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ECOSYSTEM PROPERTIES AND PRINCIPLES OF LIVING SYSTEMS AS FOUNDATION FOR SUSTAINABLE AGRICULTURE

– Critical reviews of environmental assessment tools, key findings and questions from a course process

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Centrum för uthålligt lantbruk

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Ecosystem properties and principles of living systems as foundation for sustainable agriculture
– Critical reviews of environmental assessment tools, key findings and questions from a course process

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PREFACE

This document is the outcome of a Ph.D. course titled 'Systems Principles and Sustainability for Ecological Land Use', given during the spring term 2000 at the Swedish University of Agriculture Sciences as part of a Ph.D curriculum enacted by the Research School in Ecological Land Use (RESELU).

Lennart Salomonsson was the course organizer; Steven Doherty and Torbjörn Rydberg were course leaders.

Several Ph.D students participated in one or more of the course components and six of them contributed directly to the development of this report.

INTRODUCTION

With increasing demands on limited resources worldwide, there is a growing interest in sustainable patterns of utilisation and production. Ecological agriculture is a response to these concerns.

To assess progress and compliance, standard and comprehensive measures of resource requirements, impacts and agro-ecological health are needed. Assessment tools should also be rapid, standardized, user-friendly, meaningful to public policy and applicable to management. Fully considering these requirements confounds the development of integrated methods.

Currently, there are many methodologies for monitoring performance, each with its own foundations, assumptions, goals, and outcomes, dependent upon agency agenda or academic orientation. Clearly, a concept of sustainability must address biophysical, ecological, economic, and sociocultural foundations.

Assessment indicators and criteria, however, are generally limited, lacking integration, and at times in conflict with one another. A result is that certification criteria, indicators, and assessment methods are not based on a consistent, underlying conceptual framework and often lack a management focus.

Ecosystem properties and principles of living systems, including self-organisation, renewal, embeddedness, emergence and commensurate response provide foundation for sustainability assessments and may be appropriate focal points for critical thinking in an evaluation of current methods and standards. A systems framework may also help facilitate a comprehensive approach and promote a context for meaningful discourse.

Without holistic accounts, sustainable progress remains an ill-defined concept and an elusive goal.

Objectives

Our intent was to use systems ecology as a pedagogic basis for learning and discussion to:

- Articulate general and common characteristics of living systems.
- Identify principles, properties and patterns inherent in natural ecosystems.
- Use these findings as foci in a dialogue about attributes of sustainability to:
    a. develop a model for communicating scientific rationale.
    b. critically evaluate environmental assessment tools for application in land-use.
    c. propose appropriate criteria for a comprehensive assessment and expanded definition of ecological land use.

Course description

As part of a Ph.D. program within the Research School in Ecological Land-use at the Swedish University of Agricultural Sciences, a post-graduate course titled *Systems Principles and Sustainability Assessments for Ecological Land-use* (appendices, page 77)was held to investigate land-use within a framework of systems ecology principles in order to:

- Identify technologies and management actions that support and are scaled to renewable ecological functions and sustainable processes.
- Use this framework to critically evaluate environmental assessment tools for their utility in sustainability.

Here we used systems ecology as a basis for better understanding the dimensions of sustainable, ecological land-use and for critical evaluations of environmental assessment tools.

Participants worked together to form consensus on general principles and characteristics of sustainable systems, and then developed a set of questions to aid in the understanding of methods and their application as measures of sustainable progress.

Approach

Environmental assessment tools chosen for review included: life cycle analysis, cost-benefit analysis, positional analysis, ecological footprint, emergy analysis, and the index of biological integrity. These methods were chosen to represent the variety of approaches addressing biophysical, ecological, economic, and sociocultural foundations of sustainability.

Ecosystem properties and principles of living systems were assembled from lectures, course reading, individual and group processing. Discussions facilitated consensus and generated a 'checklist' of sustainability characteristics that formed a first draft of a conceptual framework.

A questionnaire was next produced based on the framework that was used to organise the review of environmental assessment tools.

Lectures from method experts and additional readings specific to each method introduced participants to the various approaches available for research and performance monitoring. Morning lectures were followed by student processing and group discussions with the invited speakers. Questions were answered by course participants and facilitated by practitioners. The questionnaires were used to organize further in-depth reviews of the environmental assessment tools.

Each participant was assigned principal responsibility for one method and assistant to a second. Progress and summaries were presented to the group and method reviews were drafted.

The challenge was to apply the systems framework as a filter or lens for review of the assessment tools. Methods are generally presented and understood within a context of their own conceptual base.

Here, we asked the participants to comprehend and interpret the methods from the perspective of living systems principles and organizing properties of ecosystems. While we were able to draw consensus on important characteristics of and indicators for sustainable systems and on strategies for sustainable progress, application of the framework in critical reviews of environmental assessment tools was more challenging. Through continued discussions and revisions of our consensus document an aggregated model and more coherent conceptual framework was produced that furthered enabled a critical and comparative review of current methods.

This document represents our initial efforts to organize information processed during course. We report on initial efforts in our investigation of agriculture within a framework of ecological properties and principles of living systems to begin identifying assessment methods, criteria and standards that promote and coordinate actions scaled to renewable ecological functions and sustainable processes. A simple model is developed and a framework is presented to articulate the nested nature of living systems and our corresponding responsibilities and opportunities in ecological land-use. Although preliminary, a systems framework may help facilitate a comprehensive approach and promote a context for meaningful discourse. As such, it is a talking paper, a starting point for dialogue, and is open for review and comment.

LIVING SYSTEMS PRINCIPLES, ECOSYSTEM PROPERTIES

Sustainable agriculture and agro-ecosystem health

A common approach in the discourse of sustainability has been to create consensus on vague definitions rather than disagreements over sharply defined ones (Mebratu 1998).

A general definition of sustainable agriculture is 'the ability to maintain production over long time frames despite major ecological and socio-economic perturbations and stress' (Conway 1985, Altieri 1987). This requires an aspect of resilience, but because production is narrowly focused on crop yield, ecosystem services and health are not recognized as necessary or contributory, nor is attention given to constraints or indirect effects. And while definitions of sustainable agriculture are numerous, they narrowly define production (Altieri 1987), ignore biophysical limits (Abelson 1990), prioritise economic profit (Ehrenfield 1986), do not consider health (Crews et al 1991), are conflated by inclusion of poorly defined concepts (Lehman et al 1993), are not process oriented and do not recognise cross-scale relations (Peterson et al 1998). These limitations confound the development of identifiable goals (Fricker 1998) and reduce the utility and operationalisation of the concept.

Although applications of principles and patterns from nature in agriculture are well recognized (Odum 1983, Soule and Piper 1992, Jansson and Jansson 1994, Vandermeer 1995) and farming prescriptions are proffered (Altieri 1999, Shapiro and Harrisson 1999), ecosystem properties are not implicitly built into a coherent framework of agroecosystem sustainability (Jorgensen and Nielsen 1996) or health (Okey 1996). In fact, health and sustainability are inextricably related (Waltner-Toews 1996) such that ecological sustainability is proposed as meeting human needs without compromising the health of ecosystems (Callicott and Mumford 1997).

Ecological engineering solutions aim to minimally manipulate and manage ecosystems for the benefit of both nature and humanity (Mitch and Jorgensen 1989) and recognize that humanity exists on the premises of nature (Odum 1989).

Karr and Chu (1999) propose two criteria to set thresholds for land-use that require ecological health and acknowledge scale, with attention given to external and indirect effects:

- Human actions should not alter the long-term ability of places (ecosystems) to sustain the supply of goods and services those places provide.
- Resource use should not degrade off-site areas.

While the synonym (Suter 1993) and utility (Wicklum and Davies 1995) of agroecosystem health and sustainability are debated, the rise of systems theory in the discourse acknowledges the inherent complexity and dynamics of living systems (Ludwig et al 1997), that they are not adequately described in static categorical terms (Kay et al 2000).

Concepts of health and sustainability are inextricably related and in fact could be viewed synonymously. Consider their descriptions:

'*Sustainability*…is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological developments, and the institutional changes are made consistent with the future as well as present needs.' (Brundtland 1987)

'*Health* …is the extent to which an individual or group is able, on the one hand, to realise aspirations and satisfy needs and, on the other hand, to change or cope with the environment… Health is therefore seen as a resource for everyday life, not as an objective of living; it is a positive concept emphasising social and personal resource, as well as physical capacity.' (World Health Organization, 1992)

There are numerous definitions and descriptions for each, and there is a substantial and growing discourse on the concepts. Although sustainability and health concepts have detractors, much of the concern lies in the lack of coherent conceptual frameworks.

Common to both health and sustainability are the focus on human conditions and values, an emphasis on process and change, and prescriptions for present as well as future context. Less implicit is recognition of context and place, of production limits and potentials, of ecological condition, of flexibility, and of cross-scale and coupled interactions.

Living systems characteristics provide foundation for these constructs. Recognition of, adherence to and management toward living system principles and ecosystem properties are indicators of sustainable progress and system health.

Description of living systems

Characteristics of living systems (table 1) are embedded within and complimentary to one another. Common to all living systems are the development of storage and structure through transformations of available energy and circulation of materials, resulting in nested networks with commensurate and reinforcing feedbacks (i.e., complex adaptive systems).

Biological systems nested in ecosystems are living systems fit to renewable but flow-limited resources and are thus of proven sustainability.

Living systems are thermodynamically open but organizationally closed. They organize cyclically to external resource oscillations and internal design constraints, but retain characteristics necessary for self-renewal and adaptation. Living systems exhibit coherent behavior and have propensity to maintain development trajectories within local limits.

Table 1. Characteristics of living systems.

Characteristic	Description
Thermodynamically open	Living systems are open to inflows (and releases) of energy and material, and therefore exchanges with other biotic and non-living systems comprising their environmental context.
Far from equilibrium	Living systems are highly ordered in non-equilibrium states whose structural organization requires available energy supplied above environmental backgro-und gradients.
Dissipative networks	Living systems dissipate energy as byproducts of irreversible processes involving energy transformations that build and maintain structure.
Autocatalytic	Living systems build structures that reinforce energy capture, transformation, material cycling and storage.
Self-organizing	Living systems exhibit coherent behavior and generate common designs for maintenance and coupling of resource flows. These configurations are manifested across scales with reciprocal power relationships within and between component systems.
Hierarchical	Living system designs and environmental context are tiered with declining available energy, numbers of individuals, and biomass with increasing resource transformation, resulting in a convergence of resources and specialization of actions and commensurate roles.
Complex	Living systems generate component and functional richness for energy capture, maintenance, process distribution and as insurance against perturbations and uncertainty.
Self-maintaining	Living systems invest a proportion of gross production into maintenance and repair of complex structure and design.
Self-renewing	Living systems have an innate capacity to reproduce themselves in a continuous process of renewal.
Adaptive	Living systems are sufficiently robust for homeostasis and maintenance of development trajectories (resilience) but responsive to changing environmental conditions. LS are innately transcendental, creatively overcoming limits.
Nested	Living systems are intimately intertwined with and embedded within other li-ving systems; they are inseparable and interdependent. Categorization is a hu-man construct.
Oscillatory	Living systems pulse simultaneously at all space-time scales, responding to external resource oscillations and internal design constraints.
Emergent	Living system properties emerge from nested intra- and inter-actions where dependencies are mutually re-enforcing, generating multiple outcomes.
Process oriented	Living systems generate designs and maintain structure as agents of transfor-mation processes not as end products themselves.
Multi-functional	Living systems never direct gross production into single products. Instead production is allocated to diverse structure supporting nested processes.
Contextual	Living system designs, responses and descriptions are place-based, organized to external sources, local limits and internal designs, and fit to other nested systems.

Gross production in natural systems is scaled to the availability of local sources, pulsed in response to periodicity of external factors. It is also allocated to multiple nested functions and utilitarian structures. A diverse range of services and related byproducts are generated through self-organizing processes that contribute and reinforce production and that are responsive to context and shifts in external factors. Diversity generates buffers to regular and anticipated perturbations and provides resilience in chance events.

Pulsing is a common pattern in living systems, responding to periodicity of local sources and internal rhythms, and shifting strategies during stages of a resource cycle (e.g., ecosystem succession); cooperative associations, for example, increase as resources become limiting, and biogeochemical cycles are tightened, restricting loss of nutrients.

A hierarchical view identifies relationships between time, area, energy and information. Processes have characteristic time scales; components have characteristic spatial scales. While some tradeoffs/ substitutions are possible, system development in the long-term abides thermodynamic laws.

Characteristics of natural and managed agroecosystems

Natural ecosystems, whose components and processes are designed through natural selection and are scaled to renewable resources are of proven sustainability, and are therefore appropriate models for sustainable agriculture.

A comparison of natural and managed agroecosystems articulates differences and identifies commonalities for new designs and management alternatives in agriculture (figure 1). Sustainable, long-run natural ecosystems often exhibit greater gross production than managed agroecosystems, yet generally have smaller net yields of target products because more of their production is re-invested to design and maintain diverse structure and co-operative pathways. This promotes important properties for sustainable production, including aspects of autonomy, self-sufficiency, homeostasis, nutrient retention and resilience.

Ecosystems never direct resources into single products, rather nested designs are generated which support multiple services all of which are integral to agroecosystem function and many of which are delivered for human purposes with minimal or no investments from the economy.

The aim of agriculture has traditionally been to direct resources into target products of nutritional and economic importance. Subsidies in the form of fossil fuels, irrigation, pest management, direct planting and genetic engineering transform more of the managed gross production into extractable biomass producing greater yields per unit time but little 'net' contribution is delivered after accounting for investments.

Additionally, agroecosystem integrity is compromised by reducing local biodiversity, disembedding nested functions, and generating both local and indirect environmental loads. The renewal capacity of agroecosystems is diminished and requires increased engineering solutions and expensive remediation, drawing resources away from other sectors.

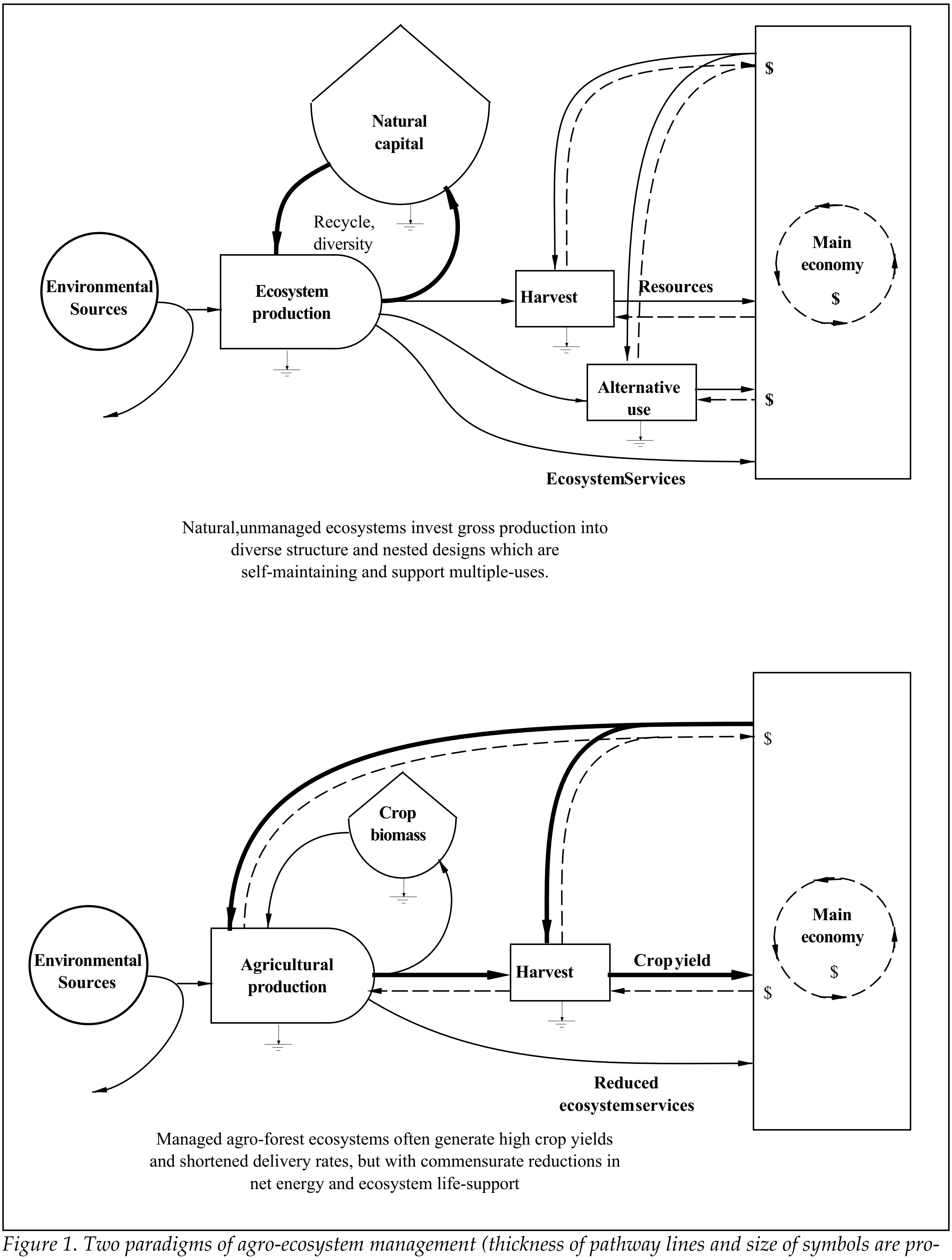


Figure 1. Two paradigms of agro-ecosystem management (thickness of pathway lines and size of symbols are proportional to production rates and quantities stored).

A conclusion is that efficiency is greater in natural ecosystems although turnover times and thus rates of delivery are slower and scaled to periodicity of local renewable resources.

Because agricultural production is narrowly focused on crop yield, ecosystem services and health are not recognized as necessary or contributory, nor is attention given to constraints or indirect effects. If non-market ecological services are considered in agroecosystem production, net benefits may be greater than single product revenue alone, agriculture is recognized as stewardship and agroecosystem health is promoted.

Mimicking structure and function of local ecosystems in the design and management of agriculture promotes sustainable production scaled to local conditions.

Sustainability characteristics as a base for a conceptual framework

The following list, on characteristics of sustainable systems, was drawn from lectures, course readings, individual and group processing. The task for participants was to come to consensus on important ecosystem properties and general characteristics of living systems that are meaningful to sustainability, and which should be addressed by environmental assessment tools that are used to indicate sustainability and impact of land-use and human actions in general.

- they are fit to available, flow-limited renewable energy
- living systems organize cyclically, responding to external resource oscillations and internal design constraints.
- pulsing systems appear to be more resilient and may maximise power
- there is a recycle of mineral, metals, nutrients
- both processes and components are organized and optimized (i.e., ecosystem functions and biodiversity)
- homeostasis is an emergent property of nested, hierarchical systems, and tends to increase with organizational scale.
- living systems design resilience (not necessarily stability)
- feedbacks are integral to performance (commensurate reinforcements; production amplifier actions)
- they develop interrelations of co-operation – mutual and symbiotic relations
- connectivity within and between systems
- components and processes are nested
- they develop hierarchies of energy transformations
- they self-design according to biophysical limits
- investment management is a strategy – not exploitation
- gross production is allocated to networks (ecosystems never direct resources into single products)
- net production is used for storage and exchange

- maintenance increases as the square of the structure/complexity – as systems become larger and/or more complex more of the available energy is required for maintenance
- mutualism increases as resources become limiting
- maximum power – designs that tend to prevail in open, self-organizing systems are those that maximise available (and useful) power.

Strategies for sustainable land-use

This list, also generated as part of course processing, describes strategies for sustainability that recognize and promote the characteristics of sustainable living systems.

- Emphasis on management and assessment tools without well-defined goals may be counterproductive.
- Participatory – direct, local and emotional.
- Ecosystem trust – acknowledge and support ecological functions
- Technological pragmatism – fully utilise *appropriate* technology
- Solutions are likely to emerge from deep seated will, not from better technology; technology has not replaced (and can not replace) biodiversity or essential life-support services.
- Stewardship (definition: individual responsibility to manage life and property with appropriate regard for the rights of others).
- Three levels of responsibility: sustainable systems start with individual health (self-maintenance), but must also provide reinforcement to the next smaller system (next generation, soil amenities, etc) as well as contribute to the next larger system (community participation, ecosystem integrity, etc). (figure 2)
- Advance planning, using holistic system assessments and predictive modelling, enables communities to proactively manage for context.
- Anticipating and preventing problems is preferred over reactive remediation.

General foundations for successful, sustainable agriculture (developed from Ewel 1999):

- Mimic as closely as possible the structure and function of local ecosystems.
- Scale production to local renewable resources and natural pulses.
- Accept biophysical limits to production and recognize and support indirect ecosystem services.
- Channel productivity into outputs of nutritional and economic importance.
- Broadly define production and efficiency to include all contributory aspects of living systems.
- Maintain biodiversity to be able to compensate for losses while still keeping the system simple enough to manage.
- Manage plants and animals to facilitate *associational resilience*, not *associational susceptibility*.

- Use perennial plants whenever possible to maintain soil fertility, guard against erosion.

Other considerations for sustainable land-use

- Context specific; place-based management (scale, stage of resource cycle).
- Use of non-renewable energy sources targeted for investments, storages – not to maintain pace (growth rate).
- Focus should be on processes.
- There's no right answer (therefore must pay attention to definitions, scale, goals) still keeping the system simple enough to manage.
- Ecosystem health, energy demands, biophysical limits, direct design and planning followed by social, economic considerations.
- Concentration of compounds and by-products not harmful to ecosystem.
- Economic values should reflect ecological realities.
- Land demand for primary production fit to renewal capacity.
- Functional diversity establishing resilience and applies to market enterprises as well as ecosystem services.
- Manage for wholes, not parts – individual production targets, ecosystem services are nested within diverse and tightly coupled networks.
- Adaptive holistic management – monitoring performance and adjusting actions according to changing conditions (it may be arrogant and even irresponsible to predetermine BMPs – best management practices – especially prescriptions developed out of context).
- Assessment and management tools require scientific foundations, firmly placed within ecological and biophysical realities.
- Flexible – plans, goals allow for chance events, uncertainty, risk.
- Socially just, equitable, humane.
- Local and on-farm labour; community involvement promotes local knowledge and empowerment. Build trust in institutions.
- Encourage new foundations for renewal that build and sustain the capacity of people, economies and nature for adapting to context and change.
- Adaptable landscapes – native, natural ecosystems are necessary for sustainable land-use; long-term sustainability of land-use is nested within adaptable landscapes.
- Diversity contributes to buffering capacities.

Vision

Build bridges between 'opposing' camps by identifying linkages (interdependencies and mutualisms) and long-term planning – seventh generation in mind.

PROPOSED SYSTEMS FRAMEWORK

Natural ecosystems, whose components and processes are designed through natural selection and are scaled to renewable resources are of proven sustainability, and are therefore appropriate models to design sustainable agro-forest systems. Systems ecology provides a basis for exploration of organizing principles and common properties characteristic of living systems. A formulation of these provides a general, open and flexible framework for assessments of sustainable land-use. As a starting point, we recognize that agriculture, land-use, and actions in general are context specific. They are also hierarchical, scale dependent and influenced by external factors as well as internal designs.

From this, we build a simple model, a metaphor, to serve as a framework and building block for articulating concepts of ecological sustainability (figure 2). From the point of view of any systems level, local direct self-interaction (1) as well as cross-scale interactions at levels both smaller (2) and larger (3) operate simultaneously in reinforcing capacities (figure 2). We use this recognition of scale to generate a framework for sustainable land-use, identifying three scales of responsibility:

1. To one self (individual health).
2. To the production base (agro-ecosystem health).
3. To the institutions and community (socio-cultural health).

Other general features of complex adaptive systems are presented in figure 2. External environmental sources are shown at the left, as independent and renewable but flow-limited. Thermodynamic constraints are shown as heat sinks, identifying entropy generated from energy and material transformations at each system level. Feedbacks reinforce lower system level processes, generating autocatalytic and self-organizing designs at multiple levels simultaneously.

A result is a nested, coupled and hierarchical system organized around the availability of external sources and self-influenced by internal design.

Finally in the example given, monetary exchanges are identified only between system levels ordered by human actions and flowing in opposition to resource flows.

We then aggregate characteristics of humanly inhabited systems into three primary foci for consideration of sustainability:

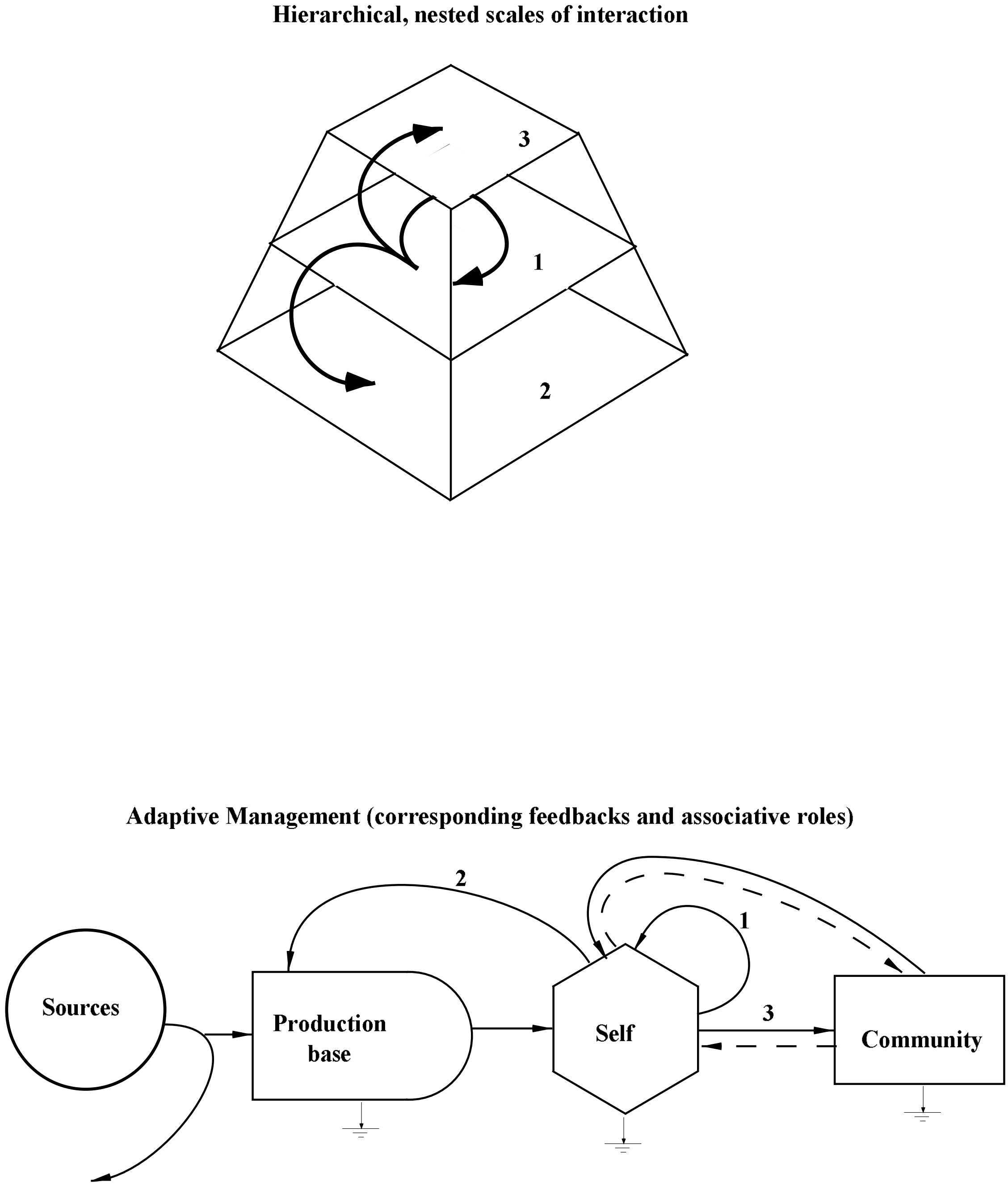
1. Biophysical limits and potentials
2. Agro-ecological health
3. Socio-cultural fit

These focal areas are prioritized into a proposed divergence framework starting first with consideration of organizing principles, biophysical limits and ecosystem health followed by co-ordination and planning necessary to meet community 'desirable' goals (social, economic and cultural).

This is not seen as an exclusion or diminishing of human considerations, rather an acknowledgement that socio-economic and cultural institutions are adaptive and can better fit to ecological designs, limits and potentials than engineering the environment to fit to our actions. Prioritising biophysical and ecological dimensions first is thus considered an empowerment tool and an optimistic challenge to our collective planning, decision and management efforts. This ordering of strategies toward sustainable futures also recognizes the environmental costs of human engineering and presents a new paradigm for the human intellect to trust in ecological functions as proven and fit technology.

Here, we present ecosystem properties as fundamental designs for sustainability. A framework of living systems principles is used to organize content and direct discussions in issues of equity, fairness, security and health. Adaptive strategies to achieve such goals include resilience, commensurability and self-reliance. Two important considerations are context and process (Naveh 1998). Living systems are responsive to and embedded within local context, they are intimately and inextricably nested to one another, and capital stores are viewed as agents and outcomes of transformation processes and not end products themselves.

Like learning, for living systems the journey is the destination. Adaptive management encourages new foundations for renewal (Holling 1978) and learning (Jiggins and Rölling 1999) that build and sustain the capacity of people, economies and nature to adapt to context and change. Fair trade, environmental justice, social responsibility and human rights are all treated and benefit from these perspectives. From this we view empowerment and trust as local phenomenon and the adage that small is beautiful is translated into place-based management where institutions and individuals are tightly bound. These perspectives generate new worldviews, critical thinking, reflection, and challenging discourse.



Commensurate responsibilities:

1) to one self
2) to the life-support base
3) to institutions and community

Figure 2. A proposed heuristic model for ecological land-use.

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REVIEW OF ENVIRONMENTAL ASSESSMENT TOOLS

LIFE CYCLE ASSESMENT

Life-cycle assessment (LCA) studies the environmental aspects and potential impacts of a product (this could be "material" products or services) throughout its life, from raw material acquisition through production, use and disposal (i.e. from cradle-to-grave) (ISO 1997).

LCA was developed for industrial products, and aims for describing resource use, ecological considerations and impact on human health. The method is not new, but the interest has increased dramatically since 1990 (Finnveden 1998). A few years later the method was applied also on agricultural products. The European commission arranged a concerted action for agricultural applications 1997 (Audsley et al 1997).

In LCA methodology, environmental impacts are classified into different impact categories. There must be a clear distinction between each category to avoid double counting. Only loss of biodiversity due reasons other than those impact categories already included (e.g. loss of biodiversity by physical disturbance is included under Impact on Biodiversity, but not losses due to pesticides, if these are accounted for under Ecotoxicological Effects).

A practical help when performing LCAs is the "Nordic Guidelines on Life-Cycle Assessment", (Lindfors et al, 1995). It recommends in the inventory phase to study the following impact categories:

- Resource use
  - Energy (renewable and non-renewable)
  - Materials (renewable and non-renewable)
  - Water
  - Land (including wetlands)
- Human health
  - Toxicological impacts
  - Non-toxicological impacts
  - Impacts in work environment
- Global warming
- Depletion of stratospheric ozone
- Acidification
- Eutrophication (and oxygen demand)
- Photo-oxidant formation
- Ecotoxicological impacts
- Habitat alteration and impacts on biological diversity

Although the ambitions of this kind of standardisation guidelines are high, real LCAs seldom include all of these aspects. The most common reason for this is lack of data.

The impact category Land use is traditionally used to describe how large area (in m^2) that is occupied by an activity. Heijungs et al (1992) suggests that the time frame also should be included (m^2, yr.), for extremely long term space use, "final space use" is used. There is furthermore a qualitative aspect of land use, expressed as different degrees of "physical damage to ecosystems": Changes from the first three to the last two are regarded as final space use.

- Natural systems
- Modified systems
- Cultivated systems
- Built systems
- Degraded systems

LCA methodology for land-use

LCA methodology for Land use give rise to a number of questions, and in order to get a common view how to treat various methodological issues a concerted action was made within the European commission, resulting in the report Harmonisation of Environmental Life Cycle Assessment for Agriculture (Audsley et al 1997).

One example of issues discussed are system boundaries. Contributions to an impact category are accounted for when a substance is leaving the technical system and entering the natural system (i.e. entering the "grave"), e.g. CO_2 emissions from a tractor or nitrate leaching from a soil.

In the report mentioned above the system boundary between the technical and natural systems on an agricultural field is considered to have both a spatial and a temporal dimension. The soil stays within the technical system down to the depth of the water table during the time period studied. After that time, effects on soil quality are included in the impact assessment.

Examples

By comparison with LCAs performed on industrial products, LCAs on agricultural products and forestry have expanded and focused more on the effect category Land use.

Agriculture

In the report by Blix and Mattson (1998), three alternative crops for production of vegetable oil have been studied.
The three crops were studied in relation to two goals:

- To preserve or possibly enhance the fertility of the soil in order to secure future biological production.
- To preserve and support a landscape with biological diversity, viable ecosystems and high aesthetic values.

In order to evaluate the goals, the effects of Land Use were studied in terms of:

- Erosion
- Hydrology
- Soil organic matter
- Soil structure
- Nutrient balance
- Soil pH
- Heavy metals
- Use of plant protection chemicals
- Biodiversity
- Landscape aesthetic value

The first eight aspects were studied in a quantitative way. Biodiversity and Landscape aesthetic value were considered in a qualitative way. In both the soybean and palm tree case natural forests are cleared to give space to the crops, whereas the rape is grown on already established fields.

The rape seed patches are much smaller and are themselves adding to the variability of the landscape otherwise dominated by wheat. Therefore the rape seed production scored better on both Biodiversity and Landscape aesthetic value.

Some of the above aspects of Land use could be included in other impact categories, (e.g. Heavy metals and Use of pesticides can be considered under the category Ecotoxicological impacts or Human health) or are already an impact category of its own (Biological diversity).

In the study by Stadig (1997), a separate impact category "Environmental impact from pesticide use" subdivided into effects on aquatic, terrestrial and humane systems, was added. The other effects of the list above were not included. Furthermore the impact categories Resources – Land and Impact on biological diversity from the standardized "Nordic guideline list" were left out.

In the paper of Cederberg and Mattsson (1999), the impact category Land use is only studied as used area (m^2/functional unit (kg milk)), divided into two classes: Area for production of Roughage and grain, and Area for production of Concentrate feed. Other impact categories considered in that study are:

- Energy use (primary) from different sources.
- Use of materials (machinery is excluded), mainly due to energy and fertiliser consumption.
- Use of land (m^2)
- Human health as amount of used pesticides (gram fungicide/ herbicide/insecticide per functional unit).
- Global warming potential
- Emission of acidifying gases
- Eutrophicating emissions
- Photo-oxidant formation
- Ozone depletion

Sustainability

LCA can be used as a tool to compare the potential sustainability of different systems, but only according to the definition in the goal and scope section in the study of current interest.

Drawing conclusions from an LCA study involves making a valuation of which environmental impacts that are the most important. If system A scores better on all points than system B, system A is probably more (biophysical) sustainable. The problem arises when A is better at some points and B at some other. No human can so far tell which system is more sustainable when different environmental aspects are set up against each other. Attempts to go around this problem are suggested in the LCA methodology, by using standardized normalisation and valuation methods (Lindfors et al 1995).

Beside the problem of comparing environmental impacts against each other, is the question if there are any important impact categories missing. If so, a true answer would still be impossible to present even if everyone agrees on the valuation method. If system A scores better on all measured points, B can still be better on some other impact categories that so far is missing from the method.

What other impact categories should be considered to make LCA a better environmental assessment tool? What is missing in the impact category Land use? This is a key research area.

The impact category "Habitat alteration and impacts on biological diversity", has in the examples above recorded differences in biological diversity between the site before and after the land use, (soybean and palmtrees instead of rainforest, and rape seed instead of wheat) the difference in biological diversity is a result of the land use.

Is it important to include ecological effects of this change in biodiversity on the surrounding ecosystem? Is there a need for a measurement of ecological health, to complement the species count approach? Would it be fruitful to complement an LCA with a measurement of Index of Biological Integrity (IBI)? In that case IBI should also be done on all other sites that are affected by the production (how do we know these areas?). Also we don't know if the changes in IBI in our area is related to production on site, or if it originates from transported emissions.

What is the reference point when comparing biological diversity? Should Land use: add more biological diversity than what is removed from a site, have the same biological diversity as a similar natural landscape or have more biological diversity than monocultures?

Systems principles

The discussion of systems principles can act as a tool to find aspects of sustainability that so far has been neglected in the LCA methodology. What systems principles are relevant to consider when assessing sustainability? Which of these principles are already accounted for in the normal set of impact categories? Which are missing?

The interaction between land use and systems principles may occur in both directions why two questions must be addressed:

1. How do land use affect systems principles?
2. How do systems principles affect land use?

In an LCA perspective the first question (1) should be treated as an impact category (or part of an impact category). There is a need to define what systems principle we want to study (Goal Definition and Scoping), through what mechanism/-s land use influence this principle (Classification), and how much each mechanism contribute to changes of the principle (Characterisation).

The second question (2) can only be considered indirectly – if we can learn how the systems principles act on land use, we may take that into consideration and thereby get a more efficient resource use, resulting in an LCA with better scores.

Many of the systems principles are connected to the presence of biodiversity. Do we want to study the biodiversity within the technical system (diversity of crops, weed population, soil microbiota, habitat for wildlife, removal of natural species when establishing the crop plantation) or effects of land use on biodiversity in the surrounding environment (through emissions and physical or ecological effects)? Maybe there is a need to include both aspects and to subdivide the impact category biodiversity into two classes: effects on internal and external biodiversity, respectively.

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COST BENEFIT ANALYSIS

Cost Benefit Analysis (CBA) is an economic analysis method, based on neo-classical economics.

The basis of a CBA is a serie of cash flows. Even such things as resource use and impact on the environment are converted into monetary flows.

The unit of measure is normally the currency of the country where the study was made or some globally recognized currency i.e. USD. This unit of measure is so established in today's society that it is very easy both to communicate the results and to compare the results with results from other methods.

The foundation that CBA is built on is from the early and mid-nineteenth century, but it was not until the 1930s in the United States that CBA became an operational analyze method (Price 1997). It was developed in order to help the federal government decide whether to undertake some large projects. Since then there has been a development of the model, especially during the 1970s (Perkins 1994).

CBA is an aid to help choosing among alternative courses of action.

The objective of conventional CBA is to select the alternative that best raises the growth rate of the nation (Niskanen 1998). It is very common to do nation-wide CBAs, but a CBA can be performed over all different scales. It is however always done out of a human perspective, i.e. resources are valued according to how much they are worth to humans.

Whether or not to include environmental values have varied and still they are not always included.

In Drake (1993) different ways of valuing environmental variables, i.e. the conversion of environmental values into money terms, are described. The valuing can be done using, by the market already established monetary values, for example if production possibilities are affected then the former producer profit could be used as a cost estimate, or values could be set by political decisions, for example taxes. There are however, many situations were these are not practically applicable then a related market could be used, to indirectly estimate preferences for a specific environmental good. The amount is then set either by the cost to travel to specific sites (travel costs (TC) studies) or by the prices paid to live in specific neighbourhoods (hedonic pricing (HP) studies). In some cases neither the market nor a related market can be used, then a market could be simulated using a social survey called contingent valuation.

The contingent valuation (CV) method uses peoples self-reports of willingness to pay (WTP) or willingness to accept (WTA) compensation in hypothetical situations (Drake 1993). One advantage with the CV method is that both use values and non-use values can be included in this method, all depending on how the WTP questions are formulated (Spash 1997) (Drake 1993).

There is critique against the CV method, as it is very difficult to decide a monetary value on most environmental objects, and all value judgements can of course be questioned, but it has not been shown that the method does not normally give reliable results (Drake 1993).

CBA and land-use examples

When a CBA is done on a specific land-use project, there is first a need to identify the environmental effects, value them according to how big they are and decide on which ones to include. Then starts the process of trying to put monetary values to the environmental impact.

Below agriculture and forestry are discussed, in the forms of which impacts that are generally included, and how the valuation is done.

Agriculture

The major environmental effects of agriculture that normally are considered are the following (Drake 1993):

- Landscape
- Biological variety
- Environmental pollution
  - Nitrogen
  - Phosphorus
  - Cadmium
  - Pesticides
  - Fossil fuels
  - Methane
- Soil erosion
- Odour problems
- Noise from agriculture

Of these environmental impact the biological diversity, nitrogen leaching (mainly its eutrophic effect) and climate change are considered to be the most serious environmental problems emanating from agriculture (Drake 1993).

The methods used for estimating values of these impacts are described below.

Landscape

When valuing the agricultural landscape CV techniques are used. The value of the landscape will depend on what aspect we consider, is it scenic beauty, biological variability, cultural history or recreation (Drake 1993). Especially when considering the biological diversity it is important to realise that existence value is a form of non-use values. 'A person can value the mere existence of a species without being interested in consuming it, or of seeing it, or value a specific site without visiting it' (Drake 1993).

Eutrophication

For calculations of the eutrophicating effects from nitrate leaching several techniques can be used: producers' surplus for fish industry, alternative costs in sewage treatment plants and technologies for reduction of nitrogen can be calculated, but a CV on for example sport fishing could also be done.

Climate change

Here mainly Swedish political decisions or American cost estimates are used. It is important that only political decisions explicitly connected to the environmental effects in question are accepted (Drake 1993).

Example of how a CBA can be done for an agricultural system

Lundström (1997) studied the conversion of conventional to organic milk production, and how that would influence the milk price, when both economic and environmental factors were included. It is important to note that it is the conversion that is studied and therefore the original alternative (conventional) is compared to the new alternative (organic). When summarising all the gains and losses a social benefit of 57 öre (1 öre = 0.01 SEK) per kg milk, was calculated (Lundström 1997).

The social benefit is calculated by taking the economic value and either add or subtract the values of the environmental impacts according to if they are regarded as benefits or losses.

The values of the environmental variables have been taken from studies using different techniques such as damage cost, restoration cost, taxes and subsidies etc.

The most important environmental impacts included in this study are shown in table 2.

Table 2. The most imortant environmental impacts included in the study made by Lundström (1997) on the conversion from conventional to organic milk production.

Benefits		Losses	
+	Increasing landscape values	-	Longer transports to and from dairy
+	Increased sequestering of C in soil and plants	-	Increased eutrophication
+	Reduced emissions due to reduced use of fertilisers	-	Increasing emissions due to more tractor hours
+	Reduced emissions due to fodder production	-	Increasing methane gas emi-ssions
+	Reduced emissions due to reduced transport of fodder and fertilisers		
+	Reduced N_2O due to reduced use of N-fertilisers		
+	Reduced alternative costs due to non-depletion of P and K		
+	Reduced use of pesticides		
+	Reduced emissions of cadmium		

This study shows that the value of the organic milk is higher compared to the conventional, when both economic and environmental factors are included (Lundström 1997).

This type of study will always include many uncertainties. The result will mainly show that there is a difference between the alternatives and not the exact value of this difference (Lundström 1997).

Other agricultural examples are presented in Nelson and Cramb (1998) and Guevara, Estevez and Stasi (1999).

Forestry

Price (1997) identified three categories of environmental impacts that normally are considered when looking at forestry. These are: impact on the environment (mostly the CO_2), forestry impacts on recreation and biodiversity.

Other forestry examples are presented in Niskanen (1998) and Palmer, Newton, Doyle, Thomson, and Stewart (1998).

Impact on the environment – CO_2

There are many methods to provide CO_2 fluxes with a monetary value, two examples are costs of using lower-carbon fuels and proposed carbon tax.

Impact on recreation

When forestry impact on recreation is valued it is most common to use the CV method, but studies have been done with both the travel cost (TC) method and the hedonic pricing (HP) method.

The TC method can easily be used wrongly (Price 1997), for example by using 'the greatest distance travelled by visitors to a particular facility rather than the distribution of willingness to travel a range of distances', so the person using the study has to be aware of what it is that has been calculated.

The HC method also has problems, for example 'woodland views reduce house prices, but the presence of 20 % woodland cover in the locality increases them' (Price 1997).

Biodiversity

When it comes to assessing the impacts of forestry on biodiversity the CV methods is used.

With direct questions a TC value can be decided for wildlife and other attributes of visits to forests.

Far more problematic are the so-called passive use values gained from the mere knowledge that habitats or species exist (Price 1997).

Sustainability

'As a rule, economic viability is also related to the sustainability of the natural productivity of soils and other natural resources on which economic production partially depends, so economic indicators depend in part on non-economic factors, and a holistic approach is needed' (Tisdella 1996).

It can be problematic to define concepts such as as sustainable land-use, so that they can become meaningful objectives that can be used in a CBA. There may also be conflicts in the pursuit of the objectives. Added to this is the difficulty to set monetary values; it is very difficult to say how accurate CBA is in its measurement of sustainability.

’A CBA can be used to compare the economic returns over time from alternative farming methods, but it is comparing two or more farming methods at a specific moment in time, over discrete periods of time. On its own, therefore, it does not provide the means for identifying soil use over time’ (Nelson and Cramb 1998).

It must not be forgotten that CBA is an economic method and the most straightforward objective is the optimisation of the level of GNP per capita, but there is often at least an attempt to include the value of the environmental damage.

Systems principles

A CBA is always done out of a human perspective so the systems principles are largely discussed in terms of calculating the usefulness to humans of preserving specific goods and services provided by environmental systems. For example in biodiversity preservation the main objective is the usefulness of species, i.e. their potential as products or drug suppliers.

The only way that non-use and future-use values can be described is with the CV method (Spash 1997). Depending on how the questions are formulated a species can have a value for its mere existence without anyone being interested in consuming it, or of seeing it.

There are several difficulties with the CV method besides the obvious one, which of course is the difficulty to set monetary values to systems principles, one is that different people value the environment differently and the other is how the questions are asked.

A CBA can be done at a specific moment in time or over discrete periods of time but it does not measure whole lifecycles. In theory any environmental impact can be considered but in practice landscape values, eutrophication, climatic change and biodiversity are the only impacts included.

When it comes to different resources, like renewable-use/non-renewable-use, direct-use vs. indirect-use and/or non-local-use these could all be included. Either by the economic value of using/not using different energy forms or as costs of using lower-carbon fuels, or long-term damage costs or as taxes or be taken from a CV. And the economic costs of using/not using alternative-uses or substitutes are included.

Strengths and weaknesses

The strengths and weaknesses of CBA are presented in table 3.

Table 3. Strengths and weaknesses of Cost Benefit Analysis (CBA).

Strenghts	Weaknesses
• Easy to interpret results • Flexible • Easily understandable unit of measure	• Difficult to evaluate environmental goods especially non-use values • Environmental values not always included • The CV creates a hypothetical situation • Formulation problems in the CV • Answer of CV depending on the one performing the study

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ECOLOGICAL FOOTPRINT

The concept of Human Carrying Capacity is a demographic accounting that estimate how many people a defined land area can sustain (Rees 1996).

For people, directly dependent on what land can produce the relationship between people and land is obvious and so is the Human Carrying Capacity concept.

Support from external land or other external sources is the only way to exceed carrying capacity. External support makes it possible to sustain on a higher level of consumption but also emancipate people from land (nature, ecosystem).

The result is a change in focus from a local biophysical reality (land dependence) to an external support system reality that is built on monetary values. For industrial countries the external supports are becoming more important than the local. A city has almost no internal support and Human Carrying Capacity is maybe no longer an appropriate assessment.

Ecological footprint has its background in Human Carrying Capacity but has been further developed to be 'more instructive than traditional carrying capacity in characterising the sustainability dilemma' (Wackernagel and Rees 1996).

The purpose of Ecological Footprint is to visualise biophysical values in order to achieve relevant information for a more sustainable development.

Ecological Footprint is an index of biophysical impact. 'Original objective was to force the international development debate beyond its focus on GDP growth to include ecological reality' (Rees and Wackernagel 1996).

Ecological Footprint is estimated in a biophysical context and is thoroughly founded in systems ecology and laws of thermodynamics. It is often taken into account at a global scale to indicate human values (fairness equity brotherhood) that relates to consumption of the earth's limited resources.

The method

A populations ecological footprint is the biologically productive land and water area required for its consumption (goods and services) and waste assimilation.

The method is simplified because it might be complicated to include all consumption items, all waste types and all ecosystem functions.

Land categories

Land area is mostly divided into six categories: arable land, pasture, forest, built-up land, fossil energy land and productive sea. All consumption and waste generation has to be related to one of the land categories. It is obvious that it is difficult to transform consumption and waste generation to appropriate required land categories. Consumption of food is more easily transformed to arable land, pasture or sea space because context is similar. Energy is a little more difficult and technological goods are really complex to transform.

Biologically productive land (arable, pasture, forest, sea)

The first step is to estimate net consumption and that is equal to production plus import minus export. Next step is to calculate the required land area for apparent consumption and that is done by dividing net consumption with yield per hectare.

Fossil energy land

There are three approaches to convert fossil energy use to land area:

- land area required to produce a renewable alternative to fossil energy
- land area required to assimilate emitted carbon dioxide
- land area required to rebuild natural capital in the same rate as fossil energy is consumed

According to the first three items in table 4 there is little difference in required land area between the three alternatives.

The carbon dioxide assimilation approach has been used on most Ecological footprint assessments. One hectare per 1.8 tonnes of carbon has been chosen as the land-for-energy ratio for fossil fuel (Wackernagel and Rees 1996). Non-harvested forests are often used as carbon dioxide sink areas, as well as oceans and wetlands.

Based on IPCC data (Intergovernmental Panel on Climate Change, 1997) Wackernagel et al. 1999b have reconsidered estimated average carbon absorption to 1.42 (t/ha/y) resulting in a lower productivity for CO_2 absorption (coal 55, liquid fuel 71, gas 93 Gj/ha/y).

Table 4. Productivity of various energy sources (Wackernagel and Rees 1996).

Energy Source	**Productivity (Gj/ha/y)**	**Footprint for 100 (Gj/ha/y)**
Fossil fuel		
Ethanol	80	1.25
CO_2 absorption	100	1.0
Biomass replacement	80	1.25
Hydro-electricity (average)	1 000	0.1
Solar hot water	up to 4 000	0.0025
Photovoltaics	1 000	0.1
Wind energy	12 500	0.008

Built up land

Built up land is land that has been consumed (roads, buildings) and where production capacity has been lost. Increasing area of built up land are reducing production capacity.

Waste assimilation
Assimilation of waste usually takes place in areas that are already used and counted in ecological footprint for other purposes. In case of significant waste production it is possible to consider it separately. Carbon dioxide and nutrients from agriculture and urban areas are examples.

Correction to global scale

The ecological footprint is expressed in productive hectare per capita. But different land categories have different productivity. One capita sustaining on arable land definitely has a larger footprint than one sustaining on the same area of pasture. That is why it is necessary to correct for the productivity with Equivalence factors. The factors are scaled to keep the total global bioproductive area constant. Global average equivalence factor (sum of bioproductive land area and sea space) is equal to 1. The aim of equivalence factors is to consider the quality of land.

Correction to local productivity

Yield factor is a correction factor for local land productivity compared to global average. The yield factor for arable land in Sweden is for example 1.6 (Wackernagel et al. 1999a) indicating that productivity for arable land in Sweden is 60 % higher than global average. It is assumed that the high yielding production on arable land in Sweden is sustainable.

Key literature review

The background of ecological footprint is found in Rees (1996) and Wackernagel and Rees (1996). More detailed descriptions of the method are found in Wackernagel and Rees (1996), Wackernagel et al. (1999a) and Wackernagel et al. (1999b).

There are several different approaches and/or perspectives for assessing ecological footprint. One example is to estimate the required ecosystem services that humanity depends on (Jansson et al. 1999; Deutsch et al. 2000). Another is to estimate natural capital requirements of the human economy at a global scale (Wackernagel et al. 1999a). That is often done for nations and relates to the nations occupation of global ecological space. A third footprint approach is to estimate 'impact of different lifestyles, organizations, sub-national regions, products and services rather than larger governmental units' (Simmons et al. 2000).

Ecological footprint with a monetary perspective has been done in a modified form of input-output analysis to calculate the ecological footprint of New Zealand (Bicknell et al. 1998). The result is a lower ecological footprint for New Zealand than Wackernagel et al. (1999b) published in their national and global accounting. Wackernagel et al. (1999a) demonstrate how Ecological footprint can be used for regions and catchment's areas.

Results from Sweden, Malmöhus county and Kävlinge catchment's area have been published.

Berg et al. (1996) compared required ecosystem support for two different aquaculture methods. Industrial and solar energy demand, ecosystem areas for feed production, oxygen and phosphorus assimilation were studied.

Another study estimated the Marine footprint or the area of marine ecosystem support to1 km^2 per ton salmon produced, approximately 20 000 - 50 000 greater than the area of the cage (Folke et al. 1998).

Fricker (1998a) refer to Ecological footprints for several nations, discuss definition of sustainability and declare that quantitative growth is clearly unsustainable. New Zealand is one of few nations not exceeding its own carrying capacity but Fricker is still arguing that New Zealand can be considered as overpopulated at present life style.

Sustainability is closely connected to Ecological footprint. Fricker (1998b) are discussing the concept of sustainability and confirms that it is more than a thing to measure since it is about quality of life. Fricker state that there are differences between sustain and survive.

There are several assessment methods for sustainability. In Hanley et al. (1999) ecological footprint is presented together with six other measures of sustainability at national level in Scotland (Green Net National Product; Genuine savings; Environmental Space; Net Primary Productivity; Index of Sustainable Economic Welfare; Genuine Progress Indicator).

As mentioned before there are great concerns about urban citizen's alienation from nature and biophysical realities. Hansson Borgström and Wackernagel (1999) assert that there is low valuation of ecosystem services. Urban citizens have been alienated from local ecosystems and their values substituted to monetary values.

Natural capital is often used in connection with Ecological footprint and is synonym to ecosystems and their services.

Society dependence on natural capital is just as important as human labor or human-made capital.

The concept of natural capital is explained in Wackernagel and Rees (1997) and some barriers to invest in natural capital are identified.

Far from all agree on Ecological footprint as a perfect assessment tool for sustainability. Several objections are stated and van den Berg and Verbruggen (1999) argue that Ecological footprint is not the comprehensive and transparent planning tool as often assumed. The procedure used to address footprint associated with energy use is most troublesome (Ayres 2000). Ayres is suggesting power plants as an alternative for sequestering carbon dioxide.

Case studies

Ecosystem services appropriated by people in the Baltic Sea drainage basin (Jansson et al. 1999)

Ecological footprint (land area and water space necessary for ecosystem services) was estimated for 85 million people within the Baltic Sea drainage basin.

Data on appropriate area per capita were obtained from national data.

Supply (defined by FAO) was used as a measure of consumption.

Consumption of renewable resources (wood, paper, fibre and food products) were translated to land area or sea space required for production.

Waste assimilation was focused on carbon dioxide, nitrogen and phosphorus. The areas of forests, agricultural lands, lakes, reservoirs, major rivers, natural wetlands and marine ecosystems required to assimilate waste, generated by the population within the Baltic Sea drainage basin, were estimated.

When aggregating consumption and waste assimilation into ecological footprint only the largest area of a certain ecosystem was accounted for. A forest is producing timber and sequestering carbon dioxide at the same time, only the largest area required was considered to avoid double counting.

Results from the study demonstrate the dominance of land area and sea space required for waste assimilation where carbon sequestering is responsible for 75 - 86 %.

'The ecological footprint of the total human population in the Baltic Sea drainage basin corresponds to an area as large as 8.5 - 9.5 times the whole Baltic Sea and its drainage basin' (Jansson, Folke et al 1999). The per capita footprint was estimated to 22 - 25 ha, which greatly exceeds outcomes in other studies. The consumption of wood, paper, fiber and terrestrial required 20 % of available forest area and 90 % of available agricultural land. A conclusion is that the consumption of renewable products is, except for seafood, within the limits of the region.

The waste footprint on the other hand is greatly exceeding limits of the region, mainly because of fossil energy use. 'The size of waste indicates the widespread "hidden demand" of industrial society for ecosystem support extending beyond national borders'.

Ecological footprint at a national and global level (Wackernagel et al. 1999b)

Calculation procedure for national Ecological footprint is done in a spreadsheet. An example for Italy is available at http://www.iclei.org/iclei/efcalcs.htm.

Main categories directly related to bioproductive land area are food, timber and other crops.

Energy consumption includes coal, liquid fossil fuel, fossil gas, nuclear energy (thermal), hydro-electric energy related to fossil energy land and bioenergy which is already included in the timber and other biotic resources accounting.

Different kinds of raw materials and manufactured goods are estimated in their embodied energy and related to fossil energy land.

The cereal production is calculated as: net consumption of cereals/global average yield x population = 0.17 ha/cap.

The footprint component for liquid fuel is: net consumption of liquid fossil fuel/global average CO_2 sequestering x population = 0.80 ha/cap.

The footprint component for goods is: net embodied energy in imported goods/global average CO_2 sequestering x population =- 0.10 ha/cap. Because of net export Italy has a negative footprint component for imported goods.

Sea space is estimated according to percentage of world marine fish catch.

The footprint components are summarized in the 'total' column in demand section (table 5).

The footprint components for each category is multiplied with the equivalence factor to keep global bio-productivity constant. The result is an ecological footprint of 4.2 ha/capita for Italy.

Compared to available capacity, after 12 % reduction for sustaining global biological diversity, Italy exceeds its capacity with 2.9 ha/cap.

Ecological footprint is estimated for 52 nations in the same way as for the Italian example. Compared with the global bio-capacity that is estimated to 2 ha/cap there are only 12 countries that 'live on footprints smaller than what the earth can offer per global citizen'.

Usefulness to address ecological land use/ sustainability

Referring to Fricker (1998b), the word sustain has an Indo-Ayran etymological origin and means to hold together with tension.

Opinions are divided whether ecological footprint is assessing sustainability or not. The method estimates energy and physical flows. If sustainability is fitness to available flowlimited renewable resources, then Ecological footprint certainly address sustainability. Although it is a rough method that systematically underestimates required fossil energy land and do not consider the 'quality' of the fossil fuel.

Ecological footprint and systems principles

Ecological footprint is founded in ecology. The method has no predictive capability, it is like a snapshot in time, and ignores many other factors important for sustainability.

Table 5. Footprint summary for Italy (Wackernagel et al. 1999b).

Demand – Footprint (per capita)				**Supply**– Existing bio-capacity within country (per capita)			
Category	Total ha/cap	Equiv. factor -	Equiv. total ha/cap	Category	Total ha/cap	Equiv. factor -	Equiv. total ha/cap
Fossil energy	1.4	1.1	1.6	CO_2 absorption land	1.49	0.00	0.00
Built-up area	0.1	2.8	0.2	Built-up area	1.49	0.04	0.17
Arable land	0.3	2.8	0.9	Arable land	6.50	0.21	0.87
Pasture	1.8	0.5	1.0	Pasture	0.80	0.08	0.26
Forest	0.3	1.1	0.3	Forest	1.00	0.12	0.11
Sea	1.0	0.2	0.2	Sea		0.32	0.07
				Total existing		0.8	1.5
Total used	4.9		**4.2**	Total available - 12 % for biodiv.			**1.3**

Ecological footprint – strengths and weaknesses

A complex reality is simplified and results aggregated to one single measure – land area – that makes results easier to understand and communicate.

It is not easy to include everything in one single assessment method, but ecological footprint has a strong educational purpose and it is desirable to improve the method for that purpose. Althought, gain in pedagogic approach often results in deficit of scientific quality.

Ecological footprint has no predictive capability and do not allow estimations of contamination.

One of the main objections is that ecological footprint does not consider energy quality, especially since energy is a dominant part of the footprint in industrial countries.

Ecological footprint does not consider that a more sustainable agriculture (lower inputs) will yield less. The question is if lower inputs reduce ecological footprint as much as lower yields increase it?

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EMERGY ANALYSIS

Emergy evaluation is a technique which can determine the values of nonmonied and monied resources, services and commodities. It measures these items in a quantitative way on a common counting base – the solar energy it took to make them. In other words the system necessary for a product or service.

Evaluations can be made on macroeconomics of states and nations or on the economic-environmental interface of microeconomics.

Emergy indices are used to evaluate areas like primary energy sources for economies, environmental impacts, economic production sectors, restoration and sustainable use of agro-ecosystems, and international trade. (Odum 1998)(Brown and Ulgiati 1999)

Emergy is often referred to as energy memory (Odum 1998). The unit is sej – solar emergy joules – or its equivalence emdollars (Em$) when to compare with evaluation in monetary terms (Odum 1996).

Emergy theory has been developed the last three decades '…as a tool for environmental policy and to evaluate quality of resources in the dynamics of complex systems' (Brown and Ulgiati 1997).

Emergy evaluation 'is based on the principles of energetics (Lotka 1922), system theory (von Bertalanffy 1968) and systems ecology (Odum 1994).' (Brown and Ulgiati 1999)

Emergy can not be measured directly, since it consists of historical events. To achieve the emergy value of a product or service, a multiplication factor is used. The factor to multiply the actual energy, weight or monetary content with, to get the emergy value, is called the transformity value. The 'transformity gives a measure of the concentration of solar emergy through a hierarchy of processes or levels; it can therefore be considered a quality factor, a measure of the global process supporting the item under study' (Brown and Ulgiati 1997).

Transformities makes the emergy evaluation method relatively fast to calculate, but they can be difficult to assess. Ten ways of calculation transformities are suggested by Odum (1996).

The method

A brief description of emergy evaluation is given by Odum (1998), and a deeper handbook of the method is provided in Odum (1996).

Brown and Ulgiati (1999) have made a recent emergy evaluation of the biosphere.

A clarifying example of emergy evaluation on national level is found in Ulgiati et al. (1994)

An emergy evaluation starts with an attempt to get a broad view of the issue evaluated. The connection to other scales are important, in accordance with the foundation of emergy in systems ecology. Therefore to understand a problem, it is needed to know both the mechanisms and if the problem is controlled mainly by the larger surrounding system. (Odum 1996)

Diagramming and aggregating

To get a systems overview the relevant parts and processes of the problem in view are diagrammed. This is at first done in detail to be sure everything relevant is considered. After this inventory phase where a complex diagram is drawn, the diagram is simplified by aggregation.

Aggregation means that items are grouped, but no emergy flows are eliminated. The aggregation is often done according to scale in space and time. For example items of smaller scales than the level of interest, like often chemical reactions and microbial activity, are grouped together. If the time scale is in years, items with turnover time shorter than one year are aggregated. If the window of time is given in hours or minutes, larger scale inputs like geologic inputs are aggregated. (Odum 1996)

By aggregating, the important contributing factors are revealed. The diagram is often adjusted to show increasing transformity from left to right.

Evaluation tables

The new simpler aggregated diagram is used for the evaluation tables. Solar emergy and emdollars are calculated for each inflow, product or other item of special interest.

The emergy value is calculated by multiplying the value of the item (in joules, gram or $), with the according transformity value of the process (in sej/J, sej/g or sej/$).

The emdollar value is calculated by dividing the emergy value with the emergy/dollar value for the particular year and country considered. The emergy/dollar value shows how much emergy a dollar can buy in an economy. The emdollar value is just a translation of the share of total emergy contribution of the item, translated to dollars of GDP.

When all desired emergy flows or storages have been calculated, comparisons of the emergy or the equivalent emdollar values show immediately which ones that are the most important, and contribute the most to the combined economy of nature and humanity (Odum 1996).

Evaluation indices

For further interpretation some useful indices can be calculated. To do this further aggregation is made, to a three-arm or five-arm diagram. The three or five arms are (figure 3):

- I, the local environmental emergy inputs, consisting of:
  - N (local non-renewable resources) and
  - R (Local renewable resources).
- F, feedback emergy from economy, consisting of:
  - M, purchased resources such as minerals, fuels, and raw materials brought to an area by the economic system
- S, services and labour, the paid work of people
- Y, the yield, the sum of I and F

Other slightly different indices comes continuously. For example, Brown and Ulgiati (1999), divide the environmental inputs into three categories instead of two: N, R and SR (slowly renewable), I = R + SR + N.
Most used indices are listed in table 6 (compare figure 3).

Emdollar
Emdollars are used for comparison with economic values. The emdollar value better reflect the contribution of resources to the wealth of an economy. As previously noted the emdollar reflects the emergy contribution in relation to the GDP for the actual year. Market assessed values of resources are normally to low in relation to the emdollar value.

Policy recommendations
The indices from the emergy evaluation provides a good decision base for policy recommendations. Odum (1996) argues that decisions can be made on the basis of maximum emergy production and use.

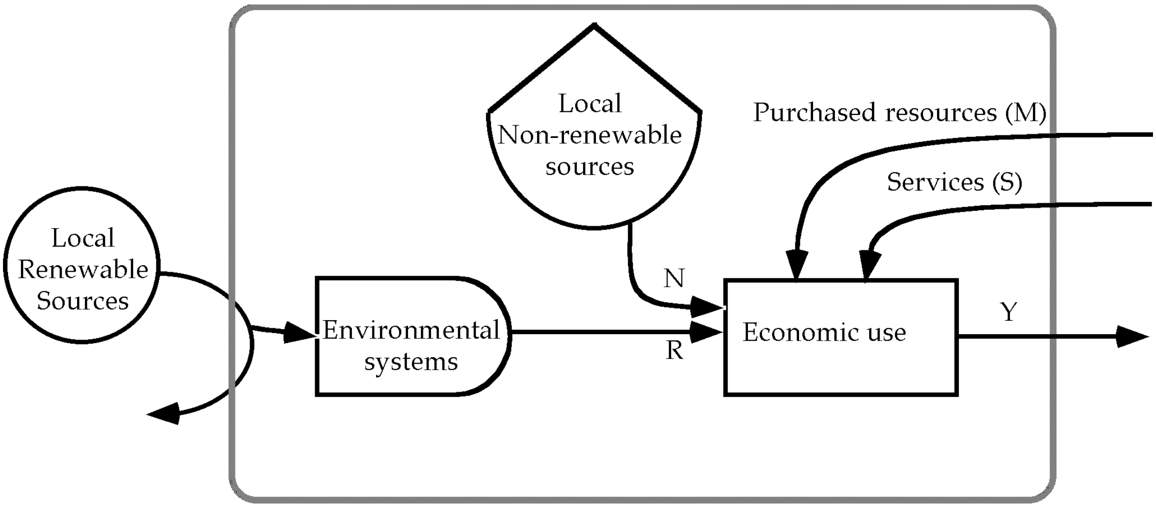

Figure 3. Definitions of R, N, Y, M and S. (Adopted from Brown and Ulgiati 1997)

Table 6. Most used emergy indices.

Name	Calculation	Explanation
%Renew	R/(R + N + F)	The percent local renewable of input.
EYR	Y/F	Emergy Yield ratio. Emergy of yield, divided by emergy of all the feedbacks from the economy including fuels, fertilisers and services.
ELR	(F + N)/R	Environmental Load Ratio. Gives a measure of the process ability to use local resources. An indicator of the pressure from the process on the local ecosystem; ecosystem stress due to production activity.
EIR	F/(R + N)	Emergy Investment Ratio. The investment compared to local resource use. Shows if the investment is boosted by free local resources.
ESI	EYR/ELR = YR/F(F + N)	Emergy Sustainability Index. ESI rises with Y and R, and decreases strongly with increasing F, and to a lesser degree with increasing N.

Case studies

Swedish food system

Johansson et al. (1999) evaluated the 1996 Swedish food system. From the total yield of 144 E20 sej in the farm production:

- R, local renewables contributed by 11 % (sun and rain)
- N, local nonrenewables by 28 % (loss of soil organic matter)
- M, purchased goods by 23 % (fuel, electricity, pesticides, calcium oxide, fertiliser, machinery and buildings)
- S, service by 39 % (direct labour 5 %, and indirect services 34 %)
- F, total purchased resources and services by 62 %, (= M + S)

Indices from these results are given in table 7, where the other parts of the Swedish food system are also included.

The investment ratio (EIR) is higher than one in farm production, showing that more resources are fed back from the society than from the free local resources. The EIR is increasing when the farm products are refined and distributed to food on the table, with eight times as much purchased resources as free local resources.

The yield ratio (EYR) is higher than one in farm production showing that the purchased inputs from society is boosted up by 60 % from the free local resources. This is less than expected. The EYR is of course decreasing to the right in the table, when the free inputs are matched with even more inputs from society. Processes with EYRs less than about two do not contribute enough to the economy to be considered a producing source, but rather a consuming source (Brown and Ulgiati 1997). The conclusion is that Swedish agriculture is to be considered as a consuming part instead of a producing part of the Swedish economy, which is normally the case in industrialized agriculture (Jansson and Jansson 1994)

The environment loading ratio (ELR) is high in farm production showing an intense production. The load is increasing threefold along the foods way to the family table.

The sustainability index (ESI) is very low, decreasing from farm production to the end use of the food. Better sustainability would require higher yields or lower environmental load.

Table 7. Some sustainability indices for the Swedish food system. (ESI counted in this paper)

Indicies	Farm production	Refinement, processing	Distribution, marketing	Storage, preperation
EIR (investment)	1.6	3.8	7.6	8.4
EYR (yield)	1.6	1.3	1.1	1.1
ELR (env. load ratio)	8.5	16.7	30.4	33.4
ESI (sustainab. index)	0.18	0.078	0.036	0.033

Five greenhouse tomato production systems

Lagerberg et al. (1999b) compared five greenhouse tomato production systems with emergy evaluation. Organic production systems, using compost and clover mulch as fertilizer, was compared to conventional systems using inorganic fertilizers.

From two real cases, five theoretical cases were constructed. The impact of alternative organic fertilizer strategy on the resource efficiency, environmental stress and sustainability of the systems were addressed. The effect of replacing fossil fuels for heating with a wood derived fuel was also studied. The systems were:

1. An upscaled version of the organic trial system; harvest level 23,2 kg/m^2.
2. A version of the organic trial system, where the harvest period was prolonged; harvest level 35 kg/m^2.
3. System 2 where oil heating was replaced by wood powder; harvest level 35 kg/m^2.
4. A conventional production system; harvest level 42 kg/m^2.
5. System 4 where oil heating was replaced by wood powder; harvest level 42 kg/m^2.

The emergy indices for the different systems are given in table 8, the conclusions are:

- The yield, Y, was comparably higher in prolonged organic and conventional systems.
- The investment ratio, EIR was much lower for wood powder based systems.
- The yield ratio, EYR showed no big differences.
- The environmental load ratio, ELR was lowered by wood powder use.
- The sustainability index, ESI was increased with wood powder use due to the lowered ELR.

The comparison also shows the well-known statement that there is a strong relationship between space and time in ecological systems. Lagerberg and Brown (1999) argues that for agriculture space, time and emergy use are interrelated and ‘may be substitutable, one for the other‘. Decrease in space or time will result in an increase in required emergy to drive the process. ‘Reducing the energy cost of agriculture will, by necessity, require an increase in the area of land that is farmed. The

Table 8. Emergy indices of different greenhouse tomato systems (Lagerberg et al. 1999b)

Indicies	**1. Organic**	**2. Organic prolonged**	**3. Organic prolonged wood powder**	**4. Conventional**	**5. Conventional wood powder**
Y, yield (sej)	1.37 E18	1.90 E18	1.35 E18	1.98 E18	1.51 E18
EIR (investment)	202.5	241.6	9.8	480	13.5
EYR (yield)	1.00	1.00	1.10	1.00	1.07
ELR (env. load)	318	441	10.1	9 910	14.1
ESI (sustainab. index)	0.003	0.002	0.11	0.0001	0.08

greenhouse tomato system clearly illustrates these tradeoffs between time, space and energy. Producing the same amount of tomatoes as the greenhouse system in the field under Swedish conditions would require about 7 hectare. Alternatively, producing the same amount of tomatoes in the field on the same area as the present intensive system (0,8 ha plant area) would prolong the time needed for production to about nine years. Thus an increase in energy inputs may reduce the acreage needed and also the time of production." (Lagerberg and Brown 1999)

A conclusions from the study was that replacing fossil fuels with more renewable fuels is an important strategy in order to improve the sustainability of tomato production systems. Increasing harvest levels for organic systems should also be given high priority.

Sustainability

Almost every article about emergy the last years have considered the sustainability concept. It is discussed more in detail by Brown and Ulgiati (1997) and Ulgiati and Brown (1998). Brown and Ulgiati (1999) evaluates the sustainability of the total biosphere and its natural capital. They show that an index of global sustainability of the global economy has declined. Sustainability of Swedish economy is discussed in Lagerberg et al. (1999a).

In sustainability debate in Sweden, the goal of steady state in resource use, are still dominant. The view of steady state in nature is more or less abandoned in ecological science today. In systems ecology the opinion is that the systems oscillate in many different scales of time and space (Odum et al. 1995) and (Odum 1994).

Brown and Ulgiati (1997) argues that authors still clinging to steady state sustainability does not seem to realize that the whole planet Earth is a self-organizing system, where resources are filled and emptied in different time scales. Matter is recirculated and organized through self-organizing activities driven by sun, geothermal and gravitational energy. The world is pulsing, but there are stable oscillating states. If oscillation is the normal state, then sustainability is about managing and adapting society to the oscillation frequencies of the natural capital.

Sustainability is not the steady state level on the classical sigmoid curve of growth, but the process to adapt to the oscillation. Human economy is limited to what is appropriate for each stadium of the global and local oscillation. 'Practices and processes that are characteristic during the growth phase may not be sustainable during transition or decline because they rely on nonrenewable energies that are diminishing. On the other hand practices that are sustainable during decline, because they have no reliance on nonrenewables, are probably not competitive with the dog-eat-dog competition that is characteristic of fast growing systems.'(Brown and Ulgiati 1997)

Adapting to pulsing means that an activity that is sustainable in growth phase when nonrenewables are abundant can be unsustainable in declining phase: the nonrenewable resource needed is no longer available.

Sustainability in emergy evaluation is measured as a function of: net yield in the process, environmental load and the use of nonrenewable resources. It is evaluated with a couple of indices that show different aspects of sustainability, earlier presented in table 6 and figure 3.

Emergy Sustainability index (ESI)

The emergy sustainability index is constructed from yield and environmental load. ESI = EYR/ELR, where EYR = Y/F and ELR = (F+N)/R, which gives ESI = YR/F(F+N).

We see that ESI increases with Y and R, and decreases highly with F and N, but in a less degree with N.

Brown and Ulgiati (1997) argues that ESI shows how well an economy and its ecosystems fits together, and suggests four different uses:

- Compare different production alternatives of the same product. The higher the ESI, the higher compatibility compared to other alternatives.
- Evaluate technical and technological innovations. A process can be modified by introducing new patterns or technologies, towards a greater yield per environmental load. A trend towards higher ESI shows a more environmental sound production .
- For nations it can compare different economies, and evaluate their long-term sustainability. The higher the ESI, the more the economy is built on use of renewable emergy flows, environmental protection, and minimized needs of purchased emergy from abroad.
- Follow trends over time for an economy.

Systems principles

Emergy evaluation stands on the same foundation as the system principles presented earlier. Therefore they fit together well.

Strengths and weaknesses

One of the strengths with emergy evaluation is its flexible approach. In the first step of getting the systems overview any focus could be chosen, and still no important flows or storage are excluded, they are just aggregated. The method emphasizes the organization of the system studied, and always connect the chosen level of scale to other important scales in time and space.

Like very few methods are able to do, emergy evaluation puts the economies of nature and society in relation to each other, and on a common counting base. This can also be done with market values, but the problem is then usually that the market underestimates the economy of nature and its contributions to the human economy. The emergy value is probably a more 'true' value on the 'free' environmental work – the work of nature.

A weakness is that the chosen one-dimension measure of emergy of course exclude or deal indirectly with qualitative aspects, like different properties of chemicals and social aspects. Another weakness is the dependence on tables of transformity values.

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BIOLOGICAL ASSESSMENT METHODS – INDEX OF BIOTIC INTEGRITY (IBI)

Biological Assessment Methods, as the Index of Biotic/Biological[1] Integrity (IBI), are developed to evaluate ecosystem health (EPA, 1998).

The IBI was developed by Karr (1981) when relating streams with various degrees of pollution into gradients of human disturbance. Unpolluted streams served as references for unimpaired integrity. In these studies of aquatic ecosystems, biological integrity was referred to as 'the ability of an aquatic ecosystem to support and maintain a balanced adaptive community of organisms having a species composition, diversity, and functional organisation comparable to that of natural habitats within a region (Karr and Dudley 1981)'.

Leopold (1949) stated integrity, stability and beauty as positive or right characteristics for a biotic community and lack of them as negative or wrong.

The concept of integrity appeared in the 1972 Amendments to the U.S. Federal Water Pollution Control Act in the USA. The concepts of ecological health and integrity have there after been introduced as an important objective in acts concerning conservation and protection of natural ecosystem areas, as Clean Water Act, Canada's National Park Act and Great Lakes Quality Agreement of 1978. The Clean Water Act is the primary U. S. federal law that protects waters, including lakes, rivers, aquifers and coastal areas.

The need for evaluation of ecological health and integrity of ecosystems affected by human disturbance, has urged for research and development of biological assessment methods. Most research has been performed in streams, but experiments in lakes and near coastal environments (Dionne and Karr 1992; Minns et al. 1994) suggest that the approach is more widely applicable.

Measures of ecosystem integrity was also performed in terrestrial ecosystems, as in Canadian National Parks by Woodley (1993) and of birds in Mid Atlantic Highlands, US, by O'Connell et al. (1998). The applicability of the concepts of ecological health and integrity in agroecosystems was discussed by Crews et al. (1991), Okey (1996) and Waltner-Toews (1996).

Definitions of ecological integrity have been proposed by Frey (1975), Karr and Dudley (1981) and later by several other authors.

Constanza (1992) defines a healthy ecosytem as being 'stable and sustainable'; maintaining its organisation and autonomy over time and is resilient to stress.

Karr and Chu (1999a) emphasize three important principles of ecological integrity:

- A biota spans over a variety of spatial and temporal scales.
- A living system includes items that one can count (the elements of biodiversity) plus the processes that generate and maintain them.

[1]Biotic/Biological – Both terms are used in the literature

- Living systems are embedded in dynamic evolutionary and biogeographic contexts.

Regier (1993) will not limit the concept in a linear closed way, but sketches it as a long sequence of ideas, which all together characterize ecosystem integrity.

Constanza and Mageau (1999) emphasize three main components of ecosystem health – vigor (function, productivity, throughput), organisation (structure, biodiversity) and resilience.

Karr (1996) distinguish between health and integrity. Health is vitality and well being whereas integrity refers to a complete or undivided state in an original condition. Health is related to time scale, an unhealthy system will not achieve its maximum normal life span (Constanza and Mageau 1999).

Indicators are key tools in assessment methods for evaluation of ecosystem health (Amir and Hyman 1993, Boulton 1999, Constanza and Mageau 1999).

Indicators of ecosystem health can be physiochemical, biological and socioeconomic; biological indicators can focus all levels from cells to landscapes (Cairns et al 1993).

Integrated measures of ecosystem health from different levels of biological organization gives an overall assessment of ecosystem health, as only one parameter cannot comprise several aspects of ecosystem performance. Integrated indices are useful to reduce information from several measurements into simple index, but involves assumptions of weighing individual measures (Cairns et al 1993).

Indices of biotic integrity (IBI) are commonly used for assessing ecosystem health in fish and bentic macroinvertebrate communities. The IBI provides a biological measure of ecosystem health or integrity using a wide spectrum of biological attributes (Karr and Chu 1999b).

The indices are built on assemblages of several parameters (metrics) that reflect individual, population, community and ecosystem attributes. Three basic types of metrics have generally been used – species richness and composition, trophic composition, and the overall abundance and condition, table 9.

Statistical evaluation of the IBI concluded that biologically meaningful differences of fish assemblages could be statistically separated (Fore et al. 1994).

Information on specific species is hidden within the IBI indices. The AMOEBA-chart, figure 4, offers an alternative (Regier 1992). It have been used on the North Sea ecosystem. Species abundance at sites with no disturbances is shown on a circle on the AMOEBA-chart. Deviations from the reference abundances on the circle show the level of disturbance and form an AMOEBA-like figure. The reference abundances on the circle in figure 4 show the situation around 1930.

Monitoring ecosystem health should be followed by managing ecosystems for preserved or increased health. Environmental management has not yet adopted the concepts of ecosystem health.

Table 9. Example of biological attributes of fish assemblages used by the Ohio EPA to calculate IBI (Fore et al *1994)*

Metric group	Metric	Correlation with degradation
Species composition	1. Total species	Negative
	2. Darter species	Negative
	3. Sunfish species	Negative
	4. Sucker species	Negative
	5. Intolerant species	Negative
	6. %tolerant individuals	Positive
Trophic composition	7. % omnivores	Positive
	8. %insectivores	Negative
	9. %top carnivores	Negative
Fish condition	10. %litophilic spawners	Negative
	11. %deformed, lesions, tumours	Positive
	12. Total number of fish	Negative

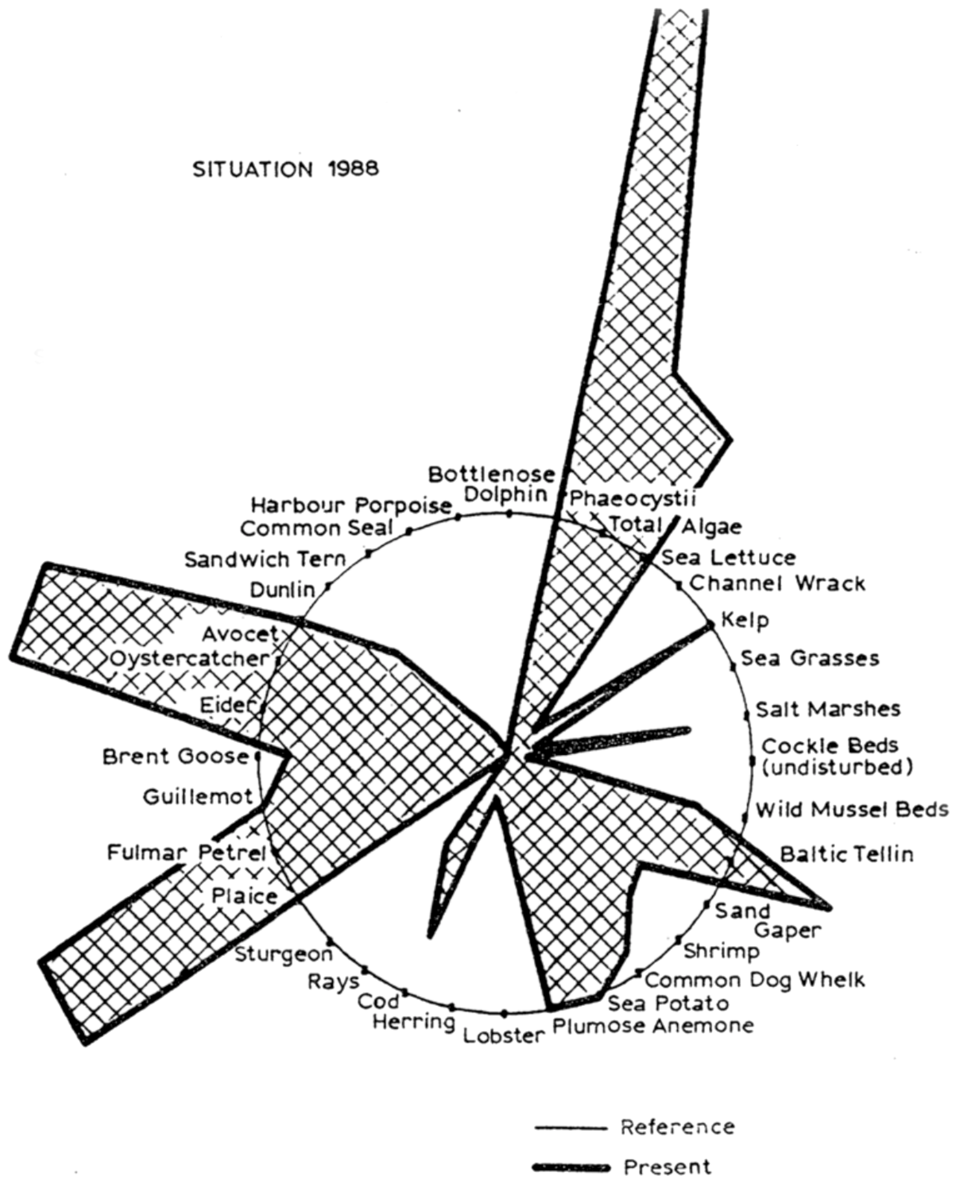

Figure 4. An illustration of the AMOEBA-chart from Regier (1992). Note that the sequence of taxa may be started with algae at the top and then progress clockwise through other plants, invertebrates and vertebrates (Regier 1992).

Chairns Jr and Niederlehner (1995) have examined the underlying assumptions and information of environmental management and re-examined them in a context of ecosystem health.

Some researchers disagree about using the concept health and integrity of ecosystems (Suter 1993, Wicklum and Davies 1994). They argue that health and integrity are not properties of ecosystems. Ecosystems change but one state cannot be considered more healthy compared to another. Indices are considered to be arbitrary, subjective and not measures of real properties.

Examples

O'Connell et al (1989) developed an index of biotic integrity for bird communities in the Mid-Atlantic Highlands of the US. The bird community index (BCI) sort bird species found at sample sites into a series of values representing the proportional species richness of 20 behavioural and physiological response guilds. Relative proportions of specialist and generalist guilds are used to assign a composite score to each site. Scores from multiple sites indicate the overall biotic integrity of the study area.

The BCI is intended to function as a landscape-scale indicator of biotic integrity, integrating conditions across large sample sites containing diverse ecological resources and intensities of human use.

Woodley (1993) reports on ecosystem integrity monitoring in Canadian National Parks. The goal is to detect long term changes in the ecosystems. The design of the monitoring program has considered that: existing knowledge of ecosystem is limited, catastrophe and surprise characterize most ecosystems, stresses on ecosystems operate differently at various spatial and temporal scales, a range of related social factors also must be monitored and that measures must be customized for specific ecosystems.

The measures chosen are primary productivity, nutrient cycling and losses, the rate of decomposition, species diversity or species richness, retrogression, habit fragmentation, minimum viable population size, minimum area requirements, population dynamics of selected species.

Sustainability

Sustainability is a main property of undisturbed ecosystems (Jansson and Jansson 1994).

An ecosystem is healthy and free from 'distress syndrome' if it is stable and sustainable (Constaza et al 1992). The definition of ecological integrity contains the biological and ecological aspects of sustainability (Karr and Chu 1999a).

The choice of indicators is critical for how well the biological assessment can tell something about the integrity of the system and thus about the sustainability of the actual composition of the biological community or ecosystem (Cairns et al 1993).

Attributing the concept of health to agroecosystems is achieved by defining criterias for health in connection with goals and needs of human and nonhuman stakeholders.

Criteria for health in terms of agroecosystems include integrity, adaptability and efficiency (Walter-Toews 1996).

Okey (1996) discuss ecosystem properties from an agroecosystem perspective and concludes that stability, resilience, diversity/complexity, efficiency and equitability provide a suitable basis for defining agroecosystem health together with aspects of human values, ethics and aesthetics. Thus, indicators of agroecosystem health should cover a wide range of aspects.

Farmers are important stakeholders for development of on-farm indicators (King et al. 2000).

Systems principles

IBI measures the status of ecosystems providing ecosystem services.

The choice of indicators is critical for how the assessment of ecological integrity relates to the framework of ecosystem properties.

The index of biotic integrity give combined measures of ecosystem properties (Constanza and Megeau 1999).

More specific knowledge of causal relations to specific system properties will be given from appropriate choice of diagnostic indicators.

Thermodynamics

Measurement of energy flow through the ecosystem can serve as an indicator of stress to the system. Flow of energy will drop and more energy will be exported from the stressed ecosystem. The networks for breaking down and recycling nutrients will be impaired. Thus, the systems will be more leaky and the detrital activities will decrease in the stressed system (Kay and Schneider 1992, Amir and Hyman 1993).

Scale and hierarchy

King (1993) reviews considerations of scale and hierarchy in relation to measurements of ecological integrity. Measurement on the entire system is not possible. Thus, all measurements come from scales smaller than of the entire system.

Natural integrators reflect the status of the entire ecosystem. Watersheds collect information from the whole discharge area. Wolfs aggregate information from lower levels of hierarchies.

However, information on finer scale variabilities can be hidden. The larger scale integrated measurements need to be supplemented by finer scale measurements to determine cause and effect. Subsystems within an ecosystem may be independent of each other, indicators should reflect a variety of perspectives.

In the monitoring of ecological integrity at Canadian National Parks different type of indicators are used depending on hierarchical scale (table 10, Woodley 1993).

Depending on the design of multimetric indexes of IBI, information will be given on various scales and hierarchies.

Stability, resistance and resilience

Resistance and resilience are two major features of ecosystem health. Resistance 'means an ability to resist external pressures', whereas 'resilience means an ability to rebound and recuperate from irresistible pressures' (Amir and Hyman 1993).

According to Holling (1986) resilience refers to the ecosystems ability to maintain its structure and pattern of behaviour in the presence of stress.

Resilience has two aspects, the magnitude of stress from which the ecosystem can recover and the length of time taken to recover from the disturbance (Constanza and Mageau 1999).

Resistance is maintained within the prevailing structure whereas resilience is promoted by redundancy and diversity that can sustain ecosystem function during stress (Amir and Hyman 1993).

Constanza and Mageau (1999) propose an overall measure of resilience that can be obtained from the ratio of the magnitude of stress allowed to the recovery time. These measures can be obtained from simulation modelling of network analysis. They propose other indicators, as the ratio of gross primary production per unit respiration, to serve as proxies for quantitative measurements of resilience.

Networks, diversity and efficiency

Diversity indices and multi-species indices give no information about interrelation between system components. Network analysis is a potential approach for measuring organisation. Indices of network analysis are reviewed by Constanza and Mageau (1999).

Assemblages of taxa richness and related measures are the key indicators in IBI.

System analyses of material flows and energy flows as indicators will assess recycling and efficiency of the ecosytem.

Table 10. Selected measures in relation to hierarchical scale for monitoring ecosystem integrity (Woodley, 1993)

Hierarchical scale	Monitoring measure
Individual	Growth and reproduction rates of indicator species
Population	Minimal viable population size Population dynamics of selected species
Community	Species diversity Succession / retrogression Nutrient Cycling
Landscape	Climate Primary productivity / respiration Minimum viable area Habit fragmentation

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POSITIONAL ANALYSIS

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Positional Analysis (PA) is a planning tool that aims at describing the effects of decision actions on systems and possible conflicts resulting from a course of action (Söderbaum 1990). It is a participatory approach, based in institutional economics, which attempts to consider multiple interests and outcomes of alternative actions (Forsberg 1996a).

Söderbaum (1987) proposes PA as a holistic, interdisciplinary and value-conscious approach to decision making and to environmental policy appraisal. The method was first presented by Söderbaum (1973) at the Business Economics Institute at the Uppsala University in Sweden.

Institutional economics is a response to perceived limits of neo-classical market economics: "The institutionalist is disinclined to accept without question the notion that the market is the solution to all public problems" (Bromley 1985).

Cost-Benefit Analysis (CBA), (reviewed earlier in this document) a neo-classical economic method commonly used for environmental evaluations, compares monetary costs assigned to action alternatives with perceived monetary benefits.

Söderbaum (1987) identifies three weaknesses of CBA:

- Actual markets are far from perfect.
- Consequences of environmental disruption are highly heterogeneous.
- Often project costs and benefits cannot be compared quantitatively with one and another.

Positional Analysis is an attempt to overcome limits of market economic analysis.

Positional Analysis framework is flexible and depending upon social, institutional and environmental context it may include (Söderbaum 1987):

- A description of the decision situation
- Identification of the problem
- Design of alternatives
- Identification of affected systems
- Identification of effects
- A study of possible irreversibilities
- Analysis of risks
- Analysis of interests related to the decision situation
- A summary of information on effects and interests
- A conclusion or decision outcome

The analysis starts with a description of the decision situation. Here, the historical background is brought forth, and the rules of players, relevant institutions and interested parties are identified. Next the problems of stakeholders are specified, and the most crucial time periods for project implementation are identified (Hillring 1995), followed by selection of alternatives (Söderbaum 1987).

The identification of systems that will be affected at any time by proposed and alternative projects is important to the decision outcome: depending upon which alternatives are selected, systems will be more or less affected. Comparisons are made between alternatives based on perceived effects (Mattsson 1991).

Positional analysis attempts to address possible inertia and irreversibilities associated with project alternatives and decision actions. From an economic point of view (Forsberg 1996a) as well as environmentally, these considerations are important due to the expense of remediation. For each activity and goal, the alternatives are ordered by stated and agreed preferences of stakeholders (Mattson 1991).

An analysis of prevailing risks and uncertainties are made, with the help of scenarios and (subjective and objective) probabilities.

Finally, information on effects and interests is summarized and used as basis for a conclusion and decision support (Söderbaum 1987).

Case studies

Positional Analysis has been used for land-use decision support in: transportation planning (Söderbaum and Zerihun 1981), environmental control and natural resource management (Söderbaum 1990), proposed redesign of a district heating plant for biofuels (Mattson 1991), a historical study of energy systems (Forsberg 1993), environmental impacts of energy systems (Forsberg 1996b), a retrospective study of forest fuel systems utilising tree-sections (Hillring 1995) and municipal forest management and market transactions (Lidestav 1997).

District heating with bioenergy

Mattsson (1991) used positional analysis for decision support in a proposed reconstruction of a district heating plant in Hedemora, Sweden. Three biofuel alternatives was compared: continue with the present system, add a unit for gasification of biomass and use the gas for co-production of heat and electrical power, or convert some of the boilers to allow for the use of wood powder as a fuel.

Effects were studied from different aspects: monetary, ecological and social in relation to know-how.

A general discussion of positional analysis as a planning tool was carried out. Projected effects from alternative designs were assessed for different aspects.

The stakeholders involved were of course decision-makers and those who deliver fuel, sell equipment and construct energy plants.

A market for locally grown Salix would create a number of jobs for the farmers.

Affects on the landscape and the ecology may conflict with environmentalists. Examples of environmental impacts and interests included were:

- Monetary effects
  - Nature and landscape

- Ecological effects
  - Air pollutions
  - Nature and scenery
- Growing energy forest close to the heating plant
- Bird-watching and nature studies
  - Protection of bird habitats
  - Protection of diversified biotopes
- Environmental control
  - Minimal disturbance of the nature
  - Minimal air pollutants
- Research and development on energy:
  - Test and demonstration of energy technology

Irreversibilities were discussed under the heading "influence of future options". Two kind of uncertainties and risks were identified: effects of the considered alternatives, and general pre-conditions like the world market energy prices.

The effects of the considered alternatives were studied with the help of scenarios. The biomass gasification alternative was found to be the best for interests related to biofuels and the worst alternative for interests like production and interests related to nature conservation. For all interests the wood powder alternative is the best or the second best alternative.

The conclusion of the study was that positional analysis 'is useful in its systematic way of illuminating consequences of the alternatives considered from different points of view and for different affected activities'.

Municipal forestry

Lidestav (1997) used positional analysis to investigate the purchase, sale, and management of municipal forests in Sweden. The study included:

- A general description of the municipality of Säter, including previous and present decisions concerning forest holdings.
- Identification and description of actors and their interests in the municipal forest.
- Identification of 17 different systems affected by the municipal forest (e.g., environmental-, nature conservation-, hunting-, and forestry-systems).
- An analysis of eight monetary and non-monetary dimensions (biological, social, institutional etc), affected by municipal forestry.
- An actor and interest analysis regarding the preference of keeping or selling municipal forest areas primarily used for timber production.
- A synthesis and conditional conclusions.

The stakeholders and their interests were analysed. The stakeholders were the local parliament, the forest manager, the local environmental committee, schools, the park department, local sawmills, the county forestry board, the county department of agriculture, the inhabitants e t c.

The alternatives were to sell or keep the municipal forest.

The conflict of interests showed that one actor can have several and sometimes contradictory interests. Therefore, the question of sales or maintenance can not only be answered on an actor-interest level.

The method used is comprehensive and time-consuming. On the other hand it makes it possible for actors, that are not (forests) experts, to become familiar with the problem and join the decision process.

Adherence to sustainability framework and systems principles

In both case studies, principles and properties of sustainable systems are not explicitly addressed. However, the open framework of positional analysis makes it possible to consider these aspects if the necessary information is available.

With positional analysis, it might be possible to include additional assessment tools and criteria to assess effects, risks, interests and irreversibilities characteristic of sustainable land-use.

All types of effects due to project alternatives can be considered in a positional analysis, and monetary and non-market effects of a decision are assessed separately but side by side (Söderbaum 1990).

Positional analysis assesses environmental loading with the aid of available, pertinent information. Units of measure are selected depending on context. Identification and choice of impacts, interests, risks and irreversibilities are subjective, conditional to context and participant interest.

Ecosystem health as a metric of sustainable land-use is not an explicit component in positional analysis, but could be included if other assessment methods are incorporated.

Positional analysis considers multiple scales and can include network aspects, and by choosing different alternatives, feedback can also be included as a decision component.

Positional analysis does not define sustainability. Participants set their own goals that makes it possible to consider environmental issues and sustainability.

The framework is loosely structured and flexible, making it adaptable and context specific.

Perhaps positional analysis provides a tool suitable to sustainability assessments due to its inclusive and open framework

Strengths and weaknesses

Positional analysis aims at decision support. Responsibility for component and criteria selection and decision outcome lies with decision-makers and not within the method itself.

Positional analysis is democratic, flexible and participatory, and can include monetary and non-market aspects and approaches. The method systematises available and pertinent information, making it possible to make relevant comparisons.

Identification of irreversible effects may be an important consideration of sustainable land-use decisions and is generally not addressed in other methods (e.g., CBA, LCA or EIA – although 'opportunity costs' represent one measure of losses and costs associated with choosing one alternative over another).

The process of engaging in a participatory approach such as position analysis generates benefits regardless of outcomes from representative, inclusive dialogues between interested parties.

By-products are not easily identified or fully assessed (e.g., specific emissions are not shown in detail).

Other environmental assessment tools are better structured to quantify impacts and outcomes. A solution is to undertake a positional analysis in concert with another tool (Forsberg 1996b).

Decision outcomes can be complex and difficult to interpret, and they may generate insufficient conclusions for action.

Stakeholders should be educated both to positively participate and to interpret the result.

The method is time consuming.

A balance is required too keep PA from becoming too extensive, without missing important information.

Because of an intentional lack of specific structures, PA may not generate any useful results if participant interests are selfish, exclusive or uniformed.

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GROUP CONSENSUS, OVERVIEW OF ASSESSMENT METHODS

Areas of application of the methods

Life Cycle Assessment (LCA)

LCA is a method for analysing and appraising the environmental effects of various products throughout the whole of their life cycle. The method was originally developed for trade and industry but has been adapted to allow energy use to be made more effective. From there, development is moving towards the study of environmental effects and the use of resources.

Cost Benefit Analysis (CBA)

CBA is the basis for decision-making for various social issues. Various decisions can be evaluated by describing use of resources and environmental effects in monetary terms. It is aimed primarily at economists and politicians. Companies use CBA as a tool prior to making an investment.

Ecological Footprint (EF)

This method functions as an alarm clock and works for the general public. It is expressed in a unit that everyone understands, and in which the use of resources is clearly shown.

Emergy Analysis (EMA)

Emergy analysis is used to evaluate the flows of energy and resources. It makes a summation of energy on all levels and is aimed at academics.

Index of Biological Integrity (IBI)

The IBI method measures the health of the ecosystem. It is an index of how changes manifest themselves in the ecosystem. It acts as an early warning system for the general public and for environmental protection authorities.

Positional Analysis (PA)

PA is used as a basis for decision-making within various functions of society. The method is suitable for practitioners but is time-consuming for politicians who want to make quick decisions. This method take the context into consideration and dialogue and resolution of conflicts are key components. PA is broad, but does not go into detail.

Can the method measure the difference between fossil energy and renewable energy utilisation?

Life Cycle Assessment (LCA)

LCA has a weighting factor for emissions associated with fossil fuels compared with those of renewable fuels.

Cost Benefit Analysis (CBA)

The market determines the value of the variables. There are various ways of calculating the cost:

- WTP – Willingness To Pay.
- ATP – Accepted to pay.
- Hedonic Price method.
- CVM – Continguent Valuation Method.

Compensatory cost is a way of allocating more realistic prices to products with negative environmental effects.

Ecological Footprint (EF)

Fossil fuel is represented as the land area needed to absorb the same amount of carbon dioxide. Renewable fuel is represented only as the area needed for its production. The fossil fuel area is underestimated.

Emergy Analysis (EMA)

A weighting factor differentiates between finite and renewable energy sources.

Index for Biological Integrity (IBI)

IBI does not include any weighting factor.

Positional Analysis (PA)

Energy is regarded in an overall way. Many different interests have to be included in the analytical process. PA is more a way of dealing with the results of other analyses than an exact method. PA is like an advanced environmental consequences report. Compared with CBA, which converts everything to money, PA is more qualitative. PA analysis is site-specific.

How do the methods deal with cyclical oscillations and pulsing?

Of all the methods, pulsing is only included as a concept in the theoretical base behind emergy analysis. However even there, it is not clearly defined. If one accepts the 'Pulsing Paradigm' (Odum: Odum and Odum 1995), it can be incorporated into every method.

How do the methods deal with waste, emissions and recycling?

Life Cycle Assessment (LCA)

LCA takes into account and quantifies emissions. Assessment of the future effects of emissions on the ecosystem is not included. LCA takes account of the effects of emissions – greenhouse effect, stratospheric ozone destruction, acidification, eutrophication, toxicology, in the form of equivalents. Dangerous chemicals can be flagged. The value of the impact categories depends on whether the material is recycled or not.

Cost Benefit Analysis (CBA)
CBA puts a price on what it costs to clean up or not clean up. The damage caused by emissions is assessed in monetary terms, as is the cost of repair.

Ecological Footprint (EF)
The method takes into account the area required to absorb the carbon dioxide formed during the combustion of fossil fuels.

Emergy Analysis (EMA)
Generally only pays indirect attention to emissions? Generally, only energy processing, the emergy value, is calculated. The transformity increases when the availability decreases. Negative effects are indirectly calculated, if they affect production capacity. For example, forest death reduces biomass production. The cycle is quantified. The more slow-renewable and non-renewable resources used the higher the environmental load.

Index for Biological Integrity (IBI)
The method does not itself measure emissions or recycling. The method gives an indication of the reaction of an organism society to a change in the ecosystem.

Positional Analysis (PA)
If desired, and if the data are available, recycling and emissions can be included.

Sustainability

Life Cycle Assessment (LCA)
LCA analyses flows of energy and material in systems. Recognized environmental problems are included in the analysis.The method distinguishes between renewable and non-renewable flows. It aims to reduce the flows, which leads to increased sustainability.Neither economic nor social sustainability is analysed.Analytical results give an understanding (basis for decision-making) of the effects which influence sustainability. Reduced flows of energy and material lead to e.g. an increase in sustainability.

Cost Benefit Analysis (CBA)
If the assessment of the work of nature and environmental damage is accurate, the method is simple and effective. Directs towards sustainability, if sustainability is evaluated in the monetary conversion process.

Ecological Footprint (EF)
Rough method which shows how sustainability changes.Also rough measure of social sustainability. Increases awareness of what is required for sustainability. The method needs to be developed and refined.

Emergy Analysis (EMA)

Sustainability index measures ecological sustainability. The method has a rough solution, but points in the direction of sustainability. Emergy analysis separates renewable and non-renewable resources. The method converts everything to a common unit, but still needs to be developed and refined.

Index for Biological Integrity (IBI)

IBI measures changes in the health of the ecosystem caused by human or natural effects on the ecosystem. Various characteristics of the ecosystem are integrated into an index. The method only deals with ecological sustainability, not economic or social sustainability. The method measures the actual status of the system. The least affected system available is the reference. It does not provide any direct information on the way the system is affected, but different types of assemblages could indicate how the system has been affected. For example, indicator plants can be used in farming to determine the harvesting time for silage.

Positional Analysis (PA)

Takes into account whatever one wants to include, or has time for. Can include all other methods. It can encompass many aspects of the concept sustainability: ecological, economic and social. The method often does not provide a simple answer.

Strengths and weaknesses

Table 11. Strengths and weaknesses of Life Cycle Assessment (LCA).

Strengths	Weaknesses
• Standardized (ISO). • A good tool for comparing the environmental effects of various production processes. • The results are easy to understand (easy to communicate). • Accepted by industry. Can thereby have a great impact in practical operations and thus produce quick results. • Gaps in available input data can easily be identified.	• Choice of system boundaries and allocation methods can affect the final result. • If the system boundaries are drawn too restricted, the method can give misleading results since it only shows fragments of reality. • It can be difficult to find reliable data. • Assessment of the final result requires knowledge of the reliability of the constituent data.

Table 12. Strengths and weaknesses of Cost Benefit Analysis (CBA).

Strengths	Weaknesses
• Good at communicating results. • Aims at being holistic.	• Difficult to assess the relevance of the value of externalities in currency. • There is a great difference between the market value of resources and their biophysical value. • Does not account for irreversible processes.

Table 13. Strengths and weaknesses of Ecological Footprint (EF).

Strengths	Weaknesses
• Provides the potential to relate resource use to the land and sea area required for the production of these resources. • Pedagogic. • Easy to communicate the results.	• Contamination not included. • The method does not take into account any environmental effect other than CO_2-emissions. • It is a rough method.

Table 14. Strengths and weaknesses of Emergy analysis (EMA).

Strengths	Weaknesses
• There is a single unit for all flows of resources. • It is holistic. • It differentiates between finite and renewable resources. • It takes transformity into account.	• Difficult to communicate the results. • The method has a poor solution.

Table 15. Strengths and weaknesses of Index for Biological Integrity (IBI).

Strengths	Weaknesses
• User friendly. • A quick and direct method to evaluate the health of an eco-system under human in-fluence, which however re-quires a gigantic preparation effort. • Inexpensive.	• Retrospective. • Cannot replace chemical analy ses, both are required to provide a complex and useful picture. • Difficult to determine if an effect is anthropological or natural. • It reveals only the symptoms of a disorder, not its causes.

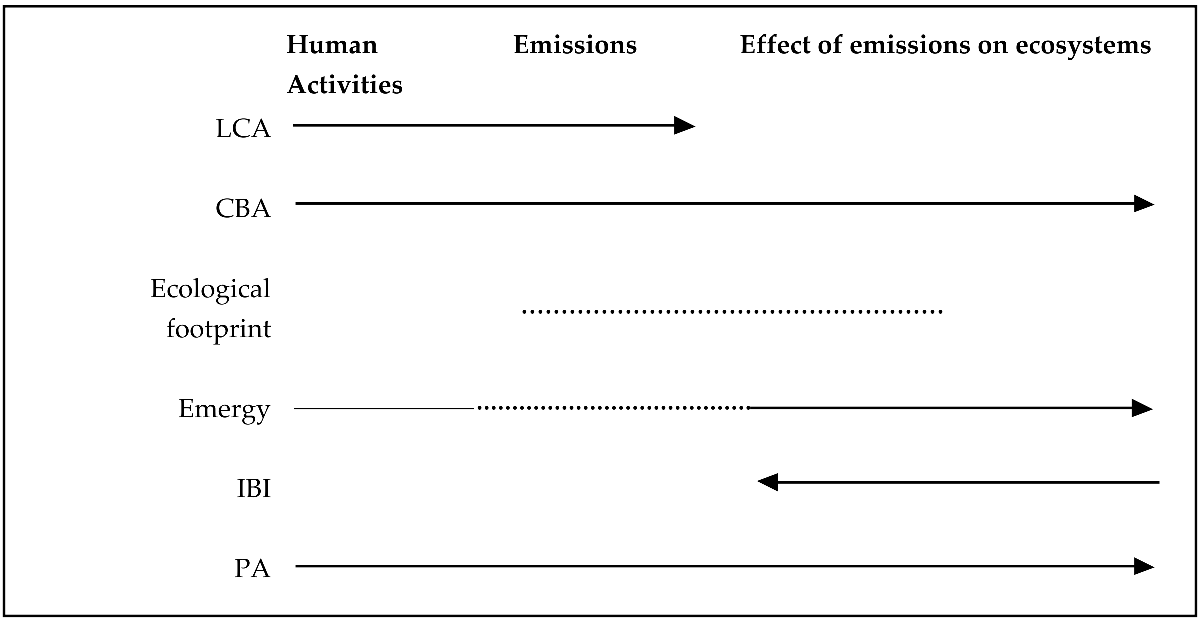
Table 16. Strengths and weaknesses with Positional Analysis (PA).

Strengths	Weaknesses
• Tries to provide a holistic perspective. • Takes context into account. • Democratic. • Users of the results have to eva-luate the results themselves before making decisions.	• Time consuming and complex. • Can only be used on a local level. Too large a system involves too great a complexity. • Users of the results have to evaluate the results themselves before making decisions.

How the methods respond to human activities, emissions and effect of emission on ecosystems.

Figure 5 shows how the different methods respond to human activities, emissions and effect of emissions. LCA for example respond to human activities and emissions, but not to effect of emissions on ecosystems.

Figure 5. The different methods respond to human activities, emissions and effect of emissions on ecosystems.



Discussion

The missing link (Component 1.5)

There was a missing link between the principles of ecosystems and the practice of the methods. We need to deal with the question of which characteristics of natural ecosystems that can be applied in agroecosystems.

The Pulse Concept

- Is the pulse concept applicable in agroecosystems?
- What pulses exist in agroecosystems?
- Is a pulse more than the oscillation patterns which can be observed in ecosystems, e.g. predator-prey as a dynamic relationship in population patterns?
- Do these oscillations provide energy reinforcement and if so, how?
- Can we use these pulses to our advantage or are pulses a threat to mankind?

How should mankind respond to 'pulses'?

- What can be included in the pulse concept? It needs more precise definition. It has been used on so many levels.
- Is the pulse an annual pulse such as the flow of nutrients over a year with ploughing, preparation etc, or is it a catastrophe pulse which happens every 5 - 50 years?
- Does the pulse refer to an intrinsic property of the ecosystem? Odum seems to imply that this is how natural systems operate.
- Can mankind cause pulses?

Slash-and-burn or occupations of flood plains (e.g. rice cultivation in Guinea-Bissau) are what we believe to be pulses.

One would like to be able to identify such pulse relationships in order to learn more about how they operate.

Is the ecosystem collapsing?

Is that which is good for the ecosystem good for the market? What are the similarities? Is it really valid for both systems?

Sustainability does not only relate to the ecosystem. The technical system needs to function in a particular way so as not to destroy the natural ecosystem. Does the agro-ecosystem need to take this in to consideration or can it be looked upon as a natural system?

Some ecologists believes that we can learn from the natural ecosystem when constructing our tech-social system.

Ecosystem interaction and shape index

Ecosystem services are required in agroecosystems. But in what amounts? Area must be set aside for ecosystem services.

The new concept was Ecosystem Interaction: the relationship between agroecosystems and contiguous natural ecosystems. E.g. rape beetle-ladybird. Ladybirds overwinter in natural ecosystems.

How are ecosystem services to be related to the agroecosystem? Plots with areas of natural ecosystem or integrated systems permaculture model? Landscape grants are available for having a high shape index (ratio area to perimeter) or fields less than 0.2 ha. Ecotone, the boundary between two biotopes. Long passages between arable land and natural ecosystems give a high shape index. Is shape index a measure of sustainability? It presupposes a positive net effect of ecosystem interaction.

Guess the method!

- Nearly everything can be evaluated in terms of money.
- Part can be evaluated in terms of money and we discuss the rest.
- Everything is evaluated and converted to solar energy.
- We account for resource use and environmental effects, weight the effects and compare.
- Vulnerable species show how mankind has destroyed the ecosystem.
- If only we discuss all this together, everything will be alright.
- The resources we use are reflected in our footprints.
- If we want to increase emergy, we have to suffer for it.

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APPENDICES

Evaluation of Environmental Assessment tools

Name of method:____
Lecturer:____
Affiliation:____
Date:____
Evaluation Team:______________________________________

1. What is the overall purpose of the method?

    Communication – provides information to others, educational, pedagogic.
    Decisions support – advises user in strategies and solutions for system operations.
    Investigate – provides data for learning behaviour and outcomes.

2. Who are the users?

Academic	Government
Industry	Public
Buisness	

3. What are the expected results?

4. In what perspective is the analysis used?

    Retrospective (accounting, monitoring, records)
    Prospective (modelling, projections, forecasts)

5. Is there an acceptance of the tool and results?

Scientific community	YES	NO	PARTIAL
General public	YES	NO	PARITAL

Where and how frequently is it being used?

6. How are system boundaries treated with the method?

Spatial – Does the method consider the whole production frame, direct and indirect components, or only immediate borders of operations?

Temporal – Does the method consider a snapshot of time, or is it evaluative of time periods (measuring change)?

Lifecycle – does the method consider the lifetime or the cycle of a product or process (past, present and future)?

7. What object(s) is/are being analysed?

Products ☐
Processes ☐
Actions ☐

8. What kind of effects are considered?

Environmental ☐ Social ☐
Economic ☐ Other ☐

9. Does the tool consider context (historical, spatial, social, economic etc.)? In other words, are conditions unique to the system accounted for in the analysis?

10. How does the method consider scale? (hierarchies, nestedness, networks)

11. What environmental impacts are considered?

To what extent (if any) does the method measure by-products?

To what extent (if any) does the method measure environmental load?

12. What is/are the unit(s) of measure?

How are the units relevant to the stated purpose of the method (question 1)?

13. What ability does the method have to communicate results?

14. Are the method and the results statistical rigorous?

15. Is it possible (and desirable) to calibrate the method?

16. Is the method standardised?

What comparisons can be made (with other analyses)?

17. Is validation of results possible?

18. Is the method quantitative or qualitative?

19. What knowledge and equipment is needed to:
   a. use methods?

   b. interpret results?

20. Are results sufficient for independent interpretation or is there a need for reference states/conditions?

21. Is the method based on specifically stated foundations?

22. Is information about internal organisation/design necessary to understand results?

23. Does the method of assessment include follow-up(s)?

24. Can the method facilitate scenarios (WHAT_IF questions)? What happens over time?

25. Does the method address (measure) different resources?
   a. Renewable-use/Nonrenewable-use

   b. Direct-use vs. indirect-use and/or non-local-use

   c. Resource quality, energy form

d. Alternative-uses or substitutes

26. How, if at all, are feedbacks treated? As positive or negative effects?

27. Is ecosystem health measured? How (e.g. biodivesity, function, biomass, NPP etc.)?

28. Are there considerations and / or measurements for socio-cultural or socio-economic aspects of the study system (i.e. fairness, justice, equity)?

29. What might the results say about eco (system) integrity, function and life-support?

30. Provide general and consensus comment on the appropriateness of the tool for sustainability assessments.

Is the tool holistic or reductionistic?

Is the tool inductive or deductive?

Strengths (+)

Weaknesses (-)

Table I. Method articulation of priorty focal areas for sustainability. (Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), Ecological Footprint (EF), Emergy Analysis (EMA), Index of Biological Integrity (IBI) and Positional Analysis (PA).)

	Strong (direct assessment)	**Weak** (indirect assessment)	**None** (no association)
Biophysical limits, potentials	EMA, EF	IBI, LCA PA	CBA
Agro-ecosystem health	IBI	LCA, EMA, EF, PA	CBA
Socio-cultural fit	PA	CBA, EMA, LCA	

Table II. Method as facilitator of change, action toward sustainability. (Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), Ecological Footprint (EF), Emergy Analysis (EMA), Index of Biological Integrity (IBI) and Positional Analysis (PA).)

	High	**Medium**	**Low**
Method procedures:			
Standardisation	EF, LCA, EMA		IBI, CBA, PA
Ease of use	EF		LCA, EMA, PA, CBA
Participatory	PA		LCA, EF, CBA
Results, outcomes:			
Ease of interpretation	EF, LCA, PA		CBA
Participatory			
Pedagogic, educational potential	EF	LCA	EMA, CBA
Prescriptive; application in adaptive management	PA		

Table III. Method perspective; consideration of scale, context and changing states. Scales include: production base (ecosystem life-support); self, local (point of view of participant), community, institutions and others.

Method perspectives	**Life Cycle Assessment LCA**	**Cost benefit Analysis CBA**	**Ecological footprint EF**	**Emergy Analysis EMA**	**Biological Integrity IBI**	**Positional Analysis PA**
Method foundation; world view	No foundation. Traditional scientific reductionistic view.	Neoclssical economics (land, labour and capital)	Ecological (systems ecology)	Systems ecology	Traditional biology, ecosystem theory	Institutional economics market values values and qualities embedded in community
Context specificity	Quantifies environmental impacts.	Human activity	Bioproductive area, ecological, context, resource based	Emergy signature	ecosystem health, impact specific	Takes the economical and environmental context into conside-ration.
Analysis boundaries Temporal, spatial	Life cycle, products and services.	Community⟺ self, narrow	Defined population	Chosen	Chosen	Chosen
Outcomes best describe which scale(s)?	Prodbase – self, also self-community	1 - 2 in figure 2.	3 - 2 in figure 2.	3 - 2 in figure 2.	Ecosystem life support scale	Tries to provide a holistic overview of 1, 2 and 3 in figure 2.
Are outcomes retrospective, prospective or both?	Prospective	Retrospective	Retrospective	Retrospective, modelling is possible	Retrospective	Prospective and retrospective

Table IV. Method features, general objective descriptions.

Method characteristics	**Life Cycle Assessment LCA**	**Cost benefit Analysis CBA**	**Ecological footprint EF**	**Emergy Analysis EMA**	**Biological Integrity IBI**	**Positional Analysis PA**
What is the goal? (what endpoints are targeted?) List of impact categories	Assess resource use and environmental impact In – Out	Most efficient allocation of resources. Values?	Add biophysical values to dominated monetary values. Required biproductive area compared to available.	Assess resource use, emergy flow and storages	Ecosystem health indices human disturbance	Effects and decisions. Action and possible conflicts or ? of action. Conflict avoidance. Impact target.
What is the purpose? (who is the audience?)	Industry Governments	Business Community	Educational. Communicative. Scientists. Ecology. Eco-nomics. There is poten-tial for a common public.	To describe system sources on system base.	Information about ecosystem health	Decision support Stakeholdeers
What are the expected results? What are the units of measure?	Emission equivalents (kg)	Same as for goal. Monetary values	Biophysical limits or possibilities.	Systems diagram. Flows. Indexes.	Public	Decision Selection unrestricted
What input data, information is required?	Emissions. Used resources. High demand of quality data.	Willingness to pay. Monetary values of productional- and opportunity cost. Use of pay principle.	Area/capita Consumption Waste production	Any flow of storage trans-formed to emergy	Dose respond curve or human impact.	Data relevant for stakeholders. Values
What effects are considered? (products, byproducts) How are effects considered?	Goal	Products and some byproducts.	Effects of consumption and waste generation.	All effects (is that possible?)	Metrics. Health conditions. Key species.	Consensus building democratic process
Adaptiveness Other... How much data	Local environment. Standards open for changes.	To market	To ecosystem services or biproductive area. Statistics.	New transformities (weak link). Much data.	A reference is needed. Reveals symptoms not causes.	Complex outcome, can be hard to interpret.

Research School in Ecological Land Use

Centre for Sustainable Agriculture

PhD-courses in Ecological Land Use

Course 6:2000:

Systems Principles and Sustainability Assessments for Ecological Land Use

Instructors

Steven Doherty, Centre for Sustainable Agriculture (CUL), and Torbjörn Rydberg Department of Ecology and Crop Production Science, SLU.

Background

With increasing demands on limited resources world-wide, there is a growing interest in sustainable patterns of utilisation and production.

Standard and comprehensive measures of resource requirements and impacts as well as appropriate assessments of ecological integrity are needed.

Currently there are many methodologies for monitoring performance, each with its own foundations, assumptions, goals, and outcomes, dependent upon agency agenda or academic orientation. Clearly, a concept of sustainability must address biophysical, ecological, economic, and sociocultural foundations.

Assessment indicators and criteria, however, are generally limited, lacking integration, and at times in conflict with one another.

Principles for sustainability, including scale, self-organisation, renewal and commensurate response may be appropriate focal points for critical thinking in an evaluation of current methods and standards.

A framework of general systems principles may also help facilitate a comprehensive approach and promote a context for meaningful discourse.

Without holistic accounts, sustainable progress remains an ill-defined concept and an elusive goal.

Course statement:

- To investigate land use within a framework of systems ecology principles in order to identify technologies and management actions which supports and are scaled to renewable ecological functions and sustainable processes.
- To use this framework to critically evaluate current assessment methodologies in land use.

Goals

- Examine the concept of sustainability.
- Define fundamental and general systems principles that support self-organising processes of ecosystem production.
- Develop these principles of systems ecology into a framework to use in evaluations of agriculture.

- Review existing evaluation methods and assessment criteria for sustainable land use, identifying strengths and weak links.
- Choose appropriate metrics addressing sustainability, and propose comprehensive methods using selected indicators to assess function and structure necessary for ecological land use.
- Apply methods in student investigations of land use case studies.

Component 1: Principles, processes, patterns and partnerships for ecological land-use

In this component, we introduce concepts of ecological land-use within a framework of systems ecology principles and discuss the foundations of sustainability.

Systems models are used to identify and describe ecosystem processes and functions that are scaled to renewable patterns of production. Perspectives are generated that facilitate critical thinking, and a framework is constructed that allows students to broadly consider agro-ecosystems within a context of sustainability.

Concepts of ecosystem "health", "function" and "integrity" are discussed as well as the goals of indicators and criteria in sustainability assessments.

During this section, student and staff members will jointly generate a checklist of general systems principles and key questions to assist in a critical evaluation of assessment methods that will be described in the second course component.

Timeframe: One week of literature reading (17 - 21/1) and one week for an interactive workshop (week 4, 24 - 28/1).
Organisation: Morning interactive lectures, afternoon discussions and modelling workshops.
Credits: Two points (3 ECTS credits)

Component 2: Assessment tools for ecological agriculture

Presentation and review of current and relevant land use assessment methods and certification programs are undertaken in this component.

Professionals from each program will present overviews, goals, procedures and relevance of their methodology.

Assessment examples may include: LCA – life cycle analysis, DSR – driving force-state-response model (OECD framework), emergy analysis, ecological footprint, positional analysis, MIPS – material intensity per unit service or IBI – index of biological integrity.

Certification examples may include: KRAV, ISO 14 000 standards, Natural Step and Smartwood.

Using a systems framework – created during our first component, participants then discuss the utility of current methods, identifying strengths and weak links in each.

Timeframe: Ten days or approximately one day per methodology (1-2 lectures/week during week 5 - 11, year 2000, no lecture at week 8).

Organisation: Morning lectures followed by afternoon discussions.
Credits: Two points (3 ECTS credits)

Component 3: Group Projects

Critical reviews of assessment methods: Student groups (3-4 individuals) extensively research and evaluate individual methods, each within a framework of systems principles.

Critical reviews are presented at the end of the term, collected and edited by course instructors into a published volume. Course participants newly proposed alternative publications: one that incorporates merits from other assessment techniques and another that is scale dependent.

Ranking and quantifying individual metrics can be considered within an organising framework of systems ecology and hierarchical scale.

Timeframe: As possible, projects begin after completion of first course component, following review of pertinent literature.
Organisation: Presentation and final comment are given during a two-day rejoinder near the end of the course section (20 - 21/3). Reports are due two weeks following.
Credits: Three points (4.5 ECTS credits)

Component 4: Individual Projects

Students may choose to take an example from their research and develop it as a case study, using selected assessment approaches and metrics that best address their research questions.

Case studies should be agro-ecological in scope and should use a systems framework for organisation and interpretation of method outcomes.

Timeframe: Projects begin after completion of the second course component.
Organisation: Course participants will come together at the end of the term for 2 additional days to present findings (preliminary 22-23/5). Reports are due 2 weeks following.
Credits: 3 points (4.5 ECTS credits)
Final comment is given based on critical processing of assessment procedures and goals, and upon evaluation results from case studies. A definition of sustainable land-use is again revisited and revised.

Course organisers:

Steven Doherty, Centre for Sustainable Agriculture (CUL), SLU; Torbjörn Rydberg, Department of ecology and crop production science, SLU and Lennart Salomonsson, Research School in Ecological land Use (ReSELU).

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