A Quantitative Method for Description & Assessment of Ecosystems: the AMOEBA-approach

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The absence of quantitative and verifiable ecological objectives for Dutch waters impedes the management of those waters. Which activities are admissible and which are not? This article describes the AMOEBA-approach, a conceptual model for the development of quantitative and verifiable ecological objectives. "AMOEBA" is the Dutch acronym for "a general method of ecosystem description and assessment". This model is based on the concept of sustainable development.

I INTRODUCTION

The absence of verifiable ecological objectives

The main objective underlying the Dutch management of the North Sea and inland waters can be loosely defined as:

The maintenance and the attainment of a water quality level to preserve the ecological values in relation to desired uses of the watersystem.

These objectives are however difficult to quantify and to verify, and pose a problem when a water authority wishes to assess a proposal for a new marina, an application for an effluent discharge permit or a sand extraction licence. What is acceptable and what is not? Where should the line be drawn? The reader can imagine the problems with which water authorities are confronted. The major question which arose during the preparation of the third National Policy Document on Water Management (further: Water Management Plan) was: how can abstract ecological objectives be made quantitative and verifiable? The need to answer this question gave rise to the development of AMOEBA-approach.

II. THE AMOEBA-APPROACH

Fundamental ecological values

Before attempting to explore the issue, we need to define the key concept of the objective described above: "ecological values". We have defined this term as "the desired state of the biotic component of the water system. "This desired state is to be determined by government". The object of study is therefore the biological component of the watersystem. The physical and chemical components are considered here as means by which to reach the ecological objectives. The landscape aspect is not taken into consideration (fig.1).

Returning to the main issue, the question arises as to which are the "ecological or natural values" to be preserved as stated in the main objective for the Dutch coastal waters? Are they seals, algae, bacteria or herring gulls? At which numbers should they be preserved? Neither the species nor the desired numbers are stated explicitly. Yet choosing species A can lead to a totally different policy from choosing species B or C (fig. 2).

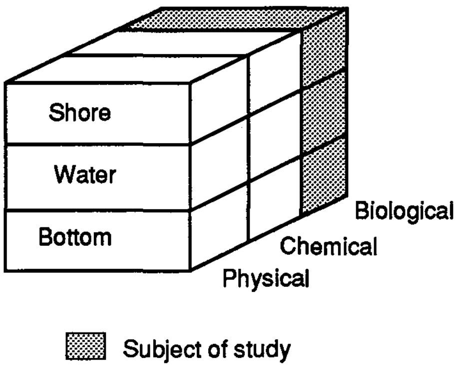

Figure 1: The object of the study is the biological component of the watersystem

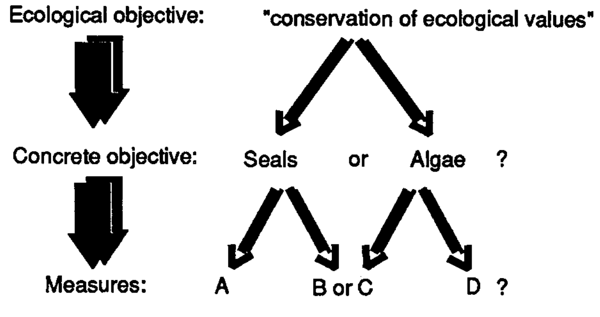

Figure 2: What must be preserved: algae or seals? This makes a big difference.

In order to establish precisely what we mean by these ecological values, we must examine what the most fundamental values are that man attributes to plant- and animal life. Nature herself does not provide an answer to this question. She accepts and reacts to whatever happens, she operates mechanistically. Only man can judge what is good or bad.

We believe that there are three categories of valuable characteristics, whose sustainability are desirable:

1. Production and yield
   These are valuable for functional reasons. This category is a prerequisite for man's existence, e.g. fisheries.

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These values are closely associated with species-abundance, the production of oxygen and the self-purifying capacity.

2. Species diversity
   This is valuable for ethical and aesthetic considerations. It involves concepts such as the preservation of species, rarity and completeness.
3. Self-regulation
   Self-regulation has ethical, aesthetic/recreational and economic considerations, which are closely related to concepts such as naturalness, stability, intactness, authenticity and visual integrity. Moreover, self-regulating ecosystems have low management costs.

A guaranteed sustainable ecosystem: the reference system

It now becomes important to determine which ecosystems and kinds of uses and measures provide guarantees for sustainable production, diversity and self-regulation. It has become clear that unrestricted discharges of contaminants threaten sustainable production and diversity. Opinions vary as to the extent to which the present-day use of coastal waters safeguards sustainability. Our knowledge of how water systems work and of their countless complex physical, chemical and biological interactions is insufficient to make any fullproof comments on this issue. Indeed, it is doubtful whether man will ever understand this nexus of interactions sufficiently to be certain that a particular use guarantees sustainability.

A system which has not, or has only slightly been influenced by human activities may provide clues to define parameters and processes essential for sustainability. Such a system has the conditions for the evolution and survival of organisms, including man, living in and around it for millennia. By definition, such a system guarantees sustainable production, diversity and self-regulation. The very existence of man and the species of plants and animals which we know today are proof of this.

But where does this lead us? To what extent can natural systems be used as the basis for policy if such systems hardly exist any longer? Man has, after all, left an indelible imprint on his environment. Some degree of deviation from the natural system is inevitable, given the trends in human population size and the impact of modern technology.

The assumption is made that the ecosystem which is not, or hardly not manipulated, offers the best guarantee for preservation of these fundamental values: the REFERENCE system. The closer one comes to the point of reference, the larger the guarantee for ecological sustainability, and vice versa. Society chooses her objectives somewhere between zero and the point of reference. This is, in essence, a weighing up between the direct costs of measures and the loss of guarantees for sustainability on the long term (fig. 3). The search for a concrete ecological objective can therefore be reduced to the question: "what is the maximum acceptable distance to the point of reference?"

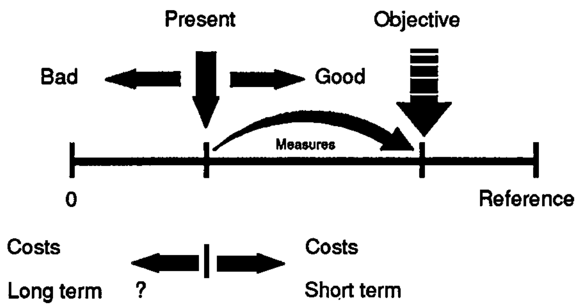

Figure 3: Society chooses the ecological objective, somewhere along the axis between zero and the reference point

The introduction of a reference system provides a standard by means of which an assessment can be made of the ecological condition of a system. The ecological objective, however, needs not necessarily to coincide with the reference system. Once a government decides on the maximum acceptable distance from the reference point, a verifiable ecological objective is established.

Species as target variables

How can a quantitative comparison between the reference system and the present-day ecosystem be made? A comparison of the entire system appears impractical. Firstly because the reference system is known only in part, and secondly because the number of organisms and processes in the system is countless.

This explains why we have confined ourselves to a number of plant and animal species. This limitation is to some extent justified by the fact that the species are expressions of numerous underlying processes. The plant and animal species which we have selected are target variables. They can be expressed in terms of:

- numbers
- distribution
- health

Together the target variables constitute the ecological objective.

The conceptual model described here has been named the AMOEBA-approach.

The choice of target variables

The following considerations contributed to the choice of target variables:

1. Quantitative data on the species must be available.
2. The species must be susceptible to human influence. It is pointless to select ecological objectives without knowing how to achieve them. Each target variable must be linked to at least one steering variable.
3. The species must be accessible to easy and accurate measurement.
4. It should have some indicative value for the condition of the system.
5. The species should, ideally, have some political and social appeal.

The importance of this consideration must not be underestimated. We believe it to be more effective and more appropriate to select species which society and the authorities know and understand, rather than developing a scientific model such as the Shannon-Wiener index, which nobody can understand. It should be said, though, that using the one variable does not necessarily exclude the other. Nevertheless, target variables are in essence policy instruments rather than scientific instruments.

6. The target variables as a whole have to be a cross-section of the entire ecosystem if they are to provide a reasonably representative picture of the ecological condition:
- species from all types of water-subsystems
- species from the benthos, water column, water surface and shores
- species from high and low parts of the food web
- plants and animals
- present-day and former species
- sessile, migratory and non-migratory species

The target variables do not necessarily need to belong to one food chain.

For several reasons processes have not yet been selected as target variables. This does not mean they can be dismissed as unimportant, but merely species are more suitable as target variables. Processes are of greater importance in identifying steering variables, i.e. measures (fig. 4).

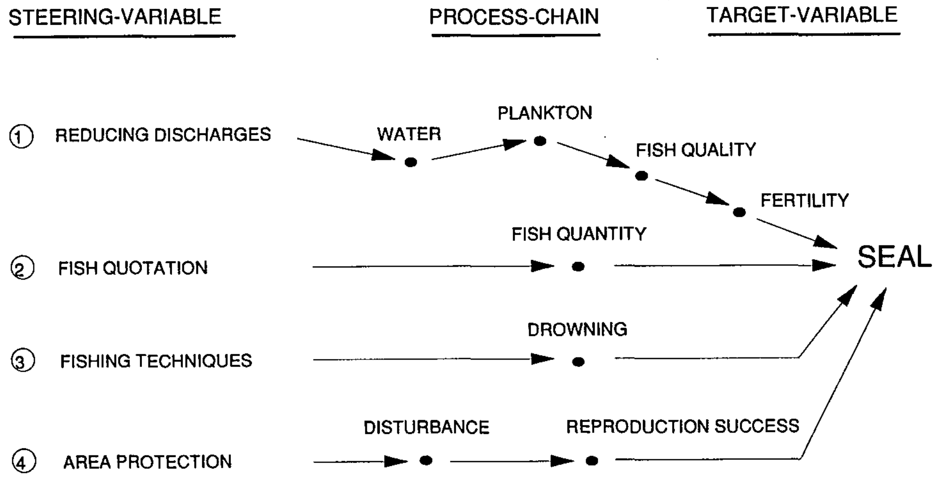

Figure 4: The relationship between one target variable and four steering variables. The process chains indicate the main physical, chemical and biological relationships.

Describing the reference system

Selecting the reference system is a crucial step in the formulation of ecological objectives. To obtain a reliable picture of the uninfluenced system, it makes sense to go back as far in time as possible. However, insufficient knowledge of the system at a particular time makes this impossible. For the North Sea and its neighbouring waters, for example, the condition as it was around the year 1930 has been selected. This is a pragmatic compromise between, on the one hand, the available knowledge and, on the other hand, a relatively low level of human interference. However, in several cases a correction was necessairy for human influences.

Three sources are used to determine the reference system:
- old inventories
- comparative research involving other systems
- ecological theory.

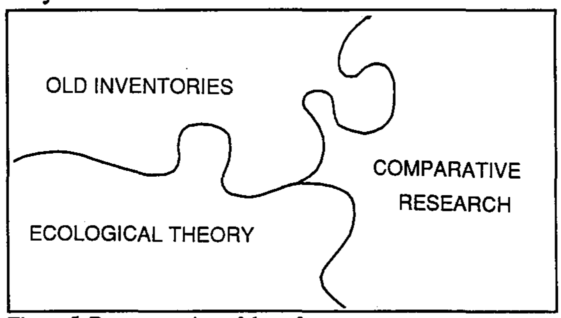

Figure 5: Reconstruction of the reference system

Where the first two sources are insufficient, ecological theory can be used to reconstruct the reference system (Baerselman & Vera, 1989). In other words, the reference system can to some extent be artificial. The reference system is reconstructed step by step using individual components in much the same way as archaeologists reconstruct the past.

A number of complications are liable to beset the formulation of reference systems: some ecosystems are subject to rapid succession (e.g. marshes) or extreme fluctuations (e.g. algal populations). The task of determining an unambiguous reference for systems with high rates of succession is not an easy one. Marshes, for example, may represent a stage in a process of desiccation, which requires several decades in which to become complete. In this example the reference selected is not static, but develops through time. This solution is also applied in other disciplines. Medicine, for example, uses reference values which vary according to a person's age.

Species which show wide fluctuations in natural conditions, such as algae, seals or migrant brent geese need to be given special attention. This can be done in three ways:
1. by taking the average over a number of years, thereby decreasing annual fluctuations (e.g. brent geese).
2. by using a range as a reference value (e.g. 4,000 to 8,000 seals).
3. by taking the numbers present at a specific time of the year (e.g. algae during the spring peak).

In most cases we applied all three methods.

III RESULTS

The AMOEBA-approach in practice

In the Water Management Plan the AMOEBA-approach is applied to the North Sea and major rivers (Rhine & Meuse). Reference numbers and actual numbers are given for 60 selected target variables, mostly species. Since water authorities and policy makers require a clear and simple presentation, a "radar diagram" has been used. This technique is also used to present company data in schematic form. The target variables are arranged in systematic order in the form of a circle. The distance from the edge of the circle to the centre represents the numbers in the reference situation for each species, for example, 2000-3000 breeding pairs of cormorants or 16,000 hectares of sea grass (=100%). The actual numbers are superimposed on this circle, for example 500 breeding pairs of cormorants and 3000 hectares of sea grass. For visualization purposes, all points are connected by a line, which produces the two amoeba-like figures. These figures, the "amoeba's" for the sea and the major rivers, present a relatively simple picture of the actual situation of these ecosystems (fig. 6).

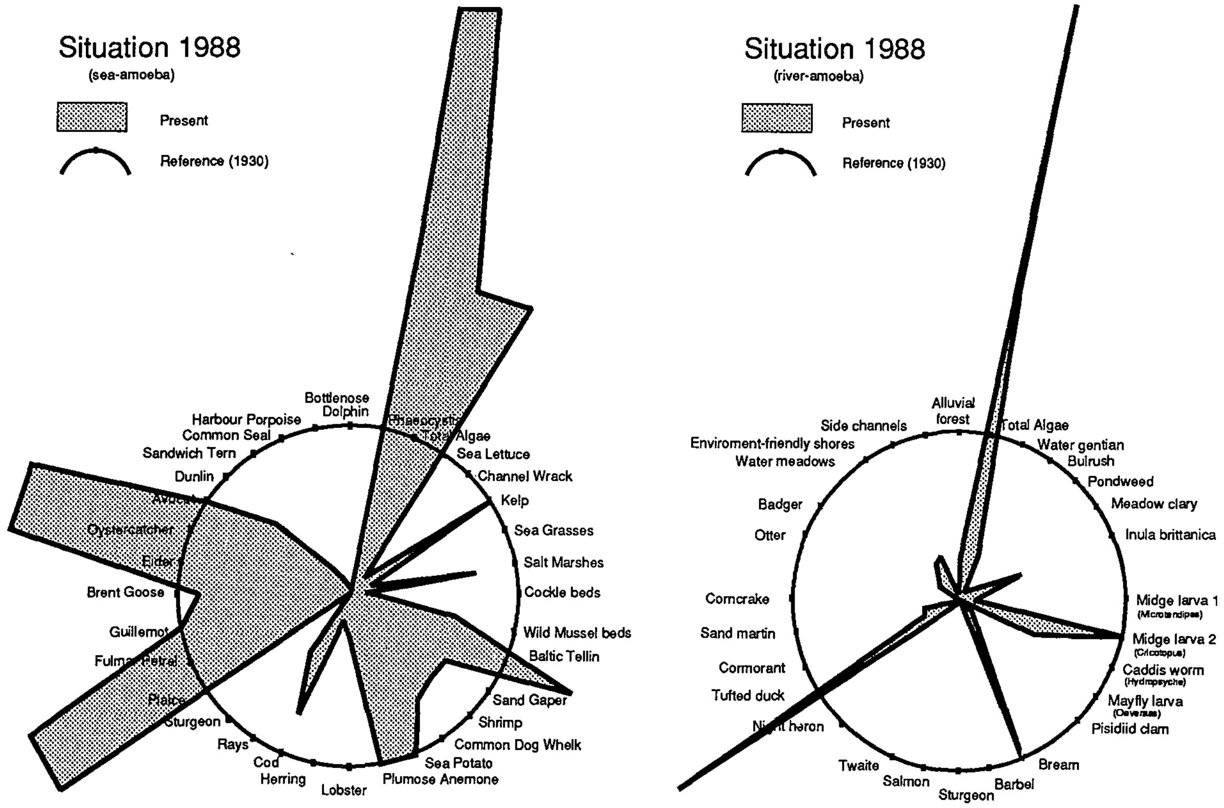

Figure 6: The selected target variables, showing the present ecological situation in the sea (A) and the major rivers (B).

They show how human use of the water systems has, unintentionally, changed the ecological situation over the past 60-90 years.

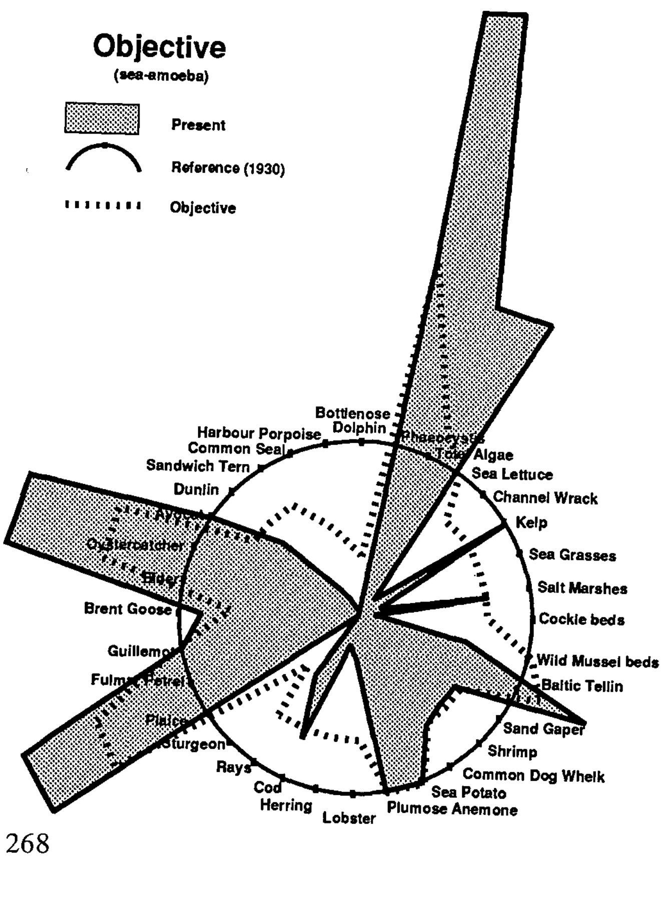

Figure 7: The ecological objective for the North Sea, the target-amoeba.

Towards an ecological objective.

The next question to be addressed is, which ecosystem does offer acceptable guarantees for sustainable development? In short, what is the ecological objective, expressed in terms of the maximum acceptable distance from the reference?

In the Netherlands, "a sustainable development will be considered to have been achieved when the numbers of the organisms in the sea and river "amoeba's" -the target variables- approach those of the reference situation. It is not necessary to return to the reference situation completely. For marine and brackish waters, the aim is to reach 75%-200% of the reference levels. For freshwater areas, the corresponding percentages are 50% and 200%". Fig. 7 shows this ecological objective in greater detail for the sea.

Impact-amoeba's

To achieve this objective, a strategy has been drawn up. Conceptual and mathematical models were developed to assess changes of all species in the "amoeba" as a result of changing steering variables like water quality, fishcatches, restoration of biotopes etc. The impact of 6 policy alternatives (packages of measures) were calculated (Ministry of Transport and Public Works, 1990). The impact of each alternative was illustrated by "impact-amoeba's". Two notable "impact-amoeba's" for the sea are shown in fig. 8.

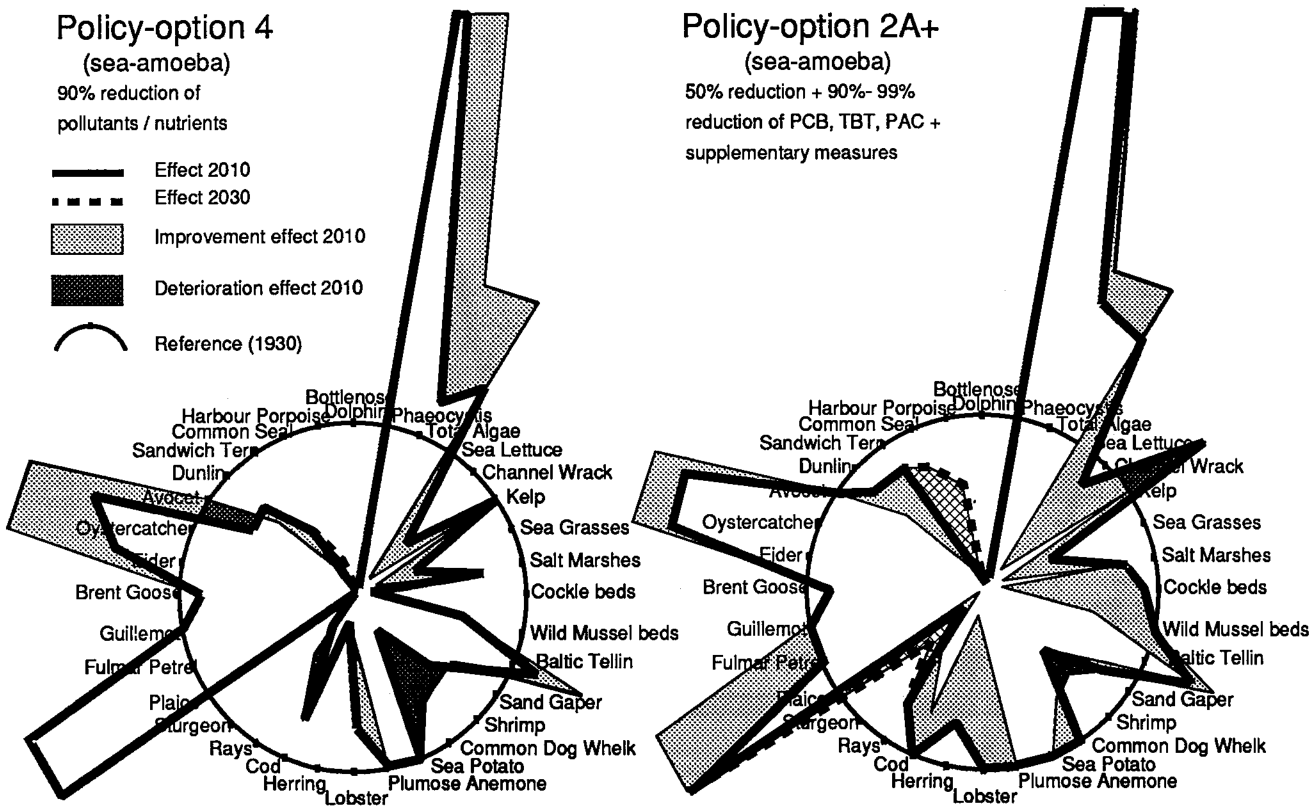

Figure 8: Expected ecological impacts of two policy alternatives: the "impact-amoeba's". Supplementary measures are a large range of physical and biological measures, such as a decrease in the intensity of fishing, prevention of human activities which disturb mammal and bird life, restoration of biotopes, restoration of the natural transition between fresh and salt water, reduction in turbidity, reintroduction of species.

"Ecological Dow Jones Index"

Due to the large number of policy alternatives, the need arose for a simple method by which the impact-amoeba's could be compared. This was achieved by adding together all of the distances (32) to the circle. We called the figure obtained the "ecological Dow Jones index". The smaller the total distance from the reference situation, the better the policy alternative. No distinction has been made between the values for the various species. If these figures are arranged on a scale from 3200 (32 x 100% distance) to 0 (32 x 0% distance), we obtain a result shown in Fig. 9.

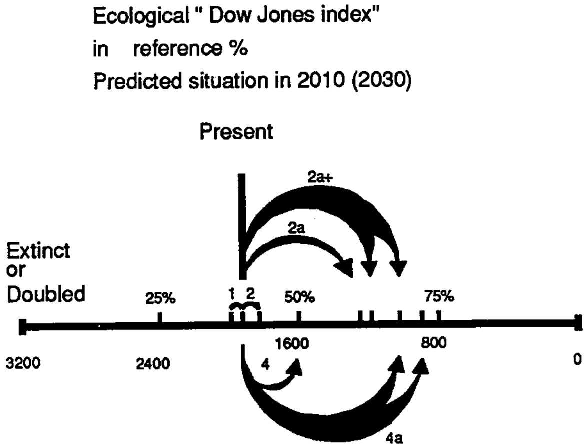

Figure 9: The "ecological Dow Jones index" of 6 "impact-amoeba's".

A new policy strategy

Based on the AMOEBA-approach the Water Management Plan (1989) concludes:

1. The Dutch watersystems are incomplete and unbalanced in composition. With continuation of the present use the ecological decline will proceed and there are no guarantees for sustainable development (alt.1).
2. The present-day policy of a 50% reduction of the discharges of contaminants -Rhine and North Sea Action Programmes- do not produce any improvement, they merely stop further decline (alternative 2).
3. The exclusive reduction of contaminants, even by 90% (alternative 4), has a relatively limited effect. Nevertheless an ongoing reduction is a necessary condition for recovery
4. Reduction of contaminants of 50% and of PCB's, PAH's, TBT and oil of 90-99%, in combination with supplementary measures is, at this moment, the best policy alternative (alternative 2a+).

These conclusions lead to a new policy and management strategy for the North Sea: the multi-track approach.

No overnight solutions

Selecting target variables, specifying the reference numbers and choosing ecological objectives are not "one-off" activities. It may take some time before general scientific agreement is reached on the reference situation. The determination of the ecological objectives will proceed, in the first few years in particular, on a trial and error basis. This is not to say at random, but testing each possibility systematically on the basis of the following criteria:

- Which objectives are both practically and economically feasible?
- Which offer reasonable guarantees for sustainable use and sustainable ecosystems?

- Which measures give high returns at low costs?
- What kind of time-scales are involved?

This is a learning process, in which provisional ecological objectives become more definite as time passes. Adjustments to ecological policy are introduced as a result of new knowledge, changed social requirements or unforeseen developments in the system itself. These are the factors behind the continuous "dialogue with the water system". A similar trial and error approach is employed in the making of economic policy. The OECD publish their economic predictions on the basis of the latest figures and perceptions. These predictions are adjusted annually, and form the basis of financial and social-economic policy. We advocate an ecological policy that is based on a similar systematic approach (ten Brink, 1989).

IV EVALUATION

Referring to the question mentioned in the introduction we now wish to evaluate the AMOEBA-approach.

1. With the AMOEBA-approach it is possible to represent quantitative objectives of nature conservation, fisheries, recreation and the functioning of the systems themselves - and to assess the extent to which the objectives have been achieved. In this way these interests are made tangible as in traditional "hard" sectors such as industry, agriculture, shipping and mining, thus making more integrated and balanced decision-making possible.
2. The AMOEBA-approach is simple and easily visualized. We expect it to make the problems of ecological decline more accessible for water authorities and the public alike. Therefore it can function as a vehicle of communication between policymakers and scientists. A better understanding of the ecological objectives, the problem areas and the measures which have to be taken will increase the collective will to act.
3. The AMOEBA-approach may add substantially to the concept of sustainable development (Brundtland, 1988) and wise use (Ramsar Convention, 1971). The model highlights changes which happen so gradually over a period of up to 60 years as to be almost imperceptible. It also highlights the overall effects of numerous interventions occurring simultaneously. In this way it provides us with an overall picture of the strain which man is placing on the biota. The "gaps" in the "amoeba's" are a measure of the extent to which man is depleting his natural environment.
4. The discussion of man's impact on the environment acquires more tangible form and concentrates on the risk that ecosystems may deviate even further from the ecological objectives. The AMOEBA-approach can be a helpful instrument to environmental impact assessments.
5. Once they have been selected, the target variables give direction to monitoring programmes and to research into dose-effect relationships, aut-ecology and reference systems. The research on bio-indicators can concentrate on the indicative value of the species selected. In this way the amoeba can act as a thermometer for the entire water system.
6. Common criteria such as rarity, diversity, authenticity, intactness and stability are difficult to define and quantify in practice. Using the AMOEBA-approach, they are related to the reference system and are therefore easier to define and quantify.
7. The AMOEBA-approach appears to be of reasonable universal application. In principle, it can be used on all scales and for every system.
8. Different choices of target variables are possible within the limits imposed by the above mentioned six criteria. Undoubtedly this leads to a different "amoeba". The ultimate aim, however is not a particular amoeba-shape, but merely the changes which occur during time and the measures to be taken. We do not expect these differences will lead to measures which differ in principle. Moreover, choices have to be made for formulating objectives, as have been done in e.g. the world of economy and the medical world.
9. The AMOEBA-approach can easily lead to oversimplification of the real situation. One solution to this is to add more target variables. We used for example 40 extra target variables for the North Sea assessment. Furthermore, it is advisable to supplement biological target variables with chemical and physical ones.
   However, many countries will not posses the financial and technical means to research and monitor so many species. Does this mean that the AMOEBA-approach will only be an instrument for rich countries? No! The amoeba can be supplemented during time with new species. One might start with species which are most critical and easy to monitor. Some information is better than none at all.
   In this way a framework of managing aquatic ecosystems can be constructed gradually.

It is of the highest importance that the natural resources of the planet are preserved. This is particularly true for developing countries with a rapid growing economy and population. The AMOEBA-approach can serve as a valuable instrument for policymakers to manage natural resources for these countries.

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