Ecosystem Management
A Management View

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Abstract

The need for management of the marine ecosystem using a broad perspective has been recommended under a variety of names. This paper uses the term Ecosystem Management, which is seen as a convergence between the ecological idea of an organisational hierarchy and the idea of strategic planning with a planning hierarchy—with the ecosystem being the strategic planning level. Management planning requires, in order to establish a quantifiable means and ends chain, that the goals at the ecosystem level can be linked to operational levels; ecosystem properties must therefore be reducible to lower organisational levels. Emergence caused by constraints at both the component and system levels gives rise to phenomena that can create links between the ecosystem and operational levels. To create these links, the ecosystem's functional elements must be grouped according to their functionality, ignoring any genetic relation. The population structure is below the ecosystem in terms of the planning level, and goals for the community's genetic structure cannot be meaningful defined without setting strategic goals at the ecosystem level for functional groups.

Contents

1 Introduction

In response to the overexploitation of the marine ecosystem and the consequences of fishing—habitat destruction, incidental mortality of non-target species, evolutionary shifts in population demographics, and changes in the function and structure of ecosystems—there has been a call for marine ecosystem management from a broader perspective (Pikitch et al., 2004). There are many terms that cover the idea of managing marine ecosystems from a broader perspective; Garcia et al. (2003) discusses some of these terms: Fishery Management, Ecosystem Management, Ecosystem Approach, Ecosystem-Based Fisheries Management, Ecosystem Approach to Fisheries, and Integrated Management. FAO has settled on the term Ecosystem Approach to Fisheries and defined this term as:

> An ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries (FAO Fisheries Department, 2003).

The term "integrated approach" is here employed to indicate a way of taking ecosystem considerations into the more conventional field of fishery management (Garcia et al., 2003). In other words, the current paradigm of fishery management is to maintain target populations through various controls. The solution is to develop this management into an Ecosystem Approach to Fishery Management through incremental improvements (FAO Fisheries Department, 2003).

Even though, as Garcia et al. (2003) notes, the various concepts are all still fuzzy, and to a great degree overlap in terms of their ideas and objectives, I will use the phrase "Ecosystem Management" in this article. I use this term because I do not necessarily adopt the approach of FAO Fisheries Department (2003), especially, as will be discussed later, not the idea of an Ecosystem Approach as an incremental extension of current fishery management. With the use of "Ecosystem Management," I will mainly depart from *The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management* (Christensen et al., 1996) and argue that this is a strategic approach to the management of ecosystems.

I do find that a central point must be *management*; that is, the development of Ecosystem Management is the development of a theory about how to manage human activities in a way that secures the objectives for the ecosystem. A theory of Ecosystem Management has two sides; on one hand, there is a need to comprehend the ecosystem, while, on the other, there is a need to develop management tools and understand the impact of humans on the ecosystem. A theory of Ecosystem Management must, in order to be complete and not render the two sides separate, build on a common ground between scientific concepts. This common ground is between science related to ecosystems and science related to management. The purpose of this paper is to discuss ideas from ecology and those from management, and find common ground for an Ecosystem Management. One of the main interfaces between the marine ecosystem and human activities is through fishery. Consequently, one of the main challenges facing the management of marine ecosystems is to confine fishery to a level that is sustainable and economically rational. Therefore, the main focus of this paper is the production of the marine ecosystem.

Ecosystem Management

In the Christensen et al. (1996), ecosystem management is defined as:

> Ecosystem management is management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function.
>
> ...
>
> Ecosystem management must include the following (1) long-term sustainability as fundamental value, (2) Clear, operational goals, (3) Sound ecological models and understanding, (4) Understanding complexity and interconnectedness, (5) recognition of the dynamic character of ecosystems, (6) attention to context and scale, (7) acknowledgment of humans as ecosystem components, and (8) commitment to adaptability and accountability. (Christensen et al., 1996, pp. 668–669)

There are in the quotes above and through the article (Christensen et al., 1996) a very comprehensive discussion on ecosystems. They have, however, very little discussion on management, besides setting objectives and goals.

As the idea of this paper is that Ecosystem Management is about both ecosystems and management, there is a need to structure the concept of management. Management can be broken down into subdisiplines in a variety of ways; I will simply divide management into three phases, according to its primary time period of focus:

1. Management activities related to the past are called "Monitoring and Evaluation" activities.

2. Management activities related to the near present are called “Operation” activities.
3. Management activities that deal with future operations are called “Planning” activities.

Some scholars, for example Mintzberg (1994), distinguish between a plan and a strategy. I will not use this difference, instead referring to all that has to do with the operation’s preparation at the right time as Planning.

In the Christensen et al. (1996) above cited definition of Ecosystem Management, the word “policies“ is used; as “policies” can indicate a mixture of Planning and Operation, the definition is not perfectly divisible according to the three categories delineated above. If, nevertheless, the definition of Christensen et al. (1996) is categorised according to the above division in time periods, then “executed by policies, protocols, and practices” is equivalent to Operation, and “made adaptable by monitoring and research . . . ” is equivalent to Monitoring and Evaluation. Planning, then, contains the following three components:

1. setting the “explicit goals,” and
2. ensuring that the operation will satisfy the “goals.”

The first and second components together form the plan. A plan has to be revised after periods of operation, therefore

3. the plan must be adjusted or adapted to new knowledge based on Monitoring and Evaluation.

The definition of management given in Christensen et al. (1996) can then be divided into the three phases of management: Planning, Operation, and Monitoring and Evaluation. It is nevertheless clear that the point of how to secure that eventual Operations will accomplish the defined goals and objectives is rather weak in Christensen et al. From a management perspective, this will be central if Ecosystem Management is to be be successful.

Also from a management perspective, a plan will be successful if the operation prescribed in the plan, when executed in the real world, ensures the goals and objectives set out for management. To ensure a plan’s success, there is a need for models that predict outcomes for various operational options. It is therefore in the planning stage of management that common ground between ecology and economy must be found, at least initially. This paper will therefore focus on the Planning stage of management, especially the search for concepts that are usable as objects for goals and planning models.

I note, however, that it is important to discuss all three phases of management. A management plan cannot be completed without an analysis of potential operational options, as well as an analysis of possibilities for monitoring Ecosystem Management. These aspects will nevertheless be left for future work.

Central to finding common ground between ecology and management is the discussion of ecological and planning concepts. This is the content elaborated in the following section 2. The concept of an ecosystem builds on the idea of an organisation hierarchy, and many papers (e.g., Christensen et al., 1996; Garcia et al., 2003; Pikitch et al., 2004) on Ecosystem Management agree that it is driven by explicit objectives and goals. In accordance with this idea, this paper's thesis is that Ecosystem Management is a management theory about how to manage human activities and their impact on ecosystems, where the management is based on strategic planning.

Ecosystem Management is then a convergence of the idea of an organisational hierarchy with the idea of a planning hierarchy where the ecosystem is the strategic planning level. In order to bridge goals at the strategic level and plans at the operational level, there is a need to quantify links between the ecosystem and the operational level. The ecosystem is a complex adaptive system, and a global restricted resource will create structure and order in the form of a predictable allocation pattern for resources. Section 3 discusses how a global restriction and associated scarcity create order and predictability, thereby allowing for the possible link between ecosystem and operating level.

In section 4, the previous section is summarised and discussed. The result is that if the focus is on global restriction and associated scarcity, the functionality of an ecosystem can be expected to be predictable, which provides the simplicity necessary for seting strategic goals. In the ecological analysis, this follows in the line of, among others, the trophic–dynamic view of Lindeman (1942) and the process–functional approaches of O'Neill et al. (1986). The contribution of this paper is to identify this relation as fundamental to creating the link between the strategic and operational levels when Ecosystem Management establishes a quantifiable means–ends chain.

2 Ecology and Management

2.1 Ecology

Ecology was defined by Haeckel in 1879: "By ecology we mean the body of knowledge concerning the economy of nature—the investigation of the total relations of animal both to its inorganic and its organic environment ..." (Hackel 1879 cited in Keller and Golley, 2000). The concept of an ecosystem came much later, first introduced by Tansley in 1935. An ecosystem, when used in a specific context, is often followed by its definition (e.g., Christensen et al., 1996; Garcia et al., 2003). As the concept of an ecosystem needs definition, it cannot be seen as a concept with a generally accepted meaning within ecology. To understand why the concept of an ecosystem, after more than 70 years, is not a generally agreed upon concept, a brief introduction to some philosophical ecology follows in the section bellow. There is, in ecology, a general acceptance of nature as an organisational hierarchy. However, controversies are related to the entities and their connections within the hierarchy. Further, there is a debate as to holism vs. reductionism as the field's proper scientific approach, these two discussion are to some extent interrelated. This section is philosophically rather incomplete; for further detail, see, for example, Hull (1974), Looijen (1999), and Keller and Golley (2000).

Reductionism and Holism

Nature is organised into a hierarchical structure, as illustrated in figure 1. At the left of the figure is a depiction of how the lower level of the hierarchy provides the building blocks for the next, more complex level. Interactions of components on one level are the origin of phenomena observed at the next level. As phenomena at a given organisational level result from lower levels, scientific explanations must look to lower levels to explain any phenomenon occuring at a given level; this is physical reduction (Hull, 1974).

At the right of the figure 1 is a depiction of the hierarchy of scientific disciplines, with various disciplines within physics as the most fundamental. As the explanation of a phenomena must contain an examination of lower levels, scientific theories can, in principle, be reduced to more fundamental theories; this is theoretical reduction (Hull, 1974). The idea of physical and theoretical reduction as the proper scientific approach is called reductionism.

Nature is, as Looijen (1999) notes, more complicated than the perfect nested hierarchy in figure 1. There are, for example, many organisms that are not built from the

biosphere	global ecology, macro-economics
↑	↓
ecosystems	systems ecology
↑	↓
communities	community ecology
↑	↓
populations	evolutionary biology, sociology
↑	↓
organisms	autecology, psychology, micro-economics
↑	↓
organs	anatomy, morphology
↑	↓
tissues	histology
↑	↓
cells	embryology
↑	↓
organelles	cell biology, genetics
↑	↓
macro-molecules	(bio)chemistry, molecular biology
↑	↓
molecules	organic chemistry, thermodynamics
↑	↓
atoms	classicle particle mechanics
↑	↓
sub-atomic particles	physical chemistry
↑	↓
quantum particles	quantum mechanics

Figure 1: Classic hierarchy of levels of organisation in nature, and associated hierarchy of scientific disciplines (Looijen, 1999, Figure 1).

blocks of organs, tissues, cells, and organelles. The idea of an organisational hierarchy in Nature is, nevertheless, an ecological paradigm in my opinion. There is general acceptance of a hierarchy with different levels of organisation. There is not, however, a general acceptance of reductionism.

Holism, in contrast to reductionism, finds that some phenomena cannot be explained by the parts. That is, they are emergent. Pressure and temperature are examples of emergent properties. Pressure and temperature are gaseous properties that do not exist at a molecular level, but rather as a result of the internal movements of molecules. So, an emergent phenomenon is novel; that is, it is not just a statistical property of its components.

This is, however, not a contradiction of reductionism's approach. The difference is the causal links: are there phenomena that can only be explained on the macro level? The origin of this dispute can be exemplified by Clements (1916)'s view of plant communities. A plant community is formed by plants invading a disturbed or abandoned area. The plants are replaced in a patten labelled succession, whereby the plant community is developed towards an endpoint specific to that climate: the Climax. In the view of Clements (1916), it is the community that, given a specific environment, causes plants to form the climax. The plant community is viewed as a superorganism, in the sense that it is an entity with a self-regulating essence.

The opposing view, that of Gleason (1939), found that a community must be seen as a random assemblage of individuals, or in the view of Lambers et al. (1998, p. 3): The species composition of a vegetation in a given place is determined by three processes:

1. A historical filter: does the species arrive?
2. A physiological filter: can the plant germinate, survive, and reproduce? and
3. A biotic filter: does the species successfully compete and defend for itself?

The filters are not constant, but rather change over time as a result of change in biota and environment. While the superorganism approach to communities may have been abandoned, the concept of the Clementsian superorganism still exists alongside other staging. The Gaia hypothesis is, for example, basically the superorganism approach applied to the entire biosphere (Keller and Golley, 2000).

Looijen (1999, p. 233) argues that holism and reductionism can only be seen as mutually exclusive if holism claims that wholes cannot be analysed and reductionism claims that there are no wholes. Science needs both of these viewpoints. The holistic approach locates phenomena at high organisational levels, while reductionism explains these phenomena. However, irrespective of one's views on holism and reductionism, there is common agreement on the paradigm of organisational hierarchy in Nature.

Dual hierarchy

Tansley (1935) introduced the concept of an ecosystem as "… the whole system (in the sense of physics), including not only the organism–complex, but also the whole complex of physical factors forming what we call the environment of the biome … (idem p. 299)." Tansley emphasizes how the ecosystem is a psychical system and a mental construction. Ecosystems can exist at any scale, and smaller systems are nested within bigger ones, which then serve as the environment for the ecosystem of interest (idem). Lindeman (1942) advanced this ecosystem concept within the trophic–dynamic view.[1] Lindeman's analytic focus is on energy flow as a consequence of organisms' feeding, and the emphasis on the dynamic aspects of an ecosystem as a result of energy flow. The components of an ecosystem are grouped according to their function. One example is the discrimination between living organisms as parts of the 'biotic community' and dead organisms and inorganic nutrients as parts of the 'environment,' which are found to be arbitrary and unnatural (Lindeman, 1942, p. 168).

While Tansley emphasises how an ecosystem is a mental construction, the Odum brothers have emphasised the ecosystem as an entity which possesses various kinds of self-regulating mechanisms, such as a cybernetic network (Patten and Odum, 1981). This view has, according to some (e.g., Simberloff, 1980), taken over the superorganism approach and applied it to ecosystems. Simberloff (1980) labels this approach "essentialism" as it seems to build on the myth of balance-in-nature. Simberloff advocates for liberating the ecosystem concept from high-level determinism and ideas of ideal states.

The traditional hierarchy in an ecological organism–population–community–biome is, since Tansley (1935) and Lindeman (1942), enriched by ecosystem and functional components; these entities do not fit nicely into an organisational hierarchy, and they are often simply added as in the left side of the figure 2, neglecting Lindeman's point that functional components are something different from populations. How the entities are arranged in the hierarchy is important in the reductionist view as explanations must come from levels below; this is especially true of the approach Dawkins (1988) called hierarchical reductionism: "To explain a complex entity at any

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[1] The meaning of *trophic* is "pertaining or connected with nutrition and feeding"

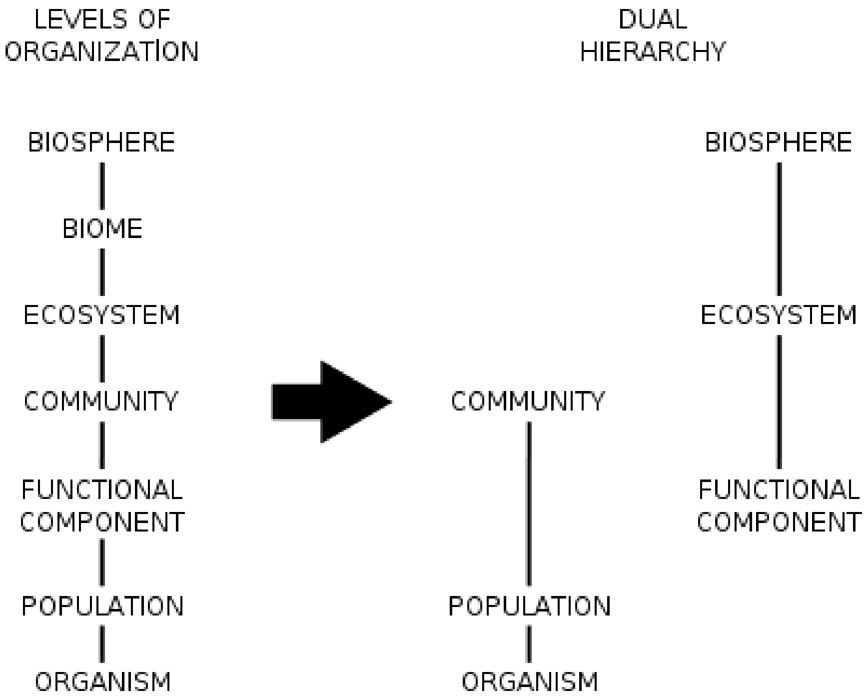

Figure 2: The dual hierarchical structure of ecological systems. To the left is shown the typical levels of organizations .... To the right the population–community and process–functional approaches are considered as separate hierarchies (O'Neill et al., 1986, Figure 9.1)

particular level of organisation, in terms of entities only one level down." The outline to the left of the figure 2 implies that ecosystem processes should be explained by inter–community dynamics.

In order to elaborate the concept of organisational hierarchicies a new approach with more hierarchies was introduced by MacMahon et al. (1978) and O'Neill et al. (1986). Here, the ecological entity is arranged in two nested hierarchies to the right in figure 2. In this way, O'Neill et al. divides nature's organisation into an explicit population–community hierarchy and process–functional hierarchy. The two hierarchies are two perspectives for observing Nature. They are interlinked, as population–community determines the functionality of the functional components (the biological part), and the process–functional restricts the population–community (idem).

Discussion

Ecology traditionally deals with three levels; The individual organism, the population, and the community (Begon et al., 1996). One can think of this as part of an organisation hierarchy; the ecosystem can then be seen as a community with a physical environment (Begon et al., 1996, p. 679). Alternatively, it can be seen as a physical system with processes created by functional components. These two views correspond to two different views of Nature's organisational hierarchy, as shown in figure 2. Often, this difference in views on organisational hierarchy is confused with the controversy regarding reductionism and holism. For example, label both Looijen (1999) and Keller and Golley (2000) ecosystems research programs with the process–functional approach as "holistic". This label is, as I see it, given for one of two reasons: Either because researchers do not follow the population–community–ecosystem hierarchical approach, or because researchers adopt a superorganism approach to the ecosystem. These two reasons are clearly not the same and ought to be distinguished. I find, consistsent with Simberloff (1980), that there are good reasons to question the community as well as the ecosystem as entities with self regulation properties, if these properties cannot be shown to exist on the premises of physical reduction. In addition, there are, as argued by O'Neill et al. (1986), reasons to distinguish between a community and an ecosystem in terms of mental constructions: When research aimed at population–communities, its questions relate to the genetic structure of the system; but when research is aimed at the ecosystem, its questions relate to ecosystem processes (i.e., flows of energy and nutrition). In the former case, the basic entity must be the vehicle for the genes, the organism; in the latter the basic entity must be Lindeman's functional components. If research in the process–functional tradition does not apply a superorganism approach to ecosystems, instead following the lines of reductionism, I find no reason to label it holistic. That is, if holistic means following the ideas of holism.

2.2 Planning

There are many different approaches to and meanings of planning and how it should be accomplished. I use a typology of three planning types in this article. Plans cannot be neatly divided into these three types, as if each type were discrete; rather, all plans contain some of each planning-type. The types are, nevertheless, important as a reference and an ideal.

The three planning types are: "Successive Limited Comparisons," "Rational Comprehensive," and "Strategic". The first two refer to Lindblom (1959), and their key

Box 1: Replication of Lindblom (1959) two planing ideals.

Rational Comprehensive	Successive Limited Comparisons
1a. Clarification of values or objectives distinct from and usually prerequisite to empirical analysis of alternative policies.	1b. Selection of value goals and empirical analysis of the needed action are not distinct from one an other but are closely intertwined.
2a. Policy-formulation is therefore approached through means–end analysis: First the ends are isolated, then the means to achieve them are sought.	2b. Since means and ends are not distinct, means–end analysis is often inappropriate or limited.
3a. The test of a "good" policy is that it can be shown to be the most appropriate means to desired ends.	3b. The test of a "good" policy is typically that various analysts find themselves directly agreeing on a policy (without their agreeing that it is the most appropriate means to an agreed objective).
4a. Analysis is comprehensive; every important relevant factor is taken into account.	4b. Analysis is drastically limited: i) Important possible outcomes are neglected. ii) Important alternative potential polices are neglected. iii) Important affected values are neglected.
5a. Theory is often heavily relied upon	5b. A succession of comparisons greatly reduces or eliminates reliance on theory.

points are replicated in box 1. Lindblom describes the planning ideal as the Rational Comprehensive. He finds, however, the comprehensive analysis in 4a. to be impossible for complex problems. He therefore rejects the Rational Comprehensive planning method. Instead, Lindblom states that Successive Limited Comparisons seems, for administrators and other policy analysts, to be the principal method for policy formulation with complex problems. Such administrators and policy analysts pretend to make plans according to the Rational Comprehensive method but, in reality, their plans are made using Successive Limited Comparison. Lindblom's point is: Instead of focusing on planning ideal that is impossible to accomplish in practice, planning researchers ought to more closely examine how plans are made in reality; that is, by Successive Limited Comparison—or, as Lindblom coined it, by *the Art of Modelling Through*.

Lindblom (1959) provides only these two types of planning. For complex problems, he is probably right to reject the comprehensive analysis in 4a. This is, however, a straw man that Lindblom (1959) built to reject, thereby leaving his "Modelling Through" method as the only alternative. It is a straw man in the sense that the real alternative is the strategic approach to planning.

The strategic approach

The general idea behind strategic planning is that planning must depart from clarifying the objectives and values of a plan's object. Planning must be preformed within a planning hierarchy, where the strategic level is at the top. At the strategic level, planning is performed on a large scale with a long time horizon, and strategic goals are set as the means of achieving the plan's objectives. With the strategic goals defined, a tactical plan can be implemented at lower spatial and temporal scales as a means of reaching the strategic goals. With a tactical plan as a guide, a plan for directing the actual operation can be set in sufficiently high resolution, though shorter in time (Helles et al., 2000).

Strategic planning differs from Rational Comprehensive planning in that Strategic planning does not require models that, based on the interaction of elements, can make predictions on the operational level over long time horizons. Rather, a detailed model is needed for the near future; for planning further into the future, models must operate with elements on a larger scale. Another difference is the way in which uncertainty is handled. In the short perspective, where details are rather well known, uncertainty can be handled by rules of rational choice. For example, one can maximise the expected value. On a larger scale, especially on a strategic level, there will be properties that are so uncertain that they are in practice unknown. Here, the strategic approach will be to place the organisation in a good position whatever the outcome of the uncertainty. This can, for example, be accomplished by allowing for different options under future plans, where choices depend on future knowledge. The idea that flexibility is better than a fixed plan based on traditional expected values, was noted by Hart (1942); for practical examples regarding management of tropical forests, see Albers et al. (1996). For examples of management related to Christmas-tree production and related contamination risks to forest watersheds, see Abildtrup and Strange (1999).

As strategic planning entails a hierarchical planning structure, and long-term goals must dominate more detailed and short term tactical and operational plans, this approach can be labelled holistic planning. This does not mean, however, that the scientific approach behind the plan cannot be theoretical and physical reductionism. It follows that the scientific concepts underlying the plan must be of different scales; for example, the plan's various levels may occur at different levels of the scientific organisational hierarchy. To provide a concrete example: The management of a fishery is, at an operational level, implemented by fishing vessels. Individual organisms are handled at the aggregate level no higher than a schoal. At higher levels, plans may relate to populations or subpopulations, while the strategic plan level must deal with the marine ecosystem as a whole. Below, I argue that Ecosystem Management combines the idea of a planning hierarchy with the idea of an organisational hierarchy of Nature.

To summarise and place strategic planning on the same plane as Lindblom (1959), I provide an outline of strategic planning below.

1c. Clarification of values and objectives is a prerequisite for an analysing potential operations.

2c. The plan secures its objective through a means–ends analysis: First the ends are isolated, then the means to achieving them are sought.

3c.
   i) The test of a "good" plan is that it shows how a prescribed operation will provide the means for achieving overall objectives.
   ii) A plan is successfully, when the operation prescribed in the plan, when executed in the real world, ensure the overall objectives.

4c. The plan's synthesis is achieved through a hierarchical planning approach. Goals are set at a large tempo–spatial scale for the system as an entire unit. The plan is developed through means–ends chains toward finer and finer resolutions. Plans are only made in detail for relatively short time horizons, whereas larger time horizons require plans at more aggregated levels.

5c. Theory is heavily relied upon to qualify and quantify the means–ends chains. As means and ends are often set at different tempo–spatial scales, theory must

> reflect this. For example, a theory may link various levels in an organisation hierarchy, corresponding to the aggregation levels in the plan.

As noted above, strategic planning can be labelled holistic planning, while a more reductionist planning approach corresponds to Lindblom (1959) Rational Comprehensive model. This holistic–reductionist dichotomy within planning does not correspond to holism and reductionism in the scientific worldview. Nevertheless, the two meanings seem to be confused. When I use the term holistic within planning and management, I refer to planning and management only, not to the scientific view, and I use the term strategic management to refer to management with a holistic planning approach.

2.3 Ecosystem Management as Strategic planning

In *The Emergence of Ecology as a New Integrative Discipline*, under the subheading *Ecology must combine holism with reductionism if applications are to benefit society*, (Odum, 1977) writes:

> It is self-evident that science should not only be reductionist in the sense of seeking to understand phenomena by detailed study of smaller and smaller components, but also synthetic and holistic in the sense of seeking to understand large components as functional wholes. (Odum, 1977, p. 1289).
>
> The need to raise thinking and action to the ecosystem level is especially evident as the practices of technology assessment and environmental impact analysis assume increasingly important roles in decision-making … (Odum, 1977, p. 1291).
>
> If hierarchical[2] theory is indeed applicable, then the way to deal with large-scale complexity is to search for overriding simplicity (Odum, 1977, p. 1292).

The holism that Odum advocates—synthesis on a large scale and a search for overriding simplicity within large-scale complexity—is a response to the need for decision-making analysis at the ecosystem level. It is holistic planning that Odum argues for, not scientific holism. Hierarchical theory and the search for large-scale simplicity is exactly what strategic planning requires.

In the quotation from Christensen et al. (1996) given in section 1, the term "clear, operational goals" is mentioned. The use of the word operational must not be confused

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[2] Odum (1977) use the spelling hierarchal

with goals at the operational level. Under the elaboration of the second point, it is written:

> … Goals must be explicitly stated in terms of specific "desired future trajectories" and "desired future behaviours" of the ecosystem component and processes for sustainability. Furthermore, these goals should be stated in terms that can be measured and monitored. (Christensen et al., 1996, p. 669)

These are long-term goals set at the ecosystem level. From these goals, the plan must be developed based on "sound ecological models and understanding." Again, this is a holistic planning approach, consistent with strategic planning. The paper is, however, relatively vague on planning aspects aside from sound ecological models. Under the elaboration of the third point "sound ecological models and understanding," Christensen et al. emphasises that ecological models cannot only be at the ecosystem level, but must include lower levels of the organisational hierarchy. The meaning of "operational goals" must therefore be that goals are related within an ecological model and understanding, such that they can be quantified, measured, monitored, and linked to the operational level. The Ecosystem Management of Christensen et al. (1996) is therefore clearly holistic in its managing approach, building on the concept of an organisational hierarchy in nature. It is vague, however, in recognising the need for a hierarchical planning.

FAO has, in their *Technical Guidelines for Responsible Fisheries: The ecosystem approach to fisheries* (FAO Fisheries Department, 2003), delineated how an ecosystem approach can be made operational. The outline of FAO's approach can be seen in box 2. The general idea is from high level ecosystem goals to establish a chain of ends and means all the way down to the operational level. There is, however, no requirement that high level goals to be operational goals, as is required by Christensen et al. (1996). On the contrary; it is clearly stated that "ecosystem health, integrity, resilience, energy flows and the like are relatively abstract concepts that are not fully understood." When concepts are so imponderable, the mean to achieving such goals as: "conserving biodiversity, maintaining fishery habitats, protecting important food chain functioning, and so on" will be very difficult to quantify. Even though biodiversity may be measurable, it is impossible to answer the question: "How much biodiversity is needed to ensure ecosystem health?" The concepts at the ecosystem level mentioned by FAO Fisheries Department are, in their own view, either too abstract for measurement or are of a non-reducible character. There is therefore no way to link strategic goals to the operational level, and the ends and means chain that links high level goals to the operational level are then only conceptually identifiable. There is no way of knowing

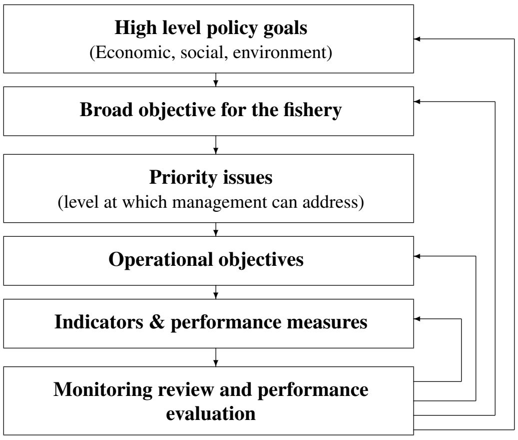
Box 2: Replication of FAO Fisheries Department (2003, Box 1)

Making EAF operational

Available international agreements and instruments along with work already undertaken at the national level in some countries reflect a wide consensus on the need for the incorporation of an ecosystem approach to fisheries (EAF). However, to make EAF operational, the principles underpinning this approach need to be “translated” first into policy goals and then into operational objectives that can be achieved by applying management measures. Without this translation, EAF will remain an important, but largely unachievable, concept.

From principles to policy goals. The principles underpinning EAF cover the full spectrum of economic, social and ecological considerations of sustainable development. Many of the “characteristics” of ecosystems, such as ecosystem health, integrity, resilience, energy flows and the like are relatively abstract concepts that are not fully understood. However, even with our current state of knowledge, higher–level policy goals can be set, such as conserving biodiversity, maintaining fishery habitats, protecting important food chain functioning and so on.

From policy goals to implementation. These higher–level policy goals then need to be broken down into more specific issues, each with its own operational objective that can be achieved by applying a management measure. These need to be at a practical operational level for stocks, habitat, by–catch, protected species, income and social aspirations of the fishers, for example. The chart below shows the step–wise process to be adopted to facilitate implementation (see Chapter 4 for more detail).



Indicators and performance measures for each operational objective provide a framework for monitoring, review and evaluation of the performance of management in achieving both the operational objective, and because of the linkages, the higher–level policy goals.

how much or how little is required at the operational level. In other words, there is no model that can verify that a certain action at the operational level will secure higher level goals and overall objectives.

The consequence of not having a quantifiable chain of means and ends is that the goals set for the operational plan will be floppy. The operational level is then left with only incremental planning, what Lindblom (1959) calls Successive Limited Comparisons. This consequence is illustrated by the Ecosystem Approach being described as an incremental extension of current fishery management (FAO Fisheries Department, 2003). A strategic approach, on the other hand, insists on identifying long-term goals for the management system; for example, this may take the form of a long-term scenario where the management system in interaction with the ecosystem delivers goods and services on a sustainable basis. From this scenario, one can develop a plan for changing a current fishery management regime into the long-term goal for the management system.

There is a general agreement that Ecosystem Management is essentially strategic management. FAO Fisheries Department (2003) do not appreciate, however, the need for the quantifiable links between planning levels, as required by strategic planning. FAO's approach looks like a strategic planning approach, but seems to result in only Successive Limited Comparisons. In order to ensure that management meets its overall objectives, there is a need to identify ecosystem properties that can be quantifiably linked to the operational level; that is, ecosystem properties that can be explained through lower level elements' interactions. There is, in other words, a need for making a holistic plan quantifiable to the operational level, and a need for high-level phenomena that can be explained through physical reduction.

3 Emergence

As argued in the previous section, Ecosystem Management can be seen as a management theory that insists on a strategic approach to management. The strategic approach brings with it the search for overriding simplicity at the ecosystem level and, at the same time, the ability to link this overriding simplicity to the operational level. In this section, I present a view of how overriding simplicity at the system level can be found. It is not my intention to point to new ecological methods—many ecologists are aware of the principle that I put forward. Rather, my intention is to explain why these specific principles provide concepts and models that can create linkages between the strategic and operation levels, and can therefore create concepts applicable to Strategic planning.

This view combines methods and theories from many disciplines, each with its own tradition and discourse. The general theme is organisational hierarchy within a two-level hierarchy: individual elements at the lower level and a system consisting of the set of elements in union, referred to as the system- or macro-level. This type of analysis is practiced in physics, economics, and ecology, and my intention is to combine traditions from these fields into a general understanding of predictions at an ecosystem level. Central to organisational theoretical discourse is the concept of emergence. Traditionally emergence can be defined as follows:

> A system exhibits emergence when there are coherent emergents at the macro-level that dynamically arise from the interactions between the parts at the micro-level. Such emergents are novel w.r.t. the individual parts of the system (Wolf and Holvoet, 2005).

This definition insists on the novelty of a property for it to be labelled Emergent. This is, in my view, too narrow, especially as a holistic plan needs properties that can create linkages between two levels. In the present paper, I shall point to emergent properties that might not be recognised as an emergence because they are basically the sum of their individual parts. Therefore, the properties may be self-evident to exits on the system level. However, I find this special type of emergent phenomena very important to planning.

In recognising different types of emergence, I am inspired by Bar-Yam (2004), who identifies four different types of emergence:

- Type 0 emergence: The system is the sum of its components
- Type I emergence: weak emergence. The interaction of components gives rise to properties that can be observed at a macro-level. However, properties at the macro level are not under a constraint
- Type II emergence: strong emergence. The interaction of components gives rise to properties, and these properties at the macro-level are under a constraint.
- Type III emergence: Lock and key systems.

It is type II emergence that I find important. In physical and production systems, constraints at the system level impose order onto the elements. In addition, a system level constraint creates, in systems with adaptive agents, scarcity that guides the allocation of resources. Finally, scarcity and allocation guides evolution. These three aspects will be discussed in the following section.

3.1 Global restriction and emergence

A physical system

The ideal of reductionism is Newton's work, which reduced Kepler's law of planetary movements and the attraction between massive bodies into "classic mechanics." By introducing the theory of universal gravity and the mechanic law, Newton was able to calculate trajectories within a two body problem, such as one planet orbiting the sun. For a three body system, however, it was impossible to find general solutions; differential equations can be written, but not solved analytically. Poincarè (1890, cited by Ekeland, 2006), was the first to identify the three body problem as a chaotic system. He found that there were solutions that, while non-increasing, were nevertheless non-periodic. Furthermore, a three body system is very sensitive to initial conditions; a small change in the initial condition will yield highly differential trajectories for the bodies.

At the core of Poincare's analysis is the "Stationary Action Principal."[3] If a system consists of, for example, three bodies, each with 10 variables describing their position, speed, rotation, and axis displacement, the mechanic laws prescribe a set of differential equations. Poincarè introduced, together with the system of differential equations, the use of global energy conservation. That is, if the 10 variables of body a at time t are $(x_{a,1}(t), x_{a,2}(t), \ldots, x_{a,10}(t))$ there is a function describing the energy of the system

$$H(t) = H\left(x_{a,1}(t), \ldots, x_{a,10}(t), x_{b,1}(t), \ldots, x_{b,10}(t), x_{c,1}(t), \ldots, x_{c,10}(t)\right)$$

The mechanic laws are energy conservative: If the initial total energy is h, then the system conserves this energy level:

$$H(t) = h \tag{1}$$

This equation (1) of energy conservation describes, together with the mechanic laws, a hypersurface in the variable space called an attractor. The curve described by the variable $\boldsymbol{x}(t)$ is a trajectory, and if the trajectory starts on the attractor it stays on that attractor.

The analysis of Poincarè combines an analysis of the parts—the bodies—with a synthesis of the total system—the energy of the system. This approach provides predictions for attractors and for the bodies' trajectories; trajectories that are too complex

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[3] The analyse of Poincarè is a "Stationary Action Principal" because it is a development of the metaphysical "Least Action Principal" (Maupertius 1745, cited by Ekeland, 2006). The minimization principle had to be abandoned in favour of the stationary principle of energy.

for analysis by other methods. Even though the conservation of energy follows from the laws of mechanics, i.e., from the conservation of energy in the interaction of parts, it is still acting as a type II emergence, where the global constraint restricts the possibly positions of the interaction parts.

Economic systems

Physical systems are often analysed using a global constraint. For example, these may be constraints imposed by energy or mass conservation. Economic systems are often analysed in a similarly way, with a global restriction on input such as that imposed by a budget restriction. Take, for example, a factory with several production units, and each with its own production function f_j based on an external input x_j and an internal input $z_{i,j}$. The internal input is the production unit's production internally distributed; that is, $z_{i,j}$ is the internal distribution from i to j. In other words, $\boldsymbol{z}$ is an input–output matrix. The outlet from the production unit j is $y_j = f_j(x_j, z_{1,j}, z_{2,j}, \ldots) - \sum_i z_{j,i}$. The production vector will be restricted by a global input $x_\bullet$ to an attractor

$$\Psi = \left\{ \boldsymbol{y} \;\middle|\; \begin{array}{ll} y_1 & = f_1(x_1, z_{1,1}, z_{2,1}, \ldots) - \sum_i z_{1,i} \\ y_2 & = f_2(x_2, z_{1,2}, z_{2,2}, \ldots) - \sum_i z_{2,i} \\ \cdots & \cdots \\ x_\bullet & = x_1 + x_2 + \cdots \end{array} \right\} \tag{2}$$

The attractor Ψ is probably some hyperspace that is a subset of the full output space, with as many dimensions as the production function. The restriction on input to the system $x_\bullet$ creates a type II emergence: the attractor of production Ψ. If we are considering a factory, the points on the attractor Ψ that are farthest away form the origin in a given direction is in economics known as the Production Possibility Frontier. In addition, the internal allocation is, when production occurs on this frontier, said to be technically efficient. An economic analysis of a production system can then be said to be an analysis of type II emergence created by a constraint, such as fixed inputs or a budget constraint.

Ecological systems

Ecosystems are far more complicated than in the simple production model (2) used above. One fundamental difference is that, in the ecological system, the product and the production unit are the same: A single fish is, for example, both a product that can be eaten by other fish or humans, and a production unit that by consuming smaller fish produces through its somatic growth or through reproduction. To have a meaningful model for this process, we must average by grouping production units into suitable groups. A production model for group j with mass s_j can therefore be

$$\frac{\partial s_j}{\partial t} = f_j(x_j, z_{1,j}, z_{2,j}, \dots, s_j) - \sum_i z_{j,i} - y_j \tag{3}$$

x_j represents the resource that is restricted to $x_\bullet$ at the system level. The elements $z_{i,j}$ in the input–output matrix represent the quantity individuals in unit j consume from a unit i per time unit. The element y_j represents the human extraction from the resource, and the production function f_j must include the maintenance, respiration, and reproduction costs of the group's units.

This model (3) is a production model, as it is built over the physical principle of conversion of mass. This principle is secured by the input–output matrix $\boldsymbol{z}$ and the global constraint $x_\bullet = \sum_j x_j$. As in the physical system and the production model (2), the global constraint may create an attractor, here the outlet $\boldsymbol{y}$. As biomass may accumulate in the form of an increase in s_j, it is a possibility in the simple model (3), that the attractor will not be defined without additional assumptions.

In a biological system, the input–output matrix is itself a function of $\boldsymbol{s}$: $\boldsymbol{z} = \boldsymbol{z}(\boldsymbol{s})$. Whether the model above will be useful depends to a high degree on whether the input–output matrix function $\boldsymbol{z}(\boldsymbol{s})$ and the production functions f_j are predictable. In addition, a system of differential equations like the above has a high probability of exhibiting chaotic behaviour. Whether the functions are predictable, and whether the attractor will be useful as an ecosystem property, will all depend on the principle for how the production units are grouped.

3.2 Self-organised systems

Economic systems

If the economic system (2) is a manufacturing factory, a manager can decide how the input $x_\bullet$ will be divided into the vector $\boldsymbol{x}$, and will also determine the internal allocation—the input-output matrix $\boldsymbol{z}$. The manager might use some type of optimisation principle and plan the operation using the Rational Comprehensive principle. On the other hand, if the system is the supply side of an economy's private sector, then the production functions f_i are the production functions of economic agents. The internal allocation, the vector $\boldsymbol{x}$, and matrix $\boldsymbol{z}$ are determined by the interaction of these agents. Under the assumption of a market with perfect competition (i.e., full information about price and quality, everybody being a price taker, firms selling identical products, costs of trading low) the allocation of resources will be efficient; that is, somewhere on the Production Possibility Frontier. Here the assumption of a perfect market can make predictions related to internal allocation. In this way, the restriction on the system level, together with knowledge about the allocation regime, reduce the production system's attractor.

If resources are allocated under another regime, for example, an open access regime, the agents will compete to get resources first. The system's production will not be at the production frontier, but the allocation will still be structured according to the allocation regime, with a reduction in the total production's attractor as a consequence. Knowing the global restriction, the internal production function, and the allocation regime will produce a relatively small attractor for production.

Ecological systems

Within a single organism, it is expected that we would find an allocation of resources as if it were optimised. For example, we would expect to find the distribution of nitrogen in a tree canopy's leavaes to follow the general rule of maximisation. In this case, the first order condition is that the marginal change in daily photosynthesis with respect to a marginal change in a leaf's nitrogen content must be equal over the entire tree. Lambers et al. (1998, Box 7) shows that the empirical distribution closely follow this principle. This allocation would not have come into place because of a perfect market; rather, it is a product of evolution. The evolutionary process has favoured those trees that utilise their resources best; that is, according to the optimisation principle.

Between organisms, however, it is normal to expect competition for resources, both between individuals of different species and between individuals of the same species. At the same time, all individuals will try to avoid being eaten. The general allocation regime in nature therefore corresponds to what is known as open access in economics. This is generally true, though with some exceptions, such as with social animals, parental care, symbiotic lifeforms, and the like.

3.3 Adaptation and evolution

Economic systems

Both economic and ecological systems are not only complex, they are Complex *Adaptive* Systems (Arthur et al., 1997*b*; Axelrod and Cohen, 2000; Gell-Mann, 1995; Holland, 1996; Levin, 1998). The complexity comes from many locally interacting components, which in economics are called agents, and the adaptivness origin in the agents' adaptive responses to local interactions. Some studies of complex systems emphasise the system's unpredictability, as with the Arthur et al. (1997*a*) stock market model, where agents adapt to signals from the marked; this adaptation will cause unpredictably fluctuations in the stock market. In contrast, the emphasis of this article is on system properties that can be predicted. Economics has long tradition of this. For example, environmental economists advocate for tradeable pollution permits (Montgomery, 1972) and tradeable extraction permits (Clark, 1990). Tradeable permits create a market, whereby the most cost efficient actors will be willing to pay most for permits, thereby creating an efficient allocation of scarce resources. This is an analysis of how the Complex Adaptive System will adapt to constraints imposed by a policy. Tradeable pollution and extraction permits are equivalent to a restriction on the input $x_\bullet$ to the model system (2), and an imposement of an free market regime. The market will, in the short run, allocate quotas to those who use the resource most efficiently, and the production $\boldsymbol{y}$ will be close to the production possibility frontier, if the market has perfect competition.

Aside from the short-run effects of production approaching the production possibility frontier, another well known consequence is that technical development will increase production efficiency with respect to the permit's object. If, for example, the restricted resource in the model is a fixed level of CO_2 quotas that are tradeable between agents, then the short run consequence is an allocation of quotas to those who use the resource most efficiently. The scarcity created by the quota also sends a signal for changing production strategies.[4] That is, production strategies may shift toward initiating development with regard to more efficient use of not only the CO_2 quota, but of all diverted products, for example more efficient energy use. In this way, global restrictions guide development not only for the primary users of the permits' object, but also creates a scarcity in the system that works as a guide for future production development.

The above discussion only considers the consequences of a perfect market regime, but what happens if the regime is open access? For example, imagine a fishery where the government, to prevent overfishing, has put a total allowable catch on fisheries, such that there is a yearly fixed catch of $x_\bullet$. When the year's catch reaches a total of $x_\bullet$, the fishery is stopped for the rest of the season. The open access regime conveys a signal that, because it threatens to close the fishery, makes the fisher consider *time* to be a scare resource. The short term outcome will be a race to catch fish before the fishery is stopped—in reality, before the other fisher catches theirs. The scarcity of time sends a signal at the same time to change production strategies. That is, firms should initiate

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[4] Strategy is used here for agents' behavioural rules given all possible circumstances, like in game theory. Unfortunately, this is also the same word used for the strategic level of a strategic plan.

development with regard to more efficient usage of time. As the allocation regime rewards those who catch fish fastest and most costefficiently, an evolution toward more and more efficient fishery strategies is the result—followed by a shorter and shorter time lap before closures of the yearly fishery.

As seen above, the scarcity created by global constraints and allocation regimes jointly guide evolution, irrespective of whether there is a perfect market or open access. Other types of allocation regimes will do the same; for example, in a system where the allocation regime is dominated by nepotism or bribery. This will send signals to agents who adapt their strategies thereafter. This will have the consequence of these regimes experiencing their special type of evolution.

Human society is generally a complex adaptive system with a great deal of subsystems, where adaptation works just as in economic systems. For example, Hull (2001) argues for science to be thought of as an evolutionary process of scientific concepts, and Gell-Mann (1995) suggests that human language changes vocabulary over time as a consequence of adaptive processes. None of these systems, however, posit a production system structure with a global restriction as the model (2). Science (hopefully) has mechanisms for testing a scientific concept's usefulness as a description of the world. Similarly, language is restricted by its usefulness for communication. They are, even though they are part of the global production system, not by themselves systems as in the production system model (2), in which a global restriction leads to scarcity. As a consequence, the evolution of these fields are not predictable in the same way. Another example is art and fashion; there is no doubt that these develop as the consequence of an adaptive process, but predictions will be difficult as there is no resource that exists under a global restraint.

For an outside spectator, these phenomena—art, fashion, and language—will constitute type I emergence. Type I emergence in a Complex Adaptive System yields evolution that is hard to predict. Type II Emergence may, on the other hand, be hard to recognise as an emergence because it can be simply a restriction on the sum of parts. Nevertheless, type II emergence has predictable consequences for the system.

Evolution in ecosystems

The economic system is, as an evolutionary system, in a state where productivity related innovation is quite staggering. Despite the possibility to predict the direction of the evolution, its pace, and the resulting production structure will be faltering. In contrast, the biosphere is, in its fundamental parts, quite old; the many metabolic systems and enzymes are shared with little difference across kingdoms, and organelles' functionality is shared by eukaryotes. Examples are the Calvin Cycle—the chemical pathway for converting water and carbon dioxide into sugar[5]—and, especially, Rubisco[6]—which is almost identical throughout the plant kingdom (Stryer, 1995). The most recent physiological invention within photosynthetic functionality was the evolution of the C_4 pathway[7] that enhances the Calvin Cycle under low carbon dioxide concentrations, high temperatures, and water shortages (Lambers et al., 1998). Based on the molecular clock of DNA mutations, the evolution of the C_4 plants seems to originate 25–32 million years ago, whereas they first show up in paleontological observation 12.5 million years ago (Osborne and Beerling, 2006). Since 6–7 million years ago significant amounts of the C_4 plants contributed to primary production in the tropic. Today they dominate the tropical savannas and grasslands, and account for approximately 30% of terrestrial carbon fixation (idem).

This evolution of physiological functionality is, from a geoecological perspective, staggering and of huge consequence—atmospheric CO_2 levels decreased, dry savannas with fire regimes emerged, and animals evolved in response to new conditions (Beerling, 2007). From a human perspective, this is nevertheless so slow that it can be seen as constant for all practical intents and purposes. In other words, organisms will all be very close to a local optimum with respect to the internal use of scarce resources. *Optimum* as an individual in evolutionary terms; competing for resources, avoiding predators, and ultimately reproducing successfully, and *local* means that evolution is an accumulation of selections deriving from small variations in the population; evolution is therefore incremental and restricted by its evolutionary history. As the allocation regime is almost always open access in ecosystems, this does not lead to efficiency on a global scale. It does mean, however, that seemingly identical solutions turn up across phylogenetic lines. One example is that the C_4 pathway, according to DNA data, developed in over 40 different places in the phylogenetic tree (Osborne and Beerling, 2006), but where the production is functionally identical.

In addition, the physical environment imposes constraints that are often tackled in a discrete set of ways. For example, where plants' buds are situated during seasons with adverse conditions (e.g., cold seasons, dry seasons) forms the basis for grouping plants according to a set of lifeforms (phanerophyte, chamaephytes, geocryptophytes,…)(Raunkiær, 1907). Raunkiær's lifeforms group plants across the phylogenetic tree, and as these plants compete in similar ways for the same resources, they will become functionally more alike than if they were grouped according to phylogeny.

These similarities in functionality lead to the possibility of grouping organisms

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[5] Triose phosphates

[6] The principal protein for deoxidiation of carbondioxide

[7] Example of important C_4 food crops are maize, sorghum, millet, and sugarcane.

across the phylogenetic tree according to how they function in relation to an ecosystem's production; that is, into the functional components of Lindeman (1942). A proper grouping of individuals according to functionality, in addition to the matching input–output matrix z, will be emergent from the scarcity imposed by global constraints. Understanding how scarcity and allocation regimes group individuals into functional groups is a key to creating linkages between the ecosystem level and the organism, linkages which are needed for strategic plans.

Within ecology, there is a niche theory with a *Competitive Exclusive Principle* that states that if two species utilise the same niche of an ecosystem, one will be better and will eventually out-compete the other (Begon et al., 1996). This theory expects that all species use the ecosystem in a different manner, which is then clearly the opposite view of the principle of functional grouping presented above. This is, however, a matter of scale. It is not expected that individuals within a functional group will perform exactly identically. On the contrary, it is expected that there will be great diversity, for example, with respect to physiological adaptation to a climate. The adaptive process works on the functional group as a whole; a change in climate will favour those among diverse functional groups that are best adapted for the change, leading to a short-term selection of the most fit, and a long-term evolution in genetic material.

3.4 Summary

Constraints working on the system level give rise to type II emergence. In this section we first show how type II emergence creates attractors in physical and economic production systems. The ecosystem will, as a physical system, show similar emergences and attractors when restraints work on the system level. We then develop a simple production model (3) for the ecosystem. As this model contains a restraint on external inputs, an internal allocation matrix, and production as a function of allocated resources, it has the properties of a production model. In addition to the attractor directly created by the constraint, the constraint also creates a scarcity of resources as seen by the agents in adaptive systems like economic and ecological ones. This scarcity will, irrespective of a market or open access regime, create knowledge about internal allocation. At the same time, the scarcity and the allocation regime will guide evolution. Evolution is therefore directional and predictable when there is scarcity. In an ecosystem seen as a physical and production system, order and predictability are expected to be related to production. The elements must be grouped according to their function in the production system in order to reveal this predictability. That is, they must be grouped into the functional components of Lindeman (1942), and the element–system hierarchy will then correspond to the process–functional hierarchy of O'Neill et al. (1986).

4 Discussion

Ecosystem Management is a management theory about how to manage human activities and their impact on ecosystems in ways that secure the ecosystem's objectives. A theory of Ecosystem Management, then, has two sides. On one hand, there is a need to comprehend the ecosystem, while on the other there is a need to develop management tools and understand their impact on the ecosystem via humans. Management activities can be categorised according to time, i.e., whether the activity is related to the past, present, or future. In this paper, the focus was on activities related to the future, which we referred to as planning. It is, however, noted that a management plan cannot be completed without an analysis of potential operational options, as well as an analysis of possibilities for monitoring in the context of Ecosystem Management. Nevertheless, as a planning activity particularly calls for common ground between ecology and management, we focus on planning concepts that can bridge disciplines in this paper.

The concept of ecosystems is inseparable from the idea of an organisational hierarchy in nature, and strategic planning operates within a planning hierarchy where long-term plans must dominate more detailed, short-term plans. In the paragraph 2.3, we find that Ecosystem Management is a convergence between the ecological idea of an organisational hierarchy and the idea of strategic planning—with the ecosystem as the strategic planning level.

From a management point of view, a plan is successful if the operation prescribed in the plan, when executed in the real world, ensures management's goals and objectives. To ensure a plan's success, there is a need for models that predict the outcome of operational options. As the strategic goals must be set at the ecosystem level, and operations are preformed lower in the organisational hierarchy, there is a need for models that can create linkages between the ecosystem level and the operation level.

Models are a simplified representation of systems and phenomena in the real world. The process of creating models can be stylized as illustrated in figure 3:

1. The real world is simplified into a conceptual model
2. The conceptual model is specified and formalized into a mathematical model
3. The mathematical model is calibrated, that is, the parameters in the mathematical model are estimated, and

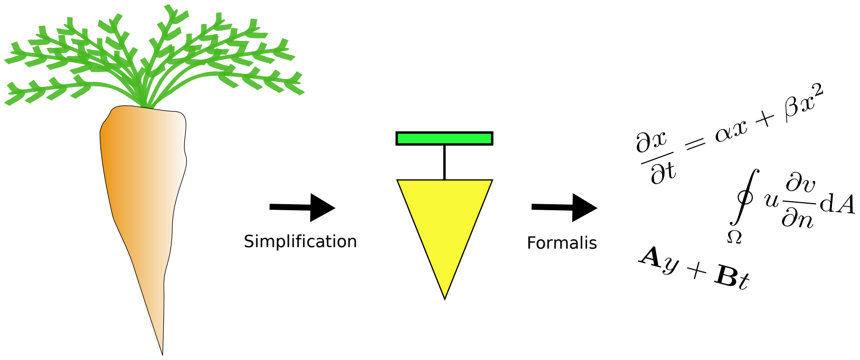

Figure 3: Mathematical modelling. (After Pedersen and Pedersen, 2005, figure A.45)

4. The model is validated, e.g., by testing the calibrated model on data not used for calibration.

The focus of this paper is on the first point: How to pinpoint models' concepts?

In ecology, there is an agreement that Nature is an organisational hierarchy. Disputes exist within ecology over causality in the hierarchy. These disputes center around approaches represented by reductionism, which demonstrate a strictly bottom-up causality, and those of holism, which demonstrate a top-down causality. Type II emergence (Bar-Yam, 2004), which is caused by a constraint working both on the component and system levels, gives rise to phenomena that create order within the system. The system level constraint can be imposed merely by summing the constraints on elements' interaction, such as the need to conserve mass or energy. Type II emergence therefore fits into the reductionist view of strictly bottom-up causality, though to some degree it also fits into the holistic view of order created at the system level.

Order and predictability as type II emergences are presented in the section 3, which is found in physical and production systems. Emergence is created by a constraint on a ressource at the system level. An ecosystem will, as a physical system, exhibit this emergence. The model (3) represents a simple ecosystem production model that, under additional assumptions, may show a similar emergence. The characteristics that make this model a production model are: a restraint on external inputs, an internal allocation matrix, and the elements' production as functions of the allocation. In a system with adaptive agents, the system level constraint creates a scarcity of resources as seen by the agents. The allocation regime under which the resources are internal allocated creates additional order. In addition, the scarcity directs evolution and makes its direction predictable. In order to profit from the order and predictability that is a consequence of type II emergence, the ecosystem's elements must be grouped according to the order evolution has created with respect to production.

Aside from the dispute in ecology with regard to causality in the organisational hierarchy, there are different views as to what the concept of an ecosystem is, as well as how Nature's organisation hierarchy works. O'Neill et al. (1986) suggested that there is a dual hierarchy: the population–community and the process–functional hierarchy. The present analysis of where type II emergence can be found converges with the dual hierarchy view, and expects order and predictability in the process–functional hierarchy. The ecosystem is considered here a physical and a production system, and elements are grouped according to their functional components in the trophic–dynamic view of Lindeman (1942).

O'Neill et al. (1986) suggests a dual hierarchy where the second hierarchy is the population–community. Questions related to this hierarchy relate to the context of genetic relations; the phenomena in this hierarchy are therefore not direct consequences of scarcity, and are therefore not caused by a type II emergence. Phenomena caused by other types of emergence are not examined in this paper, but probably are the dynamic and evolution related to this type of emergence hard to predict. The attractor related to the population–community hierarchy may therefore be very large and not useful for creating a quantifiable ends–means link between the ecosystem and operation levels, at least not by itself. This does not mean, however, that this view must be ignored. The attractors for the process–functional system restrict the population–community system; the population–community system is therefore below the ecosystem in terms of its planning level. Goals for the community's genetic structure can therefore not be meaningfully defined without strategic goals set at the ecosystem level for functional groups.

Conclusion

Generally, models are simplifications made to understand the world. The question of how to identify modelling concepts is fundamental to science and, if science is an evolution of concepts for describing the world (Hull, 2001), the question becomes akin to philosophy. Particular planning and management build on models for how the real world works—not necessarily mathematical models, but always conceptual models. This paper develops a thesis for how to select concepts for management models in the context of Ecosystem Management. As the question of how to identify concepts touches on a philosophic level, the findings of this paper cannot be seen as a proposition that can be either proven or falsified; it must be seen as a thesis that shows its usefulness by applying it as a method for practical planning and modelling problems.

In summary, the thesis of this paper is that Ecosystem Management is a convergence between the ecological idea of an organisation hierarchy and the idea of strategic planning with a planning hierarchy—with the ecosystem as the strategic planning level. Management planning requires, in order to establish a quantifiable means and ends chain, that the ecosystem level's goals can be linked to operational levels; ecosystem properties must therefore be reducible to lower organisational levels. Emergence caused by a constraint that works both on the component and system levels gives rise to phenomena that can create links between the ecosystem and operation levels. To create these links, the ecosystem's functional elements must be grouped according to their functionality, ignoring their genetic relation. The population structure is below the ecosystem in terms of planning level, and goals for the community's genetic structure cannot be meaningfully defined without strategic goals set at the ecosystem level for functional groups.

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