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Ecological performance indicators in the North Sea: development and application

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Abstract

Different signals of distress from the North Sea ecosystems started a discussion on the protection of the ecosystem at the third North Sea Ministers Conference in 1990. This was followed by a number of workshops on ecological indicators under the auspices of the North Sea Task Force and the Oslo and Paris Commissions (OSPAR). In 1997 the member countries around the North Sea agreed to develop and apply an ecosystem's approach in the management programs for both the North Sea fisheries and the marine environment. Following this agreement the identification of the ecological qualities objectives for the North Sea ecosystem started. Further work in this direction has lead to the setting up of various national projects geared towards creating a better understanding of the North Sea ecosystem.

In the Netherlands, two departments (Water management and Nature and fisheries management) from the Ministry of Transport, Public works and Water Management (V&W) and the Ministry of Agriculture, Nature and Fisheries Management (LNV) agreed to integrate their policies for the management of the Netherlands section of the North Sea. The results from these projects (started in 1996) should enable the policy makers and managers to formulate policies that could lead to the creation of a balance between the effects of human activities and the preservation of the natural qualities of the North Sea ecosystem.

One of the projects is strictly designed to develop ecological indicators for the Dutch part of the North Sea. These indicators are based on various monitoring data and related in one way or another with human activities. In this way it is possible to evaluate the effects of human impacts on the ecosystem. Long-term changes in the ecological performance of the ecosystem can be elucidated by the use of the ecological indicators. Thereby making it possible for the policy makers and the managers of the NCP to evaluate the effects of their policies and management recommendations on the quality of the ecosystem.

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This paper describes the process and the steps taken by the authorities in the countries around the North Sea to develop a set of ecological indicators for the management of the North Sea ecosystem. Focus will be made on the efforts made in the Netherlands to develop indicators that did provide the basis for the development of Water and Nature conservation policies and new management strategies for maintaining the sustainable use of the Dutch section of the North Sea.

1. The North Sea: signals of distress

The North Sea is one of the busiest used seas in the world and signals of distress are observed [1]. Natural processes are disturbed by a huge numbers of ship movements (420,000 per year), intensive fishing activities, impacts of gas and oil mining, sand and gravel extraction, recreation and military activities. Signals of distress are summarised in the recent Quality Status Report of the North Sea [1], for instance: over fishing of different fish stocks, concentrations of different compounds above natural background values and targets giving rise to negative effects on organisms, discard of non-target species by fishing activities, habitat disturbance and destruction of bottom organisms by fishing activities.

The North Sea is surrounded by Great Britain, Norway, Sweden, Denmark, West Germany, Netherlands and Belgium (Fig. 1). The North Sea has a total area of 575,000 km^2 and it is a relatively shallow in the south: on average 40 m. The Northern part is deeper with depths varying from 100 to more up to 700 m.

As most coastal zones in the world, primary production in the coastal zones of the North Sea is relatively high (200–400 g $C\,m^{-2}\,yr^{-1}$) [1]. From the north and in the south Atlantic water enters the North Sea, with a residence time between 1 and 3 years. The residual current pattern is anti-clockwise. The rivers from the surrounding countries discharge relatively large amounts of nutrients (nitrate and phosphate), metals and organic compounds (e.g. PCBs and PAHs) into the coastal zone [1,2]).

2. Ecological indicators

In 1997, policymakers in the different countries around the North Sea have agreed to develop and apply an ecosystems approach in their management for fisheries and the marine environment. As a result, various (inter)national projects for the development of ecological indicators were started.

3. Ecological quality objectives

The Oslo Paris Commissions (OSPAR) and the North Sea Task Force introduced the concept of Ecological quality objectives (EcoQos) [3]. The basis for EcOQos was

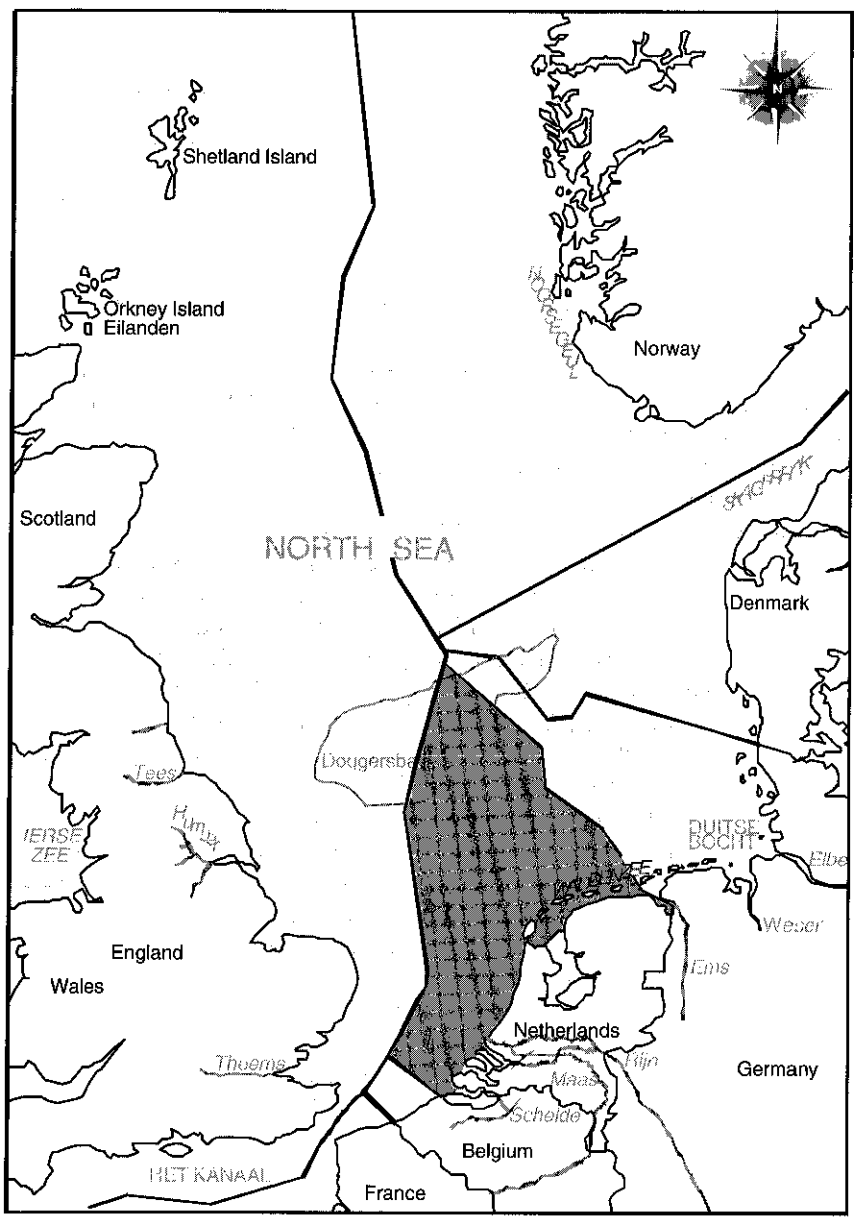


Fig. 1. The North Sea and the Dutch Continental Plate (dark area).

developed in 1992 after a series of international workshops. Discussions at these workshops and scientific meetings within the OSPAR resulted into the adoption of a conceptual framework for Ecological qualities (EcoQs) and Ecological Quality

Table 1
Ten issues for the ecological quality objectives for the North Sea

1. Reference points for commercial fish species	6.Threatened and declining species
2. Sea mammals	7. Seabirds
3. Fish communities	8. Benthic communities
4. Plankton communities	9. Habitats
5. Nutrient budgets and production	10. Oxygen consumption

objectives (EcoQos) [3]. In some countries, additional scientific effort was directed towards the further development of ecological indicators.

The basic framework for the EcoQos was presented for discussion at the Intermediate Ministerial Meeting (IMM) in Norway in 1997. During this meeting, both the Fisheries Ministers and the Environmental Ministers called for the development and implementation of an ecosystem approach for the management of the marine ecosystems.

At the following workshop in Oslo (1998), it was concluded that clear ecological objectives were needed as the basis for the development of the ecosystem approach strategy towards the management of the North Sea [4]. As a result, a special workshop on EcoQos was organised in Scheveningen, The Netherlands in 1999. Ten issues for the EcoQos for the North Sea were selected for further development (Table 1). The development was coordinated by the OSPAR Biodiversity Committee (OSPAR-BDC), with Norway and The Netherlands as co-leading countries. In the last 2 years (2000 and 2001) work was carried out by various institutions in the North Sea countries. Major assistance in this work was provided by the International Council for the Exploration of the Sea (ICES).

Ultimately, the issues were forwarded for discussion at the North Sea minister's conference in March 2002. As one of the strategies for the management of hazardous human activities in the North Sea, the Ministers emphasised the use of EcoQos as a tool for setting up of a set of clear and operational environmental objectives for the maintenance of biological diversity and sustainable development in the North Sea.

The OSPAR is charged with the task of reviewing the progress of this work in 2005 at the North Sea Ministers Conference, in collaboration with ICES and other relevant bodies. This review will be done with the aim of adopting a comprehensive and consistent scheme of EcoQos.

4. Ecological indicators at national level

Following the discussions in 1990 at the North Sea Ministers Conference over the sustainable use of the North Sea ecosystem, The Dutch ministries of Transport, Public works and Water Management (V&W) and the Ministry of Agriculture, Nature and Fisheries Management (LNV) agreed in 1996 to work towards making an integrated policy for the management of the North Sea ecosystem.

The Ministry of LNV makes policies for Nature conservation in the Netherlands including the North Sea, whilst the Ministry of V&W makes policies that will result into a sustainable use of the North Sea ecosystem.

For these two Ministries it was clear that before making sound policies for the sustainable use of the North Sea, a proper understanding of the functioning of the ecosystem is necessary. As a result of this, various projects leading to a better understanding of the North Sea were started.

One of the projects was strictly designed to develop ecological indicators which could be used to monitor the ecological performance of the ecosystem of the Dutch continental Plate [5].

5. Existing tools: AMOEBA

The existing tools were the AMOEBA [6] and Nature Target Types (NTT) [7] approaches, developed by the ministries of V&W and LNV, respectively. The AMOEBA was developed in 1990 whilst the NTT was developed in 1995. In the beginning, both tools were mainly political with very little scientific underpinning. The tools were developed separately.

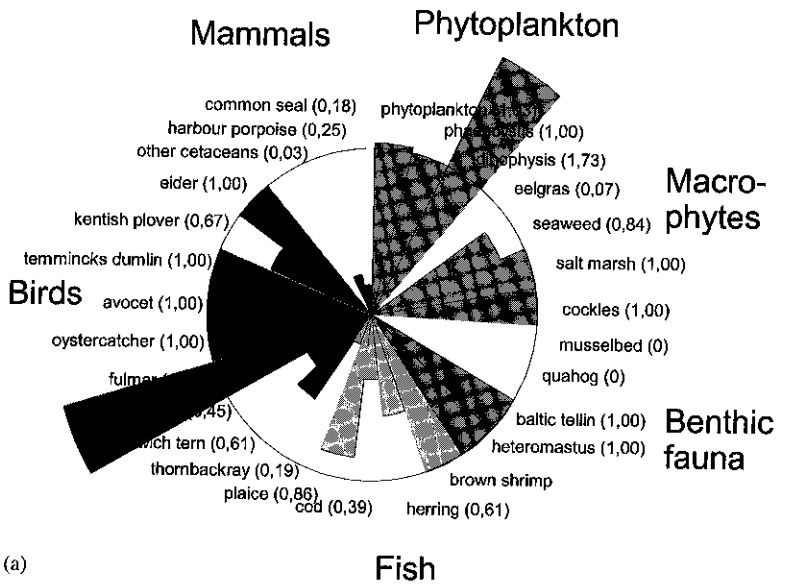
The species used for the AMOEBA and the NTT became known by the managers, the stake holders and various researchers. The occurrence of these species could be related to changes in the ecosystem, such species became the best candidates for the indicator system.

The tools took also into account policy recommendations for the ecosystem: for instance a reference situation, for example pristine conditions were considered. These pristine situations created a sense of direction in which the quality of the ecosystem should be moving towards.

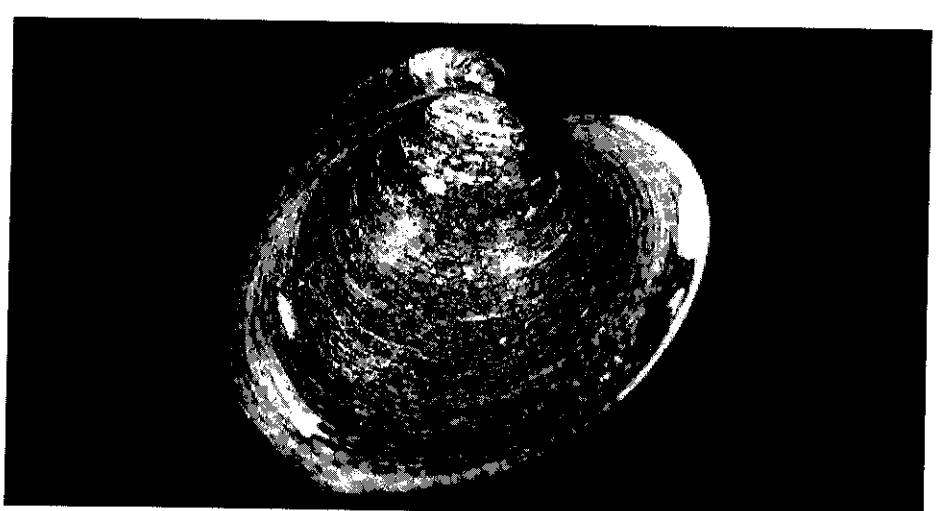
The set of ecological indicators that have been developed are presently used for describing the performance of the North Sea ecosystem. At a political level, some ministries are using the ecological indicators to develop new policies. For example, the Ministry of LNV has recently developed a set of Nature Conservation recommendations for the North Sea ecosystem [5].

The policies that are made for remote environments as marine ecosystems are in general broadly formulated and difficult to be directed to specific elements in the ecosystem. With the use of the ecological indicators for the North Sea, these policy recommendations were made concrete.

The indicators make it possible for the policy makers to exactly define their policy targets in quantitative terms (where necessary). Next to these objectives, they use the indicators to draw up policy measures that could be deployed in reaching the required policy targets. All parties concerned (researchers, managers, policy makers, users of the ecosystem and non-governmental organisations) could understand what the policies measures would require from them. They also understood which direction these policies will lead them into.



(a)



(b)

Fig. 2. (a) AMOEBA approach. Assessment of the ecological states of the Dutch part of the North Sea on 1996 with the use of the AMOEBA approach. The circle represents the target level for each indicator species. Measured levels are superimposed. (b) Artica islandica. Ocean Quahog is an exceptionally long living bivalve with slow growth rate. Average life expectance is 40–80 years with a substantial proportion of the population living longer than 100 years. Ocean Quahog lives on the sea bed and is vulnerable to bean trawl fisheries, which cause direct damage or mortality. High fishing intensity in the North Sea has made this species scarce to see. In the Nature policy management recommendation are made to ensure the return of this species. Because of this reason, the Ocean Quahog is selected as a Nature target type (NTT) for all scarce species in the North Sea.

6. Dutch project

The implementation of the Dutch project started in 1996. The framework of the indicator systematic is given in Fig. 2. The Nature and Water policies of the different governments form the basis. The broad policy objectives were analysed and interpreted into concrete ecological concepts (biodiversity end ecological functioning). These ecological concepts were further described on the basis of the characteristics of the North Sea ecosystem. The relationships between the ecosystem characteristics were used to identify the appropriate indicators and the subsequent indicator species (Fig. 3).

7. Policy recommendations

The Ministry of Transport, Public Works and Water Management (V&W) is responsible for making policies for the management of the waters in the Netherlands and the Netherlands part of the North Sea. In the Third Memorandum on Water Management policy—NW3 [8] recommendations are made to enhance the sustainable management and utilisation of the water systems. These policy recommendations are the results of a strategy which is based on the concept of integrated water management. The basic assumption behind this strategy is to archive the aims of the water policy through an integrated approach to the diverse problems of the water systems. These policy recommendations were further specified in the Fourth Memorandum on Water Management [9].

Next to the integrated approach for the management of water systems, the Fourth Memorandum on Water Management recommended the integration of all the policies (also from other ministries and departments) for water including those from LNV and VROM (Ministry of Housing, Physical planning and Environment). This policy recommendation created room for a more customised area-orientated approach: a combination of an integrated generic approach for the nationally collective objectives and a specific regional specification, taking into account the local conditions and opportunities. The objective of the Fourth Memorandum on Water Management policy is as follows:

> Having and maintaining a safe country and the development and conservation of healthy and resilient water systems which guarantee a sustainable utilisation.

This means that the water policy for the North Sea is geared towards a sustainable development and use of the water system. Fishery and ecological objectives are brought into balance using an integral approach of the fisheries in relation to the ecosystem qualities. The precautionary and ecosystem approaches are used for this purpose. Coastal expansion plans go hand in hand with investments in the coastal environment. These views were made clear and used as targets for realisation in the subsequent years after 1997 [9].

The Ministry of Agriculture, Nature Management and Fisheries is responsible for making policies for conserving and improving the quality of nature in the

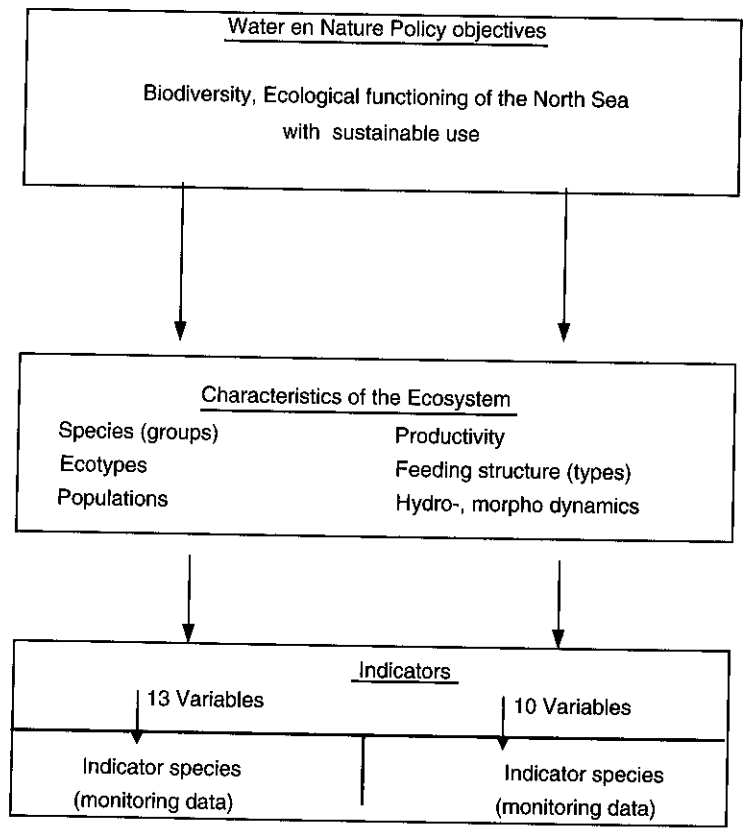


Fig. 3. The relationship between the policy objectives and the indicators for the North Sea ecosystem.

Netherlands, including fishery in the North Sea. The recommendations under the Nature conservation policy in the Netherlands are laid down in the following objective of the Nature Policy Plan [10]:

> Sustainable maintenance, recovery and development of natural and landscape values.

These objectives are made concrete with two key words: variety (or biodiversity) and naturalness. Both key words are combined in the specification of the main objectives, namely *conservation of biodiversity in the most natural way as possible.*

The most important means for the fulfilment of these objectives (biodiversity) is the realisation of the National Ecological Network (NEN). This is a connected network of ecosystems which are nationally and internationally considered important and are to be durably maintained. The network must be realised in

2018 and comprise 700,000 acres of land and 7,000,000 acres of water [11]. The Dutch Continental Plate of the North Sea is a key area within the NEN. Species protection related measures are also taken into consideration in the NEN, such as the shelter for grassland birds and geese outside the NEN.

The Dutch Water and Nature policies have a mutual aim: the development of a healthy, natural aquatic ecosystem, in which natural processes create conditions for species and ecological communities to durably preserve themselves.

The two policies differ in three aspects: conservation of biodiversity, healthy ecological functioning of the water system and ecologically responsible use of the ecosystem (utilisation attuned to the ecological quality of the water system).

8. Conservation of biodiversity

In the Rio declaration biodiversity was defined as "the variability among living organisms including, for example, terrestrial, marine and other ecosystems and the ecological complexes to which they belong: this includes diversity within species, between species and diversity of ecosystems".

Almost all of the components of the natural ecosystem are included in this definition of biodiversity. This broad definition resulted in many different interpretations of the concept of biodiversity when put into practice. In the Netherlands the specification of the concept biodiversity as described by Gray [12] was used as a starting point by in the development of indicators for biodiversity.

The following types of biodiversity were classified by Gray: (1) genetic diversity, (2) species diversity, (3) phylum diversity, (4) functional diversity, (5) ecological community diversity, (6) habitat diversity and (7) ecotope diversity.

The genetic diversity can be considered as being the biological basis for all other forms of biodiversity. After all, significant diversity generating processes can work only thanks to genetic variation. The species abundance is biodiversity's most classic approach. Often, it is not only the number of species that are taken into consideration but also the abundance (of one species). The diversity can also be calculated at the higher taxonomic levels (such as phylum). Diversity at the level of functional groups and ecological communities surpasses the level of the taxonomic groups. Habitat and ecotopes diversities are linked to the circumstances that form the stipulations for the establishment and development of species (habitats) and ecological communities (ecotopes).

It is clear that a concept as extensive as biodiversity cannot be determined using a single indicator. In the integral evaluation system biodiversity is coupled to the ecosystem characteristics species, ecological communities and ecotopes.

The following types of diversity are central in the development of indicators for biodiversity in the Netherlands:

- species diversity (including genetic variation),
- species groups and ecological communities diversity,
- habitat and ecotope diversity.

Differences between the Water and Nature policy on the item of conservation of biodiversity are: Water policy is more oriented on robust species, while criteria for the Nature are rare species that are named on international lists. In Water policy the whole functioning of the ecosystem, including habitats, is considered, while Nature policy is describing the ecosystem by different species as mentioned above. The use of water systems is not ruled out completely in the Water policy, as it is done in the Nature approach where 100% protection of the system is the ultimate aim.

9. Healthy ecological functioning of the water system

The energy currents which are linked to production, consumption and decomposition can be viewed from various angles: namely from the various trophic levels and based upon food relationships. Two types of food chain are classified within the aquatic ecosystem—those dominated by the grazers and those dominated by the detrivores. Primary production is the basis of the first type and dead organic material is the basis of the latter. As an ecosystem comprises all sorts of links between the food chains, an extremely complex structure is created, which is denoted as the food network. Also hydro- and morphological habitat characteristics are taken into account.

Therefore, the development of indicators for ecological functioning in will be carried out based upon:

- productivity,
- food network structure,
- hydro- and morphodynamics.

There are obvious common grounds between ecological functioning and biodiversity. A relationship between the complexity of the food network and the biodiversity has been defined in various studies. Research data show that the more complex the food network, the larger the biodiversity [13]. However, with an increase in productivity, domination of species occurs and there is a drop in the species abundance [14].

10. Ecologically responsible use of the water ecosystem

The policy theme 'ecologically responsible use' is dealt with primarily in the water policy, where the ecological values of the North Sea and the economic values of the utilisation are balanced against each other. An attempt is made to define the concept of 'sustainable use'. The following utilisation functions are taken into consideration for the North Sea: fisheries, the shipping industry, recreation, military activities, oil and gas extraction, sand excavation and replenishment, land reclamation and infrastructure development. In addition to this, eutrophication and micro-contamination are influencing the quality of the North Sea.

The policy theme of 'ecologically responsible use' deals with the influence of the utilisation on the quality of the ecosystem, and consequently both biodiversity and ecological functioning. Therefore, the indicators for ecologically responsible use correspond to those for biodiversity and ecological functioning.

11. Ecosystem characteristics

In the perception of the design of the evaluation system it is clear that it is necessary to define relevant and characteristic structure and processes of the ecosystem. Based on the various organisational levels to be distinguished in the ecosystem, the following general characteristics are considered to be functionally associated with various organisational levels [15]:

- species, both at individual (number of species) and populations (numbers of one species) levels,
- groups of species and ecological communities: composition, structure and succession,
- ecotopes: parts of an ecosystem that can be distinguished on the basis of factors in the hydro- and morphological surroundings that are influential to the occurrence of specific species or ecological communities,
- the productivity of the various trophic levels,
- the structure of the food chain: the food chains within an ecosystem and the inter-relations present, transverse connections and contacts,
- hydro- and morphodynamic processes: processes which cohere with water movements and sediment management that are also controlling elements for the creation of environmental conditions in which species and ecological communities can develop.

12. The integration of the policy themes and the ecosystem characteristics

In general, the linking of the indicators to both the Water and Nature policy themes is made possible by using the ecosystem characteristics, species, ecological communities and ecotopes. These characteristics are at the same time representative for the concept of biodiversity, the productivity of the ecosystem, the ecological functioning and hydro- and morphodynamics in the ecosystem.

Ecologically responsible use affects both the diversity and the ecological functioning in the system. In this way, the ecologically responsible use of the ecosystem is associated with the various characteristics of the ecosystem.

The following types of diversity which were used as bases for the development of biodiversity indicators: species diversity (inclusive genetic variation); diversity in species groups and ecological communities and diversity of habitat and ecotopes.

Although ecological processes are undoubtedly influential to the biodiversity in the ecosystem, indicators dealing these processes are not included in the

interpretation of biodiversity. In the first place, the influence of ecological processes on the biodiversity is based on the development of habitats, species, species groups and ecological communities. Secondly, the inclusion of ecological processes when defining biodiversity will result in all ecological components being incorporated in diversity. This will result in a significant overlap with ecological functioning, which in turn results in the ecosystem acquiring a non-transparent structure.

The policy theme of healthy ecological functioning is evaluated using indicators which are linked to the following ecosystem characteristics: productivity; structure of the food network and hydro- and morphodynamics.

There are distinct links between biodiversity and ecological functioning. In the evaluation system, ecological functioning and biodiversity are specified from various standpoints. In the integral evaluation system the interfaces of both themes are expressed using a common set of system indicators.

The policy theme of ecologically responsible use is principally under discussion in the Water policy via the route of integral water management in which the ecological values for the North Sea and the economical values of the utilisation are weighed up against each other. For a better understanding of the concept for integration into the indicator systematic, an attempt is made to outline the concept of "sustainable use".

The following utilisation functions are dealt with for the North Sea: fishery, shipping industry, recreation, military activities, mining industry, sand excavation and deposition, land reclamation and infrastructure.

The policy theme of ecologically responsible use deals with the keeping in balance the impact of human activities on the ecological quality of the ecosystem and consequently on biodiversity and the ecological functioning of the system. With regards to the indicators for ecologically responsible usage an overlap exists between biodiversity and ecological functioning. The indicators for describing the ecologically conscious usage are placed in a different category of indicators: indicators related to usage.

13. The selection and development of the ecological indicators

The indicators are made operational using one or more indicator parameters. The indicator parameters are ecological quantities or units (indices) derived from data on the parameters. The quality of the indicator parameter is determined using field and model data. By using these data, it is therefore possible to carry out policy evaluations both in advance (policy analysis) and in retrospect (monitoring). It is essential that reference points, or a given time frame, will be defined for the evaluation of the quality of the indicators. Reference points can be classified into more or less natural reference, based on system definitions of more or less undisturbed situations in the past or comparable systems elsewhere. A target value, based on a situation which is derived from the natural reference, taking specific social prerequisite constraints into consideration (such as safety, maintaining existing infrastructure). Standard, a value which is established by the policy and which must be complied with "base-line", a situation from the past which concerns

impact caused by human actions which serves as a reference point for the evaluation of the current situation and future planned developments. If data is only available for the current situation this can function as a base line for the evaluation of future planned developments.

After the analysis of the Water and Nature conservation policies and the marine ecosystem the step was taken to propose the indicators for the North Sea. The criteria include the following:

- the indicators must be relevant to both the Water and Nature policies,
- the relationship between indicators and ecosystem characteristics must be unambiguously expressed,
- the indicators are quantified by one or more indicator-parameters,
- in the indicator systematic, a distinction must be made between ecosystem indicators-parameters and indicator-parameters for detecting the effects of human activities,
- the total set of indicators should provide a comprehensive image of the North Sea ecosystem,
- the indicators should have a broad relationships with the existing evaluation tools (e.g. AMOEBA and NTT).

14. Criteria for the selection of indicator-parameters

- the indicator parameter must have a significant relevancy with the Water and Nature conservation policies,
- the indicator parameters must have a distinct relationship with the process and or structural characteristics of the North Sea ecosystem,
- one or more indicators-parameters must be capable of making the indicator operational,
- the total set of indicator parameters must be capable of providing a total picture of the quality of the North Sea ecosystem.

15. Indicators for the North Sea

At species level, the most typical species (groups) are incorporated in the indicator system: plankton, macrobenthos, fishes, coastal and sea birds and marine mammals. A distinction is made between indicators which are geared towards species abundance within the species groups (species diversity) and towards the development of populations. Conservation of biodiversity does not solely mean the prevention of a further degradation of biodiversity, but also the recovery of populations of species which are currently under threat from (localised) extinction.

At community level, indicators were selected for describing the structural characteristics of plankton–macrozoobenthos and fish communities. These indicators

express the impacts of human usage on the ecological quality of the North Sea. The structural characteristics of the fish and macrozoobenthos organisms are of course strongly influenced by fisheries.

With regards to the productivity (ecological functioning) of the North Sea, indicators that deal with the primary, secondary, tertiary production and the decomposition of dead organic material were selected. With regards to the functional relationship between the organisms in the North Sea indicators describing the food web structure are selected and are incorporated in the systematic. The available bulk of food, the top predators and the trophic structure of the macrozoobenthos and the fish community were selected. With regards developments in hydro- and morphodynamic processes an indicator was selected for the description of the changes in the dynamic ecotopes for the coastal area.

The integration of the policy recommendations and the characteristics of the ecosystem resulted into the identification of 23 indicators for the NCP ecosystem (see Table 2(a)).

16. First set of ecological indicators

Because of the complexities in the development and bringing into operation of all these 23 indicators, a rapid assessment study on the 23 indicators was carried out to select a set of indicators that could be developed.

The rapid assessment study on the proposed indicators was directly geared towards the selection of a set of indicators. Prior to the setting up of the selection criteria, the process of developing an ecological indicator for management purposes was described. In the description, enough attention is given to all relevant precautions to develop the indicators. Administrative and technical aspects were fully understood. Among the criteria used for the selection of ecological indicators a lot of emphasis was laid on the following:

- The set of indicators must adequately answer the questions raised by policy makers, managers and stakeholders for the North Sea ecosystem.
- The concepts underlying the usage of the set of indictors (species) must be easily understood.
- The set must give an adequate picture of the present ecological status of the North Sea ecosystem.
- The set must describe the effects of various human activities on the North Sea.
- Availability of sufficient monitoring data on the indicator-parameter.
- Consensus on the method used for developing the indicators has to be met by the participating scientific body.
- The techniques used should be simple and robust.

After the screening, 13 indicators out of the 23 proposed indicators were selected for development. These 13 indicators are shown in Table 2(b). They are grouped in

Table 2

Policy themes	Ecosystem-characteristic	Indicator	System indicator parameters	Utilisation indicator parameters
(a) The proposed indicators for the North Sea ecosystem				
Biodiversity	Species	Plankton species diversity	Phytoplankton: average number of species	Phytoplankton: average number of species
			Mesozooplankton: Simpson's index	Mesozooplankton: Simpson's index
		Macrobenthos species diversity	Diversity macrofauna: number of species	
			Shannon–Wiener index	
			Simpson's index	
			The relative abundance of the most dominant species	
		Macrobenthos population	Quahog/Islandic cyprine density	Quahog/Islandic cyprine density
			Masked Crab/Helmet Crab density	Whelk density
			Star fish density	Star fish density
		Fishes species diversity	Simpson's fish fauna index	Simpson's fish fauna index
			Simpson's fish fauna per length classification index	Simpson's fish fauna per length classification index
		Salt water fishes population	Stingray: fishery Mortality and spawning biomass	Herring: fishery mortality and spawning biomass
			Fint: spawning biomass	Cod: fishery mortality and spawning biomass
				Plaice: fishery mortality and spawning biomass
				Stingray: fishery mortality and spawning biomass
				Fint: spawning biomass
		Coastal and sea birds species diversity	Simpson's gulls and sterns index (breeding birds)	

Table 2 (*contuined*)

Policy themes	Ecosystem-characteristic	Indicator	System indicator parameters	Utilisation indicator parameters
			Herring gull: number of breeding pairs Mediterranean gull: number of breeding pairs	
		Coastal and sea bird population	Sandwich tern: number of breeding pairs and number fully fledged young birds per breeding pair	Sandwich tern: number of breeding pairs and number fully fledged young birds per breeding pair
			Kentish plover: breeding pairs Common scoter: number of mating days in winter	Kentish plover: breeding pairs Lesser black-backed gull: number of breeding pairs Common scoter: number mating days in winter
		Marine mammals population	Porpoise: number of animals	Porpoise: number of animals
			Common seal: number of animals	Common seal: number of animals
		Distribution area of marine mammals	Porpoise: distribution area	Porpoise: distribution area
			Common seal: resting area	Common seal: resting area
	Species groups and ecological communities	Plankton community structure	Phytoplankton: length–distribution ratio of densities between flagellates and diatoms	Phytoplankton: distribution of length density ratios between flagellates and diatoms
			Total duration of flowering of *Phaeocystis*, *Noctiluca* and *Dinophysis*	Total duration of *Phaeocystis*, *Noctiluca* and *Dinophysis* flowering
			Zooplankton: not yet specified	Zooplankton: not yet specified
		Macrobenthos community structure	Ratio density r- and K-strategists	

		Fish community structure	Average weight of fishes	Average weight of fishes
			Biomass percentage fishes > 25 cm in total fish biomass	Biomass percentage fishes > 25 cm in total fish biomass
	Ecotopes	Surface of ecotopes	*Spisula* banks area in ecotope shallow coastal zone undisrupted gravel banks area	*Spisula blb* area in ecotope shallow coastal zone undisrupted gravel banks area
			Area of undisrupted stone ecotopes in the area of Texelse Stenen	Area of undisrupted stone ecotopes in the area of Texelse Stenen
Ecologically functioning	Productivity	Primary production	Primary production by phytoplankton	Primary production by phytoplankton
		Secondary production	Secondary production by copepods	
			Secondary production by benthos	
		Tertiary production	Somatic fish production	Somatic fish production
		Decomposition	Star fish density	Star fish density
			Masked Crab/Helmet Crab density	
	Food network-structure	Staple food	Copepods density: *Calanus finmarchicus*	*Spisula subtruncata* density
			Temora longicornis	Small sand eel: fishery mortality and spawning biomass
			Spisula subtruncata density	Herring: fishery mortality and spawning biomass
			Small sand eel: fishery mortality and spawning biomass	
			Herring: fishery mortality and spawning biomass	
		Top predators	Cod: fishery mortality and spawning biomass	Cod: fishery mortality and spawning biomass
			Sandwich Tern: number of breeding pairs and number of fully fledged young birds per breeding pair	Sandwich Tern: number of breeding pairs and number of fully fledged young birds per breeding pair
			Porpoise: number of animals	Porpoise: number animals
			Common seal: number of animals	Common seal: number of animals
		Complexity of food network	As yet no indicators proposed	

Table 2 (*contuined*)

Policy themes	Ecosystem-characteristic	Indicator	System indicator parameters	Utilisation indicator parameters
		Trophic structure of macrobenthos-community	Macrobenthos food groups index (ITI)	
		Trophic structure of fish population	As yet no indicators proposed	As yet no indicators proposed
	Hydro- and morphodynamic dynamic	Dynamic ecotopes area	Sand bar area	Sand bar area
No.	Indicator	Indicator parameter	Methods	Criteria
(*b*) *The selected 13 ecological indicators for the North Sea*				
1	Species diversity Phytoplankton	Phytoplankton	Shannon–Weiner index, Simpsons index	To examine the scale diversity
2	Species diversity macrozoobenthos	Macrobenthos	Shannon–Weiner ind. Simpsons index	To examine the scale diversity
3	Population size macrozoobenthos	Island Muschel Masked crab, Sea star	Number found per meter square	Patterns of occurrence
4	Dominant feeding habits Macrozoobenthos	Observed feeding types	Counting individuals in de various feeding groups	To examine the level of disturbances in de environment
5	Population of marine fish species	Roker Herring, Cod Plaice en Sand eel	Number of fish per species	Fish catches, breeding grounds and fish death data
6	Population size of the coast and sea birds	Gulls en Terns Silver Gull Mediterranean Gull	Counting individuals in the various groups	Numbers at breeding places and individuals

7	Population size sea mammals	Common scoter	Counting the observed individuals	Counting individuals per 1000 cbm
8	Population Structure of Phytoplankton	Phytoplankton Zooplankton	Multivariate analyse N/P ratio	Population structure, species abundance
9	Population Structure of macrozoobenthos	Macrozoobenthos	Relationship between the short and long living forms (r/K strategist)	Response to changing conditions in the sea
10	Population Structure of the fish community	Strategic fish species Roker, Herring, Cod, Plaice	Relationship between the short and long living forms	Length-group relationships
11	Primary production levels	Nutrient concentration	Nutirient concentration as a measure for higher concentrations of phytoplankton	Measure of nutrient flow into the coast and offshore regions of the marine environment
12	Top predators	Roker, Common scooter	Counting the observed individuals	
13	Size of available prey population	*Spisula* banks as food for the birds	Counting the banks and estimating observable individuals	Higher numbers of prey indicate higher numbers of predators

the following 5 categories:

1. Species diversity: phytoplankton, macrozoobenthos
2. Production: primary production
3. Population size: macrozoobenthos, feeding types, fish species coast and sea birds, sea mammals
4. Food relationships: top predators, prey size
5. Population structure: phytoplankton, macrozoobenthos and fish community

The species (group) related information per indicator is combined to describe the total ecological status of the North Sea ecosystem. Since the information on the ecological performance of the indicators (parameters) is reported over a period of time, these changes (also changes in the ecosystem) can be shown by the long-term trends obtained on the related parameters.

Furthermore, these trends could be used to assess the impacts of planned future uses of the North Sea on the ecosystem. The results of this prognosis could be a tangible management tool for both the policy makers, managers and for the stake holders.

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