2253
Fax: (819) 994-1469

Dr. Enrique Leff
UNEP Regional Office for Latin
America and the Caribbean
PDTE Masaryk 29
11570 Mexico, D.F.
Tel: 250-15-55 (222)
Fax: 525-203-44-65

Dr. Peter Morrison
ESSA Ltd.
102 - 66 Isabella Street
Toronto, Ontario
M4Y 1N3
Tel: (416) 967-7330
Fax: (416) 967-7270

Carol L. Murray
ESSA Ltd.
425 Stannard Avenue
Victoria, B.C.
V8S 3M6
Tel: (604) 5952232
Fax: (604) 598-1210

Wendy Parkes
FEAR0
200 Sacré Coeur Blvd
Hull, Quebec
K1A OH3
Tel: (819) 953-7706
Fax: (819) 994-1469

Dr. John Pierce
Department of Geography
Simon Fraser University
1821 Blenheim Street
Bumaby, B.C.
V6K 4H7
Tel: (604) 736-4941
Fax: (604) 291-4455

Dr. A. Atiq Rahman
Bangladesh Centre for Advanced Studies
626, Road 10A, Dhanmondi
Dhaka 1205, BANGLADESH
Tel: (8802) 310538, 315793, 601925
Fax: (8802) 833379, 833664

Dr. Barry Sadler
CEARC/FEARO
200 Sacré-Coeur Blvd
Fontaine Building
Hull, Quebec
K1A OH3
Tel: (8 19) 997-2253
Fax: (819) 994-1469

Dr. Peter Stokoe
School of Resource and Environmental Studies
Dalhousie University
1312 Robie Street
Halifax, Nova Scotia
B3H 3E2
Tel: (902) 424-3632
Fax: (902) 424-3728

Dr. Mike Wells
Boom 5-4051
World Bank
1818 H Street N.W.
Washington, D.C. 20433
Tel: (202) 473-1046
Fax: (202) 477-0565

Dr. Janos Zimmerman
Organization of Eastern Caribbean States
Natural Resource Management Project
Box 1383
McVane Drive, San Souci
Castries, Saint Lucia
West Indies
Tel: (809) 452-1837
Fax: (809) 452-5313

Table 7.1 A typology of land degradation/desertification (*cont.*)

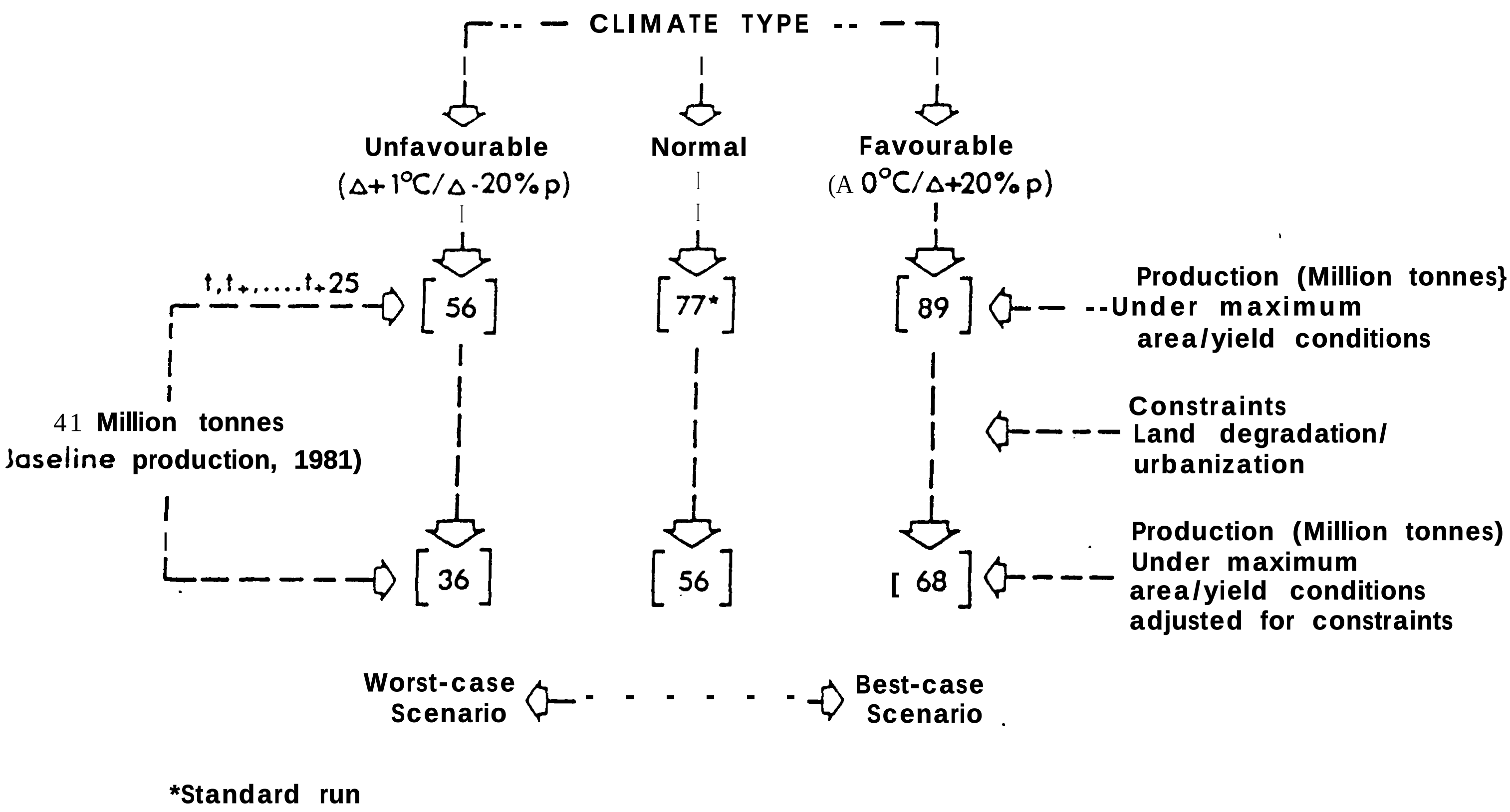
Type	*Physical/biological loss*	*Chemical change*	*Structural change*
Measurement	W–Wind erosion equation (in tonnes per hectare per year) E–Universal soil loss equation (in tonnes per hectare per year); sediment delivery ratios (in tonnes per hectare per year) OM–Change in humus/carbon content within 30 cm of surface	A–Changes in pi I; decrease iii base saturation (iii percent per year) S + A–Increase of electrical conductivity (in mmhos per cm) of saturated paste; and increase in exchangeable sodium (in percent per year) L–Percentage declines in carbon SC–Percentage increase in toxic elements (in ppm per year)	C + WL–Increase in bulk density (in grams per cm^3 per year) or decrease in permeability (in cm per hour) PD–Change in soil profile/horizons
Area/extent	W + E + OM-Wind erosion particularly acute in arid regions; water erosion in regions of high intensity rainfall with minimal natural vegetation; organic matter loss in most regions using modern/industrial agricultural methods	S+ A-Most arid regions with high evapotranspiration SC–Urban/industrial regions; localized L + A–Tropical regions those with low-based soils	C-North America WL–Numerous irrigated regions, particularly the Middle East PD–Areas of strip mining in North America and the Soviet Union

Table 7.1 A typology of land degradation/desertificatio nt.)

Type	*Physical/biological loss*	*Chemical change*	*Structural change*
Indicators	W-Dust storms. dust clouds, desert pavement, ripple marks, formation of hummocks or dunes, accumulation of sand against grass stems, tree boles, hedges, fences, road embankments, roots exposed E-Rills (small water channels), muddy water, mudflows, gullies, erosion pedestals, exposed roots Of trees and shrubs, changes in colour of bark on trunks and stems, soil deposits on gentle slopes, exposed parent material, uneven topsoil, gravel, sand and silt deposits in stream channels, trampling displacements by grazing animals, changes in vegetation species, sediment deposition in reservoirs OM–Decrease of organic matter, lighter soil colour. increased sealing, crusting, run-off, decrease Of earthworms and rodents, decrease of response to fertilisers W + E + OM -Decrease of yields	A–Advent of plants resistent to acidification, to low pI I. in fallow or following crop or between rows of crop (plants vary according to ecological region) S + A–Efflorescence or salt crust on soil surface, edges of irrigation furrows, riverbanks, barren spots or unhealthy plant growth L–Lack of response to fertilizers SC–Dispersed clay in puddles after rainfall, sticky soil. increase of plant disease, appearance Of toxicity symptoms on leaves: iron, copper, manganese, boron, zinc, deficiency symptoms of potassium, sulphur and phosphorous A + S + AL + SC–Decrease of yields	C–Platy or laminary structure of soil surface, or massive structure more or less compacted arid indurated in dry seasons, plough pan increase in run-off and decrease of water available in soil, roots limited in depth stopped short at compact horizon PD–Degradation of seed bed and poor gemination of seed WL–Sealing and crusting of soil surface after storms. mud and water stagnation after storms C + PD + WL–Decrease of yields

APPENDIX 2

Source: Pierce and Stathers (1989)



ig. 2. Growth scenarios for prairie grain production.

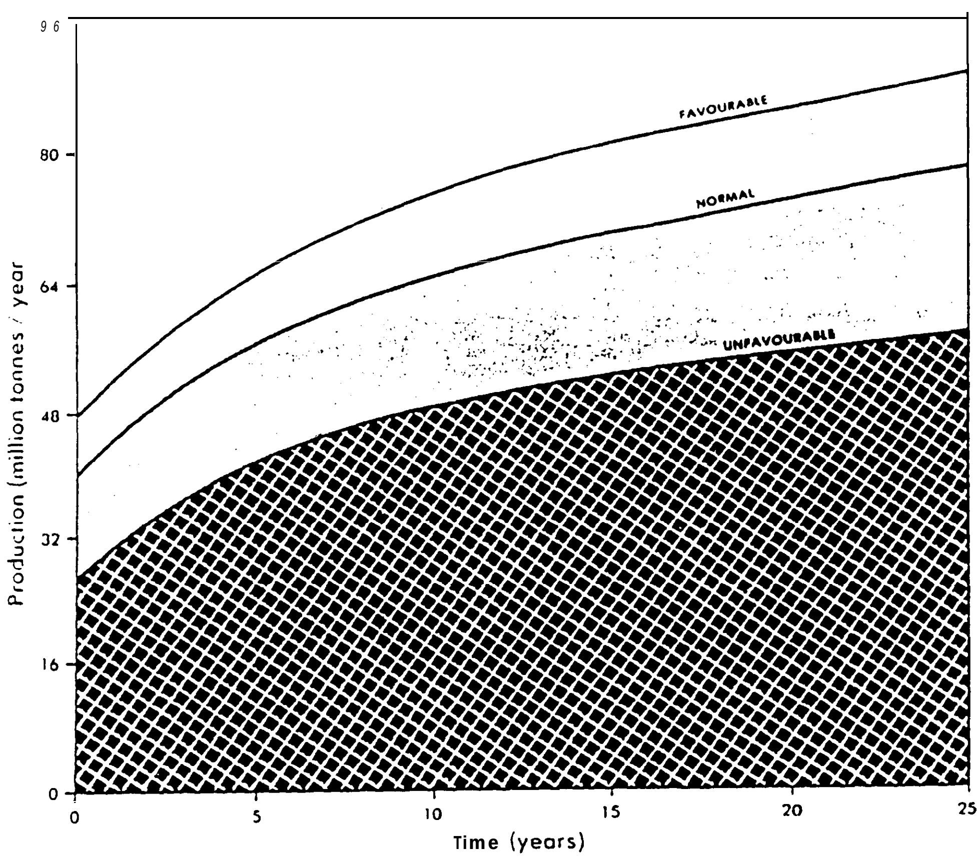


Fig. 4. Growth in production under three climatic types.

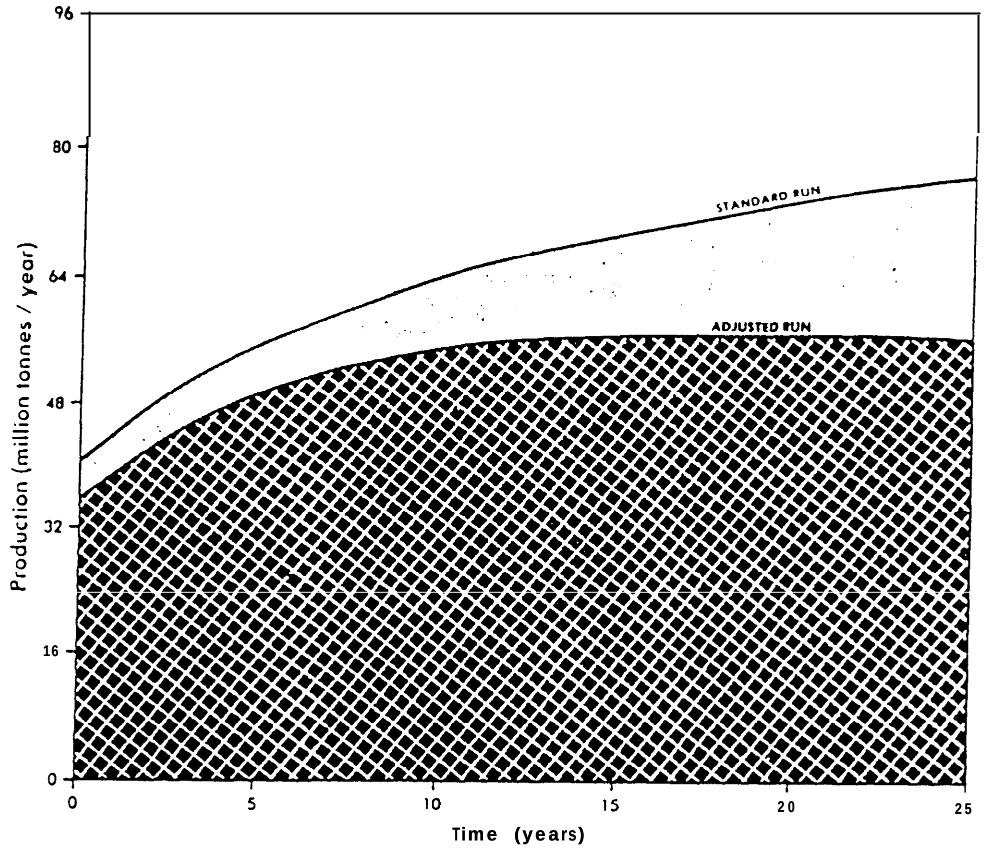


Fig. 5. Growth in production under normal climate ndjusted for constraints.

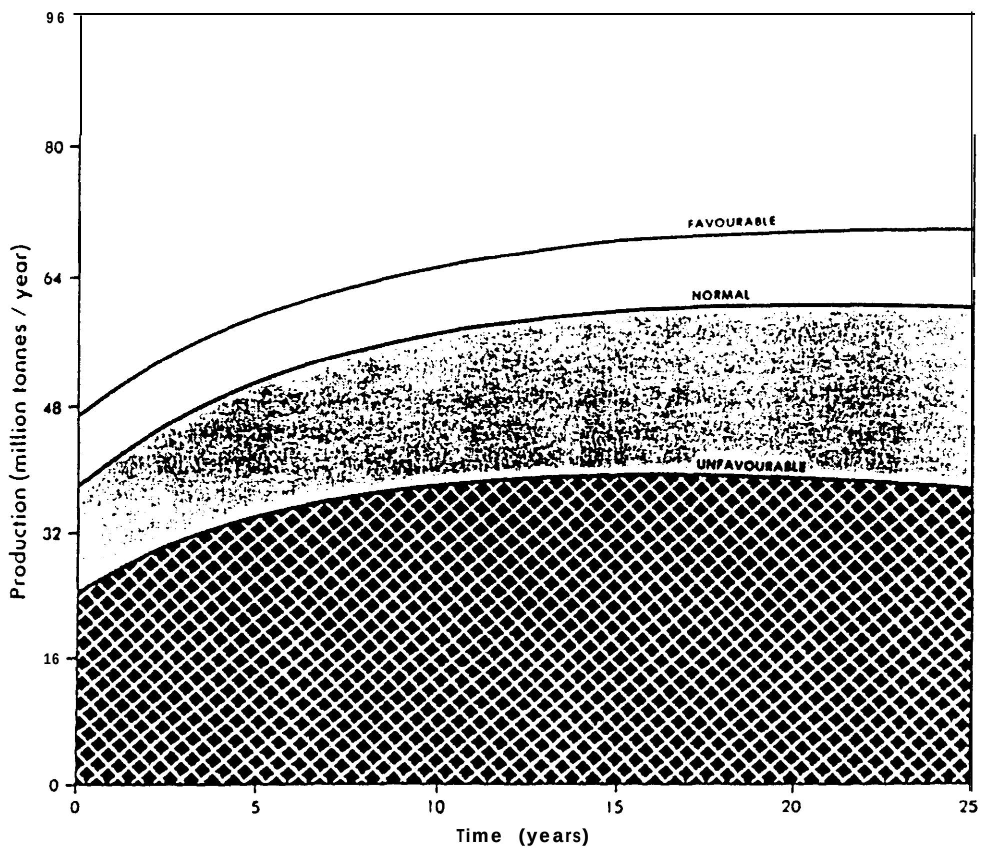


Fig. 6. Growth in production under three climatic types adjusted for constraints.

A regional approach to the assessment of natural capital.

AnnMari Jansson, university of Stockholm

Draft March, 1990

The study and management of the relationships of natural resources to economics and sustainable development has been considered at several spatial levels of scale from the global to the neighborhood, but much interest lies in the regional level. The definition of a region may be somewhat arbitrary but refers in the present context to some extensive geographic space entailing a mosaic of ecosystems and human settlements that interact among themselves and with the physical environment.

The landscape mosaic is a result of the interaction of renewable energy flows with storages of soils and geological features as well as gene pools and the actions of humans. What economists used to call "land" is thus a complex, resource generating system, the value of which needs to be analyzed in terms of its ecological functions. The argument put forward in this paper is that the utility of natural areas to human systems must be perceived not only for each type of ecosystem but also with proper regard to their mutual interactions and collected contribution to the economy.

Traditionally we have had a reductionistic approach to the study and preservation of ecosystems, generally focusing attention on small scale units without looking for higher level structures. This has been devastating for the conservation of nature and led to the extinction of many valuable species. Because life support of a species, humans included, depends on production processes in several ecosystems, it is necessary to preserve a regional spectrum of ecosystem types. Without a diverse landscape, species diversity cannot be maintained.

There is a general tendency that ecosystems show some form of hierarchical organisation in the regional space with respect to their photosynthetic activity. Over a given landscape there is an energy spectrum of land uses with large areas of low energy density (natural and agricultural lands) and small areas of high power density (cities). Forests, wetlands, agroecosystems and other types of ecosystems are linked together by a network of flows, which facilitate effective circulation of water and other limiting resources. Improved knowledge about the significance of such regional couplings for reinforcing the productivity and performance of the whole landscape seems to be of basic importance for a proper valuation and management of the natural capital.

Energy analysis

One of the primary interests of a comprehensive regional analysis is to quantify energy transfers throughout the natural and man-made system as well as cycles of materials generated as a result of the flows of energy. The photosynthetic work in terrestrial and aquatic systems, the evaporation of water that drives the hydrological cycle, the formation of soils by the erosion of rocks and the action of winds and waves all depend on solar energy. These processes are necessary for the functioning of human settlements and contribute to economic development.

Estimates are made on how much energy is fixed in photosynthesis, where it is stored, and how it is transformed through the food webs of consumers. General measures are used to characterize different ecosystems. For example, the ratio of production to respiration (P/R) tells us to what extent production is channeled into new growth. In early stages of succession of an ecosystem, without extra inflows of nutrients or organic matter, P/R > 1, while in mature older stages P/R approaches 1, a condition which states that most assimilated energy is channeled into maintenance- no net growth occurring.

Knowledge of energy storages and fluxes associated with the natural environment also help to evaluate the yields that are available for harvest and other potential services that could be directly exploited by humans. Whenever possible time-series data should be collected to assess trends of environmental change, such as changing land use that either decreases or enhances the over-all productivity of the landscape.

Establishing the relationship between energy and economic activity and its trend over time is important information in regional planning. Usually only the direct use of fuels and electricity are considered whereas the flows of energy and matter to and from the environment are not evaluated. For example, if we consider a specific industry (eg. agriculture), its production of economic value requires various kinds of energy, materials and human labor. In the process part of the energy is degraded and released to the environment as heat. At the same time waste materials and pollutants are produced and released into the environment. These often cause environmental damage, decreasing productivity of terrestrial and aquatic ecosystems and increasing health risks of the human population. For an improved assessment of the ecological and economic consequences of industrial activities an increased consideration of the energy and material cycles of the regional sys tern is essential.

Svstems models

An important approach to assess the value of ecosystems to society is the formulation of mathematical models for computer analysis to capture the interactions between the economic and environmental systems. Simulation models usually entail a mathematical description representing the time rate of change of each storage in a system as a function of its inflows and outflows. The model can be simulated over time (and space if it is a spacial model) to determine likely responses of the system to changes in key variables. Effects of harvesting natural resources, changing land use patterns and polluting emissions are examles of problems, which can be explored by means of computer simulations.

Dynamic ecosystem models are sometimes coupled to economic input-output models, which represent a useful accounting scheme for the systematic analysis of interactive effects among groups of sectors in an economy. Often a combination of input data obtained from economic statistics together with tec hnical process data available from engineering analysis gives a more reliable estimate of waste residual outputs than direct measurements. This type of model can also serve as a useful calculation scheme for predicting the indirect impacts due to some anticipated new demand in a given economy. In many circumstances interest might focus on the limitations of available resources or the level of acceptable output of wastes.

Finally one can engage in more normative mathematical modelling in the form of optimization models where there is a prescribed goal or objective function subject to a set of constraints. Optimal organization of human activities in the regional landscape to maximize the diversity of ecosystems and storages of organic matter, soils and water may be types of goals which can be explored by means of this approach.

Forest ecosvstems

Natural forests are well-ordered ecological systems often containing a mixture of vegetation, successional stages and age classes of trees. The combination of large storages of organic matter in living and dead biomass with a slow turn-over rate and small storages, which can respond rapidly to changes in energy flow, increases the over-all buffering capacity of the forest system against climatic changes and other disturbances.

Because forests occupy large areas, they often account for a dominating part of the carbon fixation in terrestrial ecosystems. There are now great expectations that increased production of tree biomass could counteract global warming and could be used as fuel resource instead of coal and oil. However, a rapid acidification of forest soils due to air pollution and the deposition of sulfuric and nitric acids may instead diminish the productive capacity of forests and lead to a vast leakage of nutrients, aluminum, iron and cadmium from forest soils. This has detrimental effects on fresh water organisms including economically important fish species and destroys the quality of ground water with increased health risks and high accompanying costs to society.

In order to keep pH of forest soils above the threshold level where leaking starts, large scale liming might become necessary. The costs of maintaining the quality of forest soils then suddenly increases by hundreds of dollars per hectar. Thus the impacts of air pollution (including transboundary pollution) on forest soils adds to the problem of estimating the value of forest ecosystems. It also demonstrates that the economic value of the life-supporting functions of natural forests have been very much underestimated and require a regional approach to be properly understood. A correct evaluation of the economic benefits of a forest ecosystem must therefore not be restricted to estimates of production of tree biomass but also reflect the role of forests as important interface ecosystems in the regional landscape providing protection and other functions for human settlements.

Wetlands

The value of natural wetlands as buffer systems, water storage facilities, filters for maintenace of water quality and gene pool reservoirs has finally started to be recognized in regional planning. In many parts of the world wetlands have been reduced significantly over the past 200 years through extensive drainage. Highly productive and diverse wetlands have been replaced by simpler agricultural systems whose productivity has been enhanced by the fertile organic storages that had accumulated in the peat soils. Thus the drainage of wetlands seemed to make sense from an economic point of view, because the benefits of using the rich organic soil storages far outweighed the perceived costs of society neglecting the accumulating impacts associated with the destruction of the wetland ecosystems. However, the present situation is different. The peat soils have diminished in drained areas and an increased use of fertiiizers and pesticides in agriculture has deteriorated water quality in areas where there are now a significantly increased demand for fresh water. From a regional perspective it might now make sense to re-establish some of the former wetlands to maintain sufficient water storage capacity.

The question has also come up whether wetlands can be used as potential waste cycling sites. Although this development may be controversial from a conservation perspective the possible loss of wildlife ought to be weighed against the costs for sewage treatment, and damage to other ecosystems due to improper waste management. Alternative strategies for the use of wetlands in the regional landscape could be evaluated by means of spatial simulation models to examine long-term effects on landscape dynamics and support to the human economy.

Agroecosystems

Energy analysis of modern agriculture has shown its strong dependence on inputs of fossil energies as well as high external costs generated by environmental impacts on soils, waters, species diversity and natural landscapes. In order to reduce the input costs and pollution it is necessary to consider croplands and pastures as functional parts of a larger regional system. There is a need to retain a funtionai balance between cultivated lands and other types of land-use, taking into account the interactions between different landformes, hydrology, soils and biological compartments. It is also essential to increase the diversity of agroecosystems by cultivating a greater variety of species and alternate between various crops. By regarding open ditches, clumps of tree, hedges, ponds and so on to be protective elements in the agricultural landscape, the effects of droughts, wind erosion and attacs by pest organisms may become less severe.

Preserving or restoring a diverse agricultural landscape may, however, in a shorter time perspective be in conflict with the economic goal of maximizing food production. But the costs of lost agricultural output should then be weighed against the advantages that would accrue for improved protection of the natural capital (soil, water, gene pool etc.) against various disturbances both natural and man-made.

Summary and conclusion

The free pathways of life support from the natural environment for maintaining air, water, landforms, soils, groundwater, species diversity etc. are not easily quantified and often very much underestimated in economic terms. The contribution of the natural lands to the overall economy may be determined in physical units using energy analysis. One important question relating to the value of natural lands is to investigate what mosaic of natural and developed land maximizes the long term contributions to society of renewable energies. This may be analyzed by means of dynamic landscape models together with optimization models.

This paper has emphasised that it is not sufficient to assess the value of the natural capital for each type of ecosystem and to manage forests, wetlands and agroecosystems independently. Each type of ecosystem modifies the hydrological and geochemical cycles of the larger regional system, which also includes human activities. The pattern and patchiness of the landscape as well as the flows of energy and matter between the systems are emergent properties of high value which also have to be recognized. As discussed in this paper negative effects in one type of ecosystem also affects structures and functions in adjacent ecosystems.

NATURAL CAPITAL AND SUSTAINABILITY

An initial view for the CEARC Worshop on Natural Capital
Vancouver, 15-16 March, 1990

Peter K. Stokoe

Natural Capital: Usefulness of the Concept

Recent theoretical developments have seen an evolution in economic terminology from the three categories of factors of production that economists originally distinguished: land, labour and capital. The concept of labour is gradually being replaced by the concept of "human capital" or know-how. Now, the concept of land (or, more generally, natural resources) is being replaced by the concept of "natural capital". To distinguish what was originally called "capital" from these two new forms, it is now qualified as "man-made capital".

These changes in terminology are interesting only insofar as they signify changes in understanding. One change in understanding is obvious from the new terms themselves: by indicating each factor of production as a form of capital, they are implicitly given equal standing. Natural capital and human capital are recognized as dynamically productive forces, of ecological productivity and creative productivity respectively.

The introduction of the concept of natural capital has also been the vehicle of a more profound shift in understanding of the sources of economic value contributing to human well-being. Natural capital contributes to well-being not only through market-oriented production of commodities, but also through household or "subsistence" production, and even more profoundly through "life-support systems". This idea suggests a way of broadening the narrow focus of modern economics so that it considers all the sources of well-being, and it also becomes more compatible with ecology.

The major problem with the concept of natural capital, which becomes apparent as soon as one tries to apply it, is its heterogeneity. Some of the dimensions of this heterogeneity have been well set out by Werner Kurz in his forestry case study for this Workshop. Among the criteria for evaluating ecological resources in natural capital, Kurz distinguishes: spatial criteria, temporal criteria, irreversibility, quantifiability and beneficiary.

To these criteria, I would add substitutibility, which is the central criterion around which the economic debate about sustainability turns. Arrayed in this debate, we have the optimists, for whom there are no practical limits to substitutibility, against the pessimists, who insist that there are theoretical limits, and also point to apparent practical limits.

An economics of sustainability must transform this evidently sterile theoretical debate into a domain of practical concern. Where we see limits, we cannot simply count on some new technology emerging of its own accord to save us from their binding force. Neither can we assume that all apparent limits, given current technology, are permanent limits that cannot be transcended: substitution has obviously been an important factor in economic history, and is likely to continue. An economics of sustainability must provide guidance in assessing the firmness or flexibility of limits, and in formulating prudent policies and actions which give due recognition to each and all of the limits that we face. In general, such prudence will require (with relative emphasis appropriate to each particular case): (1) better assessments of where the limits will begin to bind, and how soon, given our current economic path, (2) measures to slow our approach to these limits, and (3) research on substitutes to push back some limits, in order to buy time to ascertain and come to terms with the intractable limits.

The most critical issues of sustainability are those which involve both irreversibility and non-substitutibility. By this criterion, the irreversible depletion of a non-renewable resource, such as a mineral or a fossil fuel, is not among the most critical issues if there are reasonable prospects of a substitute for that resource. Now, however, we are discovering that the ecological limits to our extraction and use of non-renewable resources are not so much limits of supply, but limits on the amount of waste that can be dispersed in the environment before threatening life and life-support systems. In contrast, the depletion of a renewable, living resource is critical if if there are no substitutes for this resource and all of the ecological functions that it provides. This depletion becomes among the most critical of issues when a species is threatened with extinction, in which case we face both non-substitutibility and irreversibility.

In summary, the concept of natural capital could be a useful tool for environmental economics insofar as three sets of considerations are implicitly' recognized: (1) natural capital contributes to human well-being not only through market-oriented production, but also through household or subsistence production and the provision of safe habitation and life support systems (evaluation of the latter presents formidable challenges for conventional economics); (2) natural capital so conceived includes a broad range of ecological functions, which it will be difficult to distinquish and specify without some vast improvements in our ecological understanding; (3) natural capital is a category of heterogeneous, non-fungible economic entities, distinguishable by various economic criteria, among which some of the most relevant are: spatial criteria, temporal criteria, irreversibility, substitutibility, quantifiability and beneficiary.

Constant Natural Capital as a Condition of Sustainability

The arguments for considering constant natural capital stocks as a necessary condition for sustainability are well developed by Pearce et al. in their paper distributed for this Workshop. It is important to note that these authors do not equate constancy of natural capital with sustainability: they suggest that the former is a necessary, but not sufficient, condition for the latter.

Even so, I find some basic problems with using constancy of natural capital as a condiion for sustainability. The first problem is simply: why constancy? Pearce et al. acknowledge that some natural capital stocks are below the optimal levels, especially in some "developing countries", where resource degradation can be so extreme as to be immediately threatening to human life. This suggests that sound economic arguments can be advanced (even on the basis of conventional economics) for increasing some natural capital stocks.

There is a practical as well as a theoretical argument against aiming for constancy of natural capital stocks: it is essentially a defensive strategy of "environmental protection". With the pressures for depletion of natural capital stocks, a strategy aimed at constancy is likely to fall short. We must aim high enough so that, if we fall short, we maintain at least constancy of the most critical natural capital stocks.

This leads into a more general practical problem with constancy of natural capital as a standard of sustainability: if it is placed at the focus of attention, there is a danger that promoting sustainability will come to be seen merely as requiring policy intervention to maintain natural capital stocks, without understanding the economic processes that are responsible for depletion, and the countervailing economic forces that can help to arrest and reverse it. A policy based on the latter understanding would have to continually establish and reinforce the links between maintaining natural capital stocks and the well-being of actual persons. In general, it will also require going back to consider human capital and man-made capital, as well as natural capital, as factors contributing to economic activities and human well-being.

Consider, for example, the current problem of the cod fisheries in Atlantic Canada. In recent years, maintenance of the cod stocks has been based entirely on an interventionary policy of restricting fishing effort and catches. With the federal government taking on complete responsibility for managing the stocks, there was little room left for fishermen to exercise their responsibility in this regard. Indeed, the government enforcement efforts tended to breed resentment among fishermen, reinforcing their feeling that they were justified in trying to "beat the system" (e.g. by illicit fishing and misreporting of catches), and leading to open defiance and flouting of restrictions. At the same time as it was restricting fishing effort by regulations, the federal government was subsidizing investments in new fishing boats and gear (including sonar), expanding both the size of the fleet and its efficiency in tracking down and harvesting fish. While there were also other factors leading to the current fisheries crisis, these two misguided and contradictory policies would eventually have precipitated a crisis by themselves.

A policy for sustainability in the Atlantic fisheries must take into account man-made capital and human capital, as well as natural capital. The capacity of the fishing fleet must be reduced to allow for the restoration of stocks and harvesting a maximum sustainable yield of fish. Similarly, if the fisheries are to generate incomes of the same order of magnitude as the Canadian average, the human capital in the fisheries must change toward fewer, more efficient fishermen, while making it possible for the rest to find other occupations through support for retraining. Although the problems of sustainability in Canada's other natural resource industries may be less dramatic than those of the Atlantic fisheries, they are similar in many regards.

While there is not space here to explore further examples, suffice it to say that this suggests another kind of interpretation of environmental-economic sustainability. In this interpretation, sustainable development o'ccurs when there is stable, mutually reciprocal articulation of man-made capital, human capital and natural capital which increases the value of each. Problems of unsustainability arise when this system is thrown out of kilter by an exogenous or endogenous change (e.g. an advance in technology or another human or natural intervention). Such a change can disrupt the "fit" among existing forms of capital, rendering one or more kind obsolete, while possibly establishing a new potential capital base. Attempts to resist or ignore the obsolescence only exacerbate the problem. At the same time, the conventions that protect each form of capital and regulate distribution are often breached, or become inadequate. Then, the forms of natural capital that contribute directly to well-being can become especially vulnerable. Under this interpretation of sustainability, the role of policy is not simply to maintain constancy of natural capital stocks, but to guide and maintain <u>balance</u> in the use and transformation of each form of capital, to avoid underuse (i.e. unemployment), but at the same time to avoid overuse, especially of natural capital stocks.

This leads us to the final problem to be discussed here with regard to taking constancy of natural capital as an indicator of sustainability. This problem relates back to the previous ones, and points to the importance of the last of the economic criteria for characterizing natural capital: beneficiary. We have seen that there are severe limits on governments unaided to protect a natural capital stock. The alternative is to place much greater reliance on the beneficiaries of a natural capital stock to protect and conserve it. Governments can support this process by facilitating the organization of beneficiaries, and vesting and recognizing in them some forms of rights to protect their use of the stock. These considerations point to the need to go beyond mere economics to <u>political economy</u>; but then perhaps we should have been suspicious from the outset that there was no apparent political economy underlying the economics of constancy of natural capital stock. In practice, however, this is where the action is and must be.

We are seeing the limits of government not only in managing natural capital stocks, but also in redistributing income. Instead, the forms of equity which might accord with the new dispensation are those which can be made implicit in the definition of rights to the access and use of natural capital (if not of man-made capital and human capital, as well).

<u>Applications to Natural Capital Accounting and Management</u>

Again, there is not the space here to explore the implications of these considerations for natural capital accounting and management, but one initial suggestion follows. If natural capital management is to depend ultimately on the beneficiaries of natural capital stocks, it would make sense to have these beneficiaries (or the interest groups representing them) involved in the process of specifying the stocks of concern, refining appropriate measures and developing the accounting framework. This ensures that there is a constituency that is interested in, and activated by, the accounting results.

Some environmental functions are well represented by existing interest groups. The benefits of other environmental functions are so dispersed or universal, however, that they are represented by only the environmental movement in general, if at all. For all cases to some degree, and for some in particular, future generations are an important beneficiary group, who cannot be represented directly, but only indirectly. This state of affairs corresponds to our current human understanding, appreciation and evaluation of the ecosystem and ecosystem functions of which we are a part. The prospects for any kind of life that we would like to bequeath to future generations, if not human survival, will depend on rapid expansion of this understanding and appreciation, especially among those of us who have the most control over the global economy, and are consequently the greatest threat to the future. Our values must come to conform to the ecological necessity on which we depend. The concept of natural capital, as qualified here, can help in this.

Thoughts on Natural Capital

Colin W. Clark

Formulating an accounting system for natural capital seems to me to be an idea whose time has come. No successful businessman would operate his'business without careful accounting of his capital assets, yet in the business of survival we have woefully neglected the accounts. Natural capital is what life on earth depends upon.

I see four main problems that will have to be addressed in formulating a Natural Capital Accounting System: inventories, scale, evaluation, and uncertainty. These are all closely interrelated.

Inventories

The fist thing we will need is an inventory of inventories. Which natural resource assets are to be included in the accounting system? It is vital that nothing important be left out. We are all too aware of how easy it is for important matters to fall between the cracks when nobody is responsible for keeping track of them — think of toxic or military nuclear wastes, for esample. The following list can certainly be estended.

(1) *Living* Resources

Forests (commercial and noncommercial)

Fisheries (ditto)

Wildlife populations (not just "sport" species)

Habitats

— marshes, mudflats, estuaries, grasslands, prairies, deserts, old-growth forests, alpine meadows, ponds, etc.

Plant communities

Riverine communities

Agricultural soils

Grazing lands

Genetic resources

(2) ***Physical Resources***

Unpolluted groundwater

Rivers (including "wild" rivers)

Surface waters

Oceanic resources

Atmospheric resources

(3) **"Negative"** ***Assets***

Exotic species (i.e. introductions)

Pollution

Assessments of the quality of natural capital assets will be as important as estimates of quantity. Considerations of interactions between various assets will also be important. Likewise, assessment of trends will be important, including past history and current rates of increase or decrease.

Scale

It will be necessary to maintain inventories at several spatial scales, including local, regional, national, and global. The time scale for updating inventories also needs to be considered. Similarly, the scale of detail may differ for inventories having various purposes. Inventory databases might be constructed, from which summary inventories could be retrieved. The spatial and temporal scales of natural variability also need to be considered. For example, most fish populations undergo marked natural fluctuations, which need to be distinguished from the results of human exploitation.

Evaluation

Although economic evaluation of natural capital assets is obviously desirable, it must be realized that such evaluations are often tenuous at best, and frequently controversial. By definition the value of any capital asset is equal to the present value of the future benefits that it will yield. But many of these benefits may be hard to quantify. There may be multiple, perhaps conflicting uses for a given natural asset. Future options may be highly uncertain. Irreversible changes in assets have completely different implications than do reversible changes. Finally, the discount rate used in present-value computations strongly influences asset values, but interest rates are themselves wildly uncertain.

These limitations do not imply that natural asset evaluations should not be attempted-quite the reverse. But any evaluations must be assessed in terms of their inevitable limitations. For example, spotted owls have no known economic value. but the old-growth forests that they require surely do. How would one place a "value" on spotted owls? In British Columbia the government places zero value, but other jurisdictions take a different stance.

Uncertainty

One of the most difficult issues in resource management is how to deal with uncertainty. A major advantage to be obtained from an inventory system for Natural Capital would be the reduction of uncertainty as to what our current assets really are. Nevertheless a residue, often a significant residue, of uncertainty will usually remain regarding current inventory levels.

More to the point, uncertainty as to the implications of current management policies for future levels of natural capital will always be important. Examples are everywhere: How rapidly will greenhouse gases build up in the atmosphere? What are the implications for, and of global warming? How will atmospheric changes impact on Natural Capital assets? Or, to take a local example in time and space, could salmon populations in the Fraser River be enhanced by cutting back on present catch levels? (Some studies have projected a possible increase of several billions of dollars in catch values from such a program.) How long would it take to achieve the buildup? For that matter, how long would it take to tell whether the program was working as hoped for? The valuation of our salmon asset could be strongly influenced by such considerations.

The first requirement for addressing uncertainty is the recognition of its universality and importance. Scientists have often been guilty of conveying the impression that science can eliminate uncertainty — given adequate funding, of course. Science never eliminates uncertainty. But it can help to reduce the level of uncertainty, and to understand the options. It will be of utmost importance to assess uncertainties associated with inventories and evaluations of Natural Capital assets. (The case studies provided for this meeting were excellent in this regard.)