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The need for new paradigms in integrated socio-economic and ecological coastal policy making

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Abstract

Those that make and implement marine environmental policy require social, communication and technical instruments that allow them to explore, at a relevant level, the human-induced changes to socio-economic and ecological systems. Also needed is a holistic and integrated approach to coastal management from which a natural extension is the development of Policy and Decision Supporting Systems (DSS). Carrying out the responsibilities of governments requires knowledge and understanding of the relevant socio-economic as well as ecological structures and processes. At present there is a mismatch between the available approach and the information requirements of decision making. New paradigms in integrated coastal zone management can be derived which (1) reconsiders the use of 'energy', (2) the application of Knowledge Graph Theory to structure in a logical and transparent way the integral system, (3) the application of Ecological Network Analysis to bridge the socio-economic and the ecological systems and (4) the weighing of explored policy options by 'public decision making' based on 'imaging' of the results. Furthermore, we contend that the development of these DSS tools requires:

- Long-term project research to provide ecological data;
- Easily understood and relevant descriptions of systems at the appropriate spatial and temporal scales and based on a good fundamental understanding which in turn requires: 1. A good understanding of the structure, the inherent processes and critical links between variables of each part of the socio-economic and ecological system. 2. The full analysis of non-linear system behaviour by, *e.g.*, (knowledge) graph theory, simulation models and ecological network analysis to know how material or energy is cycled within the systems and what structure links (species) are critical in the systems processes (functioning).
- Visualisation of system behaviour, through the creation of images of differing management alternatives and scenarios at all relevant spatial and temporal scales;

- Examination of those images by a wide audience as a means of a more democratic and public decision-making approach which is based on perception and the appreciation by society instead of that by a single decision maker.

It is emphasized that public decision making is not meant to substitute governmental responsibilities.

Introduction

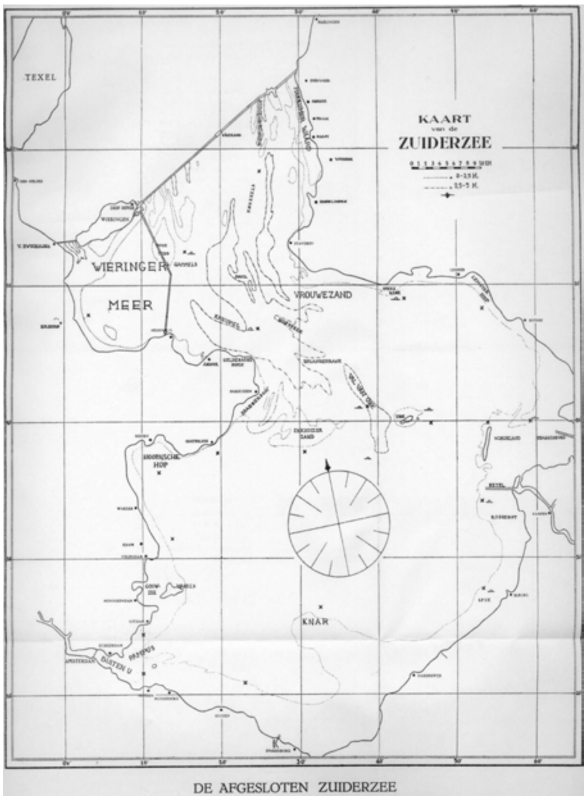
The Wadden Sea within a societal context

The Wadden Sea is an area which primarily functions as a nature conservation area (Anonymous, 1994) and so this role has to be borne in mind in all considerations. Policy-makers, decision-makers and politicians have a prime responsibility for the maintenance of the conservation integrity of the international Wadden Sea, protecting its diversity of species and habitats, guaranteeing the free development of its basic physical processes, preventing pollution, and stimulating sustainable use and sustainable development. The same players are also responsible for protecting the Wadden Sea by the implementation of the relevant EU Directives (Elliott *et al.,* 1999). However, in tandem with this is the protection by these stakeholders of the important local Wadden Sea-related economy that guarantees sufficient development in employment and which forms a suitable basis for the development of local prosperity or well-being. With the exception of recreation and tourism, the stimulation of the local economy has always been difficult because of the conservation function of the Wadden Sea and because of the traditional character of the human activities in the Wadden Sea region. Historically important human activities were agriculture (dairy and arable farming), several types of fishery, mining for gas, the extraction of (fossil) shell resources from the sediment and several forms of recreation (boating, bathing and other water sports, walking the intertidal flats). Some of these activities are in conflict with the nature function due to producing pollution or other perturbations (large-scale dredging activities, mining activities, some forms of shellfish fishery) while other activities can be regulated and carried out in a sustainable manner with nature conservation (shrimp fishery, boating for recreation, bathing and walking of the intertidal flats).

The above indicates that policymakers, decision makers and politicians need to reach a compromise between economic and ecological interests. Because of this, they require social, communication and technical instruments that allow them to predict or explore at the necessary level the environmental effects of planned human interventions, activities and their alternatives; the latter include compensation and/or mitigation measures.

The implementation of EU Directives requires a knowledge of both the structure and functioning (rate processes) of the natural system. These prerequisites have not been fulfilled so far because of a lack of knowledge about critical structure links within the local ecological communities, *e.g.,* 'who eats what and who and how much'. Because of the strong and complex interactions between the socio-economic and natural systems, it is also necessary to understand the structure and functioning of the socio-economic system within the same context. It is also important to develop the required decision tools including elements such as system structure and the integration of process and structure. In addition, there is the need to integrally weigh the outcomes at suitable spatial and temporal scales to support the decision-making process. It is suggested

Figure 1. Closure dam (Afsluitdijk) separating the former Zuiderzee from Dutch coastal waters (map reproduced from Redeke 1936).



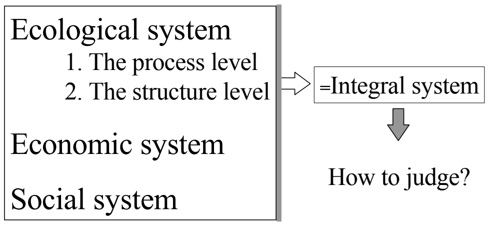
here that in this weighing process, psychological elements as ‘appreciation’ and ‘perception’ should play a more important and thus more explicit role than previously in Wadden Sea policy making.

The Wadden Sea and rational decision making

Under certain conditions and for some purposes we are able to predict changes caused by certain human activities. A good example of this relates to the changes in tidal regime and currents after the building of the 30 km long dam (Afsluitdijk) closing the former Zuiderzee (Thijsse, 1972; Fig. 1) in the period 1928 - 1932. These predictions were made possible by the availability of a physical conceptual approach on which to base tidal calculations; in effect the approach was mono-disciplinary. A similar biological conceptual understanding was not available during the 1920s to give support predictions of the changes in flora and fauna. This lack of knowledge subsequently led to a major and long-term descriptive study which aimed to follow the changes in the species composition and population distribution due to this major engineering work. The reference situation of what became later the IJsselmeer was then described in the early 1920s (Redeke, 1922, 1936) while the changes were studied during the period 1928 - 1943 (NDV, 1928 – 1944; de Beaufort, 1954).

The present Dutch environmental policy for brackish and marine waters is based mainly on socio-economic needs and the possible effects of it. The possible effects of the accompanying human activities are monitored and compared against developed reference levels of water quality criteria (e.g. concentration levels of polluting substances compared to reference levels). The collected data are used to feed poorly validated computer simulation models. Only a restricted number of species play a surrogate role, which for various reasons are judged to represent ‘the ecosystem’ or properties of it such as ‘ecosystem health’ or ‘resilience’. This approach, however, does not consider structure (species composition) and function (processes) as an integral part of the natural environment because it focuses on fragments of the environment, and it is therefore not in line with the recently adopted EU Water Framework Directive (WFD) (EU, 2000), which dictates the protection of ecological status. A good illustration may be the development of the policy and decision supporting instrument WADBOS (Engelen et al. in press) in which the effects of the shellfishery on the ecosystem are described by focussing on bivalves as functional groups and on some relevant bird species without considering other

Figure 2. Diagram presenting the integral system.



relevant aspects. An example of relevant aspects is the above mentioned critical structure links and the role of, *e.g*., mussel beds as a habitat for other species. The 'ecological status' dictated by the EU WFD is basically structure-oriented but also allows with lower priority the incorporation of processes. To date, the ecological status of the Wadden Sea has never been defined by research explicitly focused on that aspect. Consequently, the present, deteriorated ecological status as well as the desired ecological status (the Wadden Sea has been changed significantly; see the review of de Jonge *et al.,* 1993) are thus still undefined because of lack of sound data. This shortage of information leads to conflicts in the decision-making process on future policies. Now, 70 years after the closure of the Zuiderzee and after much land-claim and many closures of former marine and brackish water areas, we still lack widely accepted and operational scientific concepts incorporated into management tools that are suitable to explore the effects of human activities on the whole, the integrated system (Fig. 2). A clear, integral picture or even frame of any conceptual model is still required in order to prevent decisions being based on poorly defendable arguments such as 'gut-feeling' or 'expert-judgement', being subjective rather than objective and thus also based on too many emotions.

Aim of paper

The aim of this publication is to consider how the available instruments for supporting decision-making relate to the way final decisions are currently taken as well their role in implementing the EU Water Framework Directive (EU, 2000). It is contended here that there is a mismatch between the available instruments and the information requirements of decision making.

Questions treated in this paper are based on how to improve integration of the ecological system and aspects of the socio-economic system in the decision-making process by the formulation of a set of new paradigms in this field. These comprise Knowledge Graph Theory, Ecological Network Analysis, visualisation of the results of policy options and reconsidering the use of the variable 'energy'. This discussion, by its nature, takes into consideration subjective elements in the decision-making process, such as 'perception' and 'appreciation'.

Decision making and system theories

Some relevant concepts from general system research

The starting point for the decision-making process is the available knowledge of the system, as included in data and system models. In order to explore the possibilities for improving integration of the different systems involved, this section will describe some concepts relevant for structuring complex systems.

The notion of the importance of approaching our world as a 'system', its mathematical description and the application of it in hypothesis-testing, predictive and explorative models dates from the first half of the last century. Since the mid 1940s the 'system' concept emerged as a key approach in science in quite different disciplines varying from human behaviour and social sciences to the natural sciences, including biology (von Bertalanffy, 1968). Differences were recognised between 'closed systems' (an application of classical mathematics) and 'open systems' for which new approaches were sought because in these systems 'sets of elements are standing in interaction'. Attempts were made towards scientific interpretation following synthesis and to compose a theory with a general application named 'general system theory'. Closed systems were considered as being 'unorganised complexity' while open systems were considered as being 'organised complexity' (von Bertalanffy, 1968), showing 'strong interactions' (Rapoport, 1966) and which are usually non-linear. Contrary to closed systems, the final state in an open system is not only determined by the initial conditions, but it may be reached from different initial conditions called 'equifinality' (von Bertalanffy, 1968). Organised complexity implies the existence of some hierarchic order which may become manifest in 'structure' (order of parts) and 'function' (order of processes) of systems, among them ecosystems. Order within all the different socio-economic and ecological systems may lead to some generally applicable principles, concepts and laws allowing us to integrate these different (sub)systems at a general level. A recent paper of Holling (2001) is still on 'understanding' of the complexity of economic, ecological and social systems. It demonstrates that the discussion on how to develop a well-structured integrated socio-economic and ecological system with the proper units to describe its dynamics in space and time has not been settled yet. Apart from system theory in general, many useful and applicable theories related to systems were developed between 1940 and 1970. Within the present context the following are of interest:

1. 'Graph theory', especially the theory of directed graphs elaborating relational network structures (Rashevsky, 1956, 1960; Rosen, 1960) and applicable as relational mathematics or topology (Edens & Baretta-Bekker, 1989; Van Koningsveld, 1998).
2. 'Information theory', aimed to be used to measure the level of organization (Shannon & Weaver, 1949; Quastler, 1955) and very useful for 'network analysis' (von Bertalanffy, 1968; Ulanowicz, 1997).
3. 'Theory of automata' (Turing, 1936, see also Minsky, 1967), consisting of abstract automata, input, output, possibility of 'trial and error' and learning and suitable to simulate any complexity within given constraints. For applications of cellular dynamics in combination with Geographical Information Systems (GIS), fractal urban forms and modelling of urban land-use dynamics see, *e.g.,* White & Engelen (1993a, b) and White et al. (1997).
4. 'Decision theory' (*cf.* Arrow, 1956), a mathematical theory on choices among alternatives which has found wide application (see, *e.g.,* Pouwels, 1996 and Kolkman *et al.,* this volume).

The large-scale technical developments in computerisation have given a strong impulse to all elements of 'system research' in the social and behavioural as well as the natural sciences. Despite the finding that all these systems can be described and studied using comparable mathematical formulations, this has not led to the expected unifying approach in all these disciplines. It has merely led to a further sub-division or divergence of disciplines. This is understandable as, given all the new possibilities, there was the predisposition by scientists for mainly deepening their own fields or interests and there was less willingness for broader and interdisciplinary research. At present, there is an increasing need for an integrated approach in coastal zone management. Currently, attempts are undertaken to integrate the different disciplines involved, but the progress in this is still limited because of the complexity of the field.

Application of system theories in managing the Wadden Sea system

It is of note that out of the four theories mentioned above in relation to 'system theory', three have already found application. Graph theory is today a scientific discipline. In The Netherlands, one of its clones, the 'Knowledge Graph Theory', has been successfully applied at least twice: the applicability to structure any system as preparation for mathematical descriptions and for building a computer simulation model (Edens & Baretta-Bekker, 1989) or to develop a management strategy for the restoration of eelgrass in the Wadden Sea (van Koningsveld, 1998).

The application of cellular automata (*cf.* White & Engelen, 1993a) was incorporated in the WADBOS policy and decision support system (DSS) for the Wadden Sea (Engelen, in press; Engelen et al., in press). This DSS combines and integrates several approaches to support policy making, among them dynamic modelling, a dynamic geographical representation of model results in GIS, the valuation of options and the weighing aspects. Ecologically, it makes use of process-oriented (carbon flux) computer simulation models in which most of the species have been aggregated to 'functional groups'. The decision theory has found wide attention in management science and has found also wide application.

In contrast to the above 3 system theories, to date there has been no structural application of 'information theory' to the ecological system of the Wadden Sea. However, there has been a long tradition in the USA in the application of this theory in the form of 'network analysis', developed by Ulanowicz in the 1970s (Ulanowicz, 1980, 1997).

Omissions in present decision making

Decision process

There are many ways to structure the decision making process (*e.g.*, Ministerie van Financiën,1992; de Bruin & de Graaf, 1991; Walker, 2000). It is a rapidly developing area (Courtney, 2001) from which it is clear that the most suitable procedure is dependent on the perspective from which one starts (technically, strategically, politically). From a technical point of view Miser & Quade (1985, 1988) described that rational decision-making is not a sequential process but consists of a number of logical steps that may be followed in iterative cycles. These steps include:

a. structuring of the system and defining indicators
b. identification of alternatives
c. exploration of consequences (the effects)
d. weighing of effects
e. choice of alternatives.

Role of subjective elements

Assuming that we are able to structure our integral system satisfactorily from both the structure elements (e.g. species) and functioning (processes) point of view and that we are able to explore the consequences of the different policy alternatives, even then important problems remain. These are connected to a series of aspects containing communication, impressions and perceptions and at the end thus also the weighing process of the alternatives and the final choice.

During the decision process objective decisions need to be made but if this is not possible, as is often the case, then subjective choices have to suffice. These are based on impressions and perception of existing and new situations. Although techniques are available to transfer subjective elements to a numerical, semi-quantitative scale it remains questionable whether these data can be considered as rigorous data.

Another problem lies within the scientific arena. When discussing decision or policy supporting tools and other models, scientists necessarily ignore large parts of the ecological structures (the species composition) of natural systems simply because of lack of information. Until now, they have mainly to rely on process studies (system functioning or rate processes) because long time series on species composition in combination with the functioning of these systems are scarce or absent. This problem has to be solved by studies focusing on the ecosystem structure in combination with the functioning (rate processes). In addition there is a strong need for an improved visualisation of the final results (see below).

A further problem encountered by the decision makers is that they (politicians included) may perfectly understand the scientists but still feel the necessity to simply ignore these scientists for whatever reason. These reasons may be connected to the fact that these decision makers have to harmonize between several management interests or political interests but the consequences may be dramatic. For example, the ignorance of the expert criticism to the way the food needs for overwintering oystercatchers in the Wadden Sea was established by the responsible civil servants and the way the biological minimum of the herring population in the North Sea was misused or manipulated in favour of establishing more favourable catch quota to the fishermen.

A difficulty related to those who make decisions is that they also have their own impressions of the area under consideration or the problem. This is based on imprinted images obtained during contacts or visits. It is often and understandably focused on the impressive things like large species (usually seals and birds, i.e. the 'charismatic megafauna', the 'cute and cuddly' approach) and landscape (elements). As a remedy, we can recommend the need for an improved visualisation of the final results at different scales resulting in a real confrontation with the consequences of choices since pictures act on a deeper level in the human brain (the available impressions) than language does.

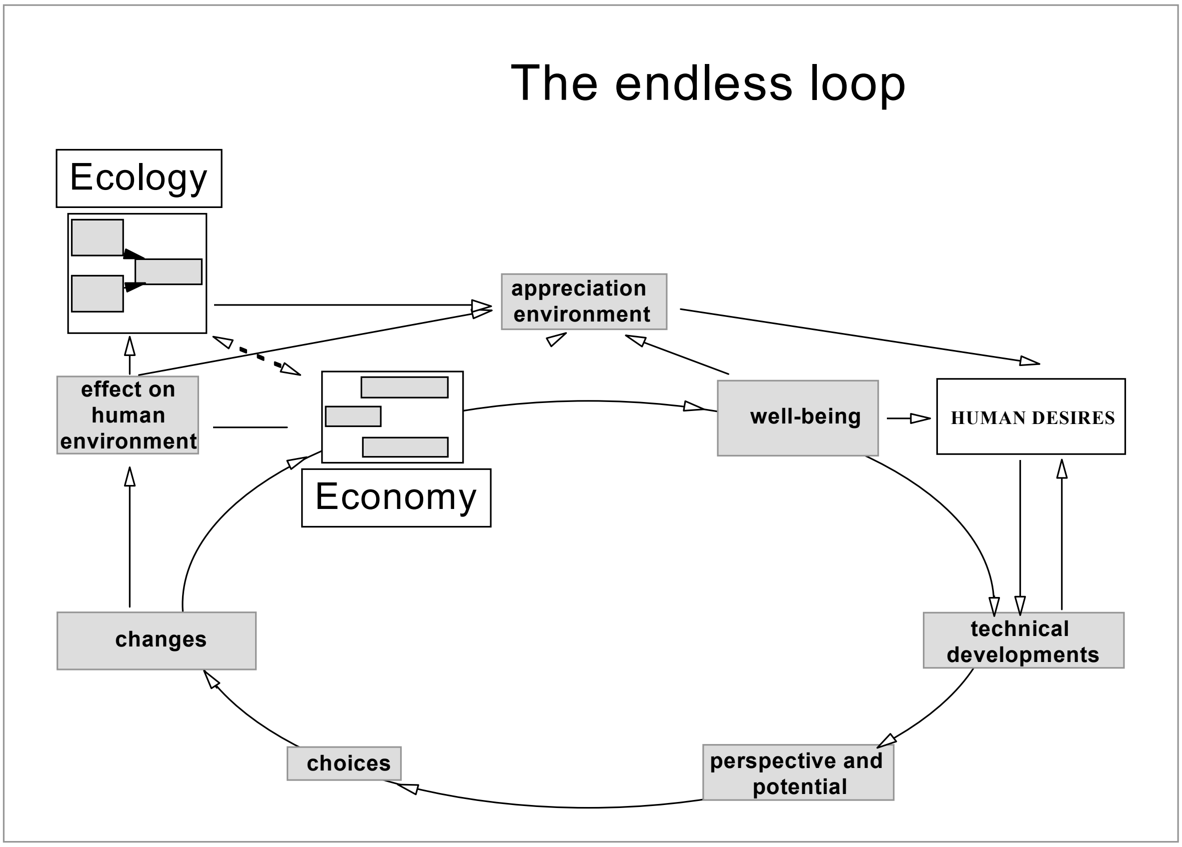
Even in case that suitable technical weighing tools are available to help to reach decisions, even then the results can be questioned because it has been demonstrated (Pouwels, 1996) that the outcome may depend on the method used.

Suggestions for how to proceed are given below.

Assessing the quality of the ecological system and the socio-economic system

Assessing the economic quality is usually done by the well-known feature of setting a financial value to both goods and services. Assessing the ecological quality of the Wadden Sea system is possible in several ways. Quality can be assessed by putting a financial value to goods as well as to nature (e.g. what price is a nice view?) (*e.g.*, de Groot, 1992). It can, however, also be done without putting financial values to it but by using a system in which the morphological and biological expression of the present Wadden Sea resources can be scaled on a relative basis. Necessary elements vary from undisturbed, free development of all

Figure 3. The 'endless loop' which is part of the human social system (*cf.* De Jonge & de Jong, in press).



processes guaranteeing the development of the basic morphological entities (providing conditions) to structure-related elements or indices as species diversity against the background of a known reference. Instead it is suggested to use an assessment based on an integrative approach in which structure and function (processes) both are incorporated by means of Ecological Network Analysis (Ulanowicz, 1997). Then the final results of this approach should at the ecosystem, assemblage or species level be converted into realistic images representing the explored policy or management alternative at quite different scales (from ecotope to landscape). The latter element has not been used to date as a means of reaching real public policy making in the Wadden Sea area.

Weighing

Pouwels (1996) and Kolkman et al. (this volume) have assessed the quality of 14 existing decision methods and they concluded that, given the specific elements of the Wadden Sea area, none of them was applicable as a specific Wadden Sea DSS. Therefore, it is suggested here to include, more widely than at present, personal opinions or judgements on management alternatives in the decision method by applying the 'nature valuation' technique developed by Ruijgrok (2000). This method consists of abiotic, biotic and psychological (perception and appreciation) components based on which the valuation of nature is determined. Especially the nature appreciation aspect (psychological component) is meant to represent the quality of nature as granted by men.

Social, Economic and Ethical Considerations

Despite the fact that we have put financial values to services and goods, the objective assessment of the economic quality is not without problems. We, as stakeholders in that system, have to judge in an objective way the quality of our own economic and social life within a natural and cultural environment for which the reference is simply a never saturated human desire. Humans usually 'want more' of elements that can be specified in quantitative terms but they also require always something 'better', which is not easy to specify. This criterion/phenomenon is part of the Endless Loop in Fig. 3. One of the dilemmas here is that what we appreciate and desire differs from the elements connected to the natural system to which we belong. Driven by well-being we easily change the natural system probably more than is good for a sustainable development of the area under consideration in the long term. It is axiomatic that these aspects are viewed anthropocentrically in that we consider aspects from human values (both financial and otherwise). Environmental management and desires, such as a healthy Wadden Sea, are easiest to argue for when related to financial yield today (e.g. better fisheries or increased attractiveness for tourism) whereas future sustainability, even to producing better fisheries in the future rather than at present, is more difficult to be accepted by the public. This is summarised by the 'Tragedy of the Commons' - the free-for-all related to fisheries (mis)management. Our own ideas, our own artificial, not nature-related goals as well-being, for which we need money as a means to realize it, have historically always been more important than a sustainable environment. The primary goal of sustainability by humans is not to sustain nature but to improve their own 'well-being', hence the arguments are reduced to financial terms. There is evidence that mainly in the well-developed rich countries, this is changing. Man becomes more aware of the ecological links between what harm we can do and what species/populations we rely on (*e.g.,* habitat destruction and the ability to find new species as medicines). Man requires food, living area and recreation possibilities but wants (see above) an exciting, continuously changing environment. In contrast, what nature needs is basically nothing more than a continuation of an over time varying set of 'providing conditions' causing the natural variability in space and time. It is axiomatic that human activities influence the natural system, but the question is when a level of irreversibility is reached from where the system may develop differently from the present one. Thus, in principle, increasing socio-economic quality can easily negatively influence the ecological quality of our environment. For example, the disposal of dredged sludge obtained from channel maintenance dredging has several consequences. One is the economical benefits of increased potential of the transportation of goods. The dredging activities, however, change the erosion – sedimentation cycle in the estuary which results in higher turbidity levels (de Jonge, 1983). The disposal of the harbour sludge in the system may cause turbidity changes at long distances from the disposal site (de Jonge & de Jong, in press). Further, due to the activity itself local habitats may be destroyed. Two other well-known examples refer to the effects of excessive beam trawling affecting benthic quality or oil-field and gas-field development affecting water quality. Whereas mitigation measures will be required, often these are either not possible or not sufficient to reduce effects, for example it is not possible to mitigate against the effects of land claim but merely to compensate for it. The

Figure 4. Pictures presenting objects at different scales. Coastal defence along the sandy coast of the south west of The Netherlands at landscape scale, macro scale (row of poles) and meso scale (pole as substrate for organisms).

accepted principle of compensation measures (Anonymous, 1994) to nature can only compensate by providing favourable conditions in which a certain habitat can develop (i.e. it produces the physical conditions in which a niche can develop and then that niche requires to be colonised naturally by relevant species). Hence, in itself the provision of conditions only represents potential for development. Habitat creation may attract certain species as a compensation for a decrease in the extent of another natural area/habitat although in some cases the loss of a particular habitat in one area (e.g. intertidal saltmarsh from land claim) may be compensated for by creating another habitat in another area (e.g. mud flat). Whether this is really an acceptable compensation measure is questionable.

The endless loop (Fig. 3) is on the one hand positively fuelling the economic system but it also forms a problem due to the waste production and due to the fact that increasing prosperity results in a need for more space per individual. The first one is negatively influencing the entire integral system while the second is mainly negatively influencing the ecological part of it. The aim for such a system is to translate a lose-lose system, or a lose (environment)-win (economy) system to a win-win situation in which sustainability of environment also equals economic improvements (i.e. better intertidal feeding area for birds and fishes).

When generalising the above it is clear that the economical starting point of 'making maximum profit' and the ecological starting point 'nature reserve' cause a tension that in the long term possibly cannot be profitable to the Wadden Sea. It is necessary to find a way to model these processes so that the ultimate effects of human activities can be visualised by images in an instrument that supports policy making or decision making. The integration of the increasing knowledge of the natural system and its interaction with Man's activities may help to resolve such conflicts.

The quality of the integral system can be assessed technically by several methods, of which the questionnaire approach (Ruijgrok, 2000) to a representative sample of the human population is widely accepted. The question, however, is whether or not this is helpful to the responsible authorities because, when looking at the final results, judging the living environment is usually a matter of perception of the decision-maker mainly. That is the reason for the above suggestion to include this aspect more explicitly in the decision method itself by creating images of the expected new situation.

The image in Fig. 4, for example, shows that the judgement of the beach is strongly dependent on the interest of the observer in either the landscape elements, the building elements at the macro scale (the poles as individual rows) or the meso scale and micro scale where the poles form the substratum for the settlement of any species, in this case mainly barnacles.

This all means that judging the integral system cannot be done objectively because this judgement is dependent on such qualities as personal interest in the subject, the personal prosperity, and the personal influence in the political arena. Moreover, the duties of the responsible politicians go far beyond the present interests of the inhabitants. Therefore, these politicians have to take the final and concrete decisions about the future of the area based on a wide 'view' or 'perspective'. However, this is also against a background of pragmatic politics which are summarised in English as the NIMBY factor ('not in my back yard') and NIMTO ('not in my term of office') - the limited spatial and temporal concerns of many politicians who are responsible only for a limited constituency and for a limited time. It is preferable to discuss this in terms of stakeholders in which politicians are one such stakeholder but so are the fishermen, the recreational public, the gas companies, etc. As with all stakeholders, the main population should be involved in the decision process making it a real democratic process, instead of only a restricted group of people, which is more and more today's practice.

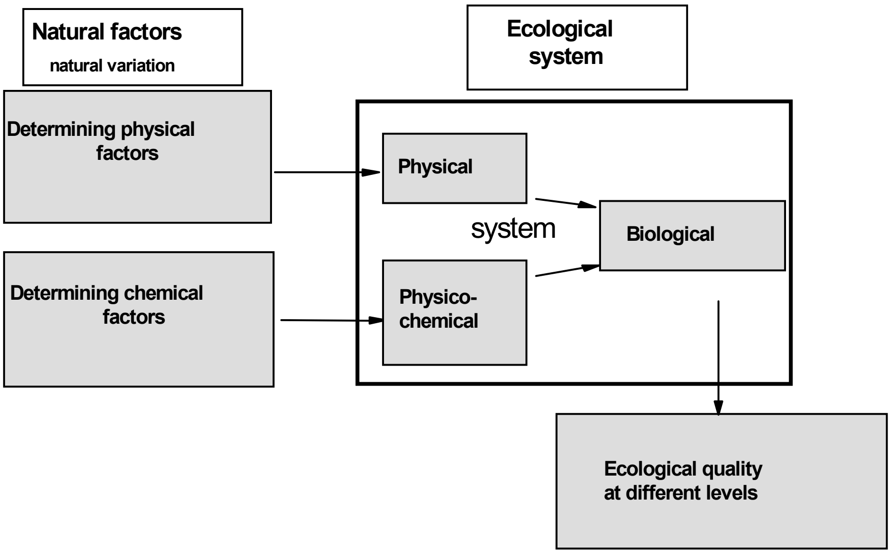
The decision making process for complex systems like the Wadden Sea, especially the structuring of the problem, involves learning processes (*e.g.,* Hisschemöller, 1993; Verbeeten, 1999). Models play an important role in this learning process by communicating assumptions, beliefs and data between science, decision maker and stakeholder (Edwards, 1996; Elliott, 2002). Most of the learning and/or communicating is done on the conceptual level (de Tombe, 1994). From this conceptual level 'images' of the state of the system will be interpreted and explored, and consequences of alternatives will be valued and judged. Therefore the learning process needs to be addressed explicitly within the integrated decision-making.

How to proceed

Structuring the integral system by Knowledge Graph Theory

Structuring the ecological system for management purposes at a highly abstract level (Fig. 5), thus for exploring human impacts, could very well be done by Knowledge Graph Theory. As a first step

Figure 5. Structuring the ecological system at the process level.

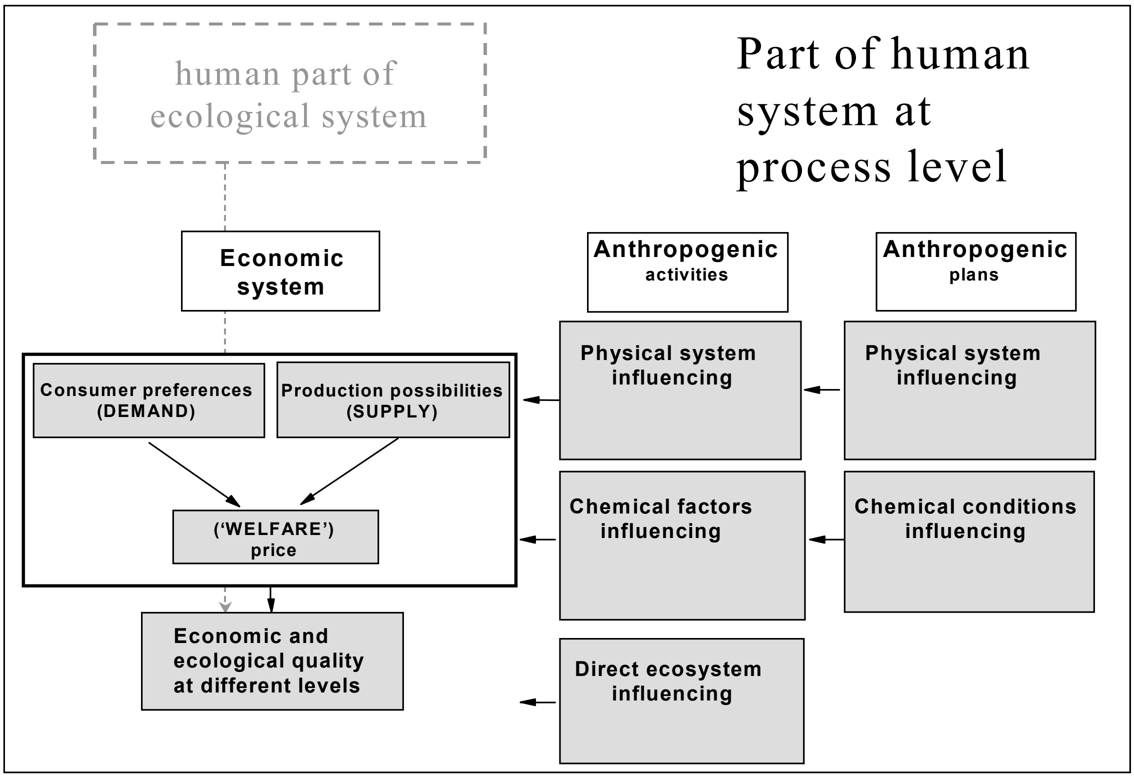


we consider the distinction between two categories or sets of main variables at the process level. The first category includes the natural variability or 'noise' while the second represents all the factors related to human society, each of which may produce an effect or signal which is to be detected and assessed against that background noise. Further, a functional structure is needed to represent the human impact on the ecological system in a general way. Identifying three subsystems - biology, chemistry and physics - has solved this, although it is acknowledged that each of these blocks itself represents a complex system. The background knowledge justifying this approach is that the energy to drive this system is derived from the underlying physiographic, geological and hydrodynamic regimes (bathymetry, geomorphology, tides, winds, density and residual currents). They are responsible for basic morphological structures and water movement, thus providing the basic conditions for organism colonisation. Conceptually, the chemical compounds are mainly responsible for 'altering the providing conditions by varying the basic potential for biological development'. For example, the overriding salinity and temperature regime will dictate which species will occur based on their inherent tolerances to salinity and temperature. The solar energy is the source for the production of natural 'goods' such as the activity of (functional) groups of species. This process can conventionally be described in terms of, *e.g.,* organic carbon fluxes and biomass at the process level. Apart from biomass, the natural goods can also be expressed in terms of species as the 'building blocks' of any ecosystem. However, since the growing interests in process studies in the 1970s, this is an uncommon approach.

A biological system will develop under a given set of conditions as long as the elements of that biology (*e.g.,* particular species) are not excessively and unsustainably taken but also as long as there is no interference in the basic resources requires by species (food, space and sexual partners/colonising stages).

Under this set of physical and physico-chemical conditions, the expression of the ecological system at the process level (in terms of production) as well as the species level (in terms of, *e.g.,* species richness) will be judged by the social system (Fig. 5). As a first step Knowledge Graph Theory can be very

Figure 6. Structuring the economic system at the process level.

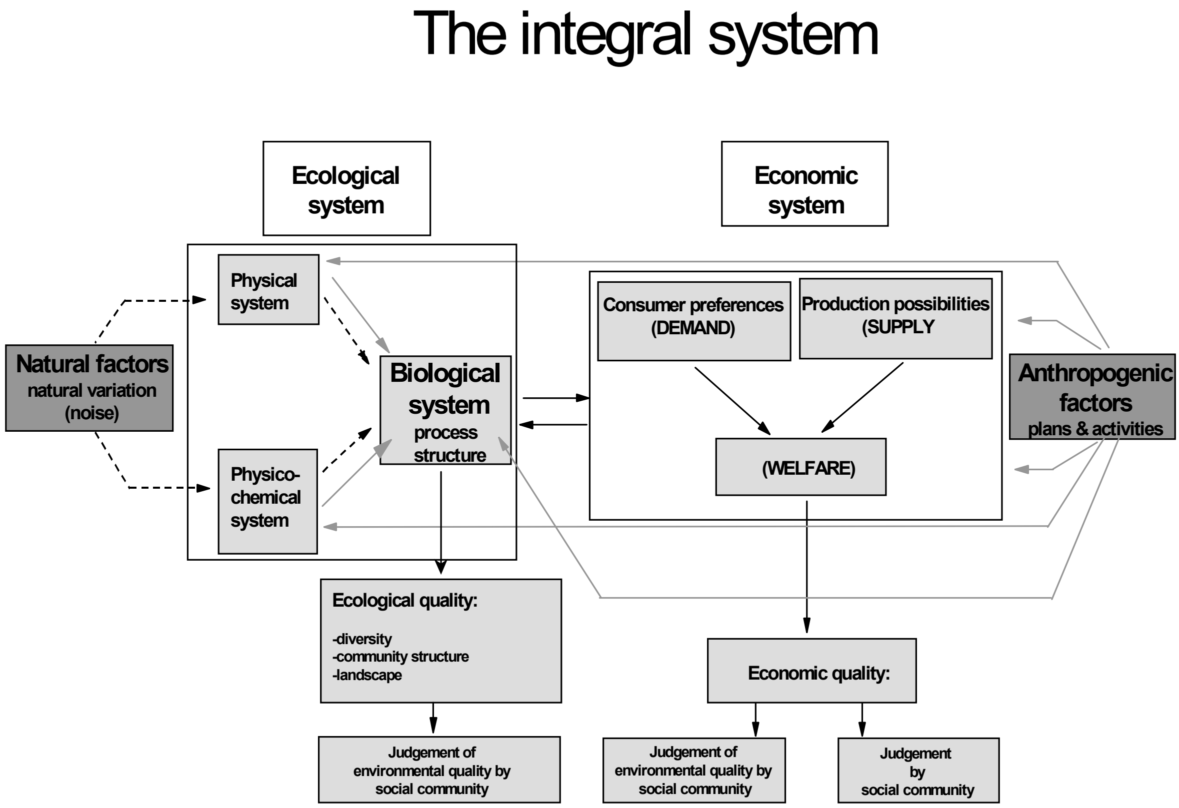


helpful in structuring the system under study. The same holds for the economic system. This system is part of the total human system, and basically consists of an ecological part and an economic part (Fig. 6). The main structuring elements of the economic system are quite different from those of the ecological one. The core of it is the cost (expressed in monetary terms) of the production of required or wanted products in relation to the possibilities to produce those products. Thus, in this system a certain imbalance between 'consumer preferences' and 'production possibilities' determines the level of well-being and the value of commodities. The production of the preferred goods or products inadvertently leads to side effects (*e.g.,* the production of chemicals), which may negatively influence the physico-chemical, physical or directly the biological system.

The fact that man is also a component of the biological/ecological system makes the situation even more complex. This is because the economic system basically consists of a natural ecological part that can be expressed in traditional carbon fluxes and an unnatural flux, which is currency and is mainly the system we are familiar with. However, there are also available natural resources not related to carbon or light energy such as like minerals (sand, gravel, ore, diamond). Two examples to illustrate this difficulty are given. The one is the production of a natural habitat in which fish and shellfish thrive and which then can be translated into fisheries (i.e. with sufficient organic production) with an economic value. The other is the exploitation of a sand and gravel seabed for building materials for habitation.

Also for the economic system it holds that under given conditions the state of the system can and will be judged in different ways (*e.g.*, well-being, appreciation; *cf.* Fig. 2), which may influence further developments as indicated in the 'endless loop' (Fig. 3).

Figure 7. Structuring the 'integral system' without the human social components.



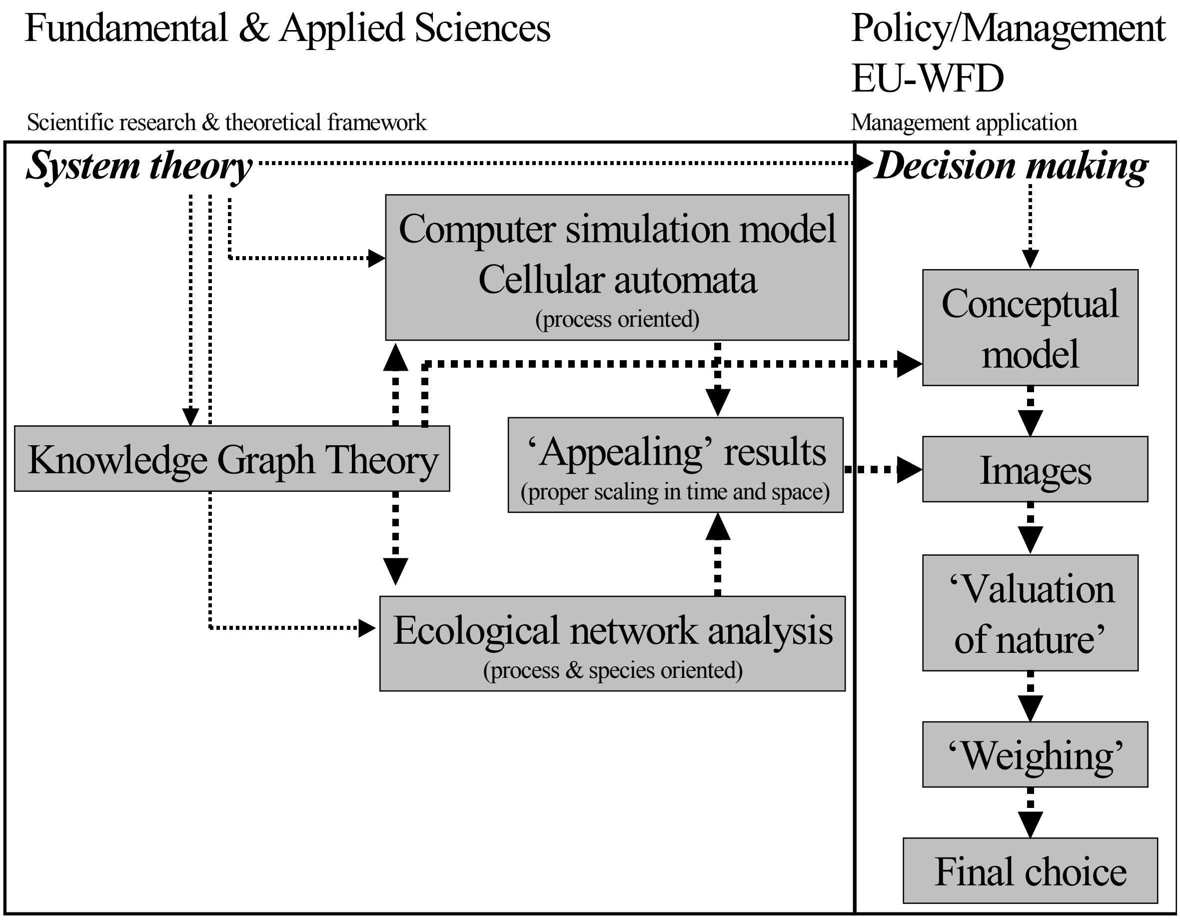
reserve; Anonymous, 1994) the structure of the integral system is given in Fig. 7. The diagram shows the way in which the socio-economic system is impacting the entire ecological system (Fig. 7, grey full arrows). Further the impacting natural processes (the noise) are indicated (Fig. 7, black dashed arrows). The ecological system can thus be thought to be impacted by natural factors and human-induced factors alike, influencing the three subsystems, the physical system, the physico-chemical system and/or the biological system. And, because the local potential for ecological development is strongly regulated by the physical and physico-chemical subsystems in total (human driven and natural stimuli and stressors), every impact to these subsystems will also impact the ecological system. The final expression

The ecological perspective suggests that there are possibilities for further combining and integrating approaches from different disciplines (Fig. 8). The relational structure of ecological communities can be analysed and visualized with help of the knowledge graph technique (Edens & Baretta-Bekker, 1989; Van Koningsveld, 1992). This provides the relations between the different system elements down to the species level.

Analysing the integral system by Ecological Modelling and Ecological Network Analysis

A Knowledge Graph diagram is a useful tool which leads to the possible next two steps which are either or both the structuring of an area specific 'dynamic

Figure 8. Diagram relating aspects from system theory to decision making.



ecological computer simulation model' as, *e.g.,* ECOWASP (Brinkman, 1993) and BOEDE (Baretta & Ruardij, 1988) or a functional analysis of the relationships within the ecosystem by 'ecological network analysis' which combines both 'process' and 'function' (Ulanowicz, 1997; Wulff *et al.,* 1989). The results of both the dynamic modelling and the network analysis may be used in combination to explore the consequences of policy alternatives of which the results have to be presented in such a way that they can be weighed against each other or a certain reference. For the economic system a comparable procedure may be followed because also these systems can be described using the same techniques (*e.g.,* Ulanowicz 1980).

Integration of the ecological and the socio-economic systems can be achieved in different ways, for example, that used in the WADBOS Decision Support System (Engelen, in press; Engelen *et al.,* in press), linking the systems by the calculation of the effect of a certain system stressor to the biota. In following this procedure, it is possible to start with the relevant stressor, *e.g.,* a polluting compound.

The unit 'Energy' as a bridging variable

Another more complicated approach is the full integration of the ecological and the economic system across a single unit or a set of units. Despite all the differences between the ecological and the economic systems, they at least share the general way these complex systems can be described and studied (von Bertalanffy, 1968; Holling, 2001) and thus the availability of basic bridging variables as 'forces and fluxes' as explained by, *e.g.,* Ulanowicz (1980). Forces and fluxes are both related to thermodynamics and thus to energy which has long been an accepted variable in marine ecology (Odum, 1971) for describing, *e.g.,* the production of organic carbon or to represent a certain amount of biomass. Other authors (*e.g.,* Glansdorff & Prigogine, 1971; Ulanowicz, 1980, 1997) explained that application of thermodynamics to complex systems provides promising opportunities.

For the biologically driven part of the economic system, such as fish yield, the same holds as for the ecological system. The fish are a population which may develop in an area depending on the local growing conditions. Energy has to be invested for the extraction of resources like coal, metals or to produce or extract economic resources, goods and services (aquaculture, fisheries, agriculture). Available naturally produced resources as coal deposits or metal ores can be expressed in terms of energy. Given the scientific progress as well as the today powerful capacity of computers, it is suggested here to re-explore the possibilities for adopting energy as a unifying and bridging ecological and socio-economic variable to Wadden Sea area oriented decision-making. If we succeed, then activities by Man as well as plant and other animal species can be described in a comparable way which means that a direct coupling between the two systems is possible. In addition, we may define some derivative (indirectly energy-related) variables. For the ecological system, derivative variables could be those related both to energy and the three subsystems (physical, physico-chemical and biological), which are, *e.g.,* meteorological conditions, wind field, nutrient loads, and contaminant concentrations and species composition. For the economic system where currency is the main variable, the acceptance of variables as employment and prosperity as derivative variables could be considered. There is, however, the difficulty with currency value of not being a conservative variable but a highly variable one due to fluctuating prosperity and market behaviour. Therefore, it should be possibly better to accept also in economics the variable 'energy' as the main one instead of a derivative one like currency.

In addition to these hard cores of the two main systems we are still left with the social component of the socio-economic system for which we have to find another solution.

It is suggested here to explore, based on this starting point, whether integration by Ecological Network Analysis within the ecological system might be valuable and how we can integrate the ecological and the socio-economic systems based on it. It may be already a step forward to use a bridging variable such as energy and to apply the rules of thermodynamics by using Ecological Network Analysis. We are the opinion that the combination of Network Analysis and the application of energy as variable is sufficient to define the approach as a 'new paradigm' in this field (see Figs. 2 and 8). The main problem for the Wadden Sea related management to date is the lack in practical progress in integrating the different disciplines (*e.g.,* Heip *et al.,* 1997). If there are interdisciplinary attempts to link these systems in a practical way then more research can be carried out to prepare the next step.

Bridging decision making and society by 'imaging' and 'public decision making'

To date scientifically sound results have not played a sufficiently clear role in reaching final political decisions. Too often final decision makers or politicians themselves (see above) conclude that the final decisions were taken based on their own emotions more than rational analyses (*cf.* Ducrotoy & Elliott, 1997).

Not only the politicians may be blamed for this but also the scientists who apparently did not present their results in an sufficiently appealing or clear way. It is emphasised here that it is necessary to present basic scientific analyses of management alternatives in a more appealing way to the decision making layer than previously. The scientific society has to find ways in which to do this. There is apparently and, *e.g.,* based on ongoing discussions on extension of the main Rotterdam harbour area, on an airport in the North Sea in front of the coast and on wind energy parks in the North Sea too large a gap in between the work of the many and various scientists studying the effects of different management alternatives and the person who has to take the final decision. This gap is related to differences in the scientific research (desk studies, model analyses and weighing processes) as well as elements as 'perception' and 'appreciation' by the final decision makers, the politicians or policy makers. The gap can be reduced by policy learning processes through carrying out serious evaluation studies instead of making promises.

At the end, environmental effects due to human activities usually refer to effects on biological levels of organisation (individuals, populations, communities, ecosystems) and landscape elements. Ecological results can be visualized in several ways, usually diagrams and tables which are often (too) complex and difficult to follow for non-experts and consequently considered as not being very exciting to policy makers. However, this is in the process of changing as recent policies require better communication of results. For example, the EU Water Framework Directive, the Habitat Directive (conservation of natural habitats and of wild fauna and flora) and others define the way in which results have to be communicated. In particular, as decision makers have their own appreciation and perception, the final outcomes of the scientific analyses of management alternatives should also be visualised in images representing the reality under the different management alternatives and at all relevant scales in space (*cf.* Holling, 2001) and time. These images should thus, where appropriate, be representing the real situation at spatial scales ranging from the entire landscape to the sub-macroscopic or even the microscopic level (Fig. 4). Also the relevant temporal scale should be taken into account in these images. These images could subsequently be widely used as input to the 'valuation of nature' technique (Ruijgrok, 2000). The results from this analysis should then be used in a real public session to base the final decision upon the most attractive or agreed management alternative.

The above does not at all mean that politicians have to loose their responsibility and thus their power. They much better than now have to define the space for doing studies and the freedom available to groups involved in the process of preparing policies or management strategies.

Discussion

Factors driving the ecological and economic system

Coastal systems are driven by mainly three factors: sun, tide and wind. They all share the unit 'energy'. The solar energy is indispensable for the production of new organic material by plant growth. The tidal currents contribute to the mixing of water, solutes and particles. The wind induced waves are responsible for the resuspension of material from the intertidal flats.

Today the ecological system is strongly influenced by human activities and hence the position of humans within the ecological system is a special one. As a biological component they form an integral part of nature and are completely dependent on the natural cycle of the production and degradation of organic carbon. However, they are capable of greatly modifying their life styles and living environment. Through agriculture, Man has learned to rely on restricted and selective parts of nature, thus creating a distinction between 'cultural land' and 'natural areas'. Moreover, and apart from a biological part, the economic system is strongly driven by typical anthropogenic variables such as 'human desires' and other elements related to what have been called the 'endless loop' (Fig. 3; de Jonge & de Jong, 2002). It is clear that for the components that give us an increased perception of well-being, thus the endless loop related aspects, also energy is required to fulfil these desires. Consequently, modern economic systems are driven by needs that completely differ from the basic driving factors of the ecological system (Fig. 3). Technology has been used in a positive way to improve our 'well-being' (*cf.* Fig. 3 and below) and may be driven by 'human desires' of which curiosity forms an aspect. The combination of 'technology' and 'desires' has proved to be a powerful driving force in our economic system. However, there are also some general axioms related to technology and curiosity:

(1) history has learned that every applicable invention in technology will be used.

(2) driven by curiosity, humans always shift their boundaries.

Due to this, the economic system, as with the natural system, is not only complex but also very dynamic. A successful coupling of socio-economics and ecology requires a transparent system with units that are useful and accepted in both disciplines, something that does not hold for the present situation in practice. One of the main problems is caused by the fact that from the structure point of view in ecology not everything can be substituted while from the production or process point of view in socio-economics as well as ecology products and services (currency) are exchangeable.

Indicators

The use of the economically popular unit 'currency' is posing problems when integrating the socio-economic system and the natural system because the rate of the 'currency' is not stable, at least not in time. This is, however, a prerequisite for any variable to be used in a general and certainly in a global way. The same holds for an indicator as 'prosperity'. Therefore the variable 'energy' should be used to relate ecology and economy in the short term.

Also the usefulness of the commonly-used simple indicators in ecology to judge both process and structure of a natural system is questionable because it neglects too much the complexity of the species structure and implicitly accepts that nature can be described by using linear processes and interrelationships, something that is not necessarily true. Therefore, it seems worth to investigate the power of the indices related to 'ecological network analysis' (Ulanowicz, 1997).

The main point behind this is that we can put some aspects in monetary terms, such as good fisheries, sand and gravel for building. We can, however, not put a good environment in financial terms, although the economists are trying, *e.g.,* the 'willingness to pay' and the 'travel to visit costs', which allow society to indicate the value they put on an aesthetic feature.

The need for structuring and the way ahead

There are few studies in which clear structures have been visualized about the general links between the natural system and the human driven system. Most papers surprisingly focus on detailed problems without presenting a clear concept of the structure of the integral system. De Groot (1992), who treated nearly all aspects on the economical and ecological function of areas, focuses mainly on the description and explanation of a real series of examples from the integral system rather than really integrating the details to a main structure. Lenders *et al.* (1998) produced a figure in which they directly conceptually focussed on 'images' at the level of the social system, the natural system and the integral system thus without structuring the system from the basic elements but starting from the near highest ('landscape') level. Costanza & Mageau (1999) treated the subject of the environmental quality or health at the near theory abstraction level, which means that it is difficult to apply it. Holling (2001) is also still searching for understanding the complexity of all these systems and looking for how to visualise and describe these systems. Haag & Kaupenjohann (2001) identify some major issues in support of decision-making by scientific research. Their suggestion about the role of constructing 'reading frames' in decision-making very well fits the ideas presented here. Reading frames are the different conceptualisations of the real world, which differ between stakeholders as a result of different perspectives, domains of phenomena of interest and decision stakes. Haag and Kaupenjohan identify five major statements in new forms of knowledge production for decision-making. One of these is their statement 2 (different perspectives lead to a plurality of legitimate system descriptions that cannot be reduced to a common denominator). In contrast to Haag and Kaupenjohan (2001), in the present paper it is suggested that a common denominator such as 'energy' can be constructed, based on the work of Glansdorff & Prigogine (1971), Ulanowicz (1980, 1997) and Holling (2001).

From the given examples it may be clear that structuring in integrated coastal zone management is really an item and considered very important. However, when treating a subject like the present one, the abstraction level as well as the scale level in time and space are very important to make the system 'transparent' and accessible for studying and understanding it. The few examples given are interesting because they focus on elements that may be of utmost importance as a contribution for realizing rational and effective decision support from the scientific community. Most of the available literature focuses on the process level of either economy or ecology and if they focus on the species level it is often a single species approach (Barbier, 1994). Hence it seems extremely difficult at present to move from the process level to the structure level when dealing with the interaction of economics and ecology. As stated above, this already could be a step forward to start the integration of structure and function in ecology by, *e.g.,* following network analysis and attempting the same to the socio-economic system.

The chaotic nature of systems and the need for structuring the system

The authors are aware of the developments in the fields of chaos, self-organization and thermo-dynamics and the attempts to apply them to the natural and social system (*e.g.,* Kay & Schneider, 1994; Nicolis & Prigogine, 1977, 1989; Schneider & Kay, 1994). Although others are more qualified to judge, we think that these theorems should be applied at quite different levels. The further exploration of these fields can take place at a very general level while the application of it could be done at the level of concrete examples. Geldof (2001) deals with complexity in integrated water management at the level of local government, by influencing the system transition from one state to another through the influencing of social processes. It is a challenge to find arguments for extending the conventional today scientific approach towards the aspects of the new ecology as presented by the above given fields and to demonstrate and explain to our governmental bodies that we should follow a new approach. In this new approach there should be sufficient opportunity for carrying out surveillance monitoring apart from trend and target (compliance) monitoring because understanding the system requires more than monitoring some indicators. There are many possible examples in the literature to illustrate that the longer-term ecological developments in the environment cannot be traced by short-term project research but need data series of sufficient length and quality to detect any impact (*e.g.,* Schmitt & Osenberg, 1996). This is one of the most important responsibilities to be taken by the government.

Does the valuation of nature make sense?

Here we reach at the boundaries between the natural and human or social sciences and philosophy. We cannot neglect these aspects in an era during which so many species become extinct as at present. It is possible that valuation of nature in economic terms will be used to push the responsibility for nature from the political arena in the direction of society as a whole. The judgement of what we like or do not like is dependent on a number of aspects of which prosperity and consequently well-being are about the most important. This means that valuation is very subjective. The consequence of this can be the further extinction of species and or the further loss of habitats, something that at least on the short term seems to be irreversible. A suitable example is the still failing attempts to re-introduce eelgrass (*Zostera marina*) in the Wadden Sea (de Jonge *et al.,* 2000, van Katwijk *et al.,* 2000) despite thirteen years of study and experimentation. The big issue is of course whether we do feel to have the right to ruin nature in favour of mankind, the growing human population or even only for 'making maximal profit'. This certainly is not the discussion to be held in this paper but it should be held more often and more explicitly than now, not least within the political arena (for example at the World Summit on Sustainable Development, Johannesburg, 2002). Against this background, we consider it necessary to try to understand the rate processes, the functioning, the interrelationships, the coherence of the natural system and the human system. We as humans are part of nature and we cannot exist without it. This means that increasingly damaging the direct living environment as we do today, including the damaging of the last remainders of nature, may in the end support our own decline.

The above discussion leads to the conclusion that application of, *e.g.,* the communication strategy with all the stakeholders in the 'Dutch Polder Model' (reaching consensus by discussion between stakeholders), to create support for any decision in any field, should be looked at critically. We have the responsibility to tell people what the consequences are and to let them make a choice in a democratic way to get maximal support for what we may call 'public decision making'. The scientist has a dual role - both to provide the information in a succinct and objective manner so that other can use it to reach a decision but also as a member of society and thus as a stakeholder who has a role in reaching a decision. This public decision-making, based on personal valuation and thus personal appreciation and perception of situations and conditions, is probably the best way ahead. However, these discussions and actions, although very helpful, cannot be a substitute for governmental responsibility. This item leads to the big issue and that is whether we can interweave natural and human functions in a nature reserve like the Wadden Sea. The real question here is: do we accept and do we respect the integrity of nature or not?

Respecting nature, a matter of self-protection?

A concept implicitly given above is to accept that we, humans, are part of nature and consequently should respect the 'integrity of natural systems'. This means the protection of entire river basins including their estuaries and coastal areas as well as the protection of the functioning of these systems in any aspect (physically, chemically and biologically); it also means protection of the biological species that populate these systems.

The Dutch 'Wadden Sea Planning Act' (Anonymous, 1994) has followed the 'Brundtland commission' (WCED, 1987) and has also formulated that in case of any doubt with respect to the potential damage of human activities we should follow the 'precautionary principle'. This principle is something in between completely respecting the integrity of natural systems and the principle of considering natural systems as being completely subordinated to mankind. The precautionary principle can be reworded to indicate that there will be a presumption that Man will have an effect on the natural system unless the contrary can be conclusively proven. Here we reach the boundary between our professional competence and 'ethics'. It is, however, important to put forward the question whether we as society should overexploit our environment in favour of the short-term benefits of it to mankind.

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