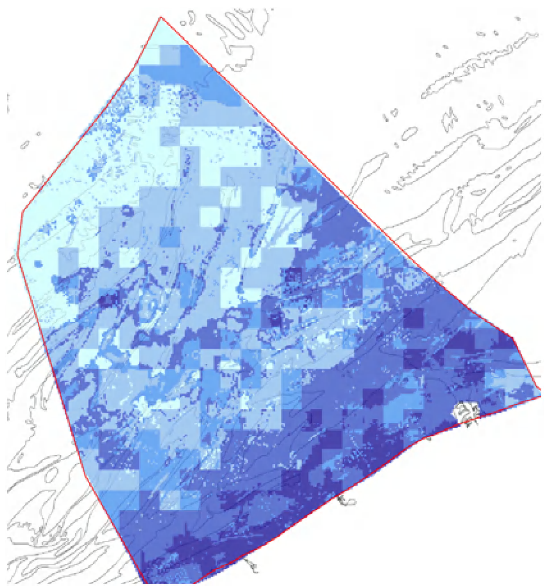
MARINE BIOLOGICAL VALUATION AS A DECISION SUPPORT TOOL FOR MARINE MANAGEMENT

MARIENE BIOLOGISCHE WAARDERING ALS EEN BESLISSINGSONDERSTEUNENDE TECHNIEK VOOR MARIEN BEHEER



SOFIE DEROUS

PROMOTOR: PROF. DR. MAGDA VINCX
CO-PROMOTOR: DR. STEVEN DEGRAER

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Thesis submitted in partial fulfilment of the requirements for the degree of Doctor in Science (Biology)

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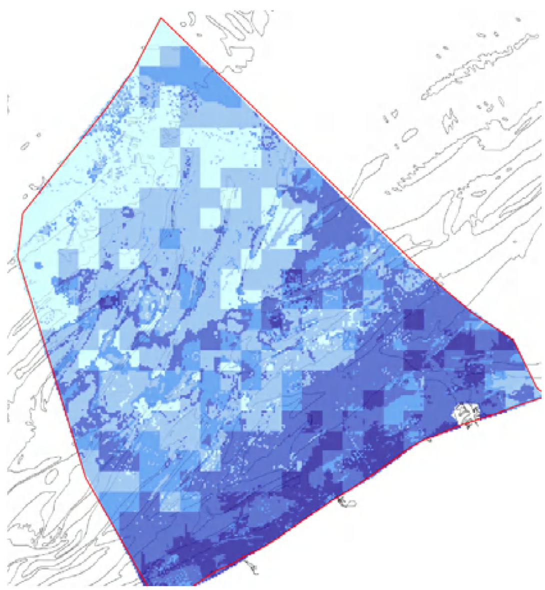
Marine Biology
Ghent University

Marine Biological Valuation as a Decision Support Tool for Marine Management

Mariene Biologische Waardering als een Beslissingsondersteunende Techniek voor Marien Beheer



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Members of the reading committee:

Prof. Dr. Magda Vincx (Ghent University, Belgium): promotor

Dr. Steven Degraer (Ghent University, Belgium): co-promotor

Prof. Dr. John Roff (Acadia University, Canada)

Dr. Vera Van Lancker (Ghent University, Belgium)

Members of the examination committee:

Prof. Dr. Wim Vyverman (Ghent University, Belgium): chair

Prof. Dr. Magda Vincx (Ghent University, Belgium): promotor

Dr. Steven Degraer (Ghent University, Belgium): co-promotor

Prof. Dr. John Roff (Acadia University, Canada)

Dr. Vera Van Lancker (Ghent University, Belgium)

Prof. Dr. An Cliquet (Ghent University, Belgium)

Prof. Dr. Eckhart Kuijken (INBO, Belgium)

Prof. Dr. Carlo Heip (NIOO, the Netherlands

Dr. Richard Eertman (RIKZ, the Netherlands)

Dr. Eric Stienen (INBO, Belgium)

Dr. Thierry Jacques (MUMM, Belgium)

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SUMMARY

Marine environments are currently experiencing intense pressures from a range of natural and anthropogenic driving forces. Marine managers and policy makers are seeking ways of better managing the causes and consequences of the environmental change process at sea. Marine areas, and especially coastal environments, are very difficult places to manage, as they are dynamic natural systems which have been increasingly pressurised by expanding socio-economic demands, due to high settlements along coastal areas and decreasing space and resources on land. A fundamental issue in the development of marine management tools is the fact that it is impossible to manage the sea or marine environments. There exists no means for significant management of most of the marine ecosystem processes. It is therefore only possible to manage human behaviours to influence what people do to marine resources and habitats. The concept that human activities can damage the marine biodiversity and ecosystems is very recent, as most people were brought up with notions of the seas as vast, remote and limitless sources of food and resources and sinks to absorb human waste.

The present thesis focuses on the development and application of a biological tool that can be used as a decision support system for marine management. The main aim of the thesis was to develop a marine biological valuation methodology that is able to integrate all available biological information of an area into one indicator of intrinsic value. This methodology should be applicable in every marine environment, independent of the amount and quality of the available biological data and the habitat type, and should be acceptable by a wide scientific audience.

The five main **objectives** of the thesis were: (1) to develop a concept for marine biological valuation which is widely applicable and scientifically acceptable; (2) to develop a protocol around this concept which defines the different steps that need to be taken to develop marine biological valuation maps; (3) to apply the protocol to different case study areas to see how it performs under different circumstances; (4) to review the possibilities of using the protocol for the implementation of several European Directives, which relate to nature conservation in the marine environment, and as part of decision support systems for marine management in general, and spatial planning in particular; and (5) to evaluate the indicator “marine biological value” on its conceptual relevance, feasibility of implementation, response variability and utility for environmental decision-making.

In **Chapter 1**, a general description of available marine management tools and a detailed overview of the ecological indicators to express biological or ecological information were given. Marine and coastal ecosystems not only support much of the world's biodiversity, but also significantly contribute to the global economy by providing many goods and services. This subjects marine biodiversity and ecosystems to intense pressure that threatens its structure and functioning and the future of the activities that depend on it. Because of increasing anthropogenic pressure, there is a need for decision support systems and management tools that allow to tackle some of the environmental problems associated with this pressure and to allocate the different uses in an integrated and sustainable way. The development and use of decision support systems that integrate both socio-economic and biological information is crucial for the implementation of sustainable, balanced developments in the future. Most marine management tools are built around the Driver-Pressure-State-Impact-Response (DPSIR) framework, where indicators are selected which are able to quantify each of these different components. Other available decision support systems are impact assessments, spatial planning, multi-criteria analyses and socio-economic valuations. While several socio-economic valuation tools have been developed and used for marine management in the past, the integration of biological information in the decision framework was usually done by using ecological indicators. Although there exists a wide variety of literature on ecological indicators, integrative, system-level indicators are still lacking. This asks for the development of a new indicator that integrates all available biological information into one value which expresses the intrinsic value of a certain marine area.

A description of the concept for marine biological valuation, which has been rationalized around a selected set of valuation criteria (first-order criteria: aggregation, rarity and fitness consequences; modifying criteria: naturalness and proportional importance) and integrates all organizational levels of marine biodiversity, is given in **Chapter 2A**. The criteria selection was based on a literature review of existing ecological criteria and the consensus reached by a discussion group of experts during an international workshop in December 2004. In **Chapter 2A,** an attempt was also made to clarify the numerous criteria and definitions of value that are current in the literature. In our concept, marine biological value is defined as 'the intrinsic value of marine biodiversity, without reference to anthropogenic use'. This is in contrast to the socio-economic value of marine biodiversity which is an assessment of the socio-economic importance of the goods and services provided by marine biodiversity to humans (**Chapter 1** and **Annex A**). Marine biological valuation provides a comprehensive concept for assessing the intrinsic value of the subzones within a study area. It is not a strategy for protecting all habitats and marine communities that have some ecological significance, but is a tool for calling attention to subzones that have particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk aversion in spatial planning activities in these subzones. Biological valuation maps (BVMs) that compile and summarize all available biological and ecological information for a study area, and that allocate an overall biological value to subzones, can therefore be used as baseline maps for future spatial planning at sea.

As this biological valuation concept was based on the consensus reached by a group of experts on this matter, it was realized that refinement of the methodology could be necessary once it has been evaluated on the basis of case study areas. After the concept was applied to the Belgian part of the North Sea, there was felt a need for adaptation of the original concept as problems appeared with overlap between the different valuation criteria and other practical application issues emerged. A second international workshop, which was a joint initiative between the ENCORA coordination action and the MARBEF Network of Excellence workshop, was therefore held in December 2006, to discuss the applicability of the concept and to adapt the methodology to make it scientifically more acceptable. This workshop resulted in fine-tuning of the concept of marine biological valuation by omitting some valuation criteria[1]. The criteria 'aggregation' and 'fitness consequences' were lumped into one criterion to avoid double counting of scores. Also, a more logical order of steps, which should be made during the valuation, was proposed by assessing biological value at two different scales (first at a local scale and then at a more regional scale) instead of incorporating 'proportional importance' as a valuation criterion. 'Rarity' was retained as a valuation criterion, while 'naturalness' was excluded from the concept due to its link with human use and impacts. These adaptations will allow a better applicability of the concept to marine areas (**Chapter 2B**).

To allow objective biological valuations of marine areas, generally applicable and transparent guidelines for the practical application of the marine biological concept are needed. All steps of the valuation protocol were described in **Chapter 3**. After dividing the study area into

[1] The criterion 'naturalness' was omitted from the original valuation concept, as it is still very difficult to assess naturalness in marine environments. Almost no natural reference sites are available due to the openness of the systems and to assess the naturalness of a marine area, one almost often goes back to identifying an area where no human activities occur. As such, it is difficult to assess naturalness, without referring to human use, which led to the exclusion of the criterion 'naturalness', to avoid conflicts with the definition of 'biological value'. One could argue that 'rarity' is also linked to anthropogenic use, as some species or habitats can be reduced in numbers due to impacts upon them. However, certain species or habitats can be impoverished naturally as well, and methods to assess rarity (without referring to human impacts) exist (see Chapter 2A), which led the workshop participants conclude that rarity can be kept within the concept of marine biological valuation.

subzones and collecting the available biological data, the applicable assessment questions should be selected, which relate the valuation criteria to the different organizational levels of biodiversity. To develop a protocol which is as objective as possible, several mathematical algorithms were defined which can be used for the practical application of the assessment questions to an existing biological dataset. This protocol allows assessing the biological value of subzones, relatively to each other, based on the proposed criteria in study areas with various levels of data available. A major benefit of the proposed marine biological valuation protocol is the fact that all available biological and ecological data are integrated for each subzone, which makes the comparison between subzones easier for the users of the maps. The resulting BVM is easy to interpret and translates complex scientific data into a tool that can be used by policy makers as a baseline layer for spatial planning at sea. Subzones that show a high biological value are areas which should preferably be avoided when new activities are implemented or existing uses are relocated. When such BVM is lacking, managers can only trust on the available best expert judgement to include biological aspects into their decisions, a process which is untransparent and lacks objectivity. Several scoring systems could be used for this integration and one example was explained in **Chapter 3** by using fictive values of a hypothetical study area. The reliability of the assessed intrinsic value should be noted by attaching a label to the different subzones. This label can display the amount and quality of the data used to assess the value of a certain subzone (data availability) or it can display how many assessment questions could be answered given the data available for each subzone (reliability of information). These reliability labels should be consulted simultaneously while using the BVMs. Next to that, they help to identify knowledge gaps which could direct future scientific research. The biological valuation protocol is developed to be as objective and flexible as possible, which should allow the inclusion of multiple ecosystem components, the use of different levels of data availability and the application to a broad range of marine environments.

The protocol for marine biological valuation was applied to a selected set of case study areas in **Chapter 4**. The case study areas were the Belgian part of the North Sea (BPNS), the Isles of Scilly in the UK (IoS) and the Dutch part of the North Sea (DPNS). The chapter explored how the methodology deals with different levels of data availability by comparing the BVM of the BPNS, where detailed quantitative data were present for different ecosystem components allowing for the creation of a full-coverage map, with the BVM of the IoS, where data availability was limited or even absent for a lot of subzones. The BVM of the BPNS integrated quantitative data (abundances, species richness, biomass,…) on seabirds, macro- and epibenthos and demersal fish. Similar data were available for the DPNS for seabirds, macrobenthos, demersal fish, phyto- and zooplankton and sea mammals. Data from the IoS were available for more ecosystem components, but were more restricted in geographical distribution and in the amount and quality of the data. Quantitative data were available for macro-, epi- and hyperbenthos, plants and sea mammals, while qualitative data (occurrence data) were present for macro-, epi-, hyper- and meiobenthos, demersal fish, algae (both phytoplankton and macro-algae), plants and sea mammals. Two types of valuation maps were constructed for the IoS, one based on quantitative data and one on qualitative data and both maps were compared to see whether the quality of data had any impact on the outcome of the valuation. Reliability maps, indicating both the data availability (sample number per subzone) and the reliability of the information (number of valuation assessment questions that can be answered for each subzone), were developed for each valuation map and these maps are essential in the interpretation of the BVMs as they give an estimate of the uncertainty of the determined value.

The final BVMs indicated clear patterns in biological value. Some areas which were estimated as highly valuable in the past (mainly based on expert judgement of ecosystem components analysed separately), like the coastal areas of the BPNS or DPNS, were also assessed highly valuable with this marine biological valuation protocol. The data availability maps clearly showed which areas did not get a lot of attention during past research efforts and should be focus points in future sampling campaigns. Collecting new data will only improve the reliability of the maps by increasing both the data availability and the number of assessment questions which can be answered (information reliability).

Misinterpretations of the BVMs could occur when the values on the maps are used without consultation of the underlying maps, the documentation of the valuation or the integrated database. Such consultation should be done to check the data which were used to determine the integrated biological value and the methodology that was used to assess the values. It is also necessary to clearly state for which purposes the developed marine biological valuation can be used. The map can only be used to determine the biological value of subzones. As such they can be considered as warning systems for marine managers who are planning new threatening activities at sea, and can help to indicate conflicts between human uses and high biological value of a subzone during spatial planning. It should be explicitly stated that these maps give no information on the potential impacts that any activity could have on a certain area, since criteria like vulnerability or resilience were not included in the valuation protocol.

They cannot be used for site-specific management (e.g. selection of marine protected areas or impact assessments) as such activities also require the assessment of other criteria (representativeness, integrity, socio-economic and management criteria). However, the BVMs could be used as a framework to evaluate the effects of certain management decisions (implementation of MPAs or new quota for resource use), but only at a more general level when BVMs are revised after a period of time to see if value changers occur in subzones where these management actions were implemented. However, these value changes cannot directly be related to specific impact sources, but only give an integrated view on the effect of all impact sources and improvement measures taken in the subzone.
BVMs are baseline maps showing the relative values of the different subzones of a study area. As such, the values are linked to the scale of the area which is valued. This means that a subzone of the BPNS given a 'high' value cannot be compared to a subzone of the IoS with the same value, although the same methodology has been used to determine the values. Comparing the values of subzones of different areas can only be done when a new valuation assessment is done where all subzones are assessed against each other.

Several European Directives for the conservation or protection of marine environments have been ordered in the past (EU Habitats and Birds Directive and EU Water Framework Directive). These Directives should be implemented by each Member State of the European Union by using appropriate methods and conversion into national legislation, resulting in the designation and protection of marine areas for conservation and in the achievement of good water quality. A new European Directive, the Marine Strategy Directive is presently being proposed, which should also contribute to the protection and preservation of the marine environment and to the prevention of its deterioration. This proposed Directive will be written specifically for the marine environment, which was not the case with previously mentioned Directives. In **Chapter 5**, it was investigated which guidelines are available to implement the Habitats, Birds, Water Framework and (proposed) Marine Strategy Directives and the results of their implementation were compared with marine biological valuation results, to see whether such valuation could be used in the future to target the questions posed by these different Directives. This was done by applying the different methodologies to data of the BPNS.
Results showed that, as far as the BPNS is concerned, the valuation protocol seemed to give good results for the implementation of the European Habitats, Birds and (proposed) Marine Strategy Directives, while it could not be used for the implementation of the Water Framework

Directive as the objective of this latter Directive (determining the ecological status of coastal waters) does not agree with the objective of marine biological valuation (determining the intrinsic value of marine areas). Ecological status and intrinsic biological value therefore need to be assessed complementary to each other. Good agreement was found between the Special Protection Areas, designated under the Birds Directive, and the high valuable areas for birds in the BPNS. Most of the criteria or species considered in the Birds Directive are also investigated during valuation, although information on seabird species which are not considered as priority species for conservation is also included in the valuation, giving a more realistic picture on the biological value of the BPNS for every bird species. The Special Areas of Conservation (SAC), selected under the Habitats Directive, were located in areas which show relatively medium to high biological values on the total BVM. The situation of medium valued areas in the SACs could be explained by the fact that biological valuation gives a more patchy result of values (as subzones are scored relatively to each other), while under the Habitats Directive it is more logical to select large, undivided areas, which can be managed more easily. The fact that a range of biological values is present in the SACs will also increase the biological diversity which is conserved, which is one of the major aims of the Habitats Directive. Marine BVMs could be used a baseline map for the implementation of the future European Marine Strategy Directive, as the protocol incorporates most of the biological and physical characteristics required by the Directive. To be more useful in the future, the BVM of the BPNS should be updated with information on other marine ecosystem components, like plankton and sea mammals, as these components need to be considered for the implementation of the Marine Strategy. Next to these baseline BVMs, maps with information on human activities and the pressures and impacts they have on the environment should be provided as overlying layers, to be able to assess the environmental status of an area.
Next to that, a comparison of the BEQI classification approach, developed for the implementation of the Water Framework Directive in the Belgian coastal zone, to other European classification methods was made in **Chapter 5**. The BEQI approach agreed well with most other European classification methods, and should be applied in the future to new datasets to investigate its general applicability and comparability.

Finally, in **Chapter 6**, the applicability of the indicator 'marine biological value' as (part of) a decision support tool for marine management was evaluated. Decision support tools should fulfill several conditions to be easy applicable and sufficiently reliable. Marine biological value is a multi-metric ecological indicator developed to be able to capture the intrinsic value of a certain area by integrating all available biological data. The indicator was screened against several guidelines for the assessment of the quality of ecological indicators for marine management, developed by the Environmental Protection Agency (EPA). This evaluation showed that the determination of marine biological value can significantly contribute to marine management decisions concerning spatial planning. The protocol for biological valuation is relatively straightforward, which makes it easy to apply to new marine areas, and is also flexible enough to allow the integration of different quantities of biological data without decreasing its reliability. The marine BVMs, developed for certain case study areas, were also used to screen past management decisions and direct future spatial planning possibilities. A conceptual scheme is developed for guidance in the use of marine biological valuation for different management actions and policy questions.

SAMENVATTING

Mariene gebieden ondervinden momenteel intense druk van zowel natuurlijke als antropogene oorsprong. Mariene beheerders en beleidsmakers zijn dan ook op zoek naar manieren om de oorzaken en gevolgen van dit veranderingsproces op zee beter te kunnen beheren. Mariene gebieden, en dan voornamelijk kustgebieden, zijn erg moeilijke plaatsen om te beheren, aangezien het dynamische natuurlijke systemen zijn die, onder invloed van de hoge populatiedruk langs de kustlijn en de afnemende beschikbaarheid van ruimte en hulpbronnen op land, steeds sterker worden geïmpacteerd door een toenemende socio-economische vraag. Een fundamenteel aspect tijdens de ontwikkeling van mariene beheerssystemen, is het feit dat het praktisch onmogelijk is om de zee of mariene milieus te beheren. Er bestaat geen middel voor het significant beheer van de meeste mariene ecosysteemprocessen. Het is daarom enkel mogelijk om het menselijk gedrag te beheren en zo te beïnvloeden welke druk mensen op mariene hulpbronnen en habitats leggen. Het concept, dat menselijke activiteiten mariene biodiversiteit en ecosystemen schade kunnen toebrengen, is erg recent, aangezien de meeste mensen werden opgebracht met het idee dat zeeën uitgestrekte, afgelegen, ongelimiteerde bronnen van voedsel en hulpbronnen zijn die het vermogen hebben om menselijke afvalstoffen tot in het oneindige te absorberen.

Deze thesis focust op de ontwikkeling en toepassing van een biologisch instrument dat kan gebruik worden als beslissingsondersteunende techniek voor marien beheer. De hoofddoelstelling van de thesis is het ontwikkelen van een mariene biologische waarderingsmethodologie die in staat is om alle beschikbare biologische informatie van een bepaald gebied te integreren in één indicator van biologische waarde. Deze methodologie zou moeten toepasbaar zijn in elke mariene omgeving, onafhankelijk van de hoeveelheid en de kwaliteit van de beschikbare biologische data en het habitattype, en zou eveneens aanvaardbaar moeten zijn door een breed wetenschappelijk publiek.
Vijf **doelstellingen** staan centraal: (1) het ontwikkelen van een concept voor mariene biologische waardering dat breed toepasbaar en wetenschappelijk aanvaardbaar is; (2) het ontwikkelen van een protocol rond dit waarderingsconcept, dat de verschillende stappen beschrijft die doorlopen moeten worden tijdens het maken van mariene biologische waarderingskaarten; (3) het toepassen van dit protocol op verschillende testgebieden om na te gaan welke resultaten het geeft onder diverse omstandigheden; (4) nagaan wat de mogelijkheden zijn voor het gebruik van het protocol bij de implementatie van verscheidene Europese Richtlijnen, die verband houden met natuurbehoud in het mariene milieu, en als deel van beslissingsondersteunende systemen voor marien beheer in het algemeen, en

ruimtelijke planning in het bijzonder; en (5) evalueren van de indicator “mariene biologische waarde” wat betreft conceptuele relevantie, uitvoerbaarheid en implementatie, responsvariabiliteit en nut voor besluitvorming in mariene milieukwesties.

In **Hoofdstuk 1** wordt een algemene beschrijving van beschikbare mariene beheersinstrumenten en een gedetailleerd overzicht van de ecologische indicatoren, die biologische of ecologische informatie beknopt weergeven, gegeven. Mariene en kustecosystemen ondersteunen niet enkel een groot deel van de biodiversiteit op aarde, maar dragen ook significant bij tot de globale economie door het beschikbaar stellen van verschillende goederen en diensten. Dit zorgt er voor dat mariene biodiversiteit en ecosystemen aan intense druk onderhevig zijn, die zijn structuur, zijn functioneren en de toekomst van de activiteiten die ervan afhangen bedreigt. Door de toenemende antropogene druk is er nood aan beslissingsondersteunende systemen en beheersinstrumenten die toelaten om bepaalde milieuproblemen, geassocieerd met deze druk, en de verschillende gebruiken op zee op een geïntegreerde en duurzame manier aan te pakken. De ontwikkeling en het gebruik van beslissingsondersteunende systemen die zowel socio-economische als biologische informatie integreren is cruciaal voor de implementatie van duurzame, welafgewogen ontwikkelingen in de toekomst. De meeste mariene beheersinstrumenten zijn ontwikkeld rond het Driver-Pressure-State-Impact-Response (DPSIR) model, waarbij indicatoren worden geselecteerd di ein staat zijn om elk van de verschillende componenten van het model te kwantificeren. Andere beschikbare beslissingsondersteunende systemen zijn milieu-effectenbeoordelingen, ruimtelijke planning, multi-criteria analyses en socio-economische waarderingen. Terwijl er reeds verschillende socio-economische waarderingsinstrumenten werden ontwikkeld en gebruik in marien beheer, werd de integratie van biologische waardering in een beslissingsmodel meestal gedaan door het gebruik van ecologische indicatoren. Alhoewel er een grote variëteit aan ecologische indicatoren beschikbaar is in de literatuur, ontbreken integratieve indicatoren op systeemsniveau nog steeds. Dit vraagt om de ontwikkeling van een nieuwe indicator die alle beschikbare biologische informatie integreert tot één waarde, die een idee geeft van de intrinsieke waarde van een bepaald marien gebied.

In **Hoofdstuk 2A** wordt het concept voor mariene biologische waardering, dat rond een geselecteerde set waarderingscriteria (eerste-orde criteria: aggregatie, zeldzaamheid en gevolgen voor de fitness; modifiërende criteria: natuurlijkheid en proportioneel belang) werd opgebouwd en alle organisatieniveaus van mariene biodiversiteit integreert, beschreven. De criteriaselectie was gebaseerd op een literatuurstudie van alle bestaande ecologische criteria en de consensus die werd bereikt door een discussiegroep van experten gedurende een internationale workshop in december 2004. In **Hoofdstuk 2A** werd ook een poging ondernomen om de vele criteria en definities van ‘waarde’ die in de literatuur voorkomen, uit te klaren en overlap aan te duiden. In ons concept wordt mariene biologische waarde gedefinieerd als ‘de intrinsieke waarde van mariene biodiversiteit, zonder referentie naar antropogeen gebruik’. Deze definitie contrasteert met wat verstaan wordt onder de socio-economische waarde van mariene biodiversiteit, waar een inschatting wordt gemaakt van het socio-economische belang van de goederen en diensten, geleverd door mariene biodiversiteit, voor mensen (**Hoofdstuk 1** en **Annex A**). Mariene biologische waardering verleent een allesomvattend concept voor de inschatting van de intrinsieke waarde van de subzones binnen een studiegebied. Het biedt geen strategie voor het beschermen van alle habitats en mariene gemeenschappen die enig ecologisch belang hebben, maar moet eerder opgevat worden als een instrument om aandacht te vestigen op subzones, die van uitzonderlijk hoog ecologisch of biologisch belang zijn, en om een groter-dan-normale mate van risico-aversie te hanteren tijdens ruimtelijke planningsactiviteiten in deze subzones. Biologische waarderingskaarten (BWKs) die alle beschikbare biologische en ecologische informatie voor een bepaald gebied compileren en samenvatten en die een globale biologische waarde aan de subzones toekennen, kunnen daarom gebruikt worden als basiskaarten tijdens toekomstige ruimtelijke planning op zee.

Aangezien dit concept voor biologische waardering is gebaseerd op de consensus van een expertengroep, is het realistisch dat verfijning van de methodologie noodzakelijk zou kunnen blijken eens ze geëvalueerd werd op basis van testgebieden. Nadat het concept was toegepast op het Belgisch deel van de Noordzee, werd aangevoeld dat er nood aan aanpassingen van het originele concept was, aangezien er problemen optraden door overlap tussen de verschillende waarderingscriteria en er ook andere toepassingsproblemen bleken te zijn. Daarom werd er in december 2006 een tweede internationale workshop gehouden, als een gezamenlijk initiatief tussen de ENCORA coordinatie-actie en het MARBEF Excellentienetwerk, om de toepasbaarheid van het concept te bediscussiëren en om de methodologie aan te passen zodat deze wetenschappelijk beter aanvaardbaard zou zijn. Deze workshop resulteerde in een verfijning van het concept voor mariene biologische waardering. De criteria ‘aggregatie’ en ‘gevolgen voor de fitness’ werden bijeengevoegd in één criterium, om zo het dubbel tellen van bepaalde scores te vermijden. Daarenboven werd er een logischer verloop van de verschillende stappen in de methodologie ontwikkeld, waarbij werd voorgesteld om de biologische waardering op twee verschillende schalen uit te voeren (eerst op lokale en daarna op regionale schaal) in plaats van ‘proportioneel belang’ als criterium te behouden. ‘Zeldzaamheid’ werd in het waarderingsconcept behouden, terwijl ‘natuurlijkheid’ werd weggelaten wegens de nauwe link met menselijk gebruik en impacten. Deze aanpassingen zullen een betere toepasbaarheid van het concept op mariene gebieden toelaten (**Chapter 2B**).

Om objectieve biologische waarderingen van mariene gebieden mogelijk te maken, zijn er algemeen toepasbare en transparante volgregels voor de praktische toepassing van het concept voor mariene biologische waardering nodig. In **Hoofdstuk 3** worden alle stappen van waarderingsprotocol beschreven. Na het opsplitsen van het studiegebied in subzones en het verzamelen van de beschikbare biologische gegevens, moeten de geschikte evaluatievragen, die de waarderingscriteria linken aan de verschillende organizatieniveaus van biodiversiteit, geselecteerd worden. Om een protocol te ontwikkelen dat zo objectief mogelijk is, werden verschillende wiskundige algoritmes gedefinieerd, die kunnen gebruikt worden voor de praktische toepassing van de evaluatievragen op een bestaande biologische dataset. Dit protocol laat toe om, op basis van de geselecteerde criteria, de biologische waarde van suzones, relatief ten opzichte van elkaar, in te schatten in gebieden met verschillende niveaus van databeschikbaarheid. Een belangrijk voordeel van de voorgestelde methodologie is het feit dat alle beschikbare biologische en ecologische gegevens binnen een subzone worden geïntegreerd, waardoor het voor de gebruikers van de kaarten gemakkelijker wordt om subzones te vergelijken. De resulterende BWK is gemakkelijk te interpreteren en vertaalt complexe wetenschappelijk gegevens naar een instrument dat door beleidsmakers kan worden gebruikt als basislaag voor ruimtelijke ordening op zee. Subzones die een hoge biologische waarde hebben, zijn gebieden die bij voorkeur vermeden zouden moeten worden wanneer nieuwe activiteiten geïmplementeerd moeten worden of wanneer bestaande gebruiksfuncties een nieuwe locaties moeten krijgen. Wanneer dergelijke BWKs niet beschikbaar zijn, kunnen beleidsmakers enkel vertrouwen op ‘expert judgement’ om biologische aspecten in hun beslissingen te integreren, wat een proces is dat ontransparant is objectiviteit mist. Verschillende scoresystemen zouden kunnen gebruikt worden voor de integratie tot één waarde en één mogelijk voorbeeld hiervan werd uitgelegd in Hoofdstuk 3 door het gebruik van fictieve waarden voor een hypothetisch studiegebied. De betrouwbaarheid van de geschatte intrinsieke waarde moet genoteerd worden door een label aan de verschillende subzones te hangen. Dit label kan de hoeveelheid en de kwaliteit van de data, die voor de waardering gebruikt werden, weergeven (data beschikbaarheid) of het kan aangeven hoeveel evaluatievragen er konden beantwoord worden per subzone (betrouwbaarheid van informatie). Deze betrouwbaarheidslabels moeten simultaan geconsulteerd worden wanneer de BWKs worden gebruikt. Het biologisch waarderingsprotocol werd ontwikkeld om zo objectief en flexibel mogelijk te zijn, zodat de toevoeging van meerdere ecosysteemcomponenten, het gebruik van verschillende niveaus in databeschikbaarheid en de toepassing op een breed gamma mariene milieus mogelijk is.

Het protocol voor mariene biologische waardering werd toegepast op een aantal testgebieden in **Hoofdstuk 4**. De geselecteerde testgebieden waren het Belgisch deel van de Noordzee (BDNZ), de Isles of Scilly in het Verenigd Koninkrijk (IoS) en het Nederlands deel van de Noordzee (NDNZ). In dit hoofdstuk wordt nagegaan hoe de methodologie omgaat met verschillende niveaus in databeschikbaarheid door de BWK van het BDNZ, waar de beschikbaarheid van gedetailleerde kwantitatieve data voor verschillende ecosysteemcomponenten het creëren van gebiedsdekkende kaarten toelaat, met de BWK van de IoS te vergelijken, waar de databeschikbaarheid gelimiteerd of zelfs afwezig is voor een groot deel van de subzones. De BWK van het BDNZ integreert kwantitatieve data (abundanties, soortenrijkdom, biomassa,...) van zeevogels, macro- en epibenthos en demersale vis. Gelijkaardige gegevens waren voor het NDNZ beschikbaar voor zeevogels, macrobenthos, demersale vis, fyto- en zooplankton en zeezoogdieren. Voor de IoS waren data voor meer ecosysteemcomponenten beschikbaar, maar deze waren wel gelimiteerd qua geografische verspreiding en qua gegevenshoeveelheid en kwaliteit. Kwantitatieve data waren beschikbaar voor macro-, epi- en hyperbenthos, planten en zeezoogdieren, terwijl kwalitatieve data (aan- of afwezigheidsdata) beschikbaar waren voor macro-, epi-, hyper- en meiobenthos, demersale vis, algen (zowel fytoplankton als macrowieren), planten en zeezoogdieren. Twee types waarderingskaarten werden daarom voor de IoS opgemaakt, één gebaseerd op kwantitatieve en één op kwalitatieve data. Beide kaarten werden vergeleken om te zien of de datakwaliteit een invloed had op de resultaten van de waardering. Voor elke waarderingskaart werden eveneens betrouwbaarheidskaarten opgesteld, die enerzijds de ‘databeschikbaarheid’ (staalname-aantal per subzone) en anderzijds de ‘betrouwbaarheid van informatie’ (aantal evaluatievragen die per subzone beantwoord konden worden) weergaven.

Deze kaarten zijn essentieel voor de interpretatie van de BWKs omdat ze een inschatting geven van de onzekerheid rond de bepaalde waarde.

De finale BWKs gaven duidelijke patronen in biologische waarde weer. Sommige gebieden, die vroeger reeds als hoog waardevol werden ingeschat (voornamelijk gebaseerd op het expertenoordeel voor de afzonderlijke ecosysteemcomponenten), zoals de kustgebieden van het BDNZ en het NDNZ, kregen ook een hoge waarde met dit waarderingsprotocol. De databeschikbaarheidskaarten gaven duidelijk aan welke gebieden onvoldoende werden bemonsterd in het verleden en die als focusgebieden voor toekomstige staalnamecampagnes kunnen beschouwd worden. Het verzamelen van nieuwe data zal de betrouwbaarheid van de kaarten verbeteren door enerzijds de databeschikbaarheid en anderzijds het aantal te beantwoorden evaluatievragen (betrouwbaarheid van informatie) te verhogen.

Verkeerde interpretaties van de BWKs zouden kunnen voorkomen wanneer de kaarten gebruikt worden zonder consultatie van de onderliggende kaarten, de beschrijving van de waardering of de geïntegreerde databank. Een dergelijke consultatie moet worden uitgevoerd om na te gaan welke data werden gebruikt om de geïntegreerde biologische waarde te bepalen en welke methodologie werd gebruikt om de waardes in te schatten. Het is ook belangrijk om duidelijk te beschrijven waarvoor de ontwikkelde biologische waardering kan gebruikt worden. De kaart kan enkel gebruikt worden om de biologische waarde van de subzones te bepalen. Op die manier kan de kaart gezien worden als een waarschuwingssignaal voor mariene beheerders die nieuwe, bedreigende activiteiten op zee plannen en kan ze helpen om, tijdens ruimtelijke planning, conflicten tussen menselijk gebruik en de hoge biologische waarde van een subzone aan te geven. Het dient expliciet aangegeven te worden dat deze kaarten geen informatie geven over de mogelijke impacten die een activiteit zou kunnen hebben op een bepaald gebied, aangezien criteria zoals kwetsbaarheid en resiliëntie niet in het waarderingsprotocol werden opgenomen. Ze kunnen niet gebruikt worden voor locatie-specifiek beheer (zoals de selectie van mariene beschermde gebieden of impact inschattingen), aangezien dergelijke beheersactiviteiten de inschatting van andere criteria (representativiteit, integriteit, socio-economische en management criteria) vereisen. Daarentegen kunnen BWKs eventueel wel gebruikt worden als een kader om de effecten van bepaalde beheersbeslissingen, zoals de implementatie van mariene beschermde gebieden of nieuwe quota, te evalueren, maar dan enkel op een algemeen niveau wanneer de BWKs na verloop van tijd gereviseerd worden om te zien of er waardeveranderingen voorkomen in de subzones waar deze beheersacties werden uitgevoerd. Toch zullen deze eventuele waardeveranderingen moeilijk direct aan een

specifieke impactbron kunnen worden gerelateerd, maar zullen ze enkel een geïntegreerd zicht geven op het effect van alle impactbronnen, die in het gebied voorkomen, en de verbeteringsmaatregelen, die in het gebied genomen werden.
BWKs zijn basiskaarten die de relatieve waarde van de verschillende subzones in een studiegebied weergeven. Hierdoor zijn de waardes gelinkt aan de schaal van het gebied dat wordt gewaardeerd. Dit betekent dat een subzone van het BDNZ, die een 'hoge' waarde toegekend kreeg, niet kan vergeleken worden met een subzone van de IoS met dezelfde waarde, ook al werd dezelfde methodologie gebruikt om de waardes te bepalen. De waardes van verschillende gebieden kunnen enkel met elkaar vergeleken worden wanneer een nieuwe waardering wordt uitgevoerd waarin alle subzones ten opzichte van elkaar gewaardeerd worden.

Verschillende Europese Richtlijnen voor het behoud en de bescherming van mariene milieus zijn reeds in voege (EU Habitat- en Vogelrichtlijn en EU Kaderrichtlijn Water). Deze Richtlijnen moeten door elke Lidstaat van de Europese Unie geïmplementeerd worden door geschikte methodes toe te passen en door de Richtlijn om te zetten in nationale wetgeving, wat moet resulteren in de toekenning en bescherming van mariene beschermingsgebieden en in het bereiken van een goede waterkwaliteit in de kustwateren. Momenteel wordt een nieuwe Europese Richtlijn, de Mariene Strategie Richtlijn, opgesteld, die eveneens zal bijdragen tot de bescherming, het behoud en de preventie van de achteruitgang van mariene gebieden. Deze voorgestelde Richtlijn wordt specifiek voor het mariene milieu ontworpen, wat voor de hiervoor vermelde Richtlijnen niet het geval was. In **Hoofdstuk 5** werd nagegaan welke methodes beschikbaar zijn voor de implementatie van de Habitat- en Vogelrichtlijn, de Kaderrichtlijn Water en de (voorgestelde) Mariene Strategie Richtlijn en werden de resultaten van hun implementatie vergeleken met de biologische waarderingsresultaten om te zien of het waarderingsprotocol in de toekomst zou kunnen gebruikt worden om de vraagstellingen van de verschillende Richtlijnen te beantwoorden. Dit werd gedaan door de verschillende methodologieën toe te passen op gegevens van het BDNZ.
De resultaten toonden aan dat, wat het BDNZ betreft, het waarderingsprotocol goede resultaten bleek te geven voor de implementatie van de Habitat- en Vogelrichtlijn en de (voorgestelde) Mariene Strategie Richtlijn, terwijl het niet kon gebruikt worden voor de implementatie van de Kaderrichtlijn Water aangezien de doelstellingen van laatstgenoemde Richtlijn (bepalen van de ecologische status van kustwateren) niet overeenkomen met deze van mariene biologische waardering (bepalen van de intrinsieke waarde van mariene

gebieden). Ecologische status en intrinsieke biologische waarde moeten daarom complementair met elkaar ingeschat worden. Er werd een goede overeenkomst gevonden tussen de Speciale Beschermingsgebieden, afgebakend onder de Vogelrichtlijn, en de gebieden met een hoge waarde voor zeevogels. De meeste criteria of soorten, die in de Vogelrichtlijn vermeld worden, worden ook onderzocht tijdens de waardering, alhoewel er eveneens informatie over zeevogelsoorten die niet als prioriteitsoorten voor natuurbehoud worden beschouwd, in de waardering wordt meegenomen. Dit zorgt ervoor dat de BWK voor zeevogels een realistischer beeld van de biologische waarde van elke vogelsoort weergeeft. De Habitatrichtlijngebieden lagen in gebieden die relatief gezien een medium tot hoge waarde bleken te hebben. De situering van subzones met medium waarde in deze gebieden kan verklaard worden door het feit dat biologische waardering een meer patchy resultaat van waardes geeft (aangezien subzones relatief ten opzichte van elkaar gescoord worden), terwijl het onder de Habitat richtlijn logischer is om grote, onverdeelde gebieden, die makkelijker beheerd kunnen worden, in te stellen. Het feit dat de Habitatrichtlijngebieden een range aan biologische waardes herbergen, zal ook de biologische diversiteit, die door de gebieden wordt beschermd, verhogen, wat één van de belangrijkste doelstellingen van de Habitatrichtlijn is. Mariene BWKs zouden ook gebruikt kunnen worden als basiskaarten voor de implementatie van de toekomstige Mariene Strategie Richtlijn, aangezien het waarderingsprotocol de meeste biologische en fysische kenmerken uit de Richtlijn incorporeert. Om de BWK van het BDNZ nog nuttiger te maken in de toekomst zou er een update van de kaart moeten gebeuren met informatie van andere ecosysteemcomponenten, zoals plankton en zeezoogdieren, aangezien deze componenten een belangrijke rol spelen bij de implementatie van de Mariene Strategie Richtlijn. Naast deze BWKs moeten er ook kaarten met informatie over menselijke activiteiten en hun impacten opgemaakt worden, om de werkelijke milieustatus van een gebied te kunnen inschatten.
In **Hoofdstuk 5** werd de BEQI classificatiemethode, die ontwikkeld werd voor de implementatie van de Kaderrichtlijn Water in de Belgische kustzone, vergeleken met andere Europese classificatiemethodes. De BEQI aanpak gaf gelijkaardige resultaten als de meeste andere Europese classificatiemethodes en zou in de toekomst op nieuwe datasets moeten toegepast worden om zijn algemene toepasbaarheid en vergelijkbaarheid verder te kunnen onderzoeken.

In het concluderende **Hoofdstuk 6** werd de toepasbaarheid van de indicator ‘mariene biologische waarde’ als (deel van) een beslissingsondersteunend systeem voor marien beheer geëvalueerd. Beslissingsondersteunende systemen zouden aan verschillende voorwaarden moeten voldoen om gemakkelijk toepasbaar en voldoende betrouwbaar te zijn. Mariene biologische waarde is een multi-metrische ecologische indicator, die in staat is om de intrinsieke waarde van een bepaald gebied te bepalen door alle beschikbare biologische gegevens te integreren. De indicator werd gescreend aan de hand van verschillende criteria voor de kwaliteitsinschatting van ecologische indicatoren voor marien beheer, ontwikkeld door het Environmental Protection Agency (EPA). Deze evaluatie toonde aan dat de bepaling van marien biologische waarde significant kan bijdragen in beheersbeslissingen rond mariene ruimtelijke planning. Het protocol voor biologische waardering is relatief eenvoudig, waardoor het gemakkelijk toepasbaar is in nieuwe gebieden, en is ook flexibel genoeg om de integratie van verschillende hoeveelheden biologische gegevens toe te laten zonder dat de betrouwbaarheid van de methodologie afneemt. De mariene BWKs, die ontwikkeld werden voor bepaalde testgebieden, werden eveneens gebruikt om beheersmaatregelen die in het verleden genomen werden te screenen en om toekomstige ruimtelijke planningsmogelijkheden te sturen. Er werd een conceptueel schema opgesteld dat richtlijnen geeft voor het gebruik van mariene biologische waardering voor verschillende beheerskwesties en beleidsvragen.

PREFACE

This preface describes the different events and projects that led to the development of the marine biological valuation concept and protocol as it stands now. It explains why it was necessary to develop this concept, how the concept has grown during recent years and who contributed to its development into a widely applicable and scientifically acceptable protocol.

This thesis describes the development, application and testing of a methodology for biological valuation in the marine environment and investigates in what way this tool can be applied in marine management. The concept of marine biological valuation has been shaped during the last years in several interdisciplinary projects and international workshops. One of these projects, GAUFRE (financed by Belgian Science Policy, project number MA/02, 2003-2005) aimed at developing a spatial structure plan for the Belgian part of the North Sea (BPNS). The increasing socio-economic interest in this part of the North Sea urges us to allocate the different use functions to their most suitable geographical sites within the BPNS, hereby integrating knowledge on socio-economic and ecological impacts of these use functions and the environmental and practical suitability of the different subzones within the area. Although a lot of biological and ecological information was available to determine these impacts and suitability factors, this information is mostly related to separate ecosystem components (benthos, seabirds, fish,…) and does not provide an integrated view on the biological value of the different subzones of the BPNS. Such baseline valuation maps would be of utmost importance for future spatial planning at sea and to implement other sustainable policy actions. Due to the lack of such maps in the past, marine managers and policy makers had to base their decisions on the expert judgement of scientists and stakeholders, which could lead to the inclusion of subjectivity in these judgements.

A new project, BWZee, financed by the Belgian Federal Science Policy (project number EV/37, 2004-2007), was therefore initiated to fulfil this need for a baseline valuation map. The project aimed at developing a biological valuation method for the Belgian marine area, taking into account the biological value of macro- and epibenthos, demersal fish and seabirds. The result of this project was an integrated, full-coverage biological valuation map (BVM) for the BPNS. Since no methodology for marine biological valuation existed yet, a novel approach had to be searched for. However, BVMs do exist for the terrestrial part of Flanders and the experience of the developers of these maps was used during the course of the BWZee project. This was done by organizing a national workshop together with the experts on terrestrial biological valuation (May 2004). During this workshop, the valuation criteria that were used in the terrestrial environment and the general valuation strategy were screened for their applicability in marine systems. The terrestrial experts also gave valuable information from their own expertise with the development of this kind of maps and their (mis)use by policy makers and managers. It was decided that marine systems are too different from terrestrial ones (high dynamics, lack of defined boundaries …) and that a new methodology should be developed for the valuation of marine areas, without neglecting their lessons learned.

Therefore, the literature on ecological criteria for marine biological assessments and the selection of nature protection areas (Bird/Habitat Directive areas, MPAs, RAMSAR areas …) was screened and a list of available criteria and their application was created. To select the most appropriate criteria for biological valuation, which constitutes the first step towards the development of a scientifically underpinned biological valuation methodology, a first international workshop was held in December 2004. The input of a team of international experts on biological valuation of the marine environment in this criteria selection helped to develop a solid and scientifically acceptable concept and protocol which should be applicable in every marine environment. So, while the scope of the BWZee project was to develop a BVM for the BPNS, the workshop enabled us to produce a valuation concept that could be applied worldwide. It was emphasized during the workshop that the concept should suit the dynamic and complex character of the marine environment and that the criteria should be simple and univocal, so they can be applied to all marine life forms and ecosystems. A marine BVM should also be easy to interpret and be useful for marine policy. At the same time this map should represent a realistic view of the value of the marine area.

A second international workshop was held from 6 to 8 December 2006 to discuss and fine-tune the developed valuation concept and protocol, after the protocol was tested on the Belgian data. This was needed because this application on Belgian data introduced some questions on the concept and the protocol developed around it (e.g. overlap between criteria, scoring issues). A new workshop, not only focusing on the concept but also discussing detailed steps of the protocol, therefore seemed a logical step towards broad applicability and acceptability of the protocol. This workshop was a joint venture between two European networks, the EU CA ENCORA (European Concerted Action on Coastal Research) and EU NoE MARBEF (European Network of Excellence on Marine Biodiversity and Ecosystem Functioning). Both Theme 7 within ENCORA ("restoration and preservation of coastal biodiversity") and Theme 3 within MARBEF ("socio-economic importance of marine biodiversity") deal with marine and coastal biological valuation and by organizing a common workshop for both themes it was possible to reach a consensus on the valuation concept which could be agreed upon by a large community of scientists and decision makers. The ENCORA community mainly consists of coastal scientist, practitioners and policy makers. By inviting members of the MARBEF theme 3 community, the expertise present during the workshop drastically increased. MARBEF also does not focus only on the coastal area, but enlarges the field of study to the entire marine system. As ENCORA focuses on end-users, participation from this network brought in the indispensable input of practioners and stakeholders as well as their experience with decision support systems in the coastal area.

After the concept was adjusted and an appropriate practical protocol for marine biological valuation was developed, the protocol needed to be tested on other case study areas to be sure that it is applicable in a wide range of habitats, ecosystems and in areas with different levels of data availability. In the framework of both ENCORA and MarBEF several case study areas were selected: the Gulf of Gdansk (Poland), the Dutch part of the North Sea (the Netherlands), the Pico-Faïal channel (Portugal), Svalbard (Norway), Lister Deep (Denmark), the Isles of Scilly and Flamborough Head Area (UK) and the Mondego estuary (Portugal). Some of the results of the valuation of these case study areas are given and compared further in this thesis.

Although the concept and protocol for marine biological valuation were developed to be applicable in every marine ecosystem (independent of the amount of available biological data), it could be that the methodology still needs to be fine-tuned after it has been tested on these case study areas. Ultimately it should evolve into a methodology which is as subjective as possible (excluding all forms of expert judgement), easy to apply and applicable in any marine environment. The concept of marine biological valuation has been shaped by the collaboration of a lot of people (both scientists as stakeholders and managers) in different projects and workshops and should be seen as an evolving tool which holds promising possibilities for future spatial planning at sea.

EXPLANATION OF FREQUENTLY USED TERMS

Other definitions or uses of the following terms may occur, but listed below are those used in this manuscript.

Marine biological value:

The intrinsic value of marine biodiversity, without reference to anthropogenic use (Derous *et al.*, 2007); or

a multi-metric, integrative, system-level biological indicator to assess the state of the marine environment.

→ expressed as a relative, non-monetary value

Note: other terms could be used to describe this value (e.g. biodiversity value, ecological value, …) and as the integrated value should capture all aspects of biodiversity (including all ecological processes and functions), the term 'ecological value' could be more appropriate. However, the term 'biological valuation' was adopted during the first international workshop by a group of experts and was used in the first publication on this topic (Derous et al., 2007) and is therefore used throughout the rest of this manuscript and papers to increase consistency in terms.

Intrinsic value of biodiversity:

The value of biodiversity on its own, in contrast to an anthropocentric, socio-economic view on value (Meffe & Carolle, 1997, Convention on Biological Diversity, 1992); or

the value in itself, unrelated to human use (Pearce & Moran, 1994).

Biological indicator:

A characteristic of an ecosystem that is related to, or derived from, a measure of a biotic or abiotic attributes that can provide quantitative information on ecological condition, structure and function (EPA, 2007); or

a measure, an index of measures, or a model that characterizes the current status of an ecosystem or one of its critical components (Jackson *et al.*, 2000).

Socio-economic value of marine biodiversity:

The value of the goods and services provided by marine ecosystems (Turpie *et al*., 2003); or

the value of a marine area in terms of importance for human use (Costanza *et al*., 1997).

→ expressed (mostly) as an absolute, monetary value

Objective of marine biological valuation:

To assess the intrinsic biological value of the subzones within a study area by scoring them relatively to each other against a chosen set of valuation criteria (Derous *et al*., 2007).

Potential use of marine biological valuation maps:

The maps provide baseline information on the intrinsic biological value of the subzones within a study area and should therefore be used as warning systems during spatial planning to give indications on potential conflicts between threatening human activities and subzones with a high biological value. By using the maps in this way, the precautionary principle can be applied.

Precautionary principle:

Principle adopted by the UN Conference on the Environment and Development (Convention on Biological Diversity, 1992) that in order to protect the environment, a precautionary approach should be widely applied, meaning that where there are threats of serious or irreversible damage to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Sustainable development:

Characteristic of a process that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (United Nations, 1987); or

socio-ecological process characterized by the fulfilment of human needs while maintaining the quality of the natural environment indefinitely (Convention on Biological Diversity, 1992).

CHAPTER 1

INTRODUCTION, OBJECTIVES AND OUTLINE OF THE THESIS

Abstract

As marine environments are under increasing anthropogenic pressure, there is a need for decision support systems (DSSs) and management tools that allow to tackle some of the environmental problems associated with this pressure and to allocate the different uses in a sustainable way. Most marine management tools are built around the Driver-Pressure-State-Impact-Response (DPSIR) framework, where indicators are selected which are able to quantify each of these different components. Other available decision support systems are impact assessments, spatial planning, multi-criteria analyses and socio-economic valuations.

The ideal DSS should integrate information on both socio-economic and ecological factors to be able to allow balanced, sustainable decisions. While several socio-economic valuation tools have been developed and used for marine management in the past, the integration of biological information in the decision framework was usually done by using ecological indicators. Although there exists a wide variety of literature on ecological indicators, integrative, system-level indicators are still lacking. This asks for the development of a new indicator that integrates all available biological information into one value which expresses the intrinsic value of a certain marine area.

The general objectives of this thesis are the development, application and testing of a marine biological valuation methodology that is able to integrate all available biological information of an area into one indicator of intrinsic value. Examples of the application of the protocol to different case study areas are discussed to see how the methodology performs under different circumstances. Next to that, the thesis reviewed the possibilities of using the protocol for the implementation of several European Directives, which relate to nature conservation in the marine environment, and as part of decision support systems for marine management in general, and spatial planning in particular. The outline of the thesis is also described at the end of this chapter.

Key words: decision support systems, ecological indicators, marine management, socio-economic valuation, biological valuation, DPSIR framework, integrated management, sustainability

Introduction

Marine environments are currently experiencing intense pressures from a range of natural and anthropogenic driving forces. Marine managers and policy makers are seeking ways of better managing the causes and consequences of the environmental change process at sea. Marine areas, and especially coastal environments, are very difficult places to manage, as they are dynamic natural systems which have been increasingly pressurised by expanding socio-economic demands, due to high settlements along coastlines and decreasing space and resources on land (Fabbri, 1998; Turner, 2000). A fundamental issue in the development of marine management tools is the fact that it is hardly possible to manage the sea or marine environments. There exists no means for significant management of most of the marine ecosystem processes. It is therefore only possible to manage human behaviour to influence what people do to the marine resources and habitats and to try to decrease the damage. The concept that human activities can damage marine biodiversity and ecosystems is very recent, as most people were brought up with notions of the seas as vast, remote and limitless sources of food and resources and sinks to absorb human waste (Kullenberg, 1995; Antunes & Santos, 1999; Maes *et al.*, 2005).

The health and sustainable use of coastal and sea resources are of critical importance given their role in food production, economic activity, genetic biodiversity and recreation. Most current marine management frameworks are predominantly sectoral and cross-sectoral and broader community matters are dealt with on an issue-by-issue basis (Maes *et al.*, 2005). The concept of integrated management emerged as an alternative to this traditional sectoral approach to environmental problems, which has resulted in inefficient procedures and sometimes in the creation of new environmental problems, mainly due to difficulties in policy coordination. In addressing integrated marine management it is essential to strike a balance between the need for economic development and the need for nature conservation within the same management plan. Therefore, integrated management and sustainable development of marine areas should include careful consideration of multiple parameters and their interactions. Planning for sustainable uses is a process that comprehensibly and holistically analyses biological values, human uses (and their related impacts) and socio-economic aspects (Antunes & Santos, 1999).

In order to achieve the goals of sustainable development, knowledge and an adequate information basis of both socio-economic and biological aspects of marine environments are required, together with the human resources capable of interpreting the information for application in management and decision making. Emphasis must be put on ensuring that understanding scientific knowledge on the state of the marine environments and how the ocean works is transmitted to other parts of society for applications and management, and for use by governments in their policy formulation and decision making (Kullenberg, 1995).

State of the art

A. Management tools and decision support systems

The conflict between economic development and marine environmental quality has led scientific research to seek appropriate methodologies for assessing environmental problems and the development of decision support systems (DSSs) for evaluating the current state and predicting future trends in marine areas (Kenchington, 1992). However, since marine management requires the integration of environmental protection and development policies to ensure a rational use of marine resources, the incompatibilities between ecological and social science perspectives and methodologies increase the complexity of developing appropriate marine management tools (Kitsiou *et al.*, 2002).

A textbook definition for a DSS is given by Turban & Aronson (1998): “Computer-based information system that combines models and data in an attempt to solve unstructured problems with extensive user involvement”. Problems are defined unstructured in this context when they are complex, fuzzy and without any straightforward solutions. Ruijs *et al.* (2007) indicated that a desirable DSS for marine management should first of all include sufficient information and insights on marine biodiversity and ecosystem functioning (Westmacott, 2001). Furthermore, the interrelations between the different stakeholders and their dependence on the ecosystem should be identified. Finally, the DSS should enable the analysis of the effects of a number of policy scenarios from a number of perspectives, which include the socio-economic, biodiversity and ecological perspective. On the basis of such

DSS, policy makers can implement or analyze in more detail those options that they consider most promising. The implemented policies should be closely monitored, in order to be able to improve the DSS and to upgrade it with more and updated information (Ruijs *et al*., 2007).

The basis for the development of most DSSs is the DPSIR framework, denoted Driving Forces, Pressure, State, Impact, Response. It is a widely used methodology for systematically identifying environmental problems (Figure 1) (Antunes & Santos, 1999; Turner, 2000; Ruijs *et al*., 2007). The main idea of the DPSIR framework is to treat the environmental management process as a feedback loop and provide assessments on environmental problems and assist policy makers with a high-level view of the problem (Peirce, 1998). The objective in this approach is to clarify multisectoral interrelationships and to highlight the dynamic characteristics of the ecosystem and socio-economic changes (Turner, 2000). The analysis begins with identifying the driving forces, which refer to social developments and economic growth elicited from macro level changes in society, such as population growth, income increases, production, consumption and waste disposal. As a consequence, these anthropogenic activities may impose pressures on the environment and therefore lead to changes in the state or environmental conditions that prevail as a result of that pressure (OECD, 1999). Furthermore, the changes in environmental quality will disturb societies and economies which rely on the provision of environmental goods and services. Finally, the loop ends up with the responses, which in fact are the possible policy options or management measures as a response to the environmental and social changes (Peirce, 1998; Ruijs *et al*., 2007).

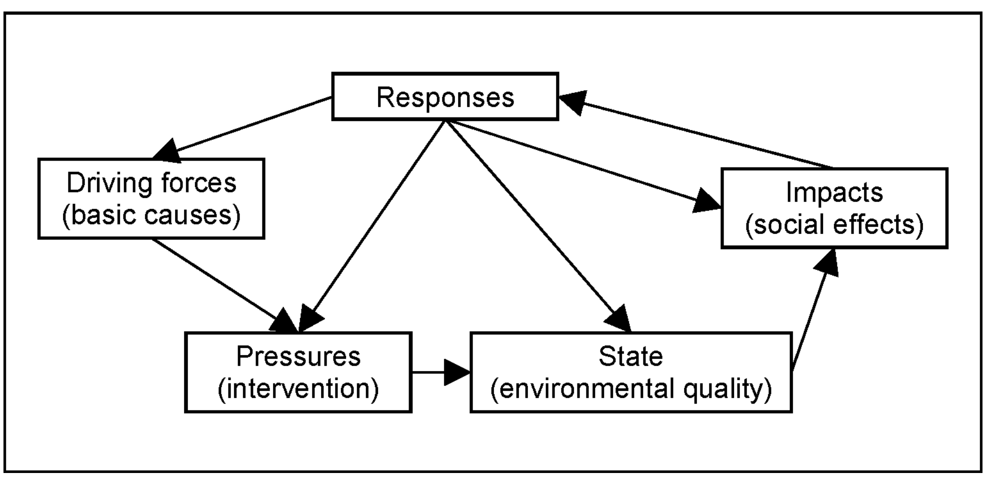

Fig. 1: Illustration of DPSIR framework

Although several difficulties arise in the application of the DPSIR framework to complex environmental problems, such as the case of marine resources (several causes contributing to a single effect, multiple effects resulting from a single pressure, interrelations among ecosystem components and indirect, synergistic or cumulative effects), the framework provides a basis for identification of information needs and for problem assessment (Antunes & Santos, 1999).

The most commonly used DSSs for marine management are environmental impact assessments (EIAs), risk assessments, economic analyses and spatial planning or zoning.

EIAs are used to identify possible impacts of a proposal (whether as a policy management plan or intended development) on the environment early on in the decision-making process, so that these considerations can be taken into account in the design and approval of the proposal. Within the EIA context, 'environment' refers not only to biophysical aspects, but also to social and economic aspects. The general aim of the EIA process is to provide decision makers with the best available information which will help to minimise the costs (both environmental and financial) and maximise the benefits of the proposed actions. EIAs are now an integral part of the environmental planning and management of coastal and marine environments of many coastal nations (Kay & Alder, 2005).

Risk assessment is concerned with assessing the probability that certain events will take place and assessing the potential adverse impact on people, property or the environment that these events may have (Suter, 2001; Newman *et al.*, 2002). The importance of integrating risk assessment consideration into coastal and marine management and planning has recently been brought into strong focus by the Indian Ocean Tsunami in 2004 (Kay & Alder, 2005).

Marine spatial planning is a DSS which has become a crucial issue in marine policy and is being developed in different marine areas all over the world (e.g. Florida Keys – USA, Cayman Islands – Carribean, Great Barrier Reef – Australia, Eastern Scotian Shelf – Canada, Galapagos Islands – Ecuador and South African waters) (Ehler & Douvere, 2007). Spatial planning approaches should preferentially be firmly based on the concept of integrated marine management, in which both the socio-economic and biological aspects of a specific marine area should be taken into account (Kidd *et al.*, 2003). To be effective, spatial planning requires accurate and relevant information about the marine environment as well as the dynamics of historical and contemporary marine resource usage patterns (Bosch, 2002). Investigating the biological value of an area can be crucial to find suitable sites for different sea-based activities. Biological valuation maps should be used as baseline map indicating which biologically high valued areas should be avoided when planning new or relocating existing marine activities. However, the selection of suitable sites for an activity cannot be based on biological information solely, as integrated management determines that anthropogenic limitations should be evaluated as well. Implementation of spatial plans and decision-making must incorporate socio-economic suitability and cultural values. Involving the community in the planning and decision-making process is an important step towards acceptability and success of sustainable management. Management plans can address the purposes and conditions of use and entry to areas of a marine ecosystem, but to do so requires an open approach to planning. It requires broad involvement of interested, affected and impacted parties in the development of decision support tools and operating principles. These should lead to the identification of reasonable constraints and opportunities for managing impacts and achieving objectives subject to an overarching objective of sustainability. Adequate policy addresses the resolution of potential use conflicts, which is often hindered by lack of information or appropriate methodologies. Also, in marine ecosystems the biology of the flora and fauna, and the consequent issues of scale, variability and linkage in space and time, limit the effectiveness of terrestrially derived concepts of spatial planning. Many uses with different levels of impact may occur in the same area (Maes *et al.*, 2005; Calewaert & Maes, 2007). The integration of a multicriteria analysis, which deals with the evaluation of alternatives according to a set of varying criteria, with GIS towards a DSS for spatial planning could be ideal to promote consistent decision making and to evaluate marine development alternatives to ensure ecological sustainability of the marine environment (Fabbri, 1998; Calewaert *et al.*, 2007).

The implementation of marine management approaches is made easier by new technologies and methods such as Geographic Information Systems (GIS). GIS assists in the development of dynamic management tools, since new or revised information can be easily inserted into the system (Stanbury & Starr, 1999; Kitsiou *et al.*, 2002). Due to the complex dynamic and spatial nature of marine systems, GIS are particularly suited for handling and analysing voluminous marine data sets (Fabbri, 1998). The MESH guidance framework to marine habitat mapping (www.searchmesh.net) holds worthwile information on defining ecologically relevant zones, data and quality assurance approaches and policy relevance of mapping products and could be an ideal starting point for for instance marine spatial planning.

B. Indicators

Indicators have always been an interesting concept in marine management. Ecological indicators are commonly used in the DPSIR framework to supply synoptic information about the state of ecosystems or the impact upon them (Jackson *et al.*, 2000). Most often they address the ecosystem's structure and/or functioning accounting for a certain aspect or component, for instance nutrient concentrations, water flows, macro-invertebrates, productivity and ecological integrity at the system's level (Salas *et al.*, 2006). Indicators and early warning systems need to be identified and developed on the basis of scientific information and understanding, and interpreted and used in management (Kullenberg, 1995; Dale & Beyeler, 2001). Indicators should reveal conditions and trends that help in development planning and decision making. Their main goal is to combine several environmental factors in a single value, which might be useful for management and for making ecological concepts compliant with the general public's understanding (Salas *et al.*, 2006).

DEFRA (2002b) summarized the criteria which need to be met by "good" indicators. The authors discriminated between two types of indicators: decision support or 'performance' indicators and environmental state or 'descriptive' indicators. Performance indicators should be easy and accurately measurable, relevant for the policy decision which has to be made, sensitive for manageable human activities, specifically linked to the human activity (and not to other causes of change) and measurable in a large part of the target area. Descriptive indicators on the other hand should be scientifically underpinned, easily communicated, sensitive, show spatial and temporal trends, give an early warning signal and be cost-effective. More specifically, ecological indicators should have the following characteristics: (1) easy to handle, (2) sensible to small variations of environmental stress, (3) independent of reference or control samples, (4) applicable in extensive geographical areas in the greatest possible number of communities or ecological environments and (5) relevant to policy and management needs (UNESCO, 2003; Salas *et al.*, 2006)

Table 1 gives an overview of some examples of indicators used in marine literature. Simple benthic indicators, which have been assessed for their ability to detect impacts from eutrophication and hazardous substances or to reflect ecological quality, are species richness, abundance, diversity index H' and key species. Species richness of benthos is dependent on sampling size, sampling gear, depth and sediment type, which makes it not appropriate as a good index of environmental health. Abundance is also a parameter which is very variable in benthic communities and is therefore no reliable measure of ecological quality. However, abundance of certain key ecological species (e.g. sensitive species, opportunistic species, habitat structurers,…) can be a good indicator of the status of the environment. This is also the case for the Shannon Wiener diversity index H', which is a combination of the number of species and their relative abundance, but when using this parameter as indicator of ecological quality it is necessary to have a background reference data set which gives the range of H' for a specific habitat (also taking into account depth, and substrate) (Baan & van Buuren, 2003).

Other indices are focused on the presence/absence of one or more indicator species (e.g. Bellan-Santini, 1980; Borja *et al*., 2000; Simboura & Zenetos, 2002) or on the different ecological strategies adopted by the organisms (e.g. Word, 1979; Petrov & Shadrina, 1996, De Boer *et al*., 2001). Another group of indices are those which are thermodynamically oriented (e.g. Marques *et al*., 1998; 2003) or are based on network analysis (Nielsen, 1990). A last group tries to include all the information about the environment in one single value through the so-named integrity indices, including indices that capture the ecosystem information from a holistic perspective (Engle *et al*., 1994; Weisberg *et al*., 1997; Van Doolah *et al*., 1999).

Several authors have considered the use of indices, based on indicator species, not advisable since often these species can occur naturally in relative high densities and no reliable methodology exists to know at which level one of those indicator species can be well represented in an unaffected communitiy, which introduces a lot of subjectivity into the assessment (Salas, 2003).

The use of ecological indicators is not exempt of criticisms. The major critique on indicators is that the aggregation results in oversimplification of the ecosystem under observation. Next to

Table 1: Overview of biological indicators to assess ecological quality occurring in the literature.

Type of indicator	Indicator	References
Univariate indices	Shannon-Wiener Diversity Index	Shannon & Wiener (1949)
	Benthic Pollution Index (BPI)	Leppäkoski (1975)
	Infauna Trophic Index (ITI)	Word (1979; 1980)
	Feeding Structure Index (FSI)	Petrov & Shadrina (1996)
	Nematodes/Copepods Index	Raffaelli & Mason (1981)
	ABC curves	Warwick & Clarke (1994)
	Annelid Index of Pollution	Bellan (1980)
	Amphipod Index of Pollution	Bellan-Santini (1980)
	Meiobenthic Pollution Index	Losovskaya (1983)
	Mollusc Mortality Index	Petrov (1990)
	Index of r/K strategies	De Boer *et al.* (2001)
	Feldman's R/P Index	Pérez-Ruzafa (2003)
	Shannon-Wiener Evenness Proportion Index	McManus & Pauly (1990)
	Taxonomic diversity index and Taxonomic distinctness	Warwick & Clarke (1995)
	Ecological Evaluation Index (EEI)	Orfanidis *et al.* (2001)
	Hurlbert Index	Hurlbert (1971)
	Coastal Endofaunic Evaluation Index (I2EC)	Grall & Glémarec (2003)
	Benthic opportunistic polychaetes amphipods index (BOPA)	Gomez & Dauvin (2000), Dauvin & Ruellet (2007)
	Other: Species number, Abundance, Biomass	Several authors (e.g. Grassle & Maciolec (1992), Gray *et al.* (1997), Zenetos *et al.* (2000))
Multi-metric indices	Pollution Coefficient	Satsmadjis (1982; 1985)
	Trophic Index (TRIX)	Wollenweider *et al.* (1998)
	Biological Quality index (BQI)	Jeffrey *et al.* (1985)
	Infauna Ratio-to-Reference of sediment quality triad (RTR)	Chapman *et al.* (1987)
	Biotic Index	Majeed (1987), Grall & Glémarec (1997), Hily (1984), Hily *et al.* (1986)
	Benthic Index of Estuarine Condition	Weisberg *et al.* (1993), Schimmel *et al.* (1991), Strobel *et al.* (1995)
	Estuarine Biological Health Index (BHI)	McGinty & Leader (1997)
	Fish Health Index (FHI)	Cooper *et al.* (1993)
	Benthic Condition Index (BCI)	Engle *et al.* (1994), Engle & Summers (1999), Macauley *et al.* (1999); Paul *et al.* (2001)
	Index of Biotic Integrity (IBI)	Nelson (1990)
	Benthic Index of Biotic Integrity (B-IBI)	Ranasinghe *et al.* (1994), Weisberg *et al.* (1997), Van Dolah *et al.* (1999), Llansó *et al.* (2002a; 2002b)
	AZTI Marine Biotic Index (AMBI)	Borja *et al.* (2000; 2003; 2004a)
	Bentix	Simboura & Zenetos (2002)
	Macrofauna Monitoring Index	Roberts *et al.* (1998)
	Ecofunctional Quality Index (EQI)	Fano *et al.* (2003)
	Indicator Species Index	Rygg (2002)
	Benthic Quality Index	Rosenberg *et al.* (2004)
	Danske Kvalitet Indeks (DKI)	Borja *et al.* (2007)
	Infaunal Quality Index (IQI)	Prior *et al.* (2004), Borja *et al.* (2007), Miles *et al.* (in prep.)
	Norwegian Quality Index (NQI)	Rygg (2002; 2006), Borja *et al.* (2007)
	Benthic Ecosystem Quality Index (BEQI)	Van Hoey *et al.* (2007), Van Damme *et al.* (2007)
	Conservation Index	Moreno *et al.* (2001)
	Ecologic Reference Index (ERI)	Baan & Groeneveld (2002)

Multivariate and modelling approaches	Benthic Response Index	Smith *et al.* (2001)
	Estuarine Trophic Status	Bricker *et al.* (2003)
	Principal Response Curves (PRC)	Pardal *et al.* (2004)
	m-AMBI	Borja *et al.* (2004b), Muxika *et al.* (2007)
	Ascendency/Emergy	Marques *et al.* (1998)
	Exergy	Nielsen (1990); Marques *et al.* (1997; 2003)

that, problems can arise from the fact that indicators also account for factors other than the system-specific ones they are designated for. It is therefore necessary that the indicators are only utilised following the right criteria and in situations that are consistent with their intended use and scope (Salas *et al.*, 2006).

Otherwise, misuse could lead to confusing data interpretations. Also, some simple indicators based on abundance of an indicator species can give information on human induced changes, but as marine environments are complex systems with inherent natural fluctuations, it can be difficult to know to what extent the change in the indicator value can be related to an anthropogenic pressure or if it is just caused by natural variation. This problem can be alleviated by using indicators that integrate information on multi-species assemblages, as similar population responses of several species should reduce noise associated with natural fluctuations in numbers of a given species. Monitoring community structural changes through abundance and diversity measures can be insensitive, so functional measures giving information on biological processes can reveal changes that abundance and diversity may miss (Soule, 1988; Linton & Warner, 2003).

It is essential that all indicators are tested and evaluated on real test case areas, where validated data are available. This will allow the quantification of the variability of the indicators and ensure its quality. Indicators should be tested on their statistical robustness and should be adaptable in case this would seem necessary after testing (DEFRA, 2002b). Despite the extensive list of available indicators for marine ecosystems given in Table 1, few of these ecological indicators fulfil all the requirements of “good” indicators listed above. They are mostly not specific for a particular stress or they are only applicable to a given type of community and/or scale of observation, and rarely their validity has been proved (Salas *et al.*, 2006).

C. Socio-economic valuation

One way of incorporating natural values into marine management decisions is to determine the socio-economic value of the goods and services provided by the marine ecosystem. Environmental valuations result in monetary values which can be easily weighted against other socio-economic factors, which enables that the environment, or the impacts of a certain human activity on it, is not neglected during decisions in marine management.

Traditional economic analysis of marine management problems did not always provide appropriate solutions, often confusing managers by not supplying realistic guidelines for their actions (Smith, 1996). However, during the past thirty years, problems with the way 'classic' economic views the environment have been tackled by the rapidly expanding field of 'environmental economics'. Environmental economics attempt to provide valuations of the non-market goods and services provided by the environment. Economics is fundamentally concerned with the concept of scarcity and with the mitigation of scarcity-related problems (Turner *et al.*, 1995). So, economics have an important part to play in marine management decisions, where the resolution of conflicts over space and resources is a fundamental issue in marine management and planning (Kay & Alder, 2005).

The first literature sources on environmental economics date back to the 1980s and deal with the terrestrial valuation of nature's goods and services in the USA. The work of Costanza *et al.* (1997) on the value of goods and services provided by global ecosystems, resulted in an increase in papers dealing with this matter and the first paper dealing with marine environmental valuations indicated that oceans contribute to 60% of the overall value of the whole biosphere (Costanza *et al.*, 1998). This shows that marine biodiversity has a fundamental role in supporting a wide range of goods and services, which are essential for the maintenance of the social and economic wellbeing of society. While environmental economics first focused on market-linked goods and services (e.g. tourism, fisheries), socio-economists now try to investigate all goods and services in order to appreciate the true socio-economic value of marine biodiversity and to be able to develop sustainable management plans that maximise the benefits received from marine biodiversity and minimize the impacts of human activities on the environment (Jones, 2000).

Beaumont *et al.* (2007) described marine ecosystem goods and services as the direct and indirect benefits people obtain from marine ecosystems. By assessing ecological processes and resources in terms of goods and services they provide, translates the complexity of marine environments into a series of functions which can be more readily understood by policy makers and other non-scientists. Beaumont *et al.* (2007) (see Annex A) described the assessment of the different goods and services (G&S) provided by marine biodiversity in seven case study areas, including the Belgian part of the North Sea (Table 2). The G&S were divided into different categories, based on the classification of de Groot *et al.* (2002).

Table 2: Goods and services provided by marine biodiversity (reproduced from Beaumont *et al.*, 2007).

Category	Good or service
Production services	Food provision
	Raw materials
Regulation services	Gas and climate regulation
	Disturbance prevention (flood and storm protection)
	Bioremediation of waste
Cultural services	Cultural heritage and identity
	Cognitive benefits
	Leisure and recreation
	Feel good and warm glow (non-use benefits)
Option use value	Future unknown and speculative benefits
Over-arching support services	Resilience and resistance (life support)
	Biologically mediated habitat
	Nutrient cycling

A fundamental distinction between the way economics and ecology use the term 'value' is the economic emphasis on human preferences (Lipton *et al.*, 1995). An important problem in valuing the uses, functions and amenities provided by marine environments is that many of these are provided 'free'. No market exists through which their true value can be revealed by the actions of buying and selling (Pearce *et al.*, 1989). Environmental economists have developed several ways to account for these non-market values (e.g. Travel Cost Method, Hedonic methods, Contingent Valuation method,…). Marine goods and services which are traded in a market are valuated by estimating the producer and consumer surplus, using market price and quantity data (Kay & Alder, 2005).

D. Need for biological valuation

As described above, a lot of initiatives for the socio-economic valuation of goods and services provided by marine biodiversity exist. To develop balanced DSSs for sustainable marine management, it is necessary to consider the non-use value, and more specifically the intrinsic value of marine biodiversity, complementary to the socio-economic aspects. Although some aspects of marine goods and services relate to a kind of "intrinsic value" (e.g. existence value), the biological value is not captured entirely by this concept and additional incorporation of intrinsic biological valuation is necessary to fully apply a holistic, sustainable ecosystem approach in marine decision making. As biological data of a certain area can be present for several ecosystem components and on different levels of biodiversity (ranging from genetic data up to information on ecosystem processes), it is difficult to provide an integrated picture of the intrinsic value of marine biodiversity in that area in a form which is suitable for marine management. This has led to a communication gap between scientists and policy makers, who need clear uniform biological information, and has sometimes even led to the exclusion of biological information from the decision process (Kullenberg, 1995). To avoid this, translation tools should be developed which integrate the available biological and ecological data into information which can be readily understood by non-scientists and used in marine management (Hiscock *et al.*, 2003).

Although there are huge sets of ecological indicators available, integrative system-level, empirically gathered indicators for the functionality of ecosystems are still lacking. Some first initiatives for the development of such integrative indicators were made by developing the so-called 'integrity' indicators (Engle *et al.*, 1994; Weisberg *et al.*, 1997; Van Doolah *et al.*, 1999), but these indicators integrate all available biological information of only one ecosystem component (mostly the benthos). Most indicators are thus reductionistic and consider only a few components of the system. Moreover, the existing indicators are often based on real activities (e.g. pollution), but not on ecosystem functions. However, to achieve environmental sustainability, it is required to maintain the environmental functions and potentials in the long run. The systematic, integrative nature of sustainability points out the importance of system-level parameters for which indicators have to be devised. Ideally, indicators should represent key information about structure, function and composition of the system under consideration (Dale & Beyeler, 2001).

The present thesis therefore has developed a methodology that captures the intrinsic biological value of an area in one indicator. This should enable the integration of biological information in a DSS, where it can be balanced against socio-economic values or indicators.

Objectives of the work

In this thesis the development of a marine biological valuation methodology, which is able to integrate all available biological information of an area into one indicator of intrinsic value, is presented. The developed methodology should be applicable in every marine environment, independent of the amount and quality of the available biological data and the habitat type, and should be acceptable by a wide scientific audience. Furthermore, the application of the protocol to different case study areas is presented in order to evaluate how the methodology performs under different circumstances. Next to that, the possibilities of using the developed marine biological valuation protocol for the implementation of different European Directives, which relate to nature conservation in the marine environment (Habitats and Birds Directives, Water Framework Directive and future Marine Strategy Directive) and as part of decision support systems for marine management are explored.

Outline of the thesis

In this work the possibilities of a newly developed management tool, marine biological valuation, within a marine related policy framework are investigated. As the socio-economic interest in marine resources and space is still increasing, this pressure urges the need for a decision support framework to objectively allocate the different user functions at sea. Marine spatial planning is such a decision support system (DSS) which has become a crucial issue in marine policy and is being developed in different marine areas all over the world. Spatial planning approaches should preferentially be firmly based on the concept of integrated marine management, in which both the socio-economic and biological aspects of a specific marine area should be taken into account. This biological information should be provided in a format which is easily understandable and which combines all available biological and ecological data. In this work the development and application of a marine biological valuation protocol is presented. The protocol is a methodology to translate rough biological data (abundance, species richness, biomass,…) from different ecosystem components into integrated biological information of an area. In this concept, the biological value of a certain site can be seen as an indicator which gives the user an idea of the intrinsic value of marine biodiversity at that site.

Marine ecosystems not only support much of the world's biodiversity but also significantly contribute to the global economy by providing many goods and services (***Chapter 1***). This also subjects marine biodiversity and ecosystems to intense pressure that threatens its structure and functioning and the future of the activities that depend on it. It is becoming increasingly urgent to take a more integrated approach to planning and management of the marine environment. The development and use of decision support systems that integrate both socio-economic and biological information is crucial for the implementation of sustainable developments in the future.

Since no methodology for marine biological valuation existed, a novel approach had to be developed. A literature review was performed to screen the range of valuation criteria circulating in literature. There seemed to be much redundancy in valuation criteria so these were screened at an international workshop to select the ones most suitable for the development of a biological valuation methodology (i.e. rarity, aggregation, fitness consequences, naturalness and proportional importance). A concept for the biological valuation of marine waters was delineated with emphasis on its general applicability in different ecosystems and on its scientific acceptability (***Chapter 2a***).

Building on the scientific acceptability during a second international workshop, which was a joint initiative between the coordination action ENCORA and the MarBEF Network of Excellence, there was felt a need for adaptation of the concept (**Chapter 2b**). The adaptation involved the limitation of the set of valuation criteria to only two criteria, being rarity and the lumped criterion aggregation-fitness consequences.

In **Chapter 3**, a valuation protocol was developed around the selected biological valuation criteria. This was done by creating a set of assessment questions for each criterion and by choosing an appropriate scoring system to integrate the scores of the different assessment questions for each grid cell within a study area.

The valuation protocol was applied to data of different ecosystem components from different case study areas (***Chapter 4***). The selected case study areas were the Belgian part of the North Sea, the Isles of Scilly (UK) and the Dutch part of the North Sea, which all differed in the amount and quality of the available biological data, the geographical scale and the intensity of human pressure on the environment. All data of every ecosystem component were integrated to produce marine biological valuation maps using GIS software. This map clearly showed where the biologically most valuable, the medium valuable and the least valuable subzones are located. A statement of the reliability of the obtained biological value (based on data availability, sampling intensity and information reliability) is attached to this information. The application of the protocol to these case study areas indicated both the opportunities and strengths as the weaknesses and the lessons learned for further improvement of the acceptability, applicability and transparency of the methodology.

In **Chapter 5** the possible role of the developed marine biological valuation protocol for the implementation of current and future European marine Directives was investigated. The implementation of the EU Birds and Habitats and the EU Water Framework Directive (WFD) in the BPNS was investigated and compared to results of the biological valuation of the BPNS to see whether this valuation methodology was able to detect important Bird or Habitat areas or could be used as a classification method within the scope of the WFD. Next to that the possibilities of marine biological valuation in the framework of the future Marine Strategy Directive were assessed.

General conclusions on the potential (mis)use of the marine biological valuation protocol in decision support systems were provided in **Chapter 6**, next to overall conclusions.

CHAPTER 2A

A CONCEPT FOR BIOLOGICAL VALUATION IN THE MARINE ENVIRONMENT

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Abstract

In order to develop management strategies for sustainable use and conservation in the marine environment, reliable and meaningful, but integrated ecological information is needed. Biological valuation maps that compile and summarize all available biological and ecological information for a study area, and that allocate an overall biological value to subzones, can be used as baseline maps for future spatial planning at sea. This paper provides a concept for marine biological valuation which is based on a literature review of existing valuation criteria and the consensus reached by a discussion group of experts.

Key words: marine biological valuation; biodiversity; ecological valuation criteria; intrinsic value; hotspot approach

Introduction

There is worldwide recognition of the benefits of management for sustainable use and conservation of the sea (e.g. Tunesi & Diviacco 1993, Vallega 1995, Ray 1999, EC Habitat and Bird Directives; proposed Marine Strategy Directive). Solid and meaningful biological and ecological information is urgently needed to inform and underpin sustainable management approaches. Biological valuation maps (BVMs), i.e. maps showing the intrinsic biodiversity value of subzones within a study area, would provide a useful 'intelligence system' for managers and decision makers. Such maps would need to make best use of available data sets, compiling and summarizing relevant biological and ecological information for a study area, and allocating an overall biological value to different subzones. Rather than a general strategy for protecting areas that have some ecological significance, biological valuation is a tool for calling attention to areas which have particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk aversion in management of activities in such areas.

Biological valuation assessments have been developed primarily for terrestrial systems and species (De Blust *et al.* 1985, 1994). The relevance of terrestrial approaches in determining specific valuation criteria for marine systems requires an understanding of both the nature and degree of differences between marine and terrestrial systems (e.g. the extent and rate of dispersal of nutrients, materials, planktonic organisms and reproductive propagules of benthic organisms, expanding the scales of connectivity among near-shore populations, communities and ecosystems (Fairweather & McNeill 1993, Carr *et al.* 2003) and seasonal variation (Ray 1984)). Concepts for the selection of valuable offshore marine areas must therefore consider the 'openness' (continuity and natural coherence) of the sea (Rachor & Günther 2001).

Problems encountered when applying terrestrial-based assessments to marine areas are currently demonstrated in the difficulties encountered implementing the EC Habitats Directive (92/43/EEC) in the marine environment. The Directive was written from a terrestrial viewpoint, and applying it to more dynamic marine systems has proved problematic (Hiscock *et al.* 2003). Criteria developed for identifying terrestrial species and habitats for conservation cannot be easily applied to the marine environment. Therefore, different valuation criteria may be needed for marine areas (see Fairweather & McNeill 1993, Carr *et al.* 2003). The

European Commission is currently developing a Marine Strategy Directive which recognizes the need for a thematic strategy for the protection and conservation of the European marine environment with the overall aim to promote sustainable use of the seas and conserve marine ecosystems. This Directive is written from a marine viewpoint and was driven by the fact that no integrated policy focused on the protection of the European marine environment. It is still in its developmental phase, but one of its goals will be the determination of good environmental status (for habitat types, biological components, physico-chemical characteristics and hydromorphology) of marine waters by 2021 (CEC, 2005). The criteria and standards to determine this good environmental status will only be established once the Directive is in force, so it could be appropriate to use the same biological valuation criteria (at least for the biological elements covered by the proposed Directive) as selected below in this paper in order to achieve better agreement amongst these initiatives.

Coastal planners and marine resource managers have utilized various tools for assessing the biological value of subzones in the past. These approaches vary in information content, scientific rigour, and the level of technology used. The most simple approach is low-tech participatory planning, which often occurs in community-based marine protected area (MPA) design (e.g. the Mafia Island Marine Park Plan, described in Agardy 1997), but the selection of such priority areas is very ad-hoc, opportunistic, or even arbitrary, resulting in decisions which are often difficult to defend to the public. The chance of selecting the areas with the highest intrinsic biological and ecological value through these methods is small (Fairweather & McNeill 1993, Ray 1999, Roberts *et al.* 2003b). Later on, a more Delphic-judgmental approach has been advocated. In this approach, an expert-panel is consulted to select areas for protection, based on expert knowledge. The method is relatively straightforward and easily explained, which may indicate why it is still common (Roberts *et al.* 2003b). However, owing to the urgency for site selection, the consultation process is usually too short, the uncertainty surrounding decisions is too high, and the information input is too generalized to permit defensible, long-term recommendations (Ray 1999). The disadvantages of these aforementioned existing methods for assessing the value of marine areas have led to an increasing awareness that a more objective valuation procedure is needed. Other existing methodologies utilize a variety of tools to optimize site selection through spatial analysis, such as Geographic Information System (GIS)-based multicriteria evaluation (e.g. Villa *et al.* 2002). The most sophisticated methods are those where planning is driven in part by high-tech decision-support tools. One such tool is MARXAN, which is a systematic conservation

planning software program used to identify reserve designs that maximize the number of species or communities contained within a designated level of representation. The methodology behind this approach is described by Possingham *et al.* (2000), and it has been incorporated into various planning efforts (e.g. the zoning of the Great Barrier Marine Park as per Pressey *et al.* 1997). This technique is mostly used for reserve selection and uses mathematical models to select those subzones which contribute most to the specified conservation goals established for the system while minimizing the costs for conservation (Stewart & Possingham 2002, Airamé *et al.* 2003, Lieberknecht *et al.* 2004b, Lourie & Vincent 2004, Fernandes *et al.* 2005). Without denying the merits of MARXAN and similar mathematical tools for conservation planning, this technique cannot be applied for the purpose of biological valuation of an area. Biological valuation is not a process to select areas for conservation according to quantitative objectives, but gives an overview of the integrated biological value of the different subzones within a study area (relative to each other). The decision to include one or more subzones in a marine reserve cannot be made on the basis of the outcome of a biological valuation, because the latter process does not take into account management criteria and quantitative conservation targets.
The element common to all the above approaches is the identification of criteria to discriminate between marine areas and to guide the selection process. Whilst the vast majority of these efforts are relevant to marine protected area design, there is no reason why such criteria cannot be equally helpful in coastal zone and ocean management more generally.

It is therefore necessary that the definition of the value of marine areas should be based on the assessment of areas against a set of objectively chosen ecological criteria, making best use of scientific monitoring and survey data (Mitchell 1987, Hockey & Branch 1997, Ray 1999, Connor *et al.* 2002, Hiscock *et al.* 2003). A first step towards such an objective valuation framework was recently made in the Netherlands, where selection criteria from the EC Habitat (92/43/EEC) and Bird (79/409/EEC) Directives and the OSPAR guidelines (OSPAR 2003) were used to determine which marine areas have special ecological values in terms of high biodiversity (Lindeboom *et al.* 2005).

This paper aims to develop a scientifically sound and widely applicable concept for marine biological valuation, drawing on existing valuation criteria and methods (literature review) and attempts to rationalize them into a single model. This concept represents a consensus reached by a large and diverse group of experts in the field (see author list) during a workshop on marine biological valuation (2-4 December 2004, Ghent, Belgium). Apart from its immediate merit as a guideline for marine biological valuation, this paper can also be regarded as an incentive to further discussion on marine biological valuation.

Definition of marine biological value

Different definitions of 'marine biological value' are currently found in the literature. What is meant by 'value' is directly linked to the objectives behind the process of valuation (e.g. conservation, sustainable use, preservation of biodiversity, etc.). Discussions on the value of marine biodiversity almost always refer to the socio-economic value of biodiversity (i.e. the so-called value of the goods and services provided by marine ecosystems, or the value of an area in terms of importance for human use), and attempts to attach a monetary value to the biodiversity in an area (Bockstael *et al.* 1995, King 1995, Edwards & Abivardi 1998, Borgese 2000, Nunes & van den Bergh 2001, de Groot *et al.* 2002, Turpie *et al.* 2003[2]). Many approaches try to highlight only the most important sites in a region in order to designate priority sites for conservation. These priority sites are often chosen on the basis of the hotspot approach, which is used to select sites with high numbers of rare/endemic species or high species richness (e.g. Myers *et al.* 2000, Beger *et al.* 2003, Breeze 2004).

For the purpose of this paper, 'marine biological value' was defined as follows: 'the intrinsic value of marine biodiversity, without reference to anthropogenic use'. This definition is similar to the definition of value of natural areas of Smith & Theberge (1986): 'the assessment of ecosystem qualities *per se*, regardless of their social interests' (i.e. their intrinsic value). By 'ecosystem qualities' the authors of the latter paper covered all levels of biodiversity, from genetic diversity to ecosystem processes.

The purpose of marine biological valuation is to provide subzones within the target study area with a label of their intrinsic biological value (at a continuous or discrete value scale, e.g. high, medium and low value). Subzones are defined as subregions within the study area that can

[2] Note after publication: additional information on the socio-economic valuation of marine biodiversity can be found in the work by Constanza et al. (1999), who can be regarded as pioneers in this area of work.

be scored relative to each other, against a set of biological valuation criteria. The size of these subzones depends on the size of the study area, on the biodiversity components under consideration and on the amount of available data and should therefore be decided on a case by case basis. In contrast to the hotspot approach (i.e. identification of priority areas for conservation), we do not want to highlight solely the most valuable subzones. The product of the valuation process, i.e. the intrinsic values of the subzones, can then be presented on marine BVMs. The BVM can serve as a baseline map showing the distribution of complex biological and ecological information.

Selected valuation criteria

Several initiatives to select biological criteria and to develop valuation methods already exist in literature. These were reviewed (see Appendix 1) and the most appropriate criteria were selected for incorporation into our system. Some of these criteria have already been assessed for their applicability, and some are included in international legislation (e.g. EC Habitat -92/43/EEC- and Bird -79/409/EEC- Directives) (Brody 1998). This latter point is very important, because any workable valuation assessment for marine areas should ideally mesh with relevant international protection or management initiatives (such as OSPAR 1992), in so far as is practical. This may maximize consistency of approach through the territorial waters, continental shelf and superjacent waters where initiatives overlap (Laffoley *et al.* 2000b).

Three distinct types of literature were included in our review: articles on the assessment of valuable ecological marine areas, literature on selection criteria for Marine Protected Areas (MPAs), and international legislative documents that include selection criteria (EC Bird/Habitat Directives, Ramsar Convention, OSPAR guidelines, UN Convention on Biological Conservation (1992), etc.). Only ecological criteria were considered relevant to this study; others (e.g. socio-economic or practical considerations) were not included in the overview.

Sullivan Sealey & Bustamante (1999) described a set of indicators that are indirect or direct measures of biological and ecological value, and whose assessment allows a ranking of the marine study area into subzones with different values. Following this first step, they applied a subsequent set of prioritizing criteria to the list of high-ranked areas to identify the priority areas for conservation. The criteria used to determine the conservation need of the area were based on changes induced by human activities, an evaluation of the potential threats to the area, the political and public concern to protect the area, and the feasibility of designation. The objective of our work is the same as for the first step of Sullivan Sealey & Bustamante's work (i.e. ranking of areas according to their inherent biological and ecological value), but we do not address issues of determination of conservation status, or the socio-economic criteria since these also involve social and management decisions. The methodology used by these authors could not be used here since they scored the different valuation criteria through expert judgement. Here, it is tried to establish a valuation concept which is as objective as possible.

The valuation concept was developed, based in part on a framework developed for the identification of Ecologically and Biologically Significant Areas (EBSAs) (DFO 2004, Glen Jamieson, *pers. comm.*), using five criteria: uniqueness, aggregation, fitness consequences, resilience and naturalness. The first three criteria were considered the first-order (main) criteria to select EBSAs, while the other two were used as modifying criteria to upgrade the value of certain areas when they scored high for these criteria.

It was decided that, for the marine biological valuation concept presented here, the criterion of 'resilience' (the degree to which an ecosystem or a part/component of it is able to recover from disturbance without major persistent change, as defined by Orians (1974)) should not be included, as it is closely related to the assessment of (future) human impacts, which is not an appropriate criterion for determining the current and inherent biological value of an area (although it is an important consideration in formulating practical management strategies). Of course, resilience can also be the intrinsic quality of a certain biological entity to be able to resist or to recover from natural stresses (e.g. resilience of mangrove communities to climate change stress), but since the term 'resilience' is used for resistance to both natural and anthropogenic stresses, it is excluded as an ecological valuation criterion. In contrast, we decided that the criterion 'naturalness' should be retained, because it is an index of the degree to which an area is currently (though not inherently) in a pristine condition. In this way, unaltered areas with a high degree of resilience against natural stresses will still be covered by the valuation concept. The criterion 'uniqueness' was renamed 'rarity' as this term is more frequently used in literature and encompasses unique features.

The criteria listed in the review were then cross-referenced with the selected valuation criteria, i.e. rarity, aggregation, fitness consequences, and naturalness, to see if additional criteria needed to be included in order to produce a comprehensive valuation concept for the marine environment. It was found that there is much redundancy in the valuation criteria, and that most, but not all, of the criteria mentioned in the literature are accounted for by the selected valuation criteria. One additional criterion was added to the framework to make it fully comprehensive: 'proportional importance' (included as a modifying criterion). The concept of 'biodiversity' (including all organizational levels of biodiversity - from the genetic to the ecosystem level, separated into biodiversity structures and processes) should also be included in the valuation framework, though not as a criterion (see below). Table 1 gives an overview of the chosen set of valuation criteria together with a brief definition of each, and the upper part of Figure 1 shows an overview of the biological valuation concept proposed in this paper. Each criterion is defined and discussed in further detail in the text below.

In summary, the valuation criteria selected for the development of marine BVMs are: rarity, aggregation, fitness consequences (main criteria), naturalness and proportional importance (modifying criteria).

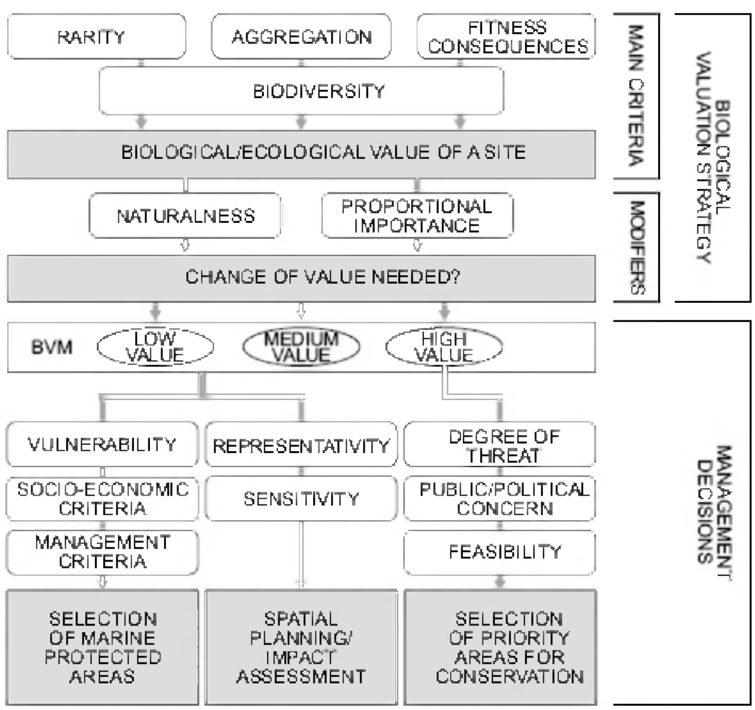

Figure 1: Overview of the concept of marine biological valuation and the possible steps to develop decision support tools.

Table 1: Final set of marine valuation criteria and their definitions

Valuation criterion	Definition	Source
1st order criteria		
Rarity	Degree to which an area is characterized by unique, rare or distinct features (landscapes/habitats/ communities/species/ecological functions/ geomorphological and/or hydrological characteristics) for which no alternatives exist.	DFO (2004); Rachor & Günther (2001), modified and complemented after Salm *et al.* (2000), Salm & Price (1995) and Kelleher (1999); UNESCO (1972)
Aggregation	Degree to which an area is a site where most individuals of a species are aggregated for some part of the year or a site which most individuals use for some important function in their life history or a site where some structural property or ecological process occurs with exceptionally high density.	DFO (2004)
Fitness consequences	Degree to which an area is a site where the activity(ies) undertaken make a vital contribution to the fitness (= increased survival or reproduction) of the population or species present.	DFO (2004)
Modifying criteria		
Naturalness	The degree to which an area is pristine and characterized by native species (i.e. absence of perturbation by human activities and absence of introduced or cultured species).	DFO (2004); Department for Environment, food and Rural Affairs (2002); Connor *et al.* (2002); JNCC (2004); Laffoley *et al.* (2000b)
Proportional importance	Global importance: proportion of the global extent of a feature (habitat/seascape) or proportion of the global population of a species occurring in a certain subarea within the study area.	Connor *et al.* (2002); Lieberknecht *et al.* (2004a, 2004b)
	Regional importance: proportion of the regional (e.g. NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subarea within the study area.	Connor *et al.* (2002); Lieberknecht *et al.* (2004a, 2004b)
	National importance: proportion of the national extent of a feature (habitat/seascape) or proportion of the national population of a species occurring in a certain subarea within territorial waters.	BWZee workshop definition (2004)

A. Rarity

Rarity can be assessed at different scales, e.g. national, regional, global. In order to be able to assess the rarity of marine species or communities at a regional or global scale, international lists of rare species, habitats or communities are needed. Unlike the terrestrial environment, however, very few marine species are included in Red Data Books, like the IUCN Red Lists or the appendices of CITES, CMS (RAMSAR COP 7, 1999)[3] and the Bern Convention (1979). This is due to the lack of systematic assessment and study of marine species at a regional scale (Sanderson 1996a, 1996b, Ardron *et al.* 2002). It should be noted that most species or communities that are mentioned on lists as mentioned above are 'rare' because their numbers have been depressed by human actions, while other species or communities are just not numerous. For the purpose of this paper both types of rare species/communities are considered. If such rare species lists at a local or regional scale are not available, species rarity within a subzone can still be assessed if data on their population size (at a national or regional scale) and trends are available. Population data are frequently lacking, which only leaves the 'area of occupancy' concept as a proxy to assess the number and location of rare species within a study area (Sanderson 1996a, 1996b, Connor *et al.* 2002). The application of this concept is shown in Table 2. This approach has been adopted for the UK's Review of Marine Nature Conservation (DEFRA 2004, Golding *et al.* 2004, Vincent *et al.* 2004, Lieberknecht *et al.* 2004a) and the UK Biodiversity Action Plan for marine species and habitats (UK BAP 2005), both in combination with other criteria.

A species described by the method of Sanderson (1996a, 1996b) as nationally rare or scarce, is not necessarily regionally or globally rare or scarce: it may simply have been reported at the edge of its range; or else this designation may indicate subtle adversity such as stress caused by human activities in the study area. However, it could also be important to give a high value to subzones containing species at the margins of their range, because these sites could host important genetic stocks of a species. Also, populations of sessile southern or northern species have a poor capacity for recovery and recruit slowly at the northern, respectively southern, margins of their distribution and are therefore particularly vulnerable to even the most minor, infrequent impacts (Sanderson 1996a, 1996b). Nationally rare or scarce species may also be restricted to specific habitat types that themselves may be rare in the study area and need to be given a high value (e.g. the rocky island habitats of Helgoland in the sedimentary southern North Sea).

A disadvantage of rarity assessment as discussed in Table 2 is that it may overlook local densities. Locally abundant species (in one or several subzones of a study area) which are

[3] Note after publication: the reference to CMS is wrong and should be omitted and replaced by CMS (1979).

restricted in their range might be considered to conflict with assertions made about national rarity, should population-based methods of assessment ever be used (Sanderson 1996a, 1996b).

Table 2: Approaches to apply the rarity criterion

Rare species	**Regionally rare** (sessile or of restricted mobility) **species** = species occurring in less than 2% of the 50 x 50 km UTM grid squares of the following bathymetric zones in the region (e.g. North East Atlantic): littoral / sublittoral / bathyal, abyssal	Connor *et al.* (2002) (only applicable to sessile species; no guidelines available for mobile species); Connor *et al.* (2004); Lieberknecht *et al.* (2004a, 2004b)
	Nationally rare species = species occurring in less than 0.5% of the 10 km x 10 km squares within the study area **Nationally scarce species** = species occurring in less than 3.5% of the 10 km x 10 km squares within the study area	Sanderson (1996a,1996b); Connor *et al.* (2004); Lieberknecht *et al.* (2004a, 2004b)
	Nationally rare species = species found in fewer than x km squares in territorial waters	Hiscock *et al.* (2003); Department for Environment, food and Rural Affairs (2002)
Rare habitats	**Regionally rare habitat** = habitat type occurring in less than 2% of the 50 x 50 km UTM grid squares of the following bathymetric zones in the region (e.g. North East Atlantic): littoral / sublittoral / bathyal, abyssal	Connor *et al.* (2002)
	Nationally rare habitat = habitat type restricted to a limited number of locations in territorial waters	Department for Environment, food and Rural Affairs (2002)

Uniqueness and distinctiveness (Roff & Evans 2002) are also considered under this criterion and to assess the number and location of unique or distinct features/genetic stocks/species/communities within the study area, information on their occurrence is needed.

B. Aggregation

The ‘aggregation’ and ‘fitness consequences’ criteria will mainly identify subzones that have high ecological importance for the wider environment. Evaluation of these criteria therefore lies at the heart of an ecosystem approach to management, assigns value to subzones that 'drive' ecological processes, and is one way to achieve preservation of the larger marine ecosystem (Brody 1998). Ecosystem management forces us to adopt a holistic view of the components as parts of the system, rather than the reductionist view of single-species management, which ignores the fact that species exist only as part of the ecosystem (Simberloff 1998). This is in agreement with the present concept of including as many components of biodiversity (both structural components and processes) in the criteria assessment as possible.

If data on the population size of a species are available at the scale of the study area, it is possible to determine whether a high percentage of a species' population is located within a cluster of subzones of the study area. If these data are lacking and qualitative information exists on certain areas where species aggregate (wintering, resting, feeding, spawning, breeding, nursery, rearing area or migration routes), this information should be used as an alternative or addition to broad-scale quantitative abundance data. When the location of these areas is not documented, their existence and location may be predicted by examination of physical processes (incl. modelling) or remote sensing data, for example as indicated by Roff & Evans (2002) in their survey of distinctive marine areas. Alternatively, traditional ecological knowledge may assist in the definition of aggregation areas. It needs to be emphasized that any data, modelled or otherwise, needs to be assessed for its reliability and degree of confidence.

The inclusion of aggregation as a criterion for biological valuation introduces a certain degree of connectivity into the valuation concept, because this criterion is used to determine the aggregation value of subzones relative to the subzones adjacent to them, allowing the clustering of those subzones with equal value.

The aggregation criterion is especially important for highly mobile species like birds, mammals or fish. For the preservation of such wide ranging species, information on their full distribution is less useful than the localisation of areas which are critical for foraging, nursing, haul-out, breeding or spawning; it is these areas that should be included when a biological valuation is done (Connor *et al.* 2002, Roff & Evans 2002, Beck *et al.* 2003). When the study area under consideration is relatively small, the foraging areas of such highly mobile species could cover the whole study area, but it is still important to include them in the biological valuation, as this can be an important signal to management as well.

Owing to the continuous nature of the marine environment, it is difficult to identify the boundaries of such aggregation areas, especially for widely dispersed, highly mobile species (Johnston *et al.* 2002, Airamé *et al.* 2003). This can be seen in the difficulties encountered by many countries to implement the EC Bird Directive (1979) and Ramsar Convention (1971), which both select important bird areas based on high densities of bird species (Johnston *et al.* 2002).

C. Fitness consequences

This criterion distinguishes subzones where natural activities take place that contribute significantly to the survival or reproduction of a species or population (DFO 2004). These are not necessarily areas where species or individuals aggregate. When genetic data are available for the study area, which is rarely the case, these can be used to locate subzones where a high diversity of genetic stocks of a species occurs. The occurrence of genetically variable individuals could significantly improve the survival of a species in the study area, because it enables the selective adaptation of the species to changing environmental conditions.

It is also possible to determine the location of subzones with fitness consequences for a species. These could be subzones where individuals stop for a certain amount of time to feed or rest, which will lead to higher reproduction (e.g. bigger/more young). Also, the presence of structural habitat features or keystone species may enhance the survival or reproduction of species by providing refuge from predators or key resources.

D. Naturalness

According to the EC Habitats Directive (1992), the criterion ‘naturalness’ is indirectly included in site selection, as several criteria need to be applied to ‘natural habitats’: these are defined as ‘(land or) water zones with special geographic, abiotic and biotic characteristics which can be either totally natural or semi-natural (as described in Annex I of the Directive)'. The problem with assessing this criterion is the fact that it is often unknown what the natural state of an area should be. Many assumptions may be made, but more studies are needed to help define what 'natural' really is (Bergman *et al.* 1991, Hiscock *et al.* 2003). There are also hardly any completely natural areas left anymore (Ray 1984) and it is difficult to assess the degree of naturalness in areas at great depth or in areas of poor accessibility (Breeze 2004). So, in order to assess the naturalness of a subzone, there is a need for comparison to appropriate pristine areas or reference sites. If such areas do not exist, an alternative way to assess naturalness is to use information on native/introduced or cultured species in the study area, which can be seen as proxies for the degree of naturalness.

Another approach to assess the naturalness of a subzone is to look at the health or composition of the inhabiting communities/species. For instance, healthy, natural benthic communities are in many cases characterized by a high biomass (dominated by long-lived species) and a high species richness (Dauer 1993). Deviations from this pattern, resulting in a reduced macrobenthic biomass and a species richness dominated by opportunistic species, could be assigned to a certain level of stress and could be used to index the naturalness of a subzone. Such health indices, however, still require some reference to a baseline level of naturalness.

Lacking even this information, one could use data on the location and intensity of human activities. The environmental and ecological state of subzones which are characterized by the absence of human disturbance can be used as a rough index of the degree of naturalness. Naturalness should not only consider the degree of disturbance to attributes of species, but also to functional processes of the marine ecosystem.

E. Proportional importance

Proportional importance measures the proportion of the national, regional and/or global resource of a species or feature which occurs within a subzone of the study area. While the 'aggregation' criterion investigates whether a high percentage of the species population at the scale of the study area is clustered within certain subzones of that area, the 'proportional importance' criterion investigates whether a high percentage of the species' population at a national (provided that the national scale is greater than the scale of the study area), regional and/or global scale can be found in the study area, regardless if this proportion is clustered within adjacent subzones.

To assess this criterion, data on the extent of marine features or population data of individual species are needed. When population data are lacking, it may be possible to use available abundance data for species within the study area, and determine the national importance of subzones for these species. This criterion was first defined by Connor *et al.* (2002) and adapted by Lieberknecht *et al.* (2004a, 2004b), who also defined thresholds for the term 'high proportion'. These thresholds are similar to those in the criteria guidance of OSPAR (2003). It was decided at the workshop on marine biological valuation that no thresholds would be set in the definition of the criterion, since they are very scale-dependent and should therefore be set for every case study separately.

The biological valuation map represents the biological values of the different subzones considered, relative to each other, but incorporation of the proportional importance criterion aims at comparing certain features or properties with the wider environment of the study area, attaching extra value to subzones where a high proportion of the population of a species occurs. It could also be possible to include the genetic (e.g. restricted distribution of a certain genetic stock) or community (e.g. restricted distribution of a defined community type) level.

F. Biodiversity: A valid valuation criterion?

When valuing marine areas, it is important to capture as many attributes of biodiversity as possible, since biological structures and processes exist on different organizational levels (viz. genes, species, population, community and ecosystem) (Zacharias & Roff 2000, 2001). According to Roberts *et al.* (2003a), valuable marine areas should be characterized by high biodiversity and properly functioning ecological processes which support that diversity. According to many authors the biodiversity of an area is simply a function of the species diversity, but we believe that a valuation framework that incorporates as many organizational levels of biodiversity as possible is far preferable.

Although the concept of biodiversity as a valuation criterion is highly attractive to managers, the practice of distilling biodiversity to a single index or a few dimensions is unjustified (Margules & Pressey 2000, Purvis & Hector 2000, Price 2002), which is why biodiversity was not used as a criterion in our valuation concept. However, biodiversity is still integrated in the concept, but in a different way (see below). Yet, because of its frequent use (IUCN 1994, HELCOM 1992, Brody 1998, UNEP 2000[4], GTZ GmbH 2002), we feel that a critical literature review and an argumentation for not including biodiversity as a valuation criterion in our concept are needed.

In most research studies only the species richness of a subzone is assessed (Humphries *et al.* 1995, Woodhouse *et al.* 2000, Price 2002), but biodiversity manifests itself on many more levels of organization (from the genetic to the ecosystem); simply counting the number of species in a subzone as a measure of biodiversity can be misleading because subzones with a high species richness do not necessarily exhibit a high diversity on other levels (Attrill *et al.* 1996, Hockey & Branch 1997, Vanderklift *et al.* 1998, Purvis & Hector 2000, Price 2002). Several authors have tried to find surrogate measures for biodiversity, in general in order to decrease the sampling effort or data requirements (Purvis & Hector 2000). For example, Ray (1999) used species richness of birds as a surrogate for overall biodiversity, an approach which is based on the fact that birds have dispersed to and diversified in all regions of the world. Yet, analyses revealed that species richness hotspots of birds coincided poorly with those of other biota. Hotspots of species richness, endemism or rarity are often less discernible in continuous marine ecosystems than in terrestrial environments. Turpie *et al.* (2000) used the hotspot approach for species richness (and weighting all species equally) and did not achieve good representation for coastal fish species. Thus, the hotspot approach based on species richness alone is not a useful starting point for the selection of biological valuable marine areas. This was also noted by Breeze (2004), who found the traditional hotspot approach to be narrowly defined and species-focused, while the criteria used for identification of highly valuable marine areas should be much broader.

The use of focal species (indicators, umbrellas, flagship species), which has been developed mainly from a terrestrial viewpoint, is not straightforward to apply in the marine environment. Since connectivity is very different in the marine environment, the concept of a particular

[4] Note after publication: reference to the Convention on biological diversity (1992) should have been included as well.

species indicating a certain size of intact habitat is not readily applicable (Ardron *et al.* 2002). Ward *et al.* (1999) also investigated the use of surrogates for overall biodiversity, and found that habitat types suited this function best. However, no surrogate was able to cover all species, from which it can be concluded that the hotspot paradigm, based on individual surrogates of biodiversity, is problematic to apply.

The concept of 'benthic complexity' was introduced by Ardron *et al.* (2002) as a proxy for benthic species diversity. The authors assume that the bathymetric (topological) complexity of an area is a measure of benthic habitat complexity, which in turn would represent benthic species diversity. However, the data needed to perform the spatial variance analyses needed to quantify 'benthic complexity' are usually lacking. Because detailed data on the diversity of species or communities are often scarce or nonexistent, Airamé *et al.* (2003) proposed to assess the habitat diversity as a proxy for overall biodiversity, because data on habitat distributions are generally available or can be constructed.

We feel that a more general framework for the assessment of biodiversity is needed (see e.g. Humphries *et al.* 1995), that this framework should use available information from a range of organizational levels (genes, species, communities, ecosystems), and that the relationships among these levels need to be examined. It is also emphasized that, in addition to biodiversity 'structures', there is also a need to include biodiversity processes such as aspects of the functioning of ecosystems, which could even be more important than high species richness or diversity indices in certain low biodiversity sites like estuaries (Attril *et al.* 1996, Bengtsson 1998). Bengtsson (1998) also stated that biodiversity is an abstract aggregated property of species in the context of communities or ecosystems, and that there is no mechanistic relationship between single measures of biodiversity and the functioning of the entire ecosystem. Ecosystem functioning can, however, be included indirectly in an assessment of biodiversity value, through the identification of functional species or groups and critical areas.

Zacharias & Roff (2000) visualised the various components of biodiversity in their 'marine ecological framework' (going from the species to the ecosystem level and including both biodiversity structures and processes). Each of these components can be linked to one or more of the selected valuation criteria, which makes it unnecessary to include biodiversity as a separate valuation criterion. By using this 'framework' it could therefore be possible to apply the valuation criteria while integrating various components of biodiversity.

Potential application of the biological valuation concept

Once the concept of biological valuation is applied to a marine study area, the result of this process could be visualized on marine BVMs.

Marine BVMs can act as a kind of baseline describing the intrinsic biological and ecological value of subzones within a study area. They can be considered as warning systems for marine managers who are planning new, threatening activities at sea, and can help to indicate conflicts between human uses and a subzone's high biological value during spatial planning.

It should be explicitly stated that these BVMs give no information on the potential impacts that any activity could have on a certain subzone, since criteria like vulnerability or resilience are deliberately not included in the valuation scheme, because the determination of the 'vulnerability' of a system is mainly a human value judgement (McLaughlin *et al.* 2002). These criteria should therefore be considered in a later phase of site-specific management (e.g. selection of protected areas) than the assessment of value of marine subzones (Gilman 1997, 2002). The BVMs could be used as a framework to evaluate the effects of certain management decisions (implementation of MPAs or a new quota for resource use), but only at a more general level when BVMs are revised after a period of time to see if value changes have occurred in subzones where these management actions were implemented. However, these value changes cannot be directly related to specific impact sources, but only give an integrated view of the effect of all impact sources in the subzone. The development of decision support tools for marine management could build on these BVMs by adding other criteria to the assessment concept. When developing a framework, suitable for the selection of Marine Protected Areas (MPAs), representativeness, integrity, and socio-economic and management criteria should also be taken into account (Rachor & Günther 2001), especially when considering the need for management for sustainable use (Hockey & Branch 1997). Managers may also want to know which areas should get the highest priority. Therefore, the sites that attained the highest biological and ecological value could be screened, with the application of additional criteria like ‘degree of threat’, ‘political/public concern’ and ‘feasibility of conservation measures’. Thus, although the ultimate selection of the priority areas may be a political decision (Agardy 1999), selection can still have a solid scientific base through the use of BVMs. An overview of the possible steps beyond the development of a marine BVM is given in the lower part of Figure 1, which shows that, although these following steps should be founded on scientific biological valuation, they cannot be based solely on such criteria.

Conclusions

Marine biological valuation provides a comprehensive concept for assessing the intrinsic value of the subzones within a study area. Marine biological valuation is not a strategy for protecting all habitats and marine communities that have some ecological significance, but is a tool for calling attention to subzones that have particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk aversion in spatial planning activities in these subzones.

Based on a thorough review of existing criteria, a selection of criteria (first order criteria: aggregation, rarity and fitness consequences; modifying criteria: naturalness and proportional importance) was rationalized, aiming at a widely applicable valuation concept. We have also attempted to clarify the numerous criteria and definitions of value that are current in the literature.

As this biological valuation concept is based on the consensus reached by a group of experts on this matter, we realize that refinement of the methodology could be necessary once it has been evaluated on the basis of case study areas.

Acknowledgements

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[5] All participants of the workshop on marine biological valuation (December 2004) are acknowledged as co-authors of this paper. The use of the plural ‘we’ in the paper reflects the fact that most ideas in this paper came from this collective exercise on valuation.

Appendix 1: Overview of existing ecological criteria for selection of valuable marine areas or marine areas in need of protection.

Criterion	Occurrence in literature	Included in final set of criteria?
Rarity	EC Bird Directive (1979); Smith and Theberge (1986); Mitchell (1987); Bergman *et al.* (1991); HELCOM (1992); Fairweather and McNeill (1993); Norse (1993); Tunesi and Diviacco (1993); IUCN (1994); Gilman (1997); Vanderklift *et al.* (1998); IMO (1999); RAMSAR COP 7 (1999); Laffoley *et al.* (2000b); Turpie *et al.* (2000); UNEP (2000); Woodhouse *et al.* (2000); Ardron *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); Hiscock *et al.* (2003); Sanderson (1996a, 1996b); Connor *et al.* (2002); OSPAR (2003); Roberts *et al.* (2003a, 2003b)	Yes, 1st order criterion
(Bio)diversity	Ray (1984); Smith and Theberge (1986); Mitchell (1987); Bergman *et al.* (1991); HELCOM (1992); Fairweather and McNeill (1993); Norse (1993); Tunesi and Diviacco (1993); IUCN (1994); Chaillou *et al.* (1996); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); Vanderklift *et al.* (1998); Zacharias and Howes (1998); RAMSAR COP 7 (1999); Ray (1999); Laffoley *et al.* (2000b); Turpie *et al.* (2000); UNEP (2000); Woodhouse *et al.* (2000); Eaton (2001); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Rey Benayas and de la Montaña (2003); Roberts *et al.* (2003a, 2003b); Roff *et al.* (2003); Breeze (2004); JNCC (2004)	Not as criterion, but all organizational levels of biodiversity are implicitly included in the valuation strategy (see text for explanation)
Naturalness	Ray (1984); Smith and Theberge (1986); Mitchell (1987); Fairweather and McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); IMO (1999); Laffoley *et al.* (2000b); Rachor and Günther (2001)[a]; Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Breeze (2004); JNCC (2004)	Yes, modifying criterion
Proportional importance	Ray (1984); Hockey and Branch (1997); Laffoley *et al.* (2000b); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); Lieberknecht *et al.* (2004a, 2004b); OSPAR (2003)	Yes, modifying criterion
	EC Habitats Directive (1992)	Yes, under 'fitness consequences' and 'aggregation', 1st order criteria
Ecosystem functioning	EC Habitats Directive (1992) ; RAMSAR COP 7 (1999)	Yes, under 'fitness consequences', 1st order criterion
Reproductive/ bottleneck areas	Breeze (2004)	
Density	EC Habitats Directive (1992); Chaillou *et al.* (1996); Zacharias and Howes (1998); RAMSAR COP 7 (1999); Connor *et al.* (2002); Beck *et al.* (2003) ; Beger *et al.* (2003)	Yes, under 'aggregation', 1st order criterion
Dependency	UNESCO (1972); Hockey and Branch (1997); Gilman (1997, 2002)	
	Ray (1984); UNEP (1990); IUCN (1994); Barcelona Convention (1995); Laffoley *et al.* (2000b); UNEP (2000); Department for Environment, Food and Rural Affairs (2002); OSPAR (2003); Roberts *et al.* (2003a, 2003b)	Yes, under 'fitness consequences', 1st order criterion
	EC Bird Directive (1979); Ray (1984); Mitchell (1987); HELCOM (1992); IUCN (1994); Brody (1998); IMO (1999); RAMSAR COP 7 (1999); UNEP (2000); Rachor and Günther (2001); Connor *et al.* (2002); GTZ GmbH (2002); Beck *et al.* (2003); Hiscock *et al.* (2003); Roberts *et al.* (2003a, 2003b) ; Breeze (2004); JNCC (2004)	Yes, under 'aggregation' and 'fitness consequences', 1st order criteria
Productivity	Ray (1984); Smith and Theberge (1986); Mitchell (1987); Fairweather and McNeill (1993); Norse (1993); Chaillou *et al.* (1996); Brody (1998); Vanderklift *et al.* (1998); Zacharias and Howes (1998); IMO (1999); Rachor and Günther (2001)[a]; BTZ GmbH (2002); Beck *et al.* (2003); Breeze (2004); JNCC (2004)	
Special features present	Smith and Theberge (1986); Fairweather and McNeill (1993); Norse (1993); Zacharias and Howes (1998); Vanderklift *et al.* (1998)	
	Tunesi and Diviacco (1993); Beck *et al.* (2003); OSPAR (2003)	Yes, under 'rarity', 1st order criterion
Uniqueness	UNESCO (1972); EC Bird Directive (1979); Tunesi and Diviacco (1993); Gilman (1997); Brody (1998); Zacharias and Howes (1998); IMO (1999); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Connor *et al.* (2002); Gilman (2002); GTZ GmbH (2002); Mouillot *et al.* (2002)	
Irreplaceability	MacDonald *et al.* (1996); Beger *et al.* (2003); Leslie *et al.* (2003)	
Isolation	EC Habitats Directive (1992) (more used in terrestrial environments)	
Extent of habitat type	Mitchell (1987); EC Habitats Directive (1992); Hiscock *et al.* (2003)	Yes, under 'proportional importance', modifying criterion
Biogeography	Hiscock *et al.* (2003)	
	Hockey and Branch (1997); Turpie *et al.* (2000); Beger *et al.* (2003); Roberts *et al.* (2003a, 2003b)	No, MPA selection criteria

Appendix 1. Continued.

Representativeness	Ray (1984); Mitchell (1987); Bergman *et al.* (1991); EC Habitats Directive (1992); Fairweather and McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey and Branch (1997); Brody (1998); Laffoley *et al.* (2000b); Rachor and Günther (2001)[a]; Ardron *et al.* (2002); Gilman (2002); GTZ GmbH (2002); Leslie *et al.* (2003); Roberts *et al.* (2003a, 2003b); JNCC (2004)	No, MPA selection criteria
Integrity	Ray (1984); Mitchell (1987); IUCN (1994); Brody (1998); IMO (1999); Rachor and Günther (2001)[a]; GTZ GmbH (2002)	
Vulnerability	UNESCO (1972); EC Bird Directive (1979); Smith and Theberge (1986); Mitchell (1987); UNEP (1990); Bergman *et al.* (1991); EC Habitats Directive (1992); HELCOM (1992); IUCN (1994); Barcelona Convention (1995); MacDonald *et al.* (1996); Gilman (1997); Hockey and Branch (1997); Brody (1998); RAMSAR COP 7 (1999); Laffoley *et al.* (2000b); UNEP (2000); Bax and Williams (2001); Rachor and Günther (2001)[a]; Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Hiscock *et al.* (2003); OSPAR (2003); Roberts *et al.* (2003a, 2003b); Breeze (2004); JNCC (2004)	No, related to 'resilience' criterion which is excluded from final list of valuation criteria (see above)
Decline	Laffoley *et al.* (2000b); Connor *et al.* (2002); Department for Environment, Food and Rural Affairs (2002); OSPAR (2003)	
Recovery potential	Mitchell (1987); Laffoley *et al.* (2000b); Department for Environment, Food and Rural Affairs (2002)	
Degree of threat	EC Bird Directive (1979); Majeed (1987); Mitchell (1987); Bergman *et al.* (1991); Dauer (1993); MacDonald *et al.* (1996); Gilman (1997); Batabyal (1999); Eaton (2001); Connor *et al.* (2002); Gilman (2002); McLaughlin *et al.* (2002); Roberts *et al.* (2003a, 2003b)	No, management criterion
Protection level	Bergman *et al.* (1991); Zacharias and Howes (1998)	
International significance	Brody (1998)	
Economic interest	Hockey and Branch (1997); Roberts *et al.* (2003a, 2003b)	No, socio-economic criterion

[a]Modified and complemented after Salm *et al.* (2000), Salm and Price (1995) and Kelleher (1999)

CHAPTER 2B

BUILDING ON THE CONCEPT FOR MARINE BIOLOGICAL VALUATION WITH RESPECT TO TRANSLATING IT TO A PRACTICAL PROTOCOL: VIEWPOINTS DERIVED FROM A JOINT ENCORA-MARBEF INITIATIVE

TO BE PUBLISHED AS:

Derous S, Austen M, Claus S, Daan N, Dauvin J-C, Deneudt K, Depestele J, Desroy N, Heessen H, Hostens K, Marboe AH, Lescrauwaet A-K, Moreno M, Moulaert I, Paelinckx D, Rabaut M, Rees H, Ressureiçao A, Roff J, Santos PT, Speybroeck J, Stienen EWM, Tatarek A, Ter Hofstede R, Vincx M, Zarzycki T, Degraer S (in press). Building on the concept for marine biological valuation with respect to translating it to a practical protocol: Viewpoints derived from a joint ENCORA-MARBEF initiative. *Oceanologia 49 (4)*

Abstract

Marine biological valuation provides a comprehensive concept for assessing the intrinsic value of subzones within a study area. This paper gives an update on the concept of marine biological valuation as described by Derous et al. (2007). This concept was based on a literature review of existing ecological valuation criteria and the consensus reached by a discussion group of experts during an international workshop in December 2004. The concept was discussed during an ENCORA-MARBEF workshop in December 2006, which resulted in fine-tuning the concept of marine biological valuation, especially with respect to its applicability to marine areas.

Keywords: marine biological valuation, ecological criteria, intrinsic value

Introduction

Derous *et al.* (2007) defined marine biological value as 'the intrinsic value of marine biodiversity, without reference to anthropogenic use'. Marine biological valuation is not a strategy for protecting all habitats and marine communities that are of ecological significance, but is a tool for calling attention to subzones that have a particularly high ecological or biological significance and to facilitate provision of a greater-than-usual degree of risk management during spatial planning activities in these subzones (for this purpose, a subzone is defined as a subdivision of the study area, which is used as the basic valuation entity). In this way, the methodology can assist in applying the precautionary principle when new (potentially damaging) developments in the marine environment are discussed (UN, 1992).

Based on a literature review, Derous *et al.* (2007) selected five valuation criteria, which formed the backbone of the valuation concept (left part of figure 1): rarity, aggregation, fitness consequences, naturalness and proportional importance. The first three criteria are considered the main (first-order) criteria, while the latter two should be regarded as modifying criteria, which should be used to upgrade the value of certain subzones when they score highly for these criteria. These criteria comprise all relevant ecological valuation criteria circulating in the literature and can be related to all components of biodiversity, as visualized in the 'marine ecological framework of biodiversity' of Zacharias & Roff (2000).

Derous *et al.* (2007) further stated that, apart from its immediate merit as a guideline for marine biological valuation, their paper should also be regarded as an incentive to further discussion on this topic. A first step towards such discussion was the translation of the concept into a practical valuation protocol which was applied to biological data from the Belgian part of the North Sea. This case study was presented during a workshop (December 2006) to stimulate discussions on the applicability of the concept. This joint EU ENCORA Coordination Action (European Network on Coastal Research)-NoE MarBEF (Network of Excellence on Marine Biodiversity and Ecosystem Functioning) workshop provided a stimulating forum for discussions between marine ecologists and biologists with different backgrounds, but with a shared interest in biological valuation and its practical application in marine environments, and resulted in fine-tuning of the concept of marine biological valuation by assessing the relevance and applicability of the selected valuation criteria.

Valuation criteria

A. Rarity

"Degree to which a subzone is characterized by unique, rare or distinct features – landscapes, habitats, communities, species, ecological functions, geomorphological and/or hydrological characteristics – for which no alternatives exist (Derous et al. 2007)"

'Rarity' was retained as a criterion for marine biological valuation. It is very important to note that when rarity is assessed for a study area, this is done in a relative way, assessing each subzone of the study area relatively to the others. This way of assessing rarity is similar to the one described by Sanderson *et al.* (1996a, 1996b) and Connor *et al.* (2002, 2004), which has been adopted successfully in the UK in the past (DEFRA 2004, Golding *et al.* 2004, Lieberknecht *et al.* 2004a, Vincent *et al.* 2004, UK BAP 2005). When assessing 'rarity', special attention should be paid to accidental recordings or vagrants. These should not be considered here as they are not inherent to the ecosystem or community under consideration and hence do not contribute to the intrinsic biological value of the study area.

B. Aggregation-fitness consequences

"Degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year; or a site which most individuals use for some important function in their life history; or a site where some structural property or ecological process occurs with exceptionally high density, either/or the degree to which a subzone is a site where the activity(ies) undertaken make a vital contribution to the fitness (= increased survival or reproduction) of the population or species present" (DFO 2004, Derous et al. 2007)"

The two other main criteria 'aggregation' and 'fitness consequences', which were retained in Derous *et al.* (2007) are strongly linked to each other, as subzones - where activities are undertaken which make a vital contribution to the fitness of a population or species (e.g. spawning or nursery areas) - are mostly those where individuals of these species tend to aggregate. To avoid double counting of these subzones for the same reasons in the final valuation, both criteria should be merged into one criterion "aggregation-fitness consequences".

C. Naturalness

"Degree to which a subzone is pristine and characterized by native species (i.e. absence of perturbation by human activities and absence of introduced or cultured species) (Connor et al. 2002, Lieberknecht et al. 2004a,b, Derous et al. 2007)"

'Naturalness' was included in the original valuation concept as a modifying criterion to give added value to pristine subzones, characterized by native species. However, in many cases it is very difficult to define what the natural state of a marine area is, as historical data are usually lacking (Hiscock *et al.* 2003). Without this knowledge 'naturalness' is usually assessed on the basis of the absence of human impacts in the subzone. This makes it almost impossible to apply this criterion without specific reference to human impacts, which is deliberately excluded from the definition of biological valuation. Therefore, it was advised to exclude 'naturalness' as a valuation criterion. The assessment of the (un)naturalness (in relation to different impact sources) should be seen as a second step after biological valuation to produce an overlying layer on the biological valuation map.

D. Proportional importance

"Proportion of the global, regional or national extent of a feature (habitat/seascape) or proportion of the global, regional or national population of a species occurring in a certain subzone within the study area (Derous et al. 2007)"

Incorporating 'proportional importance' as a modifying criterion aims at comparing certain features or properties with the wider environment of the study area, for instance by attaching extra value to subzones where a high proportion of the national (provided that the national scale is greater than the scale of the study area), regional or global population of a species occurs (Connor *et al.* 2002, Lieberknecht *et al.* 2004a, b). As all other criteria only assess the value of the subzones relative to each other, the inclusion of a wider scale can be misleading. It was hence advised not to include ‘proportional importance’ as a valuation criterion, but to do the valuation at two different scales. First, the valuation should be done at the local level of the study area and afterwards the valuation can be done on a broader (ecoregional) level, with the same criteria (‘rarity’ and ‘aggregation-fitness consequences’). A valuation at such broader scale will be very useful to see whether subzones scoring ‘high’ at a local scale (relative to all other subzones of the study area) still have a high value when comparing them to subzones at an ecoregional scale. This will allow marine managers to see the valuation of the study area in a broader perspective.

Conclusion: adapted concept for marine biological valuation

The concept of marine biological valuation as described by Derous *et al.* (2007) was reorganized to avoid double counting of scores (i.e. lumped criterion ‘aggregation-fitness consequences’) and to allow a more logical order of the steps which should be made during valuation (i.e. assessing the biological value at two different scales instead of incorporation of ‘proportional importance’ as a valuation criterion). ‘Rarity’ was retained as a valuation criterion while ‘naturalness’ was excluded from the concept. Figure 1 gives a comparison of the original and new version of the valuation concept. As can also be seen on this figure the number of value classes has changed from three to five, which gives a better (less abrupt) representation of the value patterns.

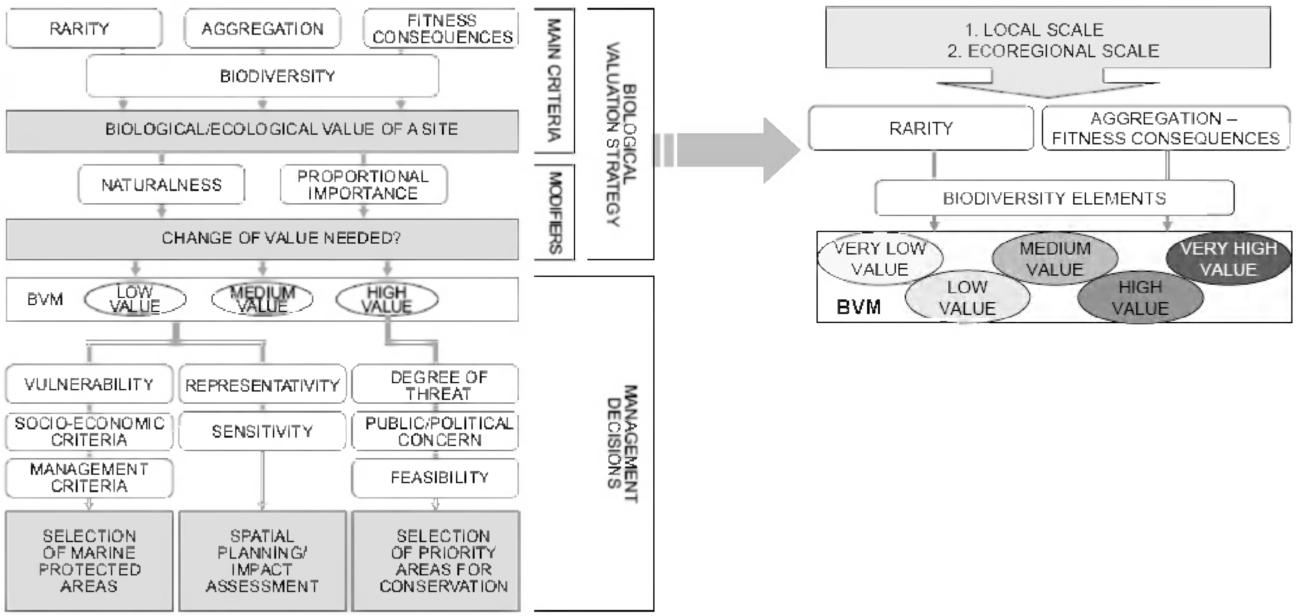

Figure 1: Adaptation of the concept for marine biological valuation. BVM = biological valuation map.

These adaptations to the original valuation concept were made after evaluating the results of applying this concept to biological data from the Belgian part of the North Sea. The adaptations will allow for a better applicability of the concept to other marine case study areas, which have been selected in the framework of the ENCORA and MarBEF projects. The results of the biological valuation of these case study areas will be described in a next paper.

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CHAPTER 3

BIOLOGICAL VALUATION: GUIDELINES FOR A TRANSPARANT AND GENERALLY APPLICABLE PROTOCOL FOR THE MARINE ENVIRONMENT

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Biological valuation: Guidelines for a transparent and generally applicable protocol for the marine environment

Aquatic Conservation: Marine and Freshwater Ecosystems

Abstract

Policy makers and marine managers request reliable and meaningful biological baseline maps to be able to make well-deliberated choices concerning sustainable use and conservation in the marine environment. Biological valuation maps aim at the compilation of all available biological and ecological information for a selected study area and allocate an integrated biological value to subzones. They can therefore be used as baseline maps for future spatial planning at sea. This paper gives guidelines on the practical application of the concept of marine biological valuation to a study area. All steps in the valuation protocol are described, starting from the selection of the valuation criteria over the determination of the appropriate assessment questions and practical algorithms to evaluate the criteria to the final scoring of all assessment questions. The marine biological valuation protocol is illustrated using a hypothetical study area.

Keywords: marine biological valuation, practical protocol, valuation criteria, assessment questions, scoring

Introduction

The continuously increasing socio-economic interest in marine resources and space urges the need for a decision-making framework to allocate objectively the different use functions at sea and to manage them in a sustainable way (Agardy, 1997, 1999; Tunesi & Diviacco, 1993). Policy makers therefore request clear and simple baseline maps in order to allow them to make well-deliberated policy choices (Hiscock *et al.*, 2003). Usage maps can be used to detect conflicts in the spatial distribution of human activities, whereas sedimentology and hydrodynamical maps allow the identification of suitable locations for new developments (e.g. aggregate extraction, dumping of dredged material, siting of windmill farms,…). Similarly, biological valuation maps (BVMs), compiling and summarizing relevant biological and ecological information for an area and differentiating between the intrinsic biological values of subzones within the study area, deliver indispensable information during spatial planning activities as has been demonstrated by the terrestrial BVMs in the past (e.g. in Belgium: De Blust, 1985, 1994). As such, the maps provide a useful “intelligence system” for managers and decision makers, indicating which biologically highly valuable subzones preferably to avoid when planning new developments. When such integrated biological information is lacking decision makers usually rely on the expert judgement of scientists, but such Delphic approach is rather subjective and lacks transparency which does not permit defensible, long-term recommendations (Ray, 1999; Roberts *et al.*, 2003b).

Based on a thorough literature review, Derous *et al.* (2007, in press) developed a generally applicable and transparent concept for marine biological valuation by selecting the most suitable valuation criteria (rarity and aggregation-fitness consequences). These criteria are applied to all the components of biodiversity and at two different scales (local and ecoregional scale), which should allow an objective and comprehensive biological valuation of a marine area. Marine biological valuation was defined as the determination of the value of the marine environment from a nature conservation perspective. As such, marine biological valuation aims at providing an integrated view on nature’s intrinsic value (i.e. without any reference to anthropogenic use), as opposed to socio-economic valuation aiming at the quantification of the goods and services provided by marine biodiversity (Beaumont *et al.*, 2007).

Figure 1 gives an overview of the concept of marine biological valuation as described by Derous *et al.* (2007, in press).

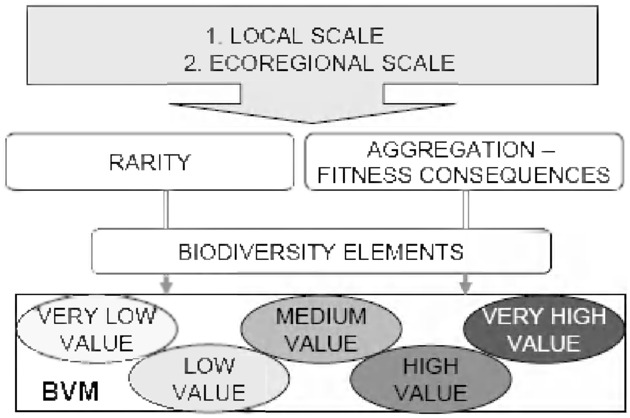

Figure 1: The concept of marine biological valuation (Derous *et al.*, 2007, in press).

The protocol for biological valuation can be designed with different levels of flexibility. The most flexible approach for biological valuation is the Delphic approach where a panel of experts is consulted to determine the value of the subzones within the area under consideration. Although this method is relatively straightforward (Roberts *et al.*, 2003b), the uncertainty and subjectivity associated with such valuation is very high. The protocol described in this paper goes beyond the use of expert judgement and provides a more objective method for biological valuation with clear guidelines. As shown in Figure 2, these guidelines can still vary according to the valuation protocol used.

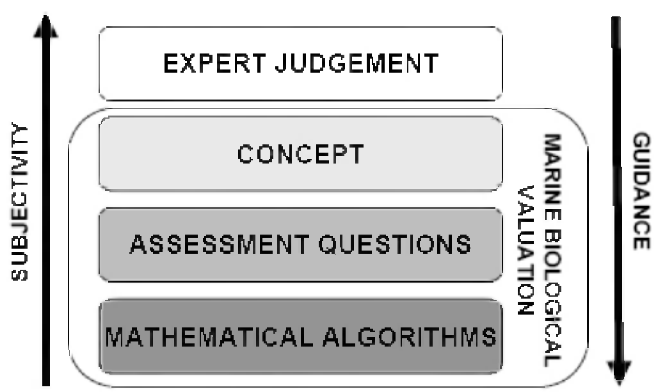

Figure 2: Different levels of complexity associated with the protocol for marine biological valuation.

The flexibility of the protocol decreases when assessment questions are linked to the valuation concept and the protocol reaches full-guidance when mathematical algorithms are determined to apply the assessment questions to a study area. Figure 2 indicates that the objectivity of the protocol increases with decreasing flexibility.

Several authors (Brody, 1998; Gilman, 2002; OSPAR, 2003; Derous *et al.*, 2007) only provide a concept for biological valuation (i.e. valuation criteria which should be considered), without determining the practical methodology to apply them. This still introduces a lot of subjectivity in the protocol and could lead to different results when different users apply this concept to the same data.

Here, the concept defined by Derous *et al.* (2007) is translated and assessment questions are determined around the selected valuation criteria. These assessment questions, relating the valuation criteria to the different organizational levels of biodiversity, provide a comprehensive framework to determine the values of the subzones, but still allow some creativity by leaving it up to the valuator how to assess these questions.

The most objective valuation protocol sets clear mathematical algorithms for the interpretation of the assessment questions which can be applied to the biological datasets of the study area. Several examples of such algorithms are given below.

This paper aims at developing a generic biological valuation protocol based on the above mentioned valuation criteria. Marine BVMs need to make best use of available datasets, compiling and summarizing the biological and ecological information available for the area, and allocating an overall biological value to the different subzones. A marine BVM is an indispensable tool to make objective and scientifically-sound policy recommendations.

Developing a protocol around the concept of biological valuation

A. Concept of marine biological valuation

The two valuation criteria used in the biological valuation concept developed by Derous *et al.* (2007, in press) are ‘rarity’ and ‘aggregation/fitness consequences’, which are respectively defined as:

> *Rarity: the degree to which an area is characterized by unique, rare or distinct features (landscapes/habitats/communities/species/ecological functions/geomorphological and/or hydrological characteristics) for which no alternatives exist*, and
>
> *Aggregation/fitness consequences: the degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year or a site which most individuals use for some important function in their life history or a site where some structural property or ecological process occurs with exceptionally high density either/or the degree to which a subzone is a site where the activity(ies) undertaken make a vital contribution to the fitness (= increased survival or reproduction) of the population or species present.*

These criteria were selected after a literature review of existing ecological criteria. While taking maximum profit of existing initiatives, Derous *et al.* (2007, in press) developed a concept to integrate the criteria towards a standarized protocol.

As visualised in figure 1, the biological valuation of a study area should be done at two different scales, first at the local (study area) scale and secondly at a broader, (eco)regional scale. This will allow putting the results at the local scale in a broader perspective, i.e. to see whether subzones scoring high at the local scale valuation are still highly valuable at the regional scale (Derous *et al.*, in press).

B. Subdividing the study area in subzones

Before the assessment of the biological and ecological value of a study area can be carried out, a division of the area into subzones (also called eco-units: Zacharias & Howes, 1998) is needed. This division should preferably be ecologically and physically meaningful (Laffoley *et al.*, 2000) and practical, allowing the comparison of the biological value between defined subzones.

Different methods to classify a study area into subzones (i.e. zoning) were proposed in literature: marine biogeographical classifications can be done in several ways and at different scales (i.e. global, regional, provincial and local scale). Ideally, classification schemes that separate a study area into biogeographically similar subzones, that can then be meaningfully compared should be used (Ray, 1984), but ecologically meaningful classifications at smaller scales (e.g. within one biogeographical region) could be suitable as well. Due to the lack of distinct biogeographical boundaries at sea, there are still no generally accepted marine biogeographical classification schemes (Lourie & Vincent, 2004). At a more local scale, a detailed, hierarchical habitat classification scheme has been developed for the benthic environment in the UK, based on a combination of physical habitat data and detailed biological data (Connor *et al.*, 2004), but this classification scheme is only suitable for inshore areas with high data availability. Most marine classification schemes, however, are more broad-scale (regional/provincial), using characteristics of the local abiotic environment such as sediment characteristics, morphological features of the seabed, and water circulation, to subdivide the marine environment (Tunesi & Diviacco, 1993; Rachor & Günther, 2001; Bax & Williams, 2001; Roff *et al.*, 2003; Golding *et al.*, 2004). Ideally, both bottom habitat features and pelagic features should be incorporated into a classification scheme, because biological valuation should be done for both layers within the ecosystem (Roff *et al.*, 2003; Breeze, 2004). Such a broad-scale, physical habitat classification is based on features that are relatively easily mapped and managed, especially in data-poor situations, typical for many marine environments (Bax & Williams, 2001). Since the distribution of marine biota, and especially of macrobenthos, mirrors well the distribution of these features, this kind of division will be biologically meaningful (Rachor & Günther, 2001; Golding *et al.,* 2004). However, small-scaled conservation actions will still need a more detailed classification scheme, like the UK habitat classification scheme (Connor *et al.*, 2004), to be effective.

For the purpose of marine biological valuation a division of the study area in subzones according to a habitat classification seems most appropriate, because biogeographical classifications do not allow fine-scaled valuations and local biotope classifications demand more data to be available. If such habitat classification is impossible due to data unavailability, the study area can be divided into subzones by simply placing a raster on the map of the study area, where each grid cell represents a different subzone. In this case, care should be taken that the size of the grid cells is ecologically meaningful for the ecosystem component under consideration. For highly mobile seabirds for instance it could be advisable to use 3x3 km grid cells, while smaller grid cells of 250x250 m could be more advisable for the less mobile benthos.

C. Available data and reliability of information

Despite extensive lists of ecological criteria on value, as presented in the concept for marine biological valuation (Derous *et al.*, 2007), the majority of such criteria cannot be applied, due either to the lack of available data and/or to the urgent (usually political) need to select valuable areas (Rachor & Günther, 2001). Most efforts for the identification of valuable marine areas are hence initiated at the ecosystem level, with particular emphasis on the structuring physical parameters (e.g. bottom topography, wave exposure, depth, and substrate type), because these are the most easily observed features in marine environments and are usually well documented in large and more often full coverage databases, which does not hold true for biological population or community structures (e.g. indicator species, species diversity, community information, etc.) (Zacharias & Roff, 2001). Before the actual biological valuation of the subzones within a study area can be done, it is however necessary to collect a maximum of biological and ecological data in a database and to assign the data to the different selected subzones. Data can be clustered according to the ecosystem component (e.g. seabirds, epibenthos, phytoplankton,…) they belong to. Marine biological valuation is thus based on an integration of all available data, which is a major advantage of the methodology compared to earlier expert judgement based valuations.

While assessing each subzone, it will become obvious that there is a great deal of information for some parts of the study area and very little or none for others. It is important to recognize the different levels of data availability in interpreting the results for each subzone. Data availability can be expressed in different ways (the number of replicates per subzone, the number of sampling stations or tracks per subzone or the number of observations per subzone), depending on the ecosystem component and the type of data that the measure relates to. Attaching such data availability label to the BVMs can give a first estimate of the reliability of the values of the subzones (Breeze, 2004). Another way of reflecting the reliability of the values, mentioned on the map, is to indicate how many assessment questions (see further) could be answered given the data available for each subzone. The more assessment questions that can be answered for a subzone, the more reliable the value of this subzone will be as the value will be based on a broader variety of data. This kind of reliability is called "reliability of information" here (see table 3 and figure 3). These reliability labels should be consulted simultaneously while using the BVMs. The reliability labels also help to identify knowledge gaps, which could direct scientific research in the future.

BVMs should not be seen as unchangeable, rigid, and fully explanatory maps depicting the relative intrinsic value of subzones. A detailed database, covering all data and information used for the value assessment, should be attached to the maps, and this should be consulted whenever the maps are used to guide advice or when used as a warning system in management decisions. It should be noted that a BVM gives the relative values of different subzones given the available data at that time. This requires that BVMs need to be revised on a regular basis to meet the dynamics of the marine ecosystem (e.g. climate change effects) and whenever new relevant data become available (e.g. on other ecosystem components).

D. Assessment questions

As suggested by Derous *et al.* (2007), as many ecosystem components as possible should be included in the biological valuation of a study area. Although the concept of biodiversity is not treated as a valuation criterion, it still overarches the biological valuation concept by assessing all other selected valuation criteria on all levels of biodiversity (as far as biological data are available for doing this). Zacharias and Roff (2000) visualised the various components of biodiversity in their ‘marine ecological framework’ (going from the species to the ecosystem level and including both biodiversity structures and processes). Their framework was further developed, including more components of structure and process/functions at the different levels. Another level which could be included in this scheme is the genetic level. However, in most of the world’s marine environments, genetic diversity is poorly understood (Attrill *et al.*, 1996; Roberts *et al.*, 2003a, 2003b) and, although being acknowledged to be important, the genetic structures and processes are therefore excluded from this valuation protocol for practical reasons.

By answering a set of possible assessment questions, related to the different structures and processes of biodiversity and coupled to the proposed valuation criteria, all aspects linked to biological and ecological valuation are visualized (see Table 1).

This question-driven approach is similar to that used by Smith and Theberge (1986) to evaluate natural areas according to a set of criteria. Detailed questions about structures and processes of biodiversity can lead to a more objective valuation, because experts could otherwise score a criterion from their own individual perspective and comparison among valuations would be difficult. When applying this framework to a given study area, experts are forced to select the appropriate questions by examining the available data and the presence of certain processes and structures in the area.

Table 1: Assessment questions relating the valuation criteria to the different organizational levels of biodiversity.

Organizational level of biodiversity	Valuation criteria: Rarity	Valuation criteria: Aggregation-Fitness consequences
Species/ population level – structure	- Is the subzone characterised by many **rare species**? - Is the subzone characterized by high abundances of **rare species**? - Are there habitats formed by **keystone species** present in the subzone? - Are there certain **indicator species** or **indicator conditions** present in the subzone? - Is the abundance of an **umbrella species** high in the subzone? - Are there ecologically significant **(keystone) species** with a controlling influence on other species present in the subzone?	- Is a **high percentage of a species population** located within the subzone? - Is the **abundance** of a certain species very high in the subzone (= is there a concentration/ aggregation of the species in the subzone)? - Is the subzone characterised by **high counts of many species**? - Is a **species** (with an otherwise restricted **distribution** within the study area) present in high densities within the subzone? - Is the abundance of **focal species** (as a surrogate for biodiversity in general?) high in the subzone?
Species/ population level – processes	- Is the species **retention** high in the subzone?	- Are there important **migration routes** for certain species located within the subzone? - Are there sites present in the subzone that provide **refuge** during adverse conditions? - Are there **wintering/resting/ feeding sites** located in the subzone? - Are there critical (key) **sites for reproduction (spawning/breeding)** present in the subzone? - Are there critical (key) **sites for recruitment (nursery/rearing)** present in the subzone?
Community level – structure	- Are there **distinctive/unique communities** present in the subzone (with respect to their species richness and abundance)? - Are there **endemic species** present in the subzone? - Are there unique **biomes** present in the subzone? - Is there a high level of ecological **heterogeneity** present in the subzone?	- Is the **species richness** in the subzone high? - Are there species living in **symbiosis** with each other present in the subzone? - Is the total **biomass** high in the subzone?
Community level – processes		- Are there species living in **mutualism** with each other present in the subzone? - Is the natural **productivity** in the subzone high?
Ecosystem level – structure	- Is the subzone characterized by a **complex topography** or **seabed morphology**? - Is the **substrate diversity** in the subzone high? - Is the subzone an outstanding example representing **significant geological processes** in the development of landforms? - Are there **distinctive/unique ecosystems** located in the subzone? - Are there subzones present which are critical for **nutrient cycling**? - Are there any **unique/distinctive oceanographic features** (with respect to temperature, salinity, stratification, anoxia, natural boundaries,…) located in the subzone?	- Are there oceanographic features located in the subzone, which are causing species to aggregate (e.g. **natural refugia**)?
Ecosystem level – processes	- Are there **upwelling** sites located in the subzone? - Are there any **unique/distinctive oceanographic processes** located in the subzone (e.g. unique tidal systems, gyres, entrainment, natural erosion and deposition, other natural disturbance…)?	- Are there oceanographic processes occurring in the subzone, which are causing species to aggregate (e.g. **nutrient retention**, **upwelling**,…)?

E. Mathematical algorithms

When all biological and ecological data of a study area are collected the different subzones of that study area can be valuated by selecting the applicable assessment questions from table

1. By developing specific algorithms for each assessment question the value of the subzones can be quantitatively assessed relatively to each other. Examples of such mathematical algorithms are given for several ecosystem components in Table 2.

Similar algorithms can be defined for the other assessment questions mentioned in table 1. Such algorithms can be developed for different types of data, ranging from presence/absence data to detailed density or biomass data. The more detailed and abundant the available data are, the more assessment questions can be answered, which will increase the reliability of the valuation (see further). But even simple presence/absence data will allow the application of some algorithms, for instance the ones dealing with species richness and rare or ecologically significant species. Also maps, giving information on spawning or nursery areas of certain species, can be incorporated in the protocol, by indicating the overlap of these areas with the selected subzones. Several subzones will be completely covered by the spawning or nursery area, while others will not or only partially be covered. The percentage of coverage can then be used to construct value classes for these assessment questions.

Table 2: Examples of algorithms which can be used to apply the assessment questions to data of different ecosystem components. If there are no data available for a certain subzone within a study area, this subzone is labeled "NA" and is not incorporated when the algorithm is applied.

	Assessment question (criterion)	Algorithm
Seabirds	High counts of many species (A-F)	1. Determine the species which are regularly occurring in your study area (i.e. species occurring in more than 5 % of the subzones). This is done to exclude rare species from the species list. 2. Determine the average density of every regularly occurring seabird species per subzone. 3. Create 5 density classes with values from 1 to 5, based on the range of the densities. 4. Assign values to data for all species and sum the values in every subzone. 5. Divide the resulting summed values again in 5 classes, based on the range of the summed values.
Macrobenthos	Habitats formed by keystone species (R)	1. Select habitat structuring species from species list (e.g. *Lanice conchilega* is a tubeworm occurring on the Belgian Continental Shelf, which is known to build small reefs on the seabed. These reefs give structure to the habitat, which attracts other species). 2. Create 5 density classes for this species with values between 1 and 5, using the density range. 3. If there are several habitat structuring species present in the study area, then create different density classes for each species separately and average the values afterwards.
	Distinctive/ unique communities (R)	1. Determine the different macrobenthic communities in the study area and calculate the average species richness (#sp/m²) and density (ind/m²) for each community (= $SPR(comm_x)_{avg}$, $DENS(comm_x)_{avg}$). 2. Determine the average species richness and density occurring in the whole study area (= SPR_{avg} and $DENS_{avg}$). 3. Calculate the ratios $SPR(comm_x)_{avg}/SPR_{avg}$ and $DENS(comm_x)_{avg}/DENS_{avg}$ for every community. 4. Multiplying the 2 ratios of each community gives unique values which can be divided into 5 value classes based on their range. 5. Assign these values to each subzone according to the community that was characterized in this subzone.
Epibenthos	High species richness (A-F)	1. Determine the epibenthic species richness of each subzone. 2. Create 5 species richness classes with values from 1 to 5, based on the range of the species richness. Assign the corresponding value to the different subzones.
Hyperbenthos	Ecologically significant species (A-F)	1. Select ecologically significant species from species list. Such species could be species which constitute important food sources of certain seabirds (e.g. *Mesopodopsis slabberi* in the coastal zone of the Belgian Continental Shelf) or species which are important for recruitment of fish stocks (e.g. fish larvae on the Belgian Continental Shelf). 2. Create 5 density classes for this species with values from 1 to 5, based on the range of the densities. 3. If there are several ecologically significant species present in the study area, then create different density classes for each species separately and average the values afterwards.
Ecosystem processes	Upwelling sites (R)	1. Determine the percentage coverage of upwelling sites in each subzone. 2. Create 5 coverage classes with values from 1 to 5, based on the range of the coverage. Assign the corresponding value to the different subzones.

F. Scoring

When evaluating subzones with the selected criteria, a scoring system needs to be applied. Due to the inherent complexity of marine ecosystems and unavailability of detailed biological data, quantitative scoring is often impossible and the subzones are weighted qualitatively against each other (Levings & Jamieson, 1999; Breeze, 2004). An alternative is to work with a semi-quantitative scoring system (i.e. ranking subzones in categories of high, medium or low value), a method that could even be used when data are incomplete and expert judgement is used to complete the information (Croom & Crosby, 1998 (cited in Brody, 1998); Levings & Jamieson, 1999; WWF, 2000; Breeze, 2004). One thing that should be noted is that there could be problems with scoring systems if the amount of information for each subzone is not equal, because the ranking scheme may undervalue unique features for which little is known and overvalue features or processes for which a lot of information is available (Breeze, 2004). This bias should be recognised and could be reflected by the reliability labels attached to the BVMs. A semi-quantitative scoring system was also used in the development of the terrestrial BVMs of Belgium (De Blust *et al.*, 1985; 1994). Although the inclusion of expert judgement in a semi-quantitative scoring system makes the valuation process less objective, it could also be the only possible scoring system in marine environments, where full-coverage biological data are lacking. Hockey and Branch (1997) suggested that the scoring system should be kept as flexible as possible so that it can be modified to be more sensitive or emphasize particular objectives if there are substantiated biological reasons for doing so. However, chosing such flexible scoring system would hamper the objectivity of the valuation process.

Other authors have used mathematical selection methods, like SITES and MARXAN to score the criteria for a certain study area (Freitag *et al.*, 1997; Pressey *et al.*, 1996, 1997; Ardron *et al.*, 2002; Gladstone, 2002; McDonnell *et al.*, 2002; Stewart and Possingham, 2002; Beger *et al.*, 2003; Roberts *et al.*, 2003b; Breeze, 2004, Lieberknecht *et al.*, 2004). Because these methods require quantitative biological data for every evaluated subzone, they will not be applicable in every marine environment.

In the proposed scoring system (Table 3), all ecosystem components are first valuated separately by summing the scores for the used assessment questions. The total biological value of the subzones is determined by averaging the values for the different ecosystem components. Each assessment question has an equal weight in the total score. When the values of certain subzones cannot be determined for an ecosystem component (due to a lack of data for these subzones), then the total biological value of these subzones should be determined by only taking into account the values that are available for the other ecosystem components. Five value classes are used in the proposed scoring system (very low, low, medium, high and very high biological value), because these classes allow a better detection of value patterns without losing too many details.

Other scoring systems could be used to determine the total biological value (e.g. addition or multiplication with weighing factors). The scoring approach, used in the terrestrial biological valuation of Belgium, is to label a subzone with 'high' intrinsic value if it scores high on only one criterion (De Blust *et al.,* 1985; 1994). These alternative scoring options are still open for discussion and should be explored in the future.

It seems impossible to set uniform thresholds which would be applicable to all marine ecosystems, so this needs to be done on a case by case basis. When all relevant questions are scored for the different subzones within a study area, all criteria (with respect to all organizational levels of biodiversity) are assessed. This will lead to subzones with different biological and ecological values (e.g. low, medium, high value) and the highly valued subzones can then be considered 'hotspots' that reflect the highest biological value within a study area, considering all possible aspects of biodiversity and habitat diversity. Thus, in our approach 'hotspots' are seen as subzones which have or are perceived to have 'more' intrinsic biological value because of their combinations or greater numbers of biodiversity attributes. This is similar to the hotspot theory of Ray (1999), but extended to the full spectrum of biodiversity attributes. In this way the hotspot approach, based on species richness or rarity, is now coupled to an extended set of other criteria and assessment questions, and the whole framework can be used to assess the intrinsic value of the different subzones within a study area.

Table 3: Example of the proposed scoring system for a hypothetical study area with 6 subzones. The individual scores for every assessment question are also hypothetical and only used to illustrate the scoring process. After each assessment question the criterion it relates to can be found (R=rarity, A-F=aggregation-fitness consequences). When no biological data are available for a certain subzone, this is indicated by NA. The values are given by the following codes (VL=very low, L=low, M=medium, H=high, VH=very high).

		Subzone					
	Assessment question (criterion)	**1**	**2**	**3**	**4**	**5**	**6**
Seabirds	high counts of many species (A-F)	2	5	NA	1	4	1
	high abundance certain species (A-F)	5	4	NA	4	3	2
	high % species population (A-F)	1	4	NA	1	3	1
	high species richness (A-F)	3	4	NA	2	3	2
	Total score (sum)	11	17	NA	8	13	6
	Value for seabirds *(see (*1))*	**M**	**VH**	**NA**	**VL**	**H**	**VL**
Macrobenthos	high counts of many species (A-F)	3	NA	2	NA	4	2
	high abundance certain species (A-F)	2	NA	4	NA	5	3
	presence of rare species (R)	1	NA	5	NA	3	2
	abundance of rare species (R)	2	NA	2	NA	2	2
	habitat formed by keystone species (R)	1	NA	5	NA	3	2
	distinctive/unique communities (R)	2	2	2	1	5	1
	ecologically significant species (R)	2	NA	3	NA	3	2
	high species richness (A-F)	3	NA	4	NA	5	1
	high biomass (A-F)	2	NA	NA	NA	2	NA
	Total score (sum)	18	2	27	1	32	15
	Value for macrobenthos *(see (*1))*	**M**	**VL**	**VH**	**VL**	**VH**	**M**

*(*1) Determination of the value*	**Range of total score (sum)**		**Value classes (numerical)**
	Min	**Max**	
X = (MAX – MIN)/5	MIN	MIN + X	VL (1)
	MIN + X	MIN + 2X	L (2)
	MIN + 2X	MIN + 3X	M (3)
	MIN + 3X	MIN + 4X	H (4)
	MIN + 4X	MAX	VH (5)

	1	**2**	**3**	**4**	**5**	**6**
Value seabirds	M	VH	NA	VL	H	VL
Value macrobenthos	M	VL	VH	VL	VH	M
Average total (numerical) value *(see (*1))*	3	3	5	1	4.5	2
Average total value *(see (*2))*	**M**	**M**	**VH**	**VL**	**VH**	**L**
Data availability for seabirds	H	L	NA	H	H	H
Data availability for macrobenthos	M	L	M	L	H	M
Total #Q answered per subzone (max total #Q = 13)	13	5	8	5	13	12
Reliability of information (in terms of #Q answered) *(see (*3))*	H	L	M	L	H	H

*(*2)Determination of total value (using the numerical equivalents of the intermediate values)*	**Range of average total numerical value**		**Total value**
	Min	**Max**	
	1	1.8	VL
	1.8	2.6	L
	2.6	3.4	M
	3.4	4.2	H
	4.2	5	VH
*(*3) Determination of reliability of information*	**Range of total #Q**		**Reliability level**
	Min	**Max**	
Y = (MAX – MIN)/3	MIN	MIN+Y	L
	MIN+Y	MIN+2Y	M
	MIN+2Y	MAX	H

G. Presentation of BVM

The results of the biological valuation of a study area can now be presented on a map, where each subzone within the area is assigned a colour corresponding with its value. Figure 3 presents a road map for the application of the valuation protocol, which is illustrated here for a hypothetical study area, eventually leading to a BVM for the area. The values given are purely indicative as they are based on the fictive data of Table 3 above. Reliability can be indicated by using different intensities of a colour or other markings.

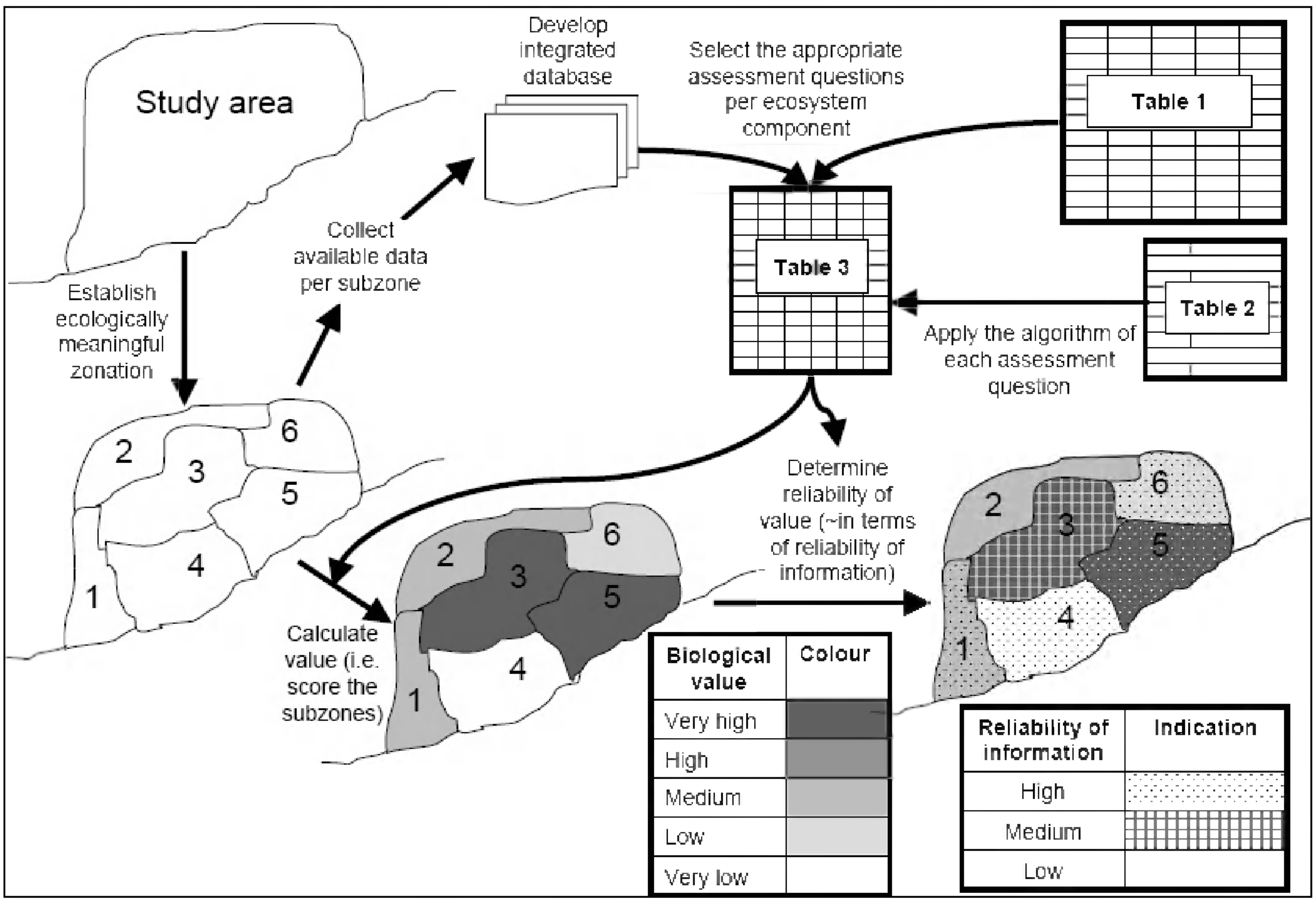

Figure 3: Example of the application of the marine biological valuation protocol to a hypothetical study area with 6 subzones. The values and reliability labels are also hypothetical and only used to illustrate the protocol.

Conclusion: a road map for marine biological valuation

To allow an objective biological valuation of marine areas, generally applicable and transparent guidelines for the practical application of the marine biological valuation concept are needed. After dividing the study area into subzones and collecting the available biological data, the applicable assessment questions should be selected, which relate the valuation criteria to the different organizational levels of biodiversity. To develop a protocol which is as objective as possible, several mathematical algorithms are defined which can be used for the practical application of the assessment questions to an existing biological dataset. This protocol allows assessing the biological value of subzones, relatively to each other, based on the proposed criteria in study areas with various levels of data available.

A major benefit of the proposed marine biological valuation protocol is the fact that all available biological and ecological data are integrated for each subzone, which makes the comparison between subzones easier for the users of the BVMs.

Several scoring systems could be used for this integration and one example is explained in the paper by using fictive values of a hypothetical study area.

The reliability of the assessed intrinsic value should be noted by attaching a label to the different subzones. This label can display the amount and quality of the data used to assess the value of a certain subzone or it can display how many assessment questions could be answered given the data available for each subzone (reliability of information). These reliability labels should be consulted simultaneously while using the BVMs. Next to that, they help to identify knowledge gaps which could direct future scientific research.

The biological valuation protocol, presented here, is developed to be as objective and flexible as possible, which should allow the inclusion of multiple ecosystem components, the use of different levels of data availability and the application to a broad range of marine environments.

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CHAPTER 4

APPLICATION OF THE PROTOCOL FOR MARINE BIOLOGICAL VALUATION TO SELECTED CASE STUDY AREAS

TO BE SUBMITTED FOR PUBLICATION AS:

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Application of the protocol for marine biological valuation to selected case study areas.

To be submitted to Ecological Applications

This research has partially been conducted within the framework of two master theses (Vanden Eede, 2007 and Forero, 2007).

Abstract

Marine biological valuation integrates all biological and ecological information that is available for a study area into a relative biological value. The resulting biological valuation map (BVM) is easy to interpret and translates complex scientific data into a tool that can be used by policy makers as a baseline layer for spatial planning at sea. When such BVM is lacking, managers can only trust on the available best expert judgement to include biological aspects into their decisions, a process which lacks transparency and objectivity. The development of an acceptable and practical valuation protocol can only be established when it is iteratively applied to different test cases.

In this paper, three case study areas are biologically valuated: the Belgian part of the North Sea (BPNS), the Isles of Scilly in the UK (IoS) and the Dutch part of the North Sea (DPNS). The paper specifically explores how the methodology deals with different levels of data availability by comparing highly monitored areas like the BPNS with less data rich areas as the BPNS and the IoS. Two types of valuation maps are constructed for the IoS, one based on quantitative data and one on qualitative presence/absence data, to see whether the quality of the data has any impact on the outcome of the valuation.

The final BVMs indicated clear patterns in biological value, with coastal areas harbouring the highest biological value in all case studies. Low data quality and quantity does not seem to hamper the development of preliminary BVMs, although the reliability of these maps is low. Subzone size selection is a crucial step in the valuation protocol and relevance for the ecosystem components under consideration should always be preferred to practical considerations to obtain better valuation coverage of the area.

Despite some weaknesses of the methodology, the availability of BVMs gives the opportunity to answer policy questions related to the biological value of areas in a transparent, objective way.

Keywords: marine biological valuation, Belgian and Dutch part of the North Sea, Isles of Scilly, data quality and quantity, geographical scale

Introduction

The continuously increasing socio-economic interest in marine resources urges the need for a decision making framework to objectively allocate the different user functions in a marine area. This calls for a spatial structure plan, preferentially firmly based on the concept of sustainability, in which biological value should be carefully taken into account. Hiscock *et al.* (2003) advised that biological information should be presented to marine managers in a format that is reliable and meaningful and that translates complex scientific data into an integrated biological value. When such integrated view on the biological value of a marine area is lacking, decision makers can only rely on the available best expert judgement of scientists, but this approach can be biased due to untransparency and subjectivity. Marine biological valuation is a methodology that has been designed to overcome this problem and to summarize complex biological information in an objective and transparent manner. It can be used as a tool to call attention to areas with particularly high ecological or biological significance. It aims at providing an integrated view on nature's intrinsic value, without any reference to anthropogenic use. By determining whether areas have a high, medium or low intrinsic value, it facilitates the provision of a greater-than-usual degree of risk aversion in management of activities in such areas (Derous *et al.*, 2007).

The development of a suitable valuation protocol should be seen as an iterative process. Applying the protocol to different test cases is necessary to increase its acceptability and practical applicability.

This paper investigates how the developed marine biological valuation method performs in different case study areas. The selected case study areas are the Belgian part of the North Sea (BPNS), the Isles of Scilly (IoS) and the Dutch part of the North Sea (DPNS). These case study areas differ in the amount and quality of the available biological value, in the anthropogenic impacts on the marine environment, in the diversity and nature of the occurring habitats and in geographical scale. The fact that these case study areas are so diverse makes them ideal to test the applicability of the protocol.

Methods

The protocol for marine biological valuation was first tested on data from the BPNS, which served as a pilot area to fine-tune the assessment method. For the comparison of the results of the application of the marine biological valuation protocol in different areas, several different case study areas along the European coast have been selected in the framework Theme 3 of the European MarBEF project (European Network of Excellence on Marine Biodiversity and Ecosystem Functioning). The main objective of Theme 3 is to understand the socio-economic, biological and cultural value of marine biodiversity across Europe. Seven case study areas were selected for this exercise, with good geographical distribution across Europe: Flamborough Head area (NE of UK), Pico-Faial Channel (Azores, Portugal), the Belgian-Dutch coast (Belgium-the Netherlands), the Isles of Scilly (SW of UK), the Lister Deep area (Denmark), the Gulf of Gdansk (Poland) and the Svalbard area (Norway). In this paper the results of the biological valuation exercise of three case study areas will be discussed, being the Isles of Scilly, the BPNS and the DPNS.

A. Case study areas

The BPNS is located in the southernmost part of the North Sea and represents about 0.6 % or 3600 km² of the total North Sea surface area. It is a rather shallow area (maximum depth of 46 m) with a complex system of sandbanks and gullies. Based on their orientation and depth, four sandbank systems can be distinguished: Coastal Banks (parallel to the coastline, 0-7 km from coast), Flemish Banks (SW-NE direction, 10-30 km from coast), Zeeland Banks (parallel to coastline, 15-30 km from coast) and Hinder Banks (SW-NE orientation, 35-60 km from coast) (Degraer *et al.*, 1999; Van Hoey *et al.*, 2004). Strong tidal currents, which run mainly parallel to the coast line, and heavy wave action make it a high energy area resulting in a well-mixed water column and reworking of the sandbank tops. The area receives constant input of fresh water from different rivers (Somme, Canche, Authie, Ijzer, Scheldt, Meuse and Rhine) leading to a gradient from turbid nutrient rich water in the coastal zone to more transparent, nutrient poorer water offshore. The sediment diversity of the BPNS is high due to the complex bathymetry and hydrodynamics, going from very fine silt up to coarse sand. Only few gravel deposits are found in this area (Maes *et al.*, 2005; Van Damme *et al.*, 2007).

The IoS archipelago is situated 43 km south-west of the western extremity of the Cornish peninsula of the UK (Figure 1). The archipelago consists of five inhabited islands (St. Mary's, St. Martin's, St. Agnes, Bryher and Tresco) and over 300 smaller islands, islets and rocks. It comprises the final decayed stage of the Armorican Mountains and is now the sole European example of a Lusitanian semi-oceanic archipelago (UK Biodiversity Steering Group, 1995). The total area delimited is approximately 95 km². The area is predominantly characterised by west to east ocean currents and an almost total lack of freshwater runoff, resulting in uniform salinity, low turbidity and kelp (*Laminaria ochroleuca*) growing to a depth of 30 metres (Harvey, 1969; Kendall *et al.*, 1996). The habitat diversity within the archipelago is high and all habitats occurring in the SW region of the UK are present, except for pure muddy intertidal and subtidal sediments (Marine Nature Conservation Review, 1998). Wave exposure varies from extremely exposed to very sheltered, often within a short distance (Munro & Nunny, 1998). While the BPNS and DPNS are intensively used by man (Anonymous, 2004; Maes *et al.*, 2005; IBN, 2005), impacts from human activities in the IoS are minimal. There is no influence from industrial pollution, mining, dumping or dredging and the presence of potentially harmful agricultural runoff is negligible due to strict legislation in the area. The current population is 2057 and this number remains more or less static. There is a small crayfishery targeting crabs and lobsters with pots, large mesh fixed nets and one small (8 meters) trawler. The use of vessels exceeding 10 tonnes gross tonnage or 11 metres overall length for fisheries from within 6 miles around the IoS is prohibited and strictly enforced (Beaumont *et al.*, 2007).

The DPNS represents 9.5 % of the total North Sea and has a relative smooth bottom topography. Locally relict glacial deposits are present (e.g. large boulders around the Cleaver Bank) (Anonymous, 2004). Depths vary between 20 and 30 m in the south up to maximum 60 m around the Dogger Bank (most northern part of DPNS). The total area of the DPNS is 57000 km². The Southern Bight, which is the southernmost part of the DPNS, is characterized by strong tidal currents, but current velocities decrease towards the northern part of the DPNS. Residual currents generally run in a north-east direction in the Southern Bight, but have no constant pattern in the north, where they are governed by the speed and direction of the wind. While the Southern Bight water column is well mixed throughout the year, stratification of the water column occurs at the Oyster Ground in summer. The Frisian Front is an area with naturally enhanced primary productivity, resulting in an enriched benthic fauna and high fish and bird abundances (Camphuysen & Leopold, 1994; Holtmann *et al.*, 1996; Arts & Berrevoets, 2005). Several mud patches are found in the DPNS of which some have anthropogenic cause (mud patches close to the coast due to input from rivers and from the Wadden Sea and due to dumping of harbour sludge), while others are natural deposits due to low current velocities in the area (mud patch around Oyster Ground) or were deposited during the last glacial period (Lindeboom et al., 2005; IBN, 2005).

Figure 1 gives an overview of the location of the case study areas which are used for this valuation exercise.

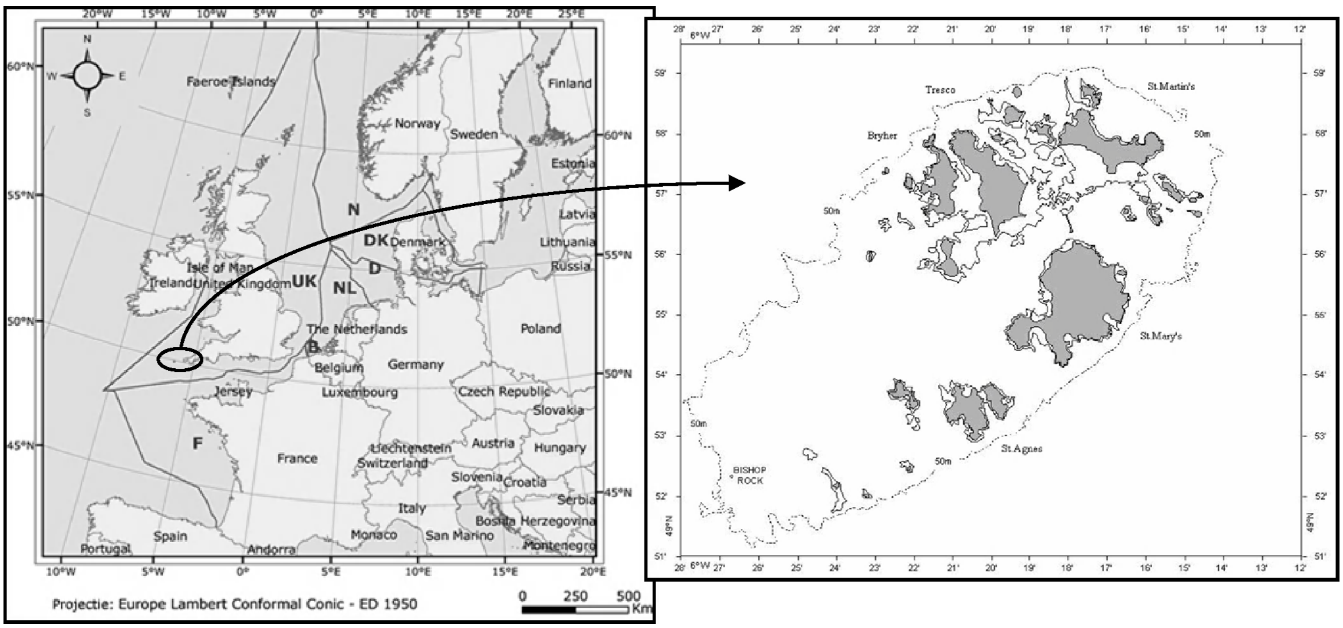

Fig. 1: Map of Europe showing the different case study areas (enlarged area = Isles of Scilly, B: Belgian part of the North Sea, NL: Dutch part of the North Sea).

B. Data availability and data treatment

A marine biological valuation map (BVM) should include and integrate information on all marine ecosystem components for which detailed spatial distribution data are available. For each case study area the amount of available data was investigated and an integrated ACCESS database was made.

The data gathering process revealed that for the BPNS detailed data are primarily available for the macrobenthos and seabirds (macrobenthos: UGent-MACRODAT database; seabirds:

IN database) for which full-coverage maps can be constructed (Table 1). To a lesser extent, but still useful from a valuing perspective, data on the spatial distribution of the demersal fish and the epi- and hyperbenthos exist. For the DPNS detailed data on phytoplankton, zooplankton, macrobenthos, demersal fish, seabirds and sea mammals were available, although the amount of data did not allow the creation of full-coverage BVMs. Data from the Isles of Scilly had to be distilled from literature as no databases existed for this area. This literature search resulted in the compilation of data for algae (both phytoplankton and macroalgae), plants (restricted to *Zostera marina*), macro-, epi-, hyper- and meiobenthos and sea mammals. Next to quantitative abundance data, the largest part of the collected data consisted out of occurrence data (presence/absence). Separate databases were made for abundance data and occurrence data and the benthos species were divided into macro-, epi-, meio- and hyperbenthos groups and into soft or hard substrates habitat groups (Table 1).

Table 1: Available datasets for the biological valuation of the selected case study areas (S: soft substrates, H: hard substrates).

Case study area	Ecosystem component	Available data/literature source	Sampling method	Time period
BPNS	Seabirds	Abundance, species richness	Ship counts	1992-2005
	Macrobenthos	Abundance, species richness, community information	Van Veen grabs	1994-2006
	Epibenthos	Abundance, species richness, biomass	Beamtrawls	1993-2005
	Demersal fish	Abundance, species richness	Beamtrawls	1996-2005
DPNS	Seabirds	Abundance, species richness	Airplane counts	1993-2005
	Macrobenthos	Abundance, species richness, biomass	Reineck boxcores	1991-2005
	Demersal fish	Abudance, species richness, biomass	Beamtrawls	1996-2005
	Phytoplankton	Abundance, species richness	Pump samples	1990-2005
	Zooplankton	Abundance, species richness	Pump samples	2000-2005
	Sea mammals	Abundance, species richness	Airplane counts	1993-2005
IoS	Macrobenthos S Macrobenthos H Epibenthos H Epibenthos S Fish Algae Plants Hyperbenthos Meiobenthos Sea mammals	As some authors give data on several ecosystem components, they are listed alphabetically here: Bishop (1986), Bowden *et al.* (2001), Browne & Vallentin (1904), Dipper (1981a; b), Faubel & Warwick (2005), Foster-Smith (1990), Fowler (1990, 1992), Fowler & Pilley (1991), Hiscock (1984a; b; 1985), Hocking & Tompsett (2002a; b), Holme (1983), Irving (1987), Kendall *et al.* (1996), Munro & Nunny (1998), Norton (1968), Rostron (1983; 1988), Russell (1968), Smith & Gault (1983), Summers (1974).	See literature	See literature

1. Belgian part of the North Sea

Data were provided by the Marine Biology Section of the University of Ghent (macrobenthos), the Research Institute for Nature and Forest (seabirds) and the Institute for Agricultural and Fisheries Research (demersal fish and epibenthos).

During ship-based seabird counts at the BPNS, the standardized strip-transect-method, using 10-minute tracks (Tasker *et al.*, 1984), and the snapshot method (Komdeur *et al.*, 1992) were used to count both swimming and flying birds. In order to compensate for missed small and dark birds, the mean density of swimming birds was corrected with an internationally accepted correction factor (Stone *et al.*, 1995). The results of these counts were transformed into densities by taking into account the speed of the research vessel. All counts were reduced to the spatial midpoints of the concerned 10-minute tracks. Since ferry counts may result in an underestimation of the densities of certain species (e.g. Alcidae and divers), because of the higher speed and the height of the observation platform, the data collected from ferries were not retained in the processed dataset. For the calculation of species per subzone all counts (including counts from ferries) were used. The seabird database of the BPNS consists of a set of midpoints where densities are known. The observer effort of these data is not evenly distributed over the study area which is due to fixed monitoring routes during the last year and to the fact that some sites are too shallow or too far away to fit in a one-day observing schedule. In order to cover the entire Belgian marine area and to resolve the bias in observer effort, a GIS-aided inter- and extrapolation was performed. To account for confounding effects of within-year fluctuations in densities and distribution of seabirds (some species occur the whole year, others only in winter or during breeding season), an *a priori* selection of the months in which a certain species occurs in the highest densities (at least 25 % of value of month with maximal density) was made. This procedure is based on the idea that the occurrence of a species in a certain density in a certain location is a reflection of the suitability of this location at that time. The final dataset was interpolated for each species separately using the Inverse Distance Weighting method of Spatial Analyst package (ArcGis 9.0). Each 500x500 m grid was given the mean density of the 24 midpoints closest to their centre. For further analysis, these grids were converted into grid cells of 3x3 km (by using the Map Calculator option in Spatial Analyst Extension), which matches best with the mean distance covered by the research vessel (2.98 km) during a 10-minutes track.

Contrary to the avifauna data, in which direct observations almost provide full-coverage information for numerous areas of the BPNS, macrobenthos data should be regarded as point data. Degraer *et al.* (2003) demonstrated that –for instance in the geomorphologically highly diverse Belgian coastal zone – even a dense grid of sampling stations (120 sampling stations in 5x5 km grids) did not allow to spatially extrapolate the macrobenthic community distribution patterns. As an alternative to obtain a full coverage spatial distribution map, a predictive model, based on the close link between the macrobenthic communities and their physical habitat (mud content and median grain size), was set up. Once this model was developed and validated, it enables the extrapolation of the spatial distribution of the habitat suitability for the different macrobenthic communities to the full BPNS. The availability of detailed abiotic habitat information allows for small-scale patchiness within the macrobenthos to be detected. The model takes into account four macrobenthic communities occurring in the BPNS: (1) *Macoma balthica* community, (2) *Abra alba-Mysella bidentata* community (or *Abra alba* community (Van Hoey *et al.*, 2005), (3) *Nepthys cirrosa* community and (4) *Ophelia limacina* community (Van Hoey *et al.*, 2004). Each community is restricted to a specific habitat, with median grain size and mud content of the sediment being the major structuring physical variables. The predicted habitat suitability of the communities was used in the valuation of macrobenthos next to point data on densities and species richness.

Epibenthos and demersal fish were sampled twice a year (spring and autumn) with a shrimp trawl, equipped with an 8 m beam trawl, a fine meshed net (22 m) and a boll-chain in the groundrope. The duration of each trawl was 30 minutes with an average speed of 3.5 knots (giving an average distance of 3500 m trawled). Density and biomass were standardized to an area of 1000 m², based on the trawled distance and the width of the beam trawl.

2. Dutch part of the North Sea

Data were provided by the RWS National Institute for Coastal and Marine Management (RWS RIKZ) and the Institute for Marine Research and Ecosystem Studies (IMARES).

The seabird and sea mammal datasets were obtained by an aerial counting methodology, by which individuals are counted from an airplane in a track of 100 meters width at a flight height of 150 meters during one minute. Flights are conducted along fixed routes. One complete count exists out of three flights which allows reaching a good coverage of the DPNS. Each count is conducted 6 times per season. The counts were transformed into densities per square kilometer for every species, using the speed, time and width of the track count (Arts & Berrevoets, 2005).

The demersal fish data consisted out of average density per haul (beam trawl), average weight of individuals per haul and an extrapolation of these data as density and weight per 1000 m² was possible by using the characteristics of each haul (transect).

For macrobenthos, microzooplankton and phytoplankton data were available from fixed monitoring stations, which were recurrently sampled during the year mentioned in Table 1.

3. Isles of Scilly

Both quantitative (abundance) and qualitative (occurrence) data were extracted from the literature and two separate databases were constructed to allow the creation of two types of BVMs. The units of abundance from the different literature sources were transformed to have comparable units in the final database. Macro- and epibenthos were divided into species occurring in soft or hard substrate habitats and these were valuated as separate ecosystem components.

C. Dividing the case study areas

The biological valuation protocol suggests that the division of a marine study area in workable subzones, which can be scored relatively to each other, should preferably be done by using a habitat classification system. The size of the grid cells is then ecologically meaningful for the ecosystem component and the area under consideration. However, such habitat classification cannot be performed in the case study areas due to a lack of available habitat data and an appropriate classification system, the division in subzones is done by placing a GIS (Geographic Information System) raster over the map of the case study area so that each grid cell represents a different subzone. The choice of the size of these grid cells should be ecologically meaningful for the ecosystem components under consideration. It is possible to use different grid cell sizes for different ecosystem components, because GIS allows easy transformation of data to smaller or larger grid cells. However, the boundaries of the chosen grid cells should overlap, to allow overlap between grids with different sizes.

The case study areas BPNS and DPNS are delimited by their legal coordinates (Exclusive Economic Zone – EEZ coordinates). The BPNS was divided into 250x250 m grid cells for the valuation of phyto- and zooplankton, macro- and epibenthos and demersal fish and into 3x3 km grid cells for seabirds. To determine the total biological value, values for seabirds and sea mammals in a 3x3 km grid cell are simply taken over in each of its constituent 250x250 m grid cell. The DPNS was divided into subzones according to data distribution (density and distribution of stations) of the different ecosystem components. The area was divided in grid cells of 15x15 km. For the development of the marine BVM of the IoS a rough GIS map depicting the coast lines of the archipelago has been used. The 50 meter depth line was chosen as the boundary for this case study area. The division of this case study area into subzones was done by choosing grid cells of 250x250m. The different grid size choices in the case study areas were made to see which grid sizes can be advised in the future.

The coordinates of each sampling station were included in the database. When no coordinates were available but a map of the stations was included in the literature source (IoS case study area), a procedure in ArcView was followed to acquire the corresponding coordinates. By doing so, data from the sampling stations could be linked to their corresponding subzone (grid cell). When time series or replicate data for the same station were available, these data were averaged before entering them in the database. Also, data from different stations within the same grid cell were averaged to obtain one value per grid cell. Trawl data covering multiple grid cells were treated so that every grid cell that was passed by the trawl got the density or biomass value of the entire trawl.

D. Marine bioiogicai valuation protocol

The marine biological valuation protocol as described by Derous *et al.* (submitted) was used to valuate the different case study areas. Subzones are scored at a relative scale against two biological valuation criteria: rarity and aggregation/fitness consequences. The biological valuation of a study area should preferably be done at two different scales, first at the local (study area) scale and secondly at a broader (eco)regional scale (Derous *et al.*, in press). Assessment questions relate the available biological data to the valuation criteria and to a specific organizational level of biodiversity (from the genetic to the ecosystem level, considering both structures and processes, as described by Zacharias & Roff (2000)). By developing specific mathematical algorithms for each assessment question, a quantitative assessment of the datasets becomes possible. When evaluating the subzones, a semi-quantitative scoring system is applied, using value categories of very low, low, medium, high and very high value. The scores for all the assessment questions for an ecosystem component are averaged and this average is divided into five value classes. The total biological value is determined by taking the average of the intermediate values for the different ecosystem components. Each assessment question has an equal weight in the total score. When the values of certain subzones cannot be determined for an ecosystem component, due to the lack of data for these subzones, the total biological value should be determined by only taking into account the values that are available for the other ecosystem components. The results of the biological valuation of the case study areas are presented on marine BVMs. Each subzone within the area is assigned a colour corresponding with its value.

The reliability of the assessed intrinsic value should be noted for each BVM. Such label can either display the amount and quality of the data used to assess the criteria in a certain subzone (“data availability” level) or it displays how many assessment questions could be answered given the data available for each subzone (“information reliability” level). These reliability labels should be consulted simultaneous while using the BVMs. Data availability maps are made by analysing the number of samples taken in each subzone for each ecosystem component. The range in number of samples is sorted into three classes (level 1, level 2 and level 3). The data availability map for the total BVM is constructed by averaging the separate data availability scores for each ecosystem component and reclassifying this range into three classes. Information reliability is only determined for the total BVM by classifying the range of answered assessment questions for each subzone into three classes.

E. Comparison with expert judgement

Another, more subjective and untransparent way of determining the biological value of an area is the use of best expert judgement (Derous *et al.*, 2007; submitted). In this approach a panel of experts on the biological characteristics of an area are asked to determine the value of the subzones of an area based on their personal experience or knowledge. Such exercise was performed for the Isles of Scilly case study area. A panel of five biologists and ecologists, each with their own expertise, was consulted and each of them had to determine these values individually. These maps were then plenary discussed to come to a consensus. Comparison of the expert judgement with the BVMs can also assist in increasing the acceptability of the valuation protocol.

Results

Due to differences in the amount and quality of the available data of each of the case study areas, different sets of assessment questions could be answered (Table 2). For each of these questions mathematical algorithms were developed as described in Derous *et al.* (submitted).

Table 2: Overview of the assessment questions that could be answered per ecosystem component (MaB = macrobenthos, EB = epibenthos, HB = hyperbenthos, MeB: Meiobenthos, F = fish, P = plants, PP = phytoplankton, ZP = zooplankton, AL = algae, SB = seabirds, SM = sea mammals) for the different case study areas (BPNS = Belgian part of the North Sea, DPNS = Dutch part of the North Sea, IoS = Isles of Scilly) and according to the data type (S = soft sediments, H = hard sediments, A = abundance data, O = occurrence data).

Assessment question (R: rarity / A-F: aggregation-fitness consequences)	Case study area – Ecosystem component
Number of rare species (R)	BPNS: MaB / DPNS: MaB / IoS: AL (O), HB (A,O), MaB (S/H,O/A), EB (S/H,O/A), F (O)
Abundance of rare species (R)	BPNS: MaB / DPNS: MaB / IoS: HB (A), MaB (S/H,A), EB (S/H,A)
Presence habitat-forming species (R)	IoS: AL (O), MaB (S/H,O), EB (S/H,O)
Abundance habitat-forming species (R)	BPNS: MaB / DPNS: MaB / IoS: MaB (S/H,A), EB (S/H,A)
Presence ecologically significant species (R)	IoS: AL (O), P (O), MeB (O), HB (O), MaB (S/H,O), EB (H,O), F (O), SM (O)
Abundance ecologically significant species (R)	BPNS: MaB, EB / DPNS: MaB / IoS: P (A), HB (A), MaB (S/H,A), EB (H,A), SM (A)
Distinctive/unique communities (R)	BPNS: MaB
Species richness (A-F)	BPNS: MaB, EB, F, SB / DPNS: MaB, F, SB, SM, ZP, FP / IoS: AL (O), P (O/A), MeB (O), HB (O/A), MaB (S/H,O/A), EB (S/H,O/A), F (O), SM (O/A)
High counts many species (A-F)	BPNS: MaB, EB, F, SB / DPNS: MaB, F, SB, SM, ZP, FP / IoS: P (A), MaB (S/H, A), EB (S/H, A), SM (A)
Abundance certain species (A-F)	BPNS: MaB, EB, F, SB / DPNS: MaB, F, SB, SM, ZP, FP / IoS: P (A), MaB (S/H,A), EB (H,A), SM (A)
Mutualism and/or symbiosis (A-F)	IoS: MaB (S,O/A), EB (H,O)
Highly productive (A-F)	BPNS: EB

Some of these assessment questions relate to specific keystone species, which play an important ecological role in the ecosystem (“ecologically significant species”, “habitat-forming species” and “mutualistic or symbiotic species”). The species listed in Table 3 were selected as keystone species for each of the case study areas, based on references from literature.

Table 3: List of keystone species per case study area (MaB = macrobenthos, EB = epibenthos, HB = hyperbenthos, MeB: Meiobenthos, F = fish, P = plants, PP = phytoplankton, ZP = zooplankton, AL = algae, SM = sea mammals, BPNS = Belgian part of the North Sea, DPNS = Dutch part of the North Sea, IoS = Isles of Scilly).

	Ecologically significant species			
	MaB	**EB**	**AL**	**P**
BPNS	*Abra alba* *Spisula subtruncata*	*Crangon crangon*		
DPNS	*Abra alba* *Spisula subtruncata*			
IoS	*Abra alba* *Arenicola sp.* *Atelecyclus rotundatus* *Echinocardium sp.* *Odostomia sp.* *Polinices pulchellus* *Spatangus purpureus*	*Alcyonium digitatum* *Alcyonium glomeratum* *Alcyonium sp.* *Asterias rubens* *Asterina gibbosa* *Astropecten irregularis* *Crossaster papposus* *Echinus esculentus* *Henricia oculata* *Hinia incrassata* *Marthasterias glacialis* *Monodonta lineata* *Psammechinus miliaris*	*Ascophyllum nodosum* *Fucus serratus* *Fucus spiralis* *Fucus vesiculosus* *Pelvetia canaliculata*	*Zostera marina*
	MeB	**HB**	**F**	**SM**
IoS	*Haplogonaria simplex* *Pseudaphanastoma psammophilum* *Simplicomorpha gigantorhabditis*	*Astrorhiza limicola* *Halyphysema tumanowiczii* *Hippolyte varians* *Palaemon serratus* *Pandalus propinquus*	*Ctenolabrus rupestris* *Labrus bergylta* *Labrus bimaculatus* *Pollachius pollachius* *Pomatoschistus sp.* *Scyliorhinus canicula*	*Delphinus delphis* *Halichoerus grypus*
	Habitat-forming species			
	MaB	**EB**	**AL**	**P**
BPNS	*Lanice conchilega*			
DPNS	*Lanice conchilega*			
IoS	*Amphithoe sp.* *Chaetopterus variopedatus* *Janua pagenstecheri* *Lanice conchilega* *Owenia fusiformis* *Pomatoceros triqueter* *Pygospio elegans* *Sabella pavonina* *Sabellaria spinulosa* *Tubulanus annulatus*	*Balanophyllia regia* *Distomus variolosus* *Leptopsammia pruvoti* *Membranipora membranacea* *Modiolus modiolus* *Umbonula littoralis*	*Laminaria sp.*	*Zostera marina*
	Symbiotic species			
	MaB	**EB**		
IoS	*Megatrema anglicum*	*Adamsia carciniopados* *Megatrema anglicum*		

The selection of keystone species appeared to be a rather difficult process, as subjectivity cannot always be excluded. Some species, selected as keystone species for the IoS, were not selected for the BPNS or DPNS as no literature sources could be found to base the selection on. However, it seems logical that these species will play a similar role in the ecosystem of the BPNS or DPNS as they do in the IoS. As the literature on the ecological function of marine species is still very fragmentary, the selection of keystone species should be regarded as a preliminary assessment.

A. Biological valuation of the Belgian part of the North Sea

The BVM shows that the most valuable areas can be found in the coastal area of the BPNS (Figure 2), with high to very high values found for the entire coastal strip, stretching out to the Oostende sandbank in the west and to the Akkaert bank in the east. High values are also found in the area around the Thornton Bank and in the area south of the Hinder Banks. The offshore area of the BPNS is almost always characterized by a low biological value. For most areas the reliability of the valuation is rather low (Figure 3). The most reliable valuations are situated in the coastal area and in the eastern part of the BPNS.

The valuation maps for each of the ecosystem components clearly indicate the high ornithological value of the coastal zone (Appendix 1), which coincidences with results from earlier analyses (Seys *et al.*, 1999; Seys, 2001; Stienen & Kuijken, 2003; Haelters *et al.*, 2004). The valuation map for seabirds, however, throws a new light on the value of more offshore sites. Where previous studies failed to identify these sites as particularly important for seabirds, the valuation method clearly pinpoints the high value of the Thorntonbank, the waters north of the Vlakte van de Raan and parts of the Hinder Banks. The highest biological value for macrobenthos is found in the coastal zone, especially near shore in the western coastal area and diverging to the Akkaert bank in the eastern coastal area. This pattern, and especially the high value in the western coastal zone, could be expected following the results of Degraer *et al.* (2002, 2003). Other valuable areas for macrobenthos are the gully above the Thorntonbank and an area between the Flemish and the Hinder Banks. The lowest values are found offshore and in the coastal area around the harbour of Zeebrugge and the mouth of the Westerschelde. The valuation map for epibenthos shows a high value of the coastal zone. The Flemish and Zeeland Banks have an intermediate to high value, whereas the offshore areas have a low to very low biological value based on epibenthos data. The demersal fish valuation map does not indicate real hot spots of high value, but rather shows an evenly distribution of different values.

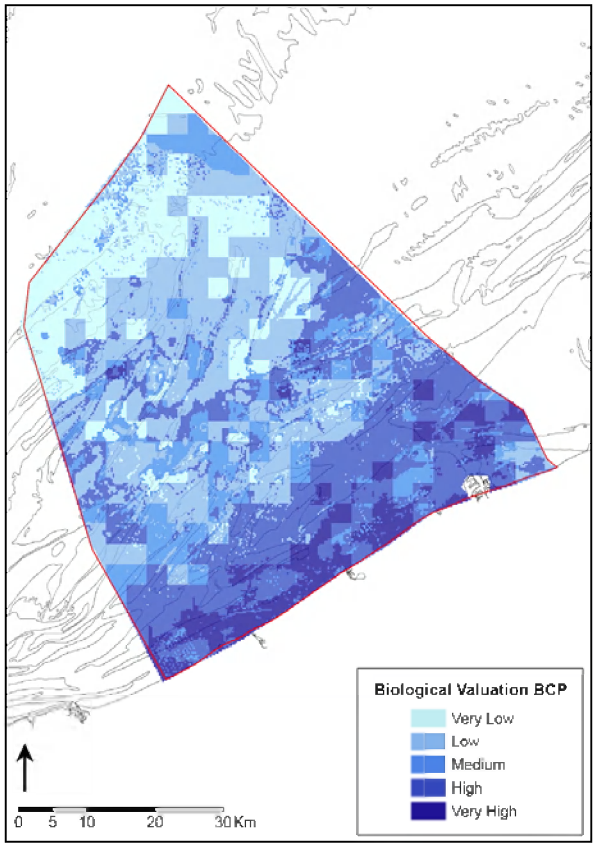

Fig 2: The marine biological valuation map of the BPNS which integrates the seabird, macrobenthos, epibenthos en demersal fish valuation maps.

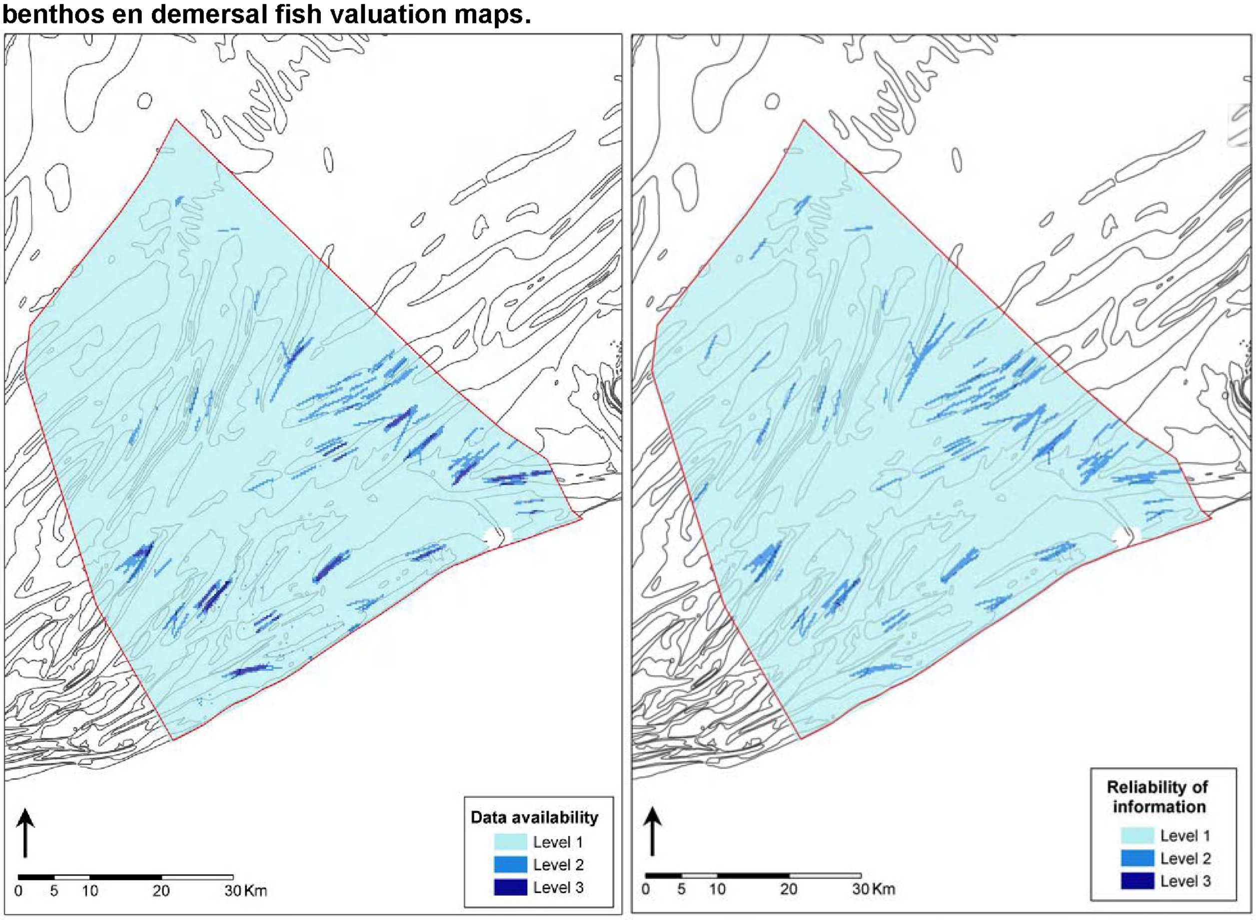

Fig 3: Data availability and information reliability of the total biological valuation map of the BPNS.

B. Biological valuation of the Isles of Scilly

Since two types of data (quantitative and qualitative data) are available for the Isles of Scilly, two separate BVMs are constructed (Figures 4 and 6). The covered area of the integrated BVMs seems restricted to the coastal region of the Isles of Scilly, which coincides with the areas where the valuation seems to be most reliable (Figures 5 and 7). Especially the open sea region in the west of the study area is very poorly sampled and surveyed. When both integrated BVMs are compared, it is noticed that the BVM based on occurrence data allows for more subzones to be valuated than the one based on quantitative data. This is due to the higher availability of occurrence data for the area. No subzones are assessed as having a very low or low biological value on both BVMs. The trends in the values of both maps are similar, with the highest biological values found south of St. Martin's, along the eastern shores of St. Mary's, in the channel between the two islands of St. Agnes and around Tresco.

The valuation maps for each ecosystem component show similar trends as the total BVMs although several additional hotspots for some ecosystem components can be detected (Appendices 2 and 3). The subzones south of St. Agnes are highly valuable for algae, while the zone between Bryher and St. Agnes seems to be important for both macrobenthos and epibenthos (soft substrates). The eastern part of the IoS show high values for epibenthos (hard substrates), while the southern part of the study area holds high values for fish. Several hotspots for macrobenthos occurring on hard substrates can be found around the smaller islands and rocks in the area.

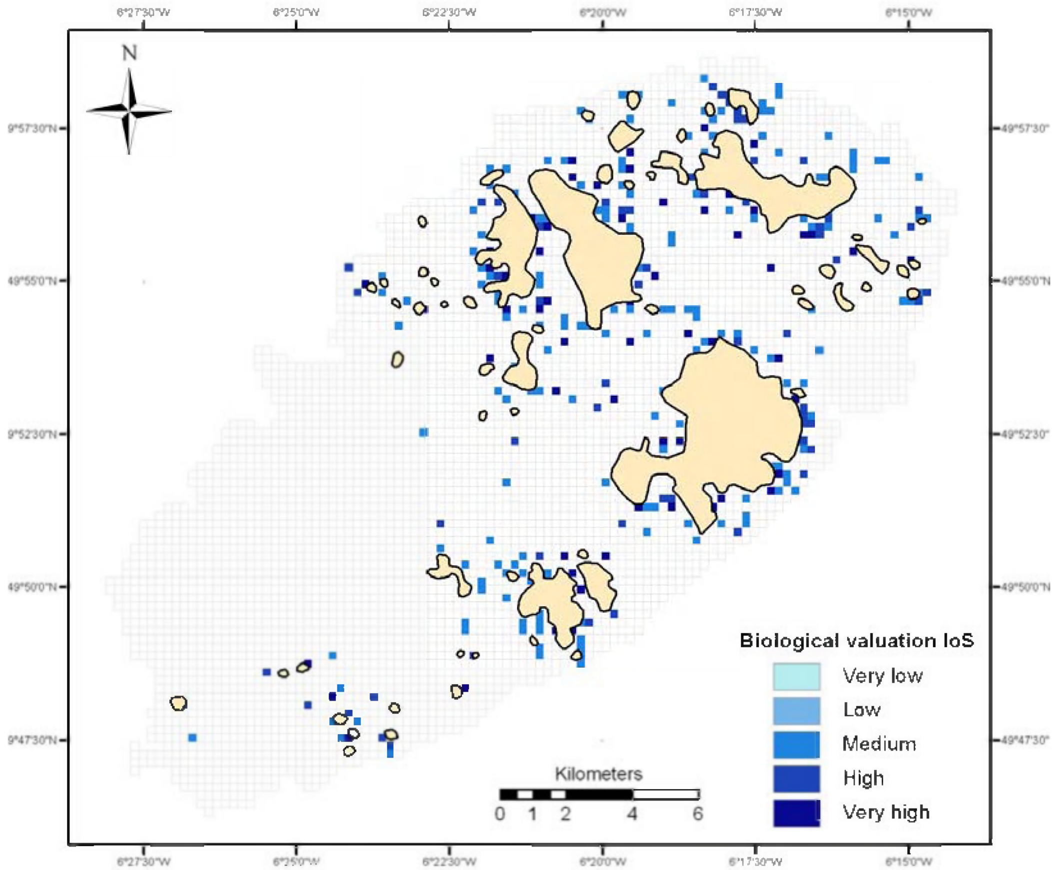

Fig 4: The marine biological valuation map of the Isles of Scilly integrating all occurrence data.

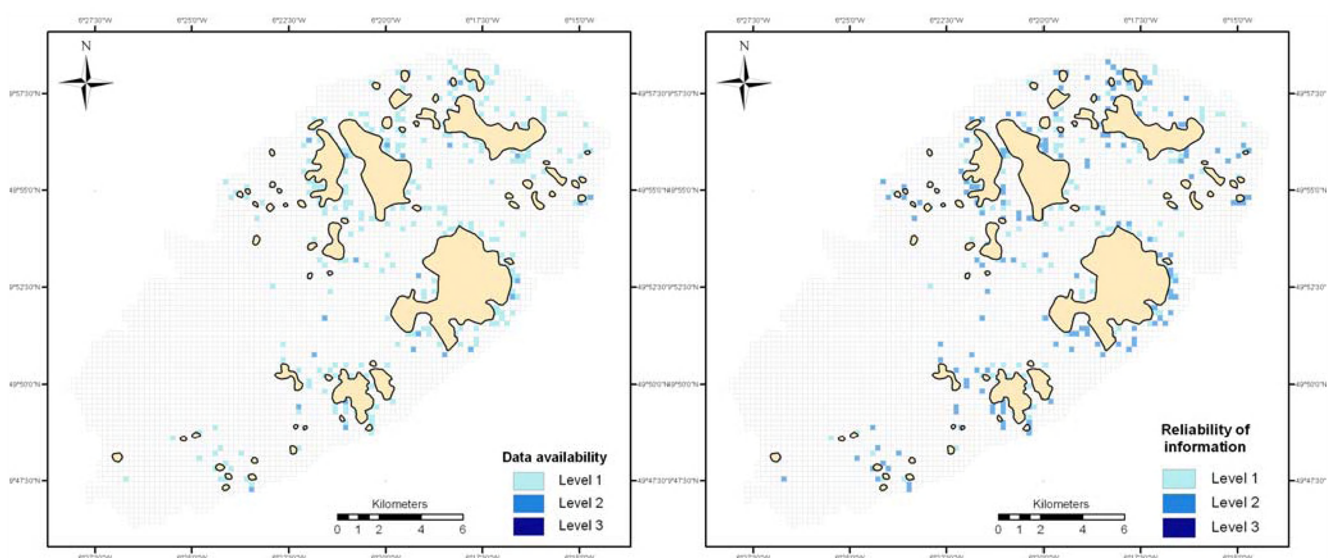

Fig 5: Data availability (left) and information reliability (right) of the total biological valuation map based on occurrence data of the Isles of Scilly.

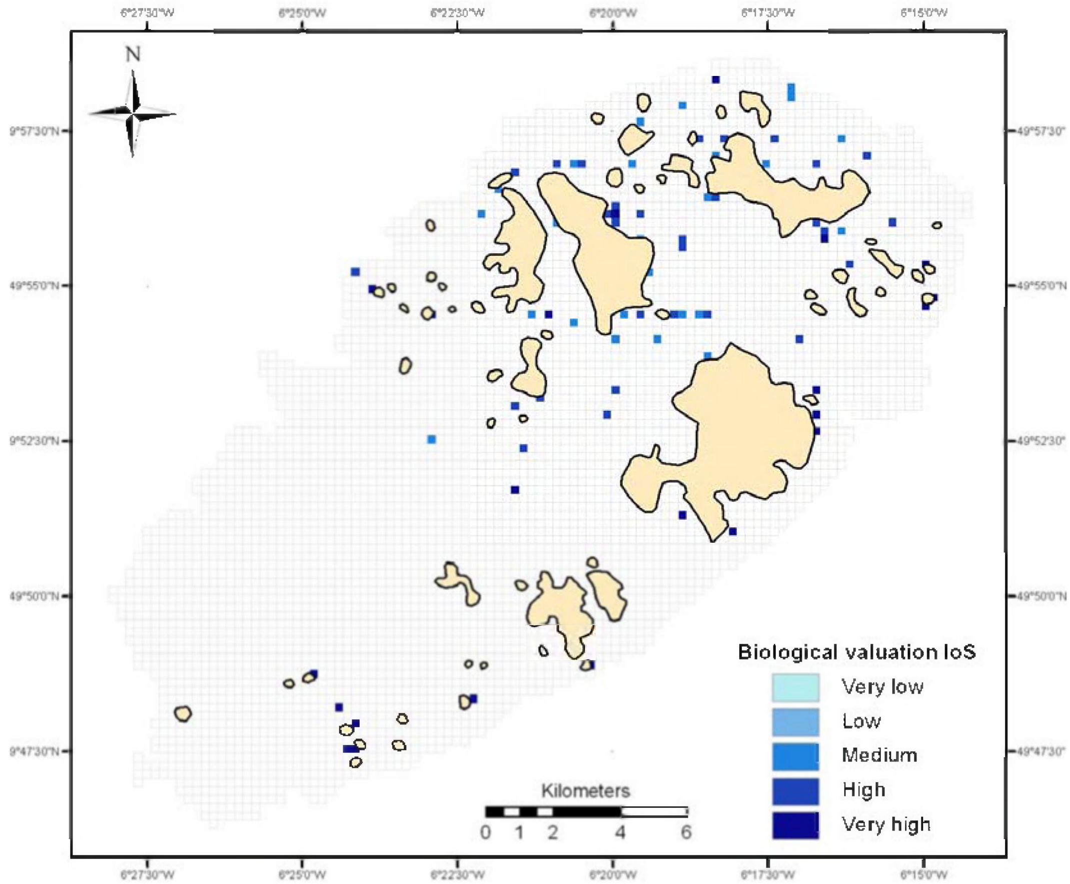

Fig 6: The marine biological valuation map of the Isles of Scilly integrating all quantitative data.

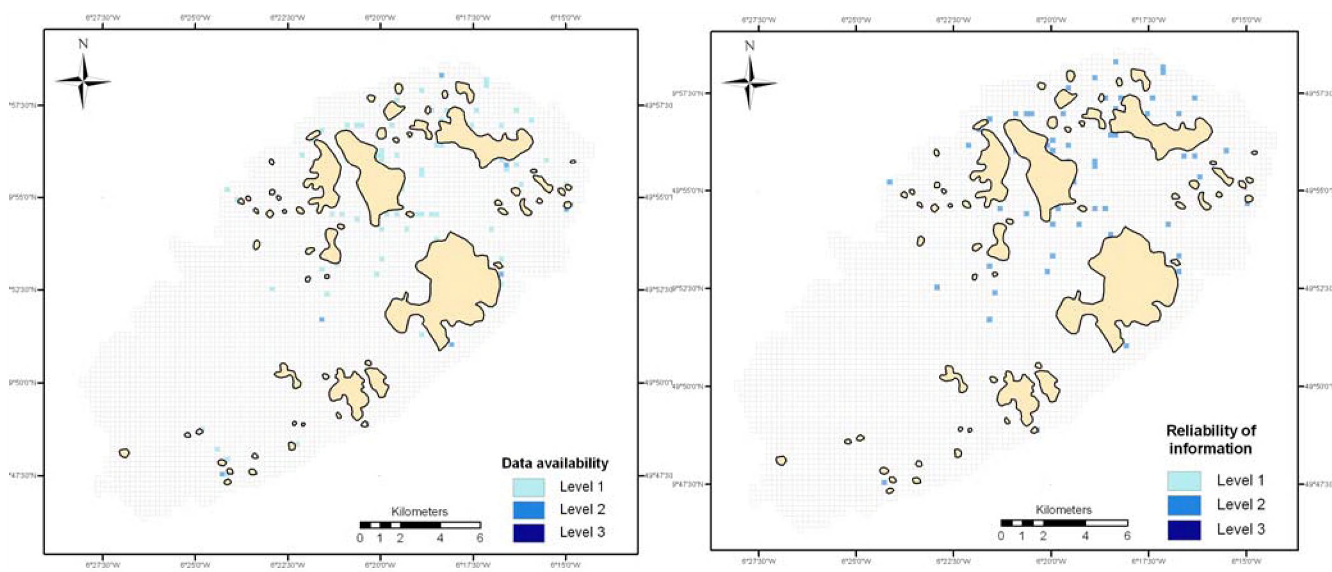

Fig 7: Data availability (left) and information reliability (right) of the total biological valuation map based on quantitative data of the Isles of Scilly.

The total BVMs were compared to the map constructed after consulting a panel of experts on the biological features of the Isles of Scilly (Table 4). The consensus of the experts was a map selecting the subzones around Darrity's Hole, Bishop Rock, St. Agnes and the area south of St. Martin's as having the highest biological value. Other areas with assumed high value were the channel between Tresco and Bryher and the area east of St. Mary's.

Table 4: Agreement between expert judgement and marine biological valuation of the IoS (NA = no data available to determine value). Highlighted values are values which agree according to both expert judgement and valuation methodology.

	Expert judgement	Marine biological valuation (quantitative)	Marine biological valuation (qualitative)
North of St. Martins	Medium	High	Medium to high
East of St. Martins	High	High	Medium
South of St. Martins	Medium	High to very high	Medium to very high
West of St. Martins	High	Medium	High
North of St. Marys	Medium	Medium	Medium to high
East of St. Marys	High	Very high	High
South of St. Marys	High	Very high	Medium to very high
West of St. Marys	Low	NA	Medium
North of St. Agnes	Medium	NA	Medium
East of St. Agnes	Medium	NA	Very high
South of St. Agnes	High	NA	Medium
West of St. Agnes	High	NA	Medium
North of Tresco	High	Medium to high	Medium to very high
East of Tresco	Medium	High	High
South of Tresco	Low	Medium	Medium
West of Tresco (= channel between Tresco and Bryher)	High	Very high	High to very high
North of Bryher	High	High	Medium
South of Bryher	Medium	Medium	Medium to very high
West of Bryher	Medium	Medium	Medium to high
Darrity's Hole	High	High	High
Bishop Rock	High	NA	Medium
Southern part of IoS	Low	Very high	Medium to high
Eastern part of IoS	Low	Very high	High
Western part of IoS	Low	NA	NA

The experts based their valuation mainly on their knowledge of the presence of special habitats (e.g. seagrass beds, rock pools, exposed shores) or specific species (e.g. seals) in a certain location, without performing any data analyses. It should be noted that the experts were asked to express their value estimate by using only three value classes (rather than five, as is done in the valuation of the IoS). The subzones indicated by the experts to have a high biological value largely overlapped the ones depicted as having a (very) high value on the BVMs, although most areas indicated by the experts were larger. This is due to the restriction of samples to the inshore areas, which are easily accessable to take samples. No samples are available for a lot of subzones further from the coasts, disabling the determination of their biological value. However, where data are available for these offshore areas, the biological value seems to be higher than expected by the experts.

C. Biological valuation of the Dutch part of the North Sea

The total BVM of the DPNS shows that, due to the choice of large grid cells (15x15 km) a good coverage of the DPNS (74% of the grid cells valuated) was achieved (Figure 8). Highest values are found in the coastal area but also subzones more offshore (e.g. around Frisian Front, northern part of DPNS) were assessed as having a high biological value, based on the six ecosystem components under consideration. It should be stressed that very little were available for the Wadden Sea and its biological value can therefore not be evaluated based on the BVM. From the data availability map (Figure 9) it can be seen that the high coastal values coincide with the areas for which most data are available, rendering the valuation of this zone as reliable.

The valuation maps for each ecosystem component indicate that the DPNS seems to share its high ornithological value of the coastal zone with the Belgian case study area, although results could be biased by the higher data availability for this zone (Appendix 4 and Figure 9). Due to time restrictions, no spatial extrapolation of seabird data, as was done for the BPNS, was performed to reduce the observer bias towards the coastal area. The largest part of the DPNS seems to have medium to high value for fish, with the exception of the offshore area. The highest macrobenthic values are found in the central and northern part of the study area, which contrast with the results for sea mammals where high values are mainly found in the coastal area around the Wadden Sea. Data for microzooplankton and phytoplankton are too scarce to be able to show trends in their valuation.

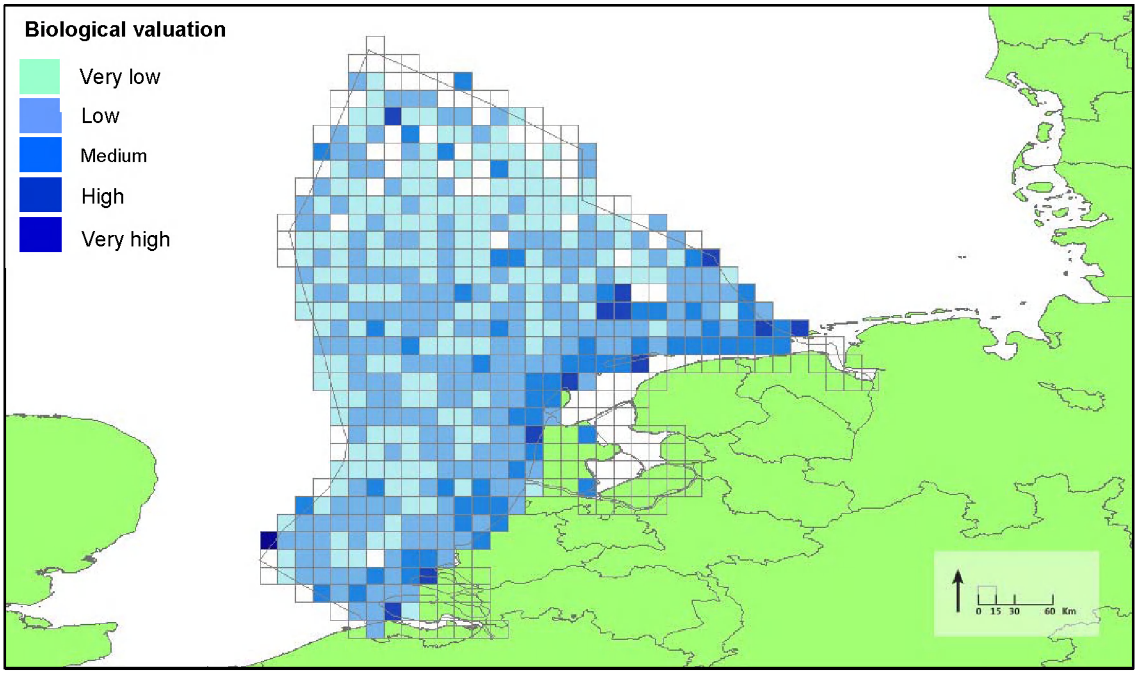

Fig 8: The marine biological valuation map of the DPNS.

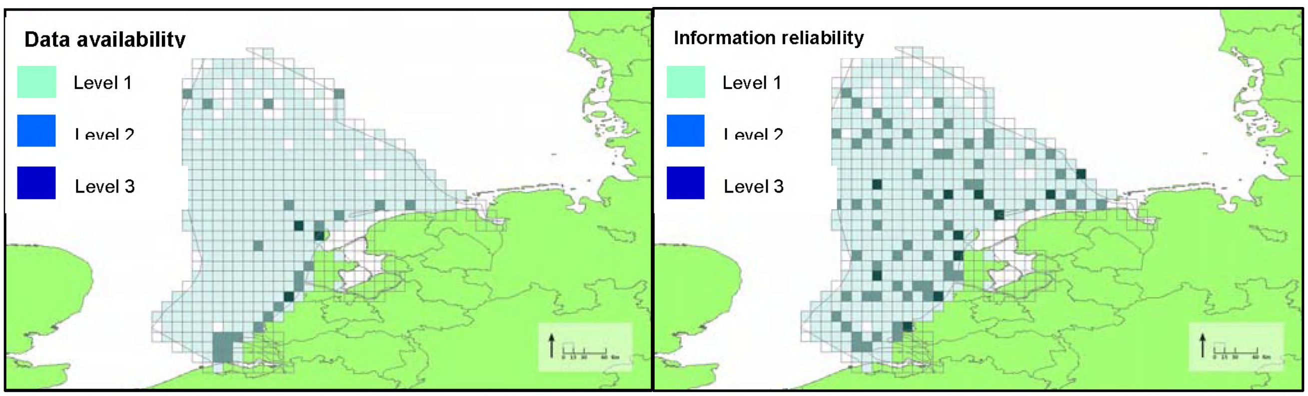

Fig 9: Data availability (left) and information reliability (right) of the total biological valuation map of the DPNS.

Discussion

A. Comparison with previous studies

The BPNS is, despite its relatively small surface area, a highly important area for seabirds, not only for wintering birds but also for migrants and breeding birds (e.g. Seys *et al*., 1999; Seys, 2001; Stienen & Kuijken, 2003). Being a bottleneck area for seabirds migrating from the northern breeding areas to the southern wintering areas, more than 5 % of the biogeographical population of 12 species migrates through the southern part of the North Sea (Seys, 2001, Stienen & Kuijken, 2003; Stienen *et al*., 2007). Also, the BPNS functions as a major feeding area for the internationally important tern colonies in the harbour of Zeebrugge (Alvarez, 2005; Stienen *et al.*, 2005). The importance of the BPNS for birds was acknowledged by the designation of three Marine Protected Areas under the Birds Directive in 2005 (Dienst Continentaal Plat, 2005). The delineation of these areas was based on a selection of species, listed in Annex I of the Bird Directive and occurring frequently and with high densities (Sandwich Tern, Common Tern and Little Tern) or having more than 1 % of their biogeographical population situated in the BPNS between 1992 and 2002 (Great-Crested Grebe, Little Gull, Common Scoter and Great Skua) (Haelters *et al.*, 2004). Although the study of Haelters *et al.* (2004) was very important in terms of conservation of threatened species, unlike this study it did not aim to valuate the broader ornithological importance of the BPNS. The valuation exercise of the BPNS also takes into account non-threatened and more widely distributed seabird species. The final valuation map of seabirds gives a good view of the relative ornithological importance of the different subzones of the BPNS.

Results from the DPNS valuation were compared to an earlier biological analysis by Lindeboom *et al.* (2005), who identified five zones of high ecological importance being (1) the Dogger Bank, (2) the Cleaverbank, (3), the central Oyster Grounds, (4) the Frisian Front and (5) the Coastal Sea (Figure 10). Two sites in the Coastal Sea zone (Voordelta and coastal sea north of Petten) are also designated as Special Conservation Areas under the Bird Directive and proposed as Habitat Directive areas due to their importance for benthos, birds, fish and sea mammals (Camphuysen *et al.*, 1994; Arts & Berrevoets, 2005; Lindeboom *et al.*, 2005; IBN, 2005). Several of these areas (or parts of these areas) coincide with high value subzones from this exercise (e.g. coastal subzones, parts of the Dogger bank area in the north and the central Oyster Grounds). It is striking that the Frisian Front does not harbour a lot of high valued grids, both on the total BVM (Figure 8) and the birds BVM (Appendix 4b). This is in contrast to the results of Camphuysen *et al.* (1994), who described the high significance of this area for seabirds (e.g. thousands of Common Guillemots use this area to moult). Because the valuation of the DPNS was done by a scientist without a background on this area and its specifications, these particular aspects were neglected (could be addressed by additional assessment questions dealing with ‘aggregation-fitness consequences’) and the ecological importance of the Frisian Front is not reflected by the valuation. The importance of the Dogger Bank, Oyster Grounds, Frisian Front and Cleaverbank for macrobenthos (Lavaleye, 2000; Lindeboom *et al.*, 2005) seems to be reflected relatively well by the valuation results (Appendix 4a).

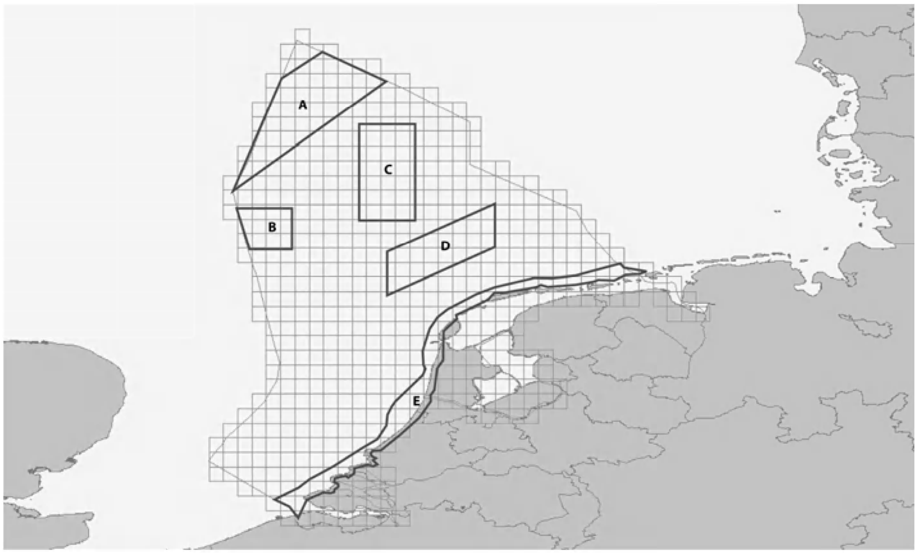

Fig. 10: Areas with high ecological importance as reproduced from Lindeboom et al. (2005). (A) Dogger Bank, (B) Cleaverbank, (C) Central Oyster Grounds, (D) Frisian Front, (E) Coastal Sea.

For the IoS archipelago, different clusters of high to very high value could be determined and these all overlap with areas which are being protected under different national and international designations (e.g. Area of Outstanding Natural Beauty, Heritage Coast, Ramsar sites, Bird and Habitat areas,…) (IoS-AONB, 2007; JNCC, 2007). This is not surprisingly as almost the entire coastal region of the IoS, where most biological data were available, is being protected by one or more designations. The results from the valuation exercise also agreed well with the results from the expert judgement. But the BVM is objectively developed by applying the valuation protocol, while the maps provided by experts will always include some subjectivity as they are based on the knowledge of scientists of specific features or species in the area, while neglecting information on other biological aspects. It should also be noted that the IoS BVMs for plants, hyperbenthos and sea mammals show a very high biological value for most of the grid cells and this is due to the fact that the amount of species under consideration is very low. For plants there is only one species being considered, namely *Zostera marina*. For hyperbenthos (only five species) and sea mammals (only two species) a similar output can be seen. These maps can be regarded as distribution maps of the corresponding ecosystem component and should be considered carefully for valuation purposes.

B. Weaknesses and threats of the developed valuation protocol

It has to be emphasized that the BVM for macrobenthos of the BPNS is strongly biased by the output of the assessment question on ‘distinctive communities’, which was answered with the use of a predictive model, as this is the only question which could be answered for most of the grid cells. Where the macrobenthic value of a grid cell is based on more than one question, this value will be more reliable as this value integrates both predicted community information and information from samples. Another important consideration concerning the model results, is the fact that each grid cell was assigned a certain (community) habitat suitability based on the probability which was highest for this grid cell. When the probabilities for different communities differed only slightly (e.g. 0% for community 1 - 30% for community 2 - 34% for community 3 - 36% for community 4), then the grid is assigned to the community with the 36% probability, which is rather artificial and could be a wrong interpretation of the information since three communities could occur in such habitat.

The data availability maps of the BPNS and DPNS show that, in contrast to seabirds and sea mammals, data availability for macro- and epibenthos, phyto- and zooplankton and demersal fish was mostly restricted to certain areas. This is due to the fact that sampling the latter ecosystem components is more time consuming than counting seabirds or sea mammals, which can be done by observations. Despite the large databases which are already available for macro- and epibenthos and demersal fish, they can not be extrapolated to create full-coverage valuation yet, although this was done for the habitat suitability of the macrobenthic communities of the BPNS through the use of predictive modelling. When the BVMs of the DPNS are considered, it can be recommended that in this case extrapolation of the data for seabirds should have been possible, given the good distribution of the observations. Next to that, it could be advisable to exclude the plankton data from the valuation analysis since very little data are available for plankton. Including such insufficient information could lead to bias in the development of the reliability maps.

When the case study area of the IoS is investigated, where no ready-to-use data archive was available, it should be noted that it was impossible to integrate all existing biological data in this valuation assessment due to time restrictions and the maps described above should therefore be seen as preliminary maps based on a fraction of the existing data. It should also be noted that the data abstracted from literature are sometimes very old, which seriously decreases the reliability of the outcome as marine areas are dynamic systems where changes in biological communities can happen very fast. This is certainly true for the exposed coast of the archipelago.

The use of these BVMs could be misleading, as managers should always keep in mind that the maps show the biological values of the subzones relatively to each other. No comparison between the map of the IoS can be made with the map of the BPNS or DPNS because their subzones were not compared to each other. The fact that no grid cells with low or very low value appear in the IoS archipelago does not necessarily mean that this is an area of special biological value. To investigate this further the IoS should be valuated at a broader geographical scale, for instance the entire UK coastline, to know its relative value at a more regional scale.

It was not possible to exclude some subjectivity from the protocol as it stands now, as some assessment questions are still difficult to assess due to the lack of appropriate data or information sources. This was particularly the case for the selection of keystone species (habitat-forming species or other ecologically significant species). The literature on the ecological functions of most marine species is still fragmentary, so the choice of keystone species for the case study areas should also be seen as a first step towards more objective selections once the literature on this subject has grown.

The scoring method which was used for the valuation of the case study areas is only one of the possible scoring systems. Here, the value is based on the range of values for a certain parameter (species richness, density…). Five value classes are determined based on this range. The total value is the average of the individual values for the different ecosystem components. One could easily suggest other scoring or integrating methods, for instance that subzones automatically get a (very) high value when they scored (very) high for one of the ecosystem components. This could increase the values of the obtained BVMs. As can be seen, by chosing another scoring system, other BVMs could be produced. Again, this could introduce subjectivity in the protocol as scientists could apply different scoring systems to the data and chose the one that best suits their personal hypotheses. More strict rules concerning the scoring system to be used are therefore necessary. In the future, these alternative scoring systems should be tested on other case study areas to see which one is best suited for the valuation protocol.

C. Opportunities and lessons learned for the future

Due to different sampling methodologies used in the IoS, two BVMs were created, one based on quantitative data and one on qualitative (occurrence) data. Since all ecosystem components can be easily surveyed by recording their presence or absence, the map based on occurrence data would seem like a more likely candidate for the outcome of a worldwide applicable marine biological valuation method. However, a BVM should not only indicate whether some species is there or not, but indications on its number of individuals present adds a lot of valuable information (e.g. aggregation of species) to such maps. It could be possible that some rare species was only counted once at five different subzones in the entire archipelago, but information on the fact that it appeared 4 times with a high density and one time with only one individual gives more details on this species and will give a more diverse picture on these subzones. So, although BVMs based on quantitative abundance data require more time-consuming sampling campaigns and data treatment, their outcome will be more reliable and give a better representation of the intrinsic value of the subzones within the study area. However, the methodology seems to be flexible enough to make BVMs based on occurrence data and such preliminary maps can be used while more quantitative data are being gathered.

Since BVMs provide the relative values of different subzones given the available data at that time, managers should keep in mind that BVMs will need to be revised on a regular basis to meet the dynamics of the marine ecosystem and whenever new relevant data become available. The inclusion of new data will not only make the BVM more reliable but can also increase the coverage on the maps, which allows a better relative comparison between subzones.

The choice of the grid cell size is very important and should always be ecologically relevant for the ecosystem component under consideration. Smaller grid sizes (e.g. 250x250 m) should be chosen for benthic ecosystem components which are relatively immobile, while such small grid sizes are not appropriate for the valuation of highly mobile groups like seabirds or sea mammals, as was shown for the IoS case study. Grid sizes should also not be too small, to allow for good coverage of the study area, while too large grid cells could result in the loss of site-specific information, which is most relevant to marine decision makers and managers. The implications of the geographical scale of a study area can be seen when the BVMs of the BPNS and DPNS are compared. For the DPNS, which is a substantially larger area than the BPNS, a grid cell size of 15x15 km was chosen. Although this did allow having better coverage, it is questionable whether sampling data for macrobenthos or phytoplankton can be extrapolated to such large grid cells. It is therefore recommended not to use such large grid sizes for sessile ecosystem components in the future. The resolution of the BVM for the BPNS is much higher, allowing for more detailed valuation information for a specific location. Despite these different grid sizes, the overall trend of higher biological value in the coastal zone is visible on both maps.

The choice of the grid sizes can also lead to conflicts in the biological valuation of neighbouring areas. This is illustrated in Figure 11, where the BVMs of the BPNS and DPNS are plotted next to each other. An integrated valuation of both areas, or an increase in the similarity of grid cell sizes, would be a usefull exercise to indicate more realistic biological values near the shared border of both areas.

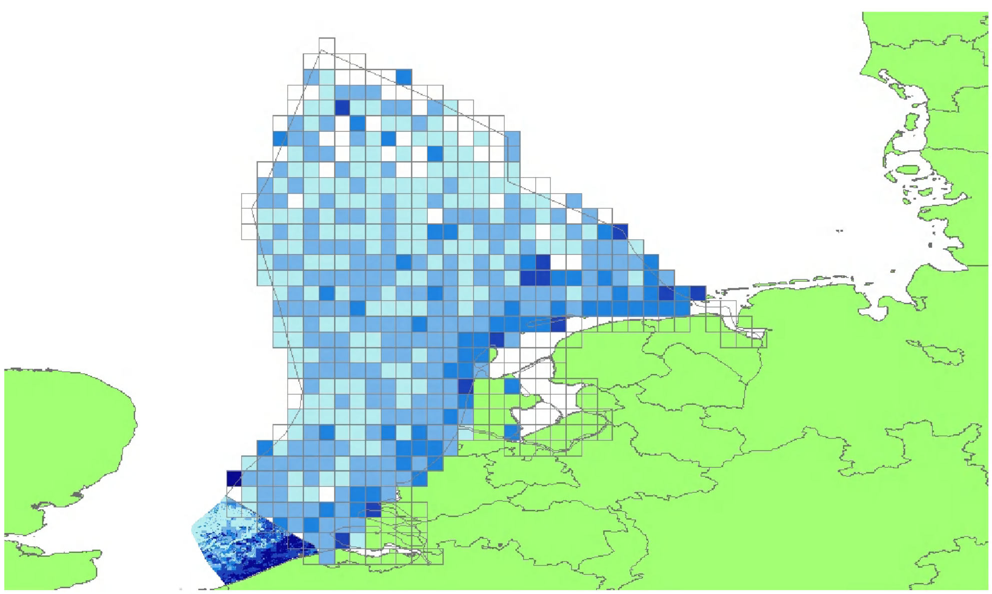

Fig. 11: BVMs of the Belgian and the Dutch parts of the North Sea plotted next to each other to illustrate border issues.

Another point worth mentioning is the fact that, instead of chosing GIS grid cells as working units for the valuation, in the future attempts should be made to use marine landscapes as ecologically relevant subzones. These are now available for the BPNS (Schelfaut *et al.*, 2007).

The BVMs developed in this paper show the integrated value of a selected set of ecosystem components. Other ecosystem components are not included in the assessments because there are not enough data available for a valuation. However, the methodology is flexible and allows the incorporation of new data when these become available in the future. Data can easily be added to the integrated database and similar assessment algorithms could be developed for these new ecosystem components as well.

Application of the protocol to future test areas should always be done by marine scientists who are familiar with the area and the ecosystem components which are included in the valuation, or at least after consultation of such experts. This was particularly proven by the case study area of the DPNS, where the valuator was not aware of the significance of the Frisian Front area for seabirds, which led to the neglection of certain assessment questions dealing with 'aggregation-fitness consequences' in the protocol.

BVMs are baseline maps showing the relative values of the different subzones of a study area. As such, the values are linked to the scale of the area which is valued. This means that a subzone of the BPNS given a 'high' value cannot be compared to a subzone of the IoS with the same value, although the same methodology has been used to determine the values. Comparing the values of subzones of different areas can only be done when a new valuation assessment is done where all subzones are assessed against each other. In the future more case study areas should be valuated on a regional scale to see how this higher level valuation compares to the valuation on a local scale. The combination of the BPNS and DPNS would be an ideal test case for such regional valuation.

Conclusions

As many marine areas (such as the BPNS and DPNS) are heavily exploited, there is an ever increasing awareness that it is necessary to use their resources and space in a sustainable matter. Policy makers who want to implement sustainable policy actions need good decision support systems (DSS). Such DSS should not only provide information on the socio-economic value and impacts of the BPNS but should also integrate biological and ecological information. To objectively allocate the different user function of marine areas, a spatial structure plan, which is based on the concept of integrated marine management, is needed. One of the baseline maps needed for such spatial structure plan is a BVM, which indicates the biological value of each of the subzones of the area on a relative basis. BVMs that compile and integrate all available biological information of an area are therefore promising tools for future spatial planning activities. The development and use of these maps will prevent the inclusion of subjective, untransparant expert judgement in the preparation of management decisions, an approach that was used frequently in the past.

The final BVMs indicate clear patterns in biological value. Some areas which were estimated as highly valuable in the past (mainly based on expert judgement of ecosystem components analysed separately), like the coastal areas of the BPNS or DPNS, were also assessed highly valuable with this marine biological valuation protocol.

Next to the final BVMs, the underlying valuation maps and integrated database are also valuable end products. These can also be consulted when managers have more specific questions about one or more ecosystem components.

A lot of quantitative data were available for the development of the biological valuation map of the BPNS and DPNS. In contrast to other countries, these are well-studied areas (both biologically and geologically) and large databases are available for certain ecosystem components. The high data availability for seabirds in the BPNS allowed a (statistically significant) spatial interpolation of the data to create full-coverage maps for this component. The same thing was possible for the distribution of the habitat suitability of the macrobenthic communities of the BPNS, by using full-coverage sediment information and a predictive model. Most data available for the IoS are qualitative data (presence/absence data), but the data availability for this case study area was substantially lower than that of the other two study areas. This was largely due to the lack of data archiving and integration for this area and the poor geographical distribution of the sampling locations (mainly restricted to the coastal strip around the isles). The BVM of the IoS should therefore be seen as a preliminary map, indicating future sampling opportunities.

When the BVMs are used it is recommended to consult the underlying valuation maps and the maps explaining the data availability and information reliability of the different grid cells. The data availability maps clearly show which areas did not get a lot of attention during past research efforts and should be focus points in future sampling campaigns. Collecting new data will only improve the reliability of the maps by increasing both the data availability and the number of assessment questions which can be answered (information reliability). Misinterpretations of the valuation maps could occur when the values on the maps are used without consultation of the underlying maps, the documentation of the valuation or the integrated database. Such consultation should be done to check the data which were used to determine the integrated biological value and the methodology that was used to assess the values. In this way users of the map will get a better idea of the reliability of the values. It is also necessary to clearly state for which purposes the developed marine biological valuation can be used. The map can only be used to determine the biological value of subzones. As such they can be considered as warning systems for marine managers who are planning new threatening activities at sea, and can help to indicate conflicts between human uses and high biological value of a subzone during spatial planning. It should be explicitly stated that these maps give no information on the potential impacts that any activity could have on a certain area, since criteria like vulnerability or resilience were not included in the valuation protocol. They cannot be used for site-specific management (e.g. selection of marine protected areas or impact assessments) as such activities also require the assessment of other criteria (representativeness, integrity, socio-economic and management criteria). However, the BVMs could be used as a framework to evaluate the effects of certain management decisions (implementation of MPAs or new quota for resource use), but only at a more general level when BVMs are revised after a period of time to see if value changes occur in subzones where these management actions were implemented. However, these value changes cannot directly be related to specific impact sources, but only give an integrated view on the effect of all impact sources and improvement measures taken in the subzone.

Despite the threats and weaknesses which are recognised above, the availability of marine BVMs gives the opportunity to answer policy questions related to the biological value of certain subzones of the areas under consideration in a transparent, objective way. When future spatial planning activities (e.g. installation of new windmill parks or selection of low valuable sites for new developments) require information on the integrated value of a subzone these maps could prove to be an excellent tool. Of course improvements of the maps are possible (integrating more data, filling in sampling gaps,…), but waiting for these improvements and neglecting the maps as they stand now, only leaves the alternative of returning to the use of best expert judgement when new policy questions are posed. Because such expert consultation process is very untransparent and subjective, relying on the marine biological valuation maps and simultaneously consulting the data availability and underlying valuation maps will give a more reliable and objective answer.

Acknowledgements

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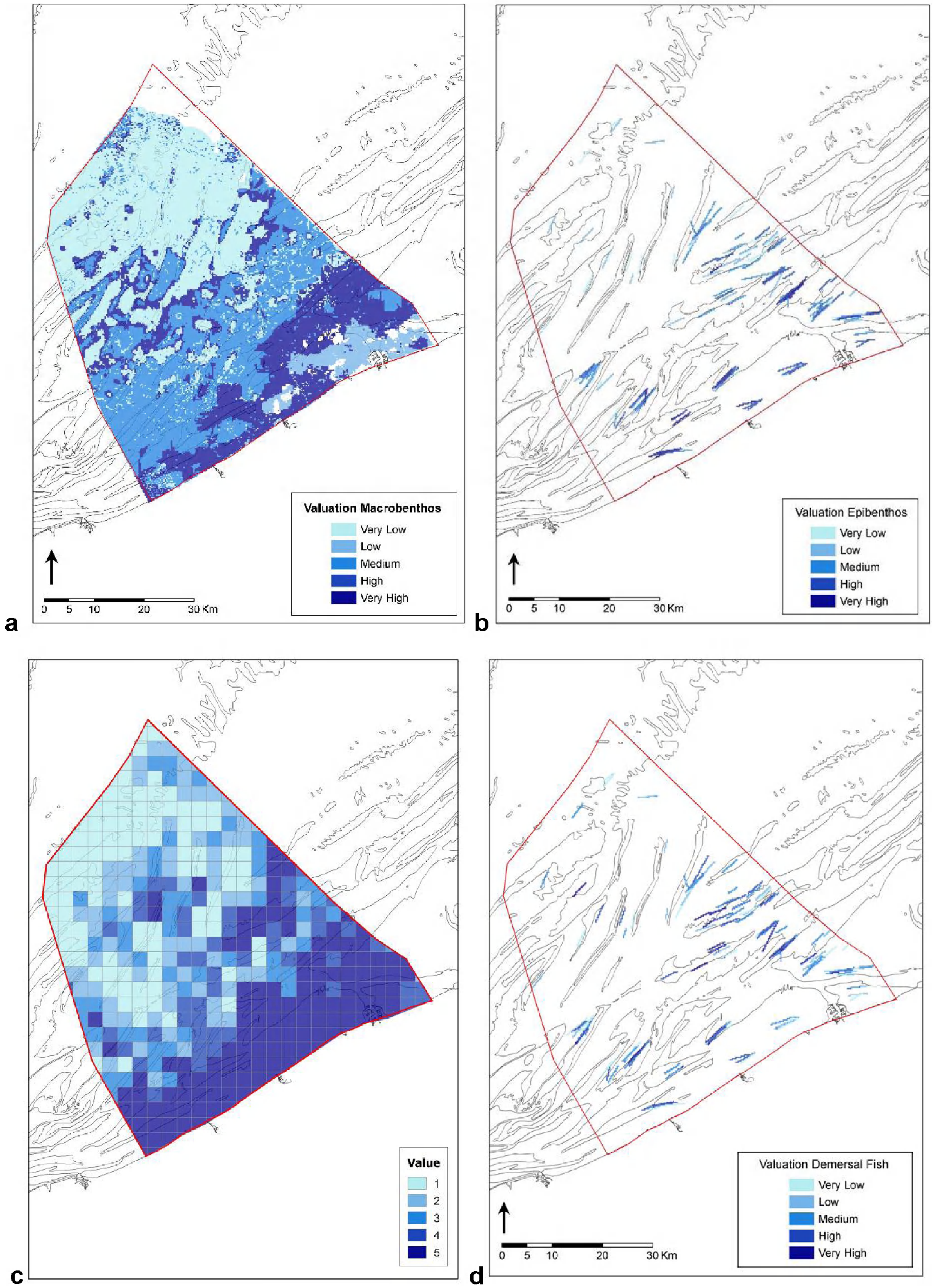
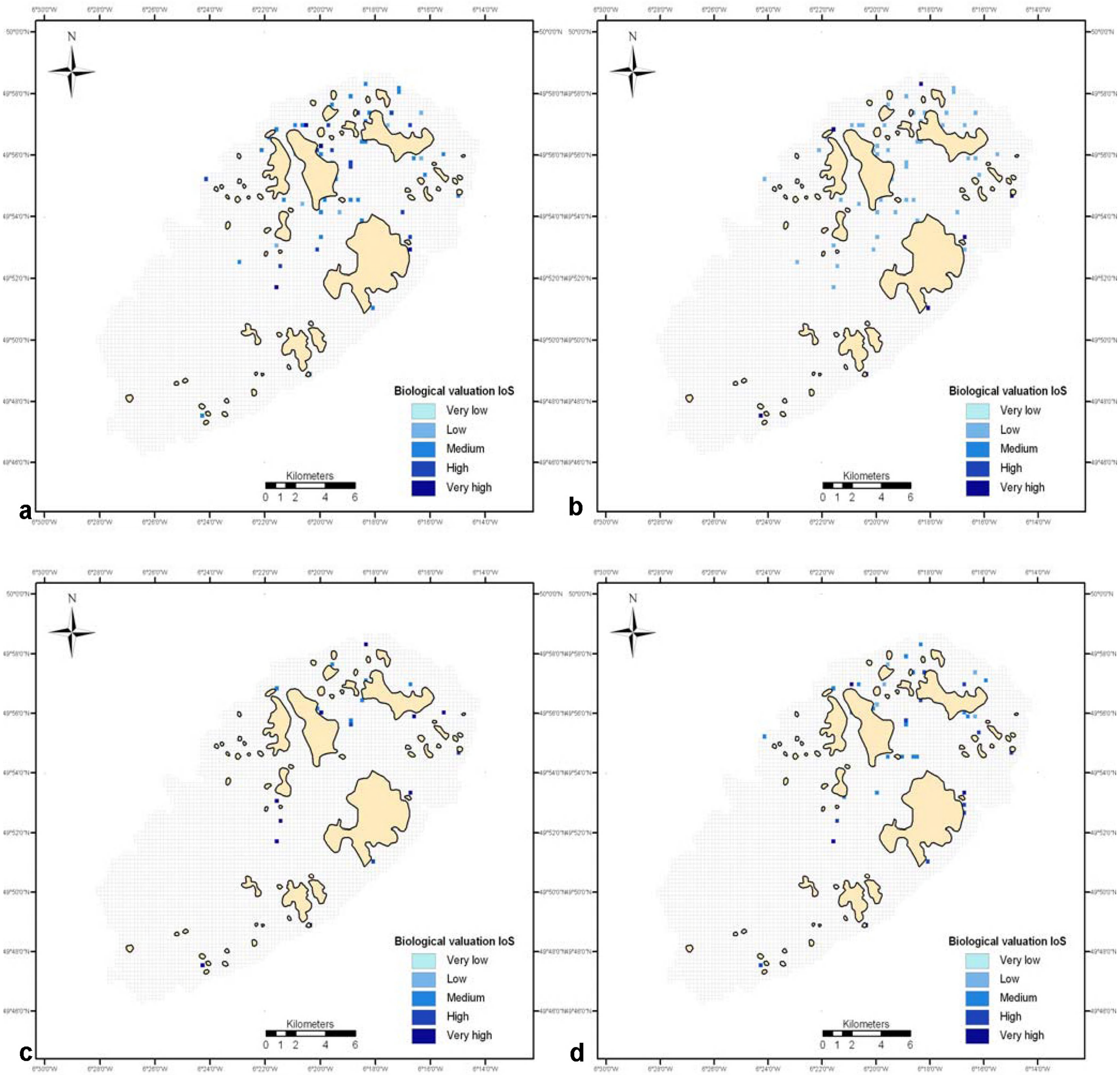
Appendix 1: Biological valuation maps for macro- and epibenthos, seabirds and demersal fish of the BPNS.

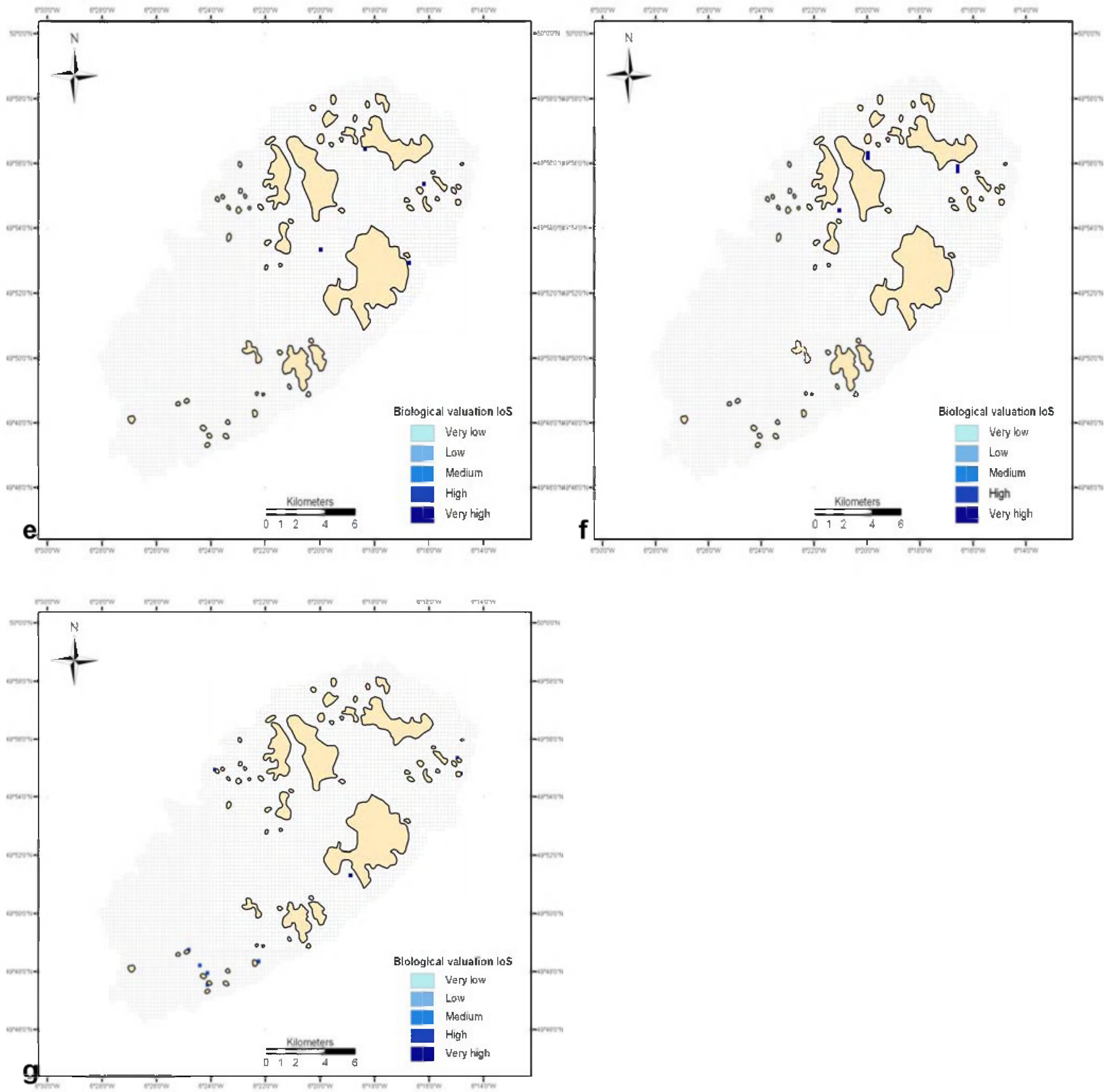
Figure a: macrobenthos – figure b: epibenthos – figure c: seabirds – figure d: demersal fish



Appendix 2: Biological valuation maps based on quantitative data for macro- and epibenthos (soft and hard sediments), hyperbenthos, plants and sea mammals of the Isles of Scilly.

Figure a: macrobenthos soft – figure b: macrobenthos hard – figure c: epibenthos soft – figure d: epibenthos hard – figure e: hyperbenthos – figure f: plants – figure g: sea mammals

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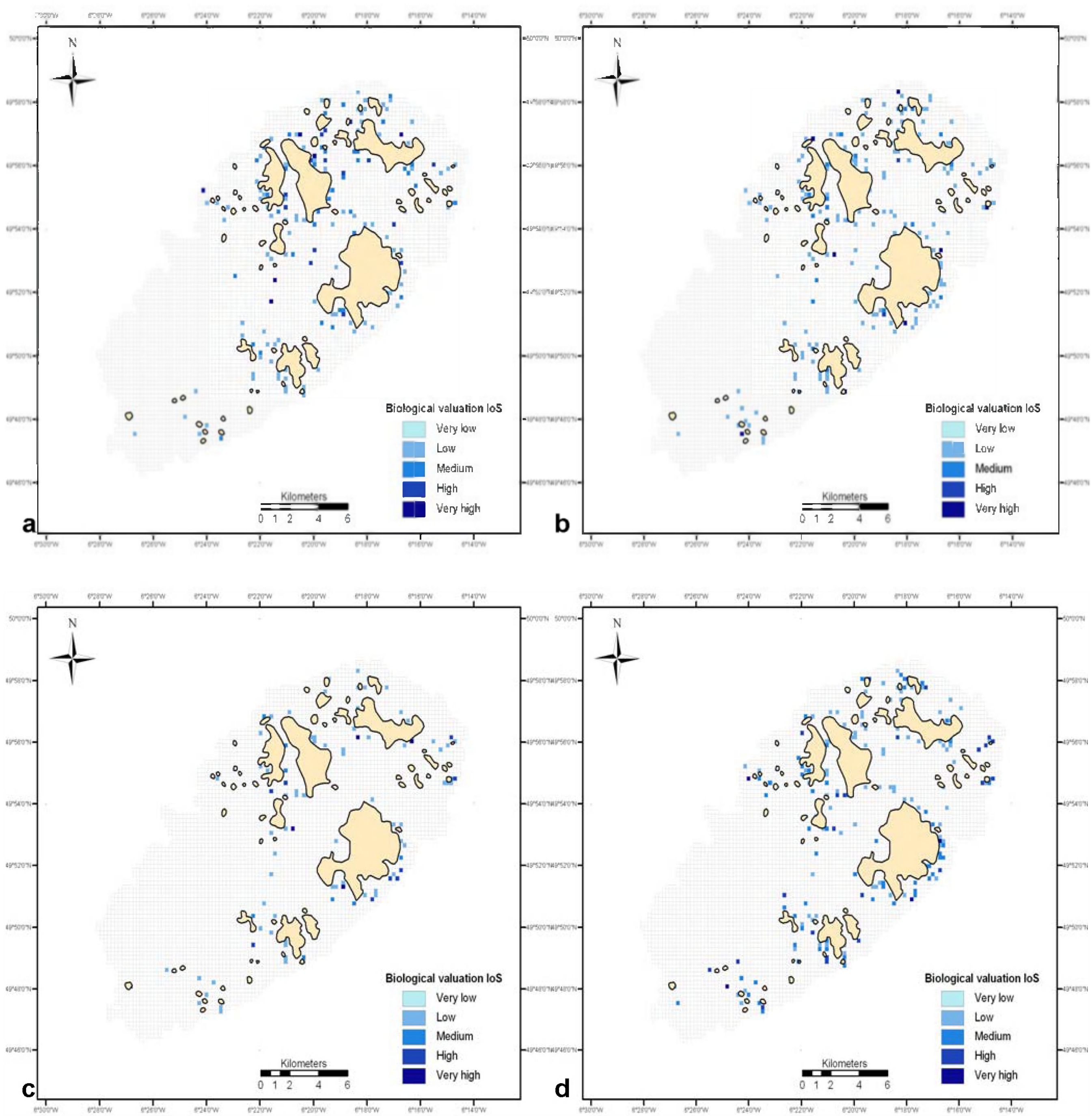
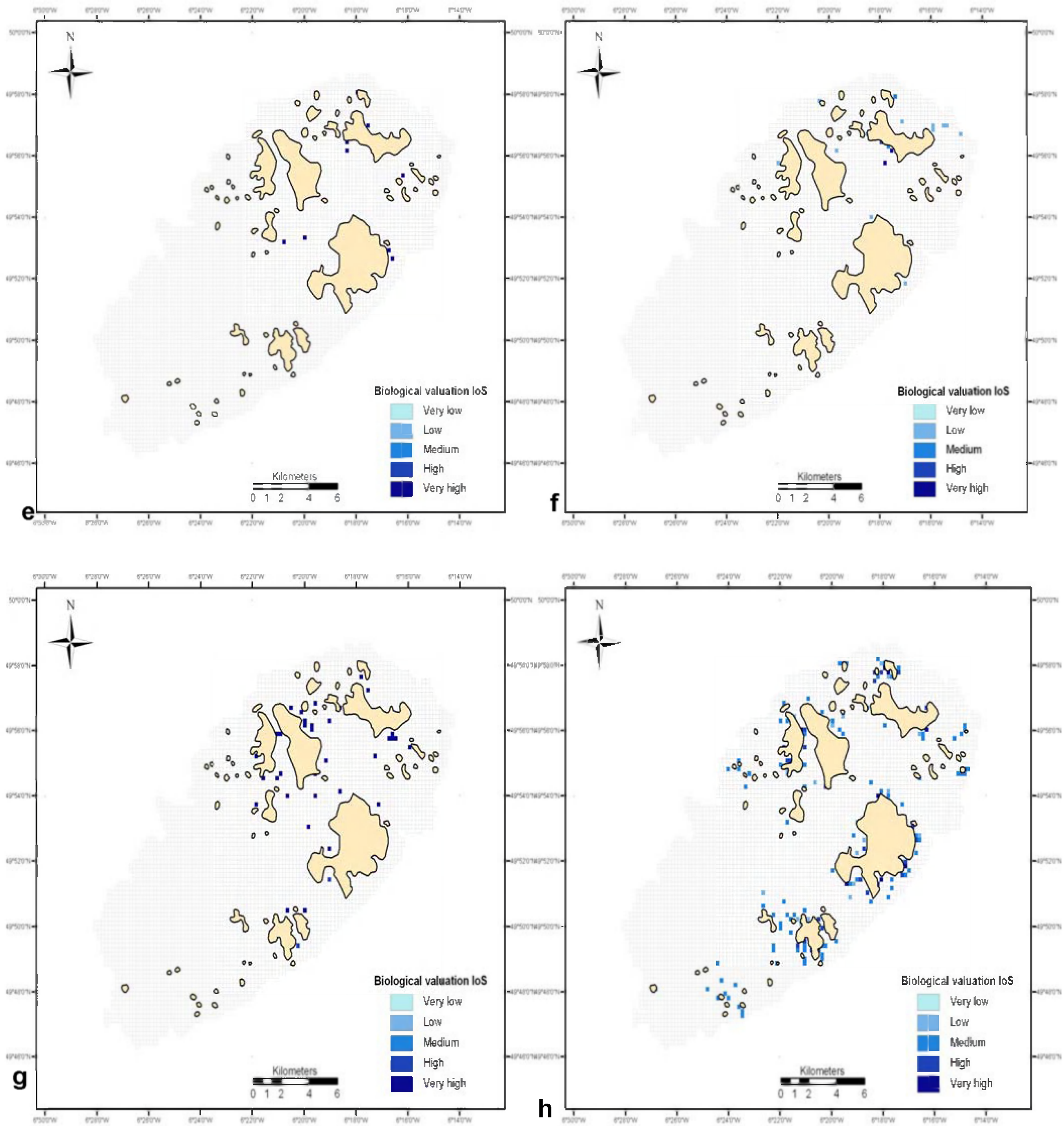
Appendix 3: Biological valuation maps based on occurrence data for macro- and epibenthos (soft and hard sediments), hyper- and meiobenthos, plants, algae, demersal fish and sea mammals of the Isles of Scilly.

Figure a: macrobenthos soft – figure b: macrobenthos hard – figure c: epibenthos soft – figure d: epibenthos hard – figure e: hyperbenthos – figure f: meiobenthos – figure g: plants – figure h: algae – figure i: demersal fish – j: sea mammals

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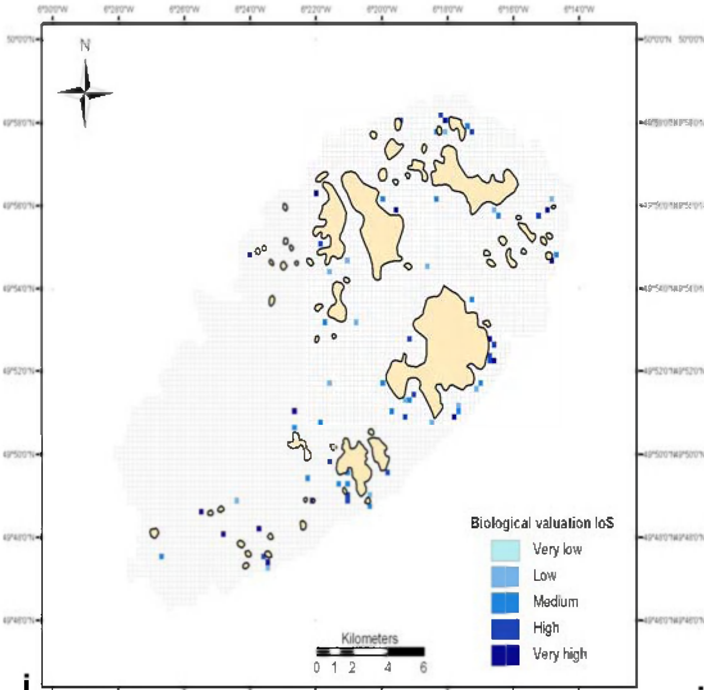
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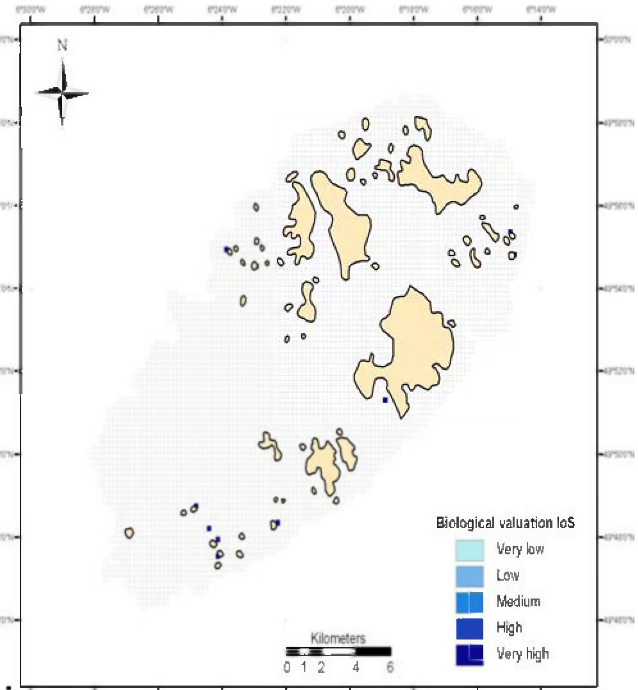
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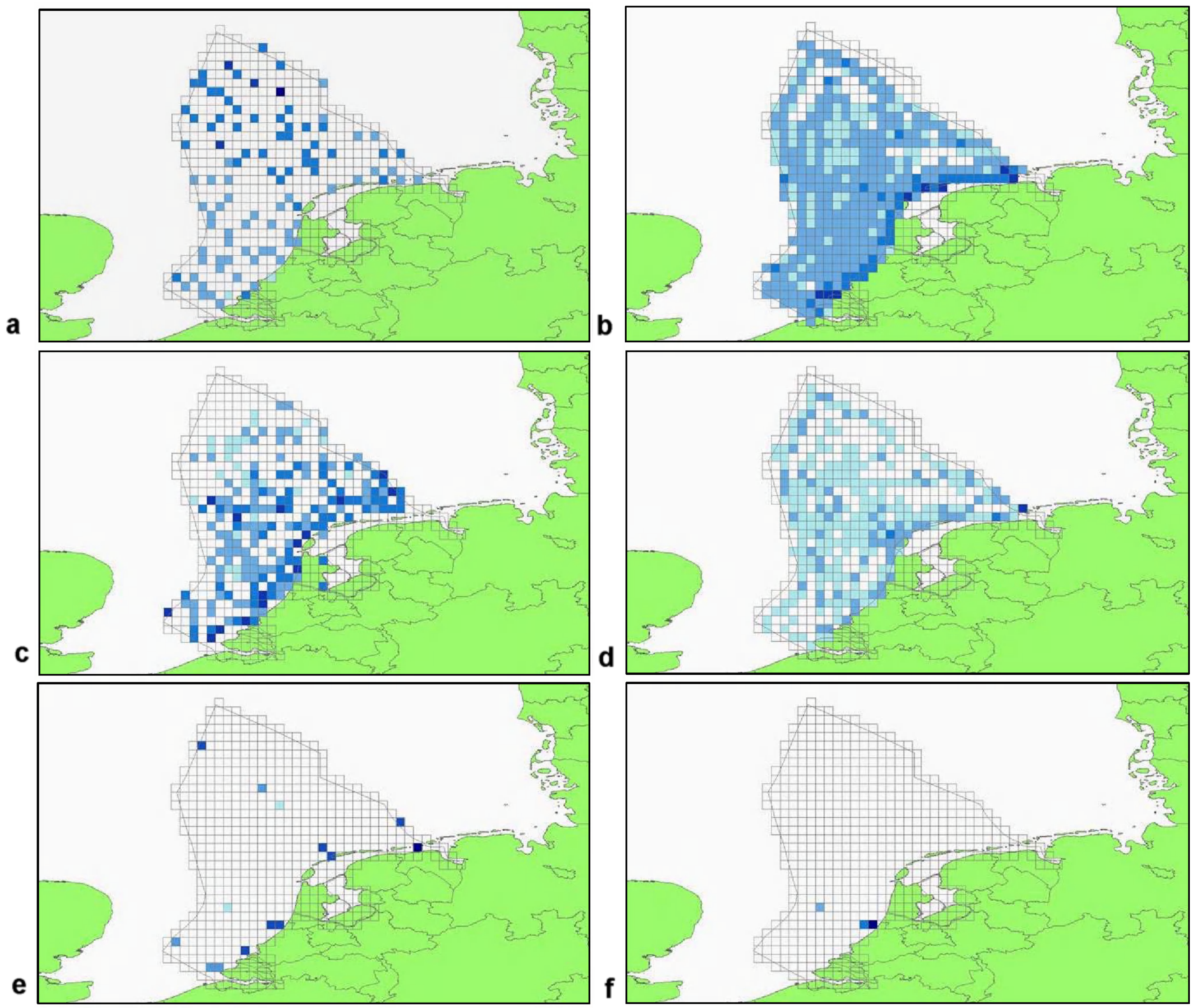
Appendix 4: Biological valuation maps for macrobenthos, seabirds, demersal fish, sea mammals and phyto- and zooplankton of the DPNS.

Figure a: macrobenthos – figure b: seabirds – figure c: demersal fish – figure d: sea mammals – figure e: phytoplankton – figure f: zooplankton



CHAPTER 5

RELEVANCE OF THE MARINE BIOLOGICAL VALUATION PROTOCOL FOR THE IMPLEMENTATION OF PRESENT AND FUTURE MARINE EUROPEAN DIRECTIVES: COMPARISON WITH OTHER IMPLEMENTATION METHODS

TO BE SUBMITTED FOR PUBLICATION AS:

Derous S, Van Hoey G, Van Damme S, Vincx M, Degraer S (in preparation). Relevance of the marine biological valuation protocol for the implementation of present and future marine European Directives: Comparison with other implementation methods.
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Abstract

Several European Directives for the conservation or protection of marine environments exist (Habitats and Brids Directives and Water Framework Directive) or are in development (Marine Strategy Directive) and should be implemented by each Member State. Here, the guidelines which are available to implement these Directives are investigated and the results of their implementation are compared to the results of the marine biological valuation, to see whether such valuation could be used to target the questions posed by the Directives. The Belgian part of the North Sea is used as a test case. The valuation protocol gives good results for the implementation of the Habitats, Birds and Marine Strategy Directives, while it cannot be used for the implementation of the Water Framework Directive as this latter Directive aims at determining the ecological status of coastal waters while marine biological valuation aims at determining the intrinsic value of marine areas. The intrinsic biological value and the ecological status need to be assessed complementary to each other. Therefore, a classification method based on the Benthos Ecosystem Quality Index (BEQI) is developed to evaluate the ecological status of the benthos in the Belgian coastal zone and compared to other European classification methods. Results show that the BEQI approach agrees well with most other European classification methods.

Keywords: EU Water Framework Directive, Habitat and Bird Directive, Marine Strategy, biological valuation, marine conservation, classification, ecological status, BEQI

Introduction

Many recent developments in European marine and estuarine science have been evolved from the demands of European Union legislation (Habitats and Birds Directive, Water Framework Directive,…). Each of these Directives requires the development of generic guidelines and protocols for the implementation and use of national enforcing legislation. An important issue in this context is the translation and implementation of scientific data into environmental management strategies (Elliott *et al.*, 1999). Other international organisations (OSPAR-HELCOM; ICES) are also identifying the necessity to have new ‘tools’ to assess the ecological status or anthropogenic impacts on marine habitats (Borja *et al.*, 2003; Fano *et al.*, 2004), which is being addressed by the implementation issues of the Water Framework Directive and the future Marine Strategy Directive.

A. EU Birds Directive (79/409/EC) concerning the conservation of wild birds

Following the Birds Directive Member States (MS) need to take protection measures for the sea and coastal areas where birds, described in Annex I, are living, so that they can continue to exist and reproduce in these places. Similar measures need to be taken for bird species that are not mentioned in Annex I, but which occur in high densities in an area or are threatened or very rare. The Directive asks for the protection, the conservation and the regulation of these birds species and sets rules for their exploitation. MS should also take actions to keep or bring the population of Annex I species to a level which is in agreement with the ecological, scientific and cultural demands, keeping in mind the economic and recreational demands. They should all take actions to protect, conserve or restore a sufficient variation of (surface area of) habitats for these species. Measures that can be taken to fulfil these needs are the designation of special protection areas (SPAs), the maintenance and spatial planning in agreement with the ecological characteristics of the habitats inside and outside the protected areas and/or the restoration or creation of destroyed biotopes (Maes & Cliquet, 1997).

B. EU Habitats Directive (92/43/EC) concerning the conservation of the natural habitats and the wild fauna and flora

The Habitats Directive aims at guaranteeing the maintenance of a minimum level of biodiversity in Europe. This is done by establishing a coherent ecological network of special protection areas (NATURA 2000). The network should integrate areas which harbour the natural habitat types listed in Annex I and the habitats for the animal and plant species mentioned in Annex II. This ecological network should also contain the SPAs designated under the Birds Directive. Protection measures have to be taken for the special areas of conservation (SACs) to ensure that the quality of the habitats does not deteriorate and that no negative impacts occur on the species for which the SACs are designated (Maes & Cliquet, 1997).

C. EU Water Framework Directive (2000/60/EC)

The WFD establishes a framework for the protection and improvement of all European surface and ground waters (including transitional and coastal waters). Its final objective is to achieve an -at least- ‘good ecological water status’ for all water bodies by 2015. The WFD requires MS to assess the ecological status of water bodies by analysing the biological, hydromorphological and physico-chemical quality from recent monitoring samples against reference (undisturbed) conditions, thereby deriving an Ecological Quality Ratio (EQR). The biological quality of coastal waters should be determined for macrobenthos, phytoplankton and macro algae. Reference conditions are type-specific and are therefore different for different types of coastal waters, which take into account the diversity of ecological regions in Europe (CEC, 2005; Borja et al., 2007).

D. Future EU Marine Strategy Directive

The European Commission acknowledged certain threats in the way protection and management of marine ecosystems was implemented in the past and adopted a new Marine Thematic Strategy, including a proposal for legislative action (i.e. Marine Strategy Directive). This new Strategy should overcome problems encountered in marine management, including the inadequate framework for the management of sea areas, the institutional and legal complexities and the number of actors concerned, the insufficient basic knowledge due to insufficient links between research areas in need of action and priorities and the lack of dedicated policy (European Commission, 2007). The proposed Marine Strategy Directive should establish a framework for the protection and preservation of the marine environment, the prevention of its deterioration and, where practicable, the restoration of that environment in areas where it has been adversely affected. The ultimate objective is to achieve or maintain 'good environmental status' in the marine environment by the year 2021 at the latest. 'Good environmental status' is defined as the state of the environment (including structure, function and processes of the marine ecosystems and natural physiographic, geographic and climatic factors and physical and chemical conditions) which provides ecologically diverse and dynamic marine waters, which are clean, healthy and productive within their intrinsic conditions and where the use of the marine environment is at a level that is sustainable. The status should be assessed by a set of generic qualitative descriptors (Annex VI). The proposed Directive will establish European Marine Regions as management units for implementation. This Directive aims at both the implementation of an ecosystem-based approach in marine waters and sustainable use of marine goods and services. It also wants to contribute to the coherence between and integration of environmental concerns into the different policies, agreements and legislative measures which have an impact on the marine environment.

E. Marine biologicai valuation

Marine biological valuation aims at determining the intrinsic value of marine areas, without reference to anthropogenic use (Derous *et al.*, 2007). Subzones within a marine area are scored relatively to each other by answering specific assessment question which relate selected valuation criteria (rarity and aggregation/fitness consequences) to all organizational levels of marine biodiversity (from the species to the ecosystem level, regarding both structures and processes). The marine biological valuation protocol (Derous *et al.*, submitted) was applied to the BPNS as a first test case and Figure 1 gives the resulting biological valuation map (BVM) (Derous *et al.*, in prep.). This map is based on the integration of data for four ecosystem components: seabirds, macrobenthos, epibenthos and demersal fish. The selected assessment questions were translated into practical mathematical algorithms (see Derous *et al.*, submitted) which could be applied to the database. The different algorithms were scored and integrated for each ecosystem component. The final biological value for each of the subzones within the BPNS was determined by averaging the intermediary score for each ecosystem component. The total biological value is given by five classes, ranging from 1 (very low) to 5 (very high). For each BVM at the ecosystem component level, the reliability of the values was determined by indicating the level of data which were available to determine the value ("data availability" score) and by indicating the number of assessment questions that could be answered for a particular subzone ("reliability of information" score).

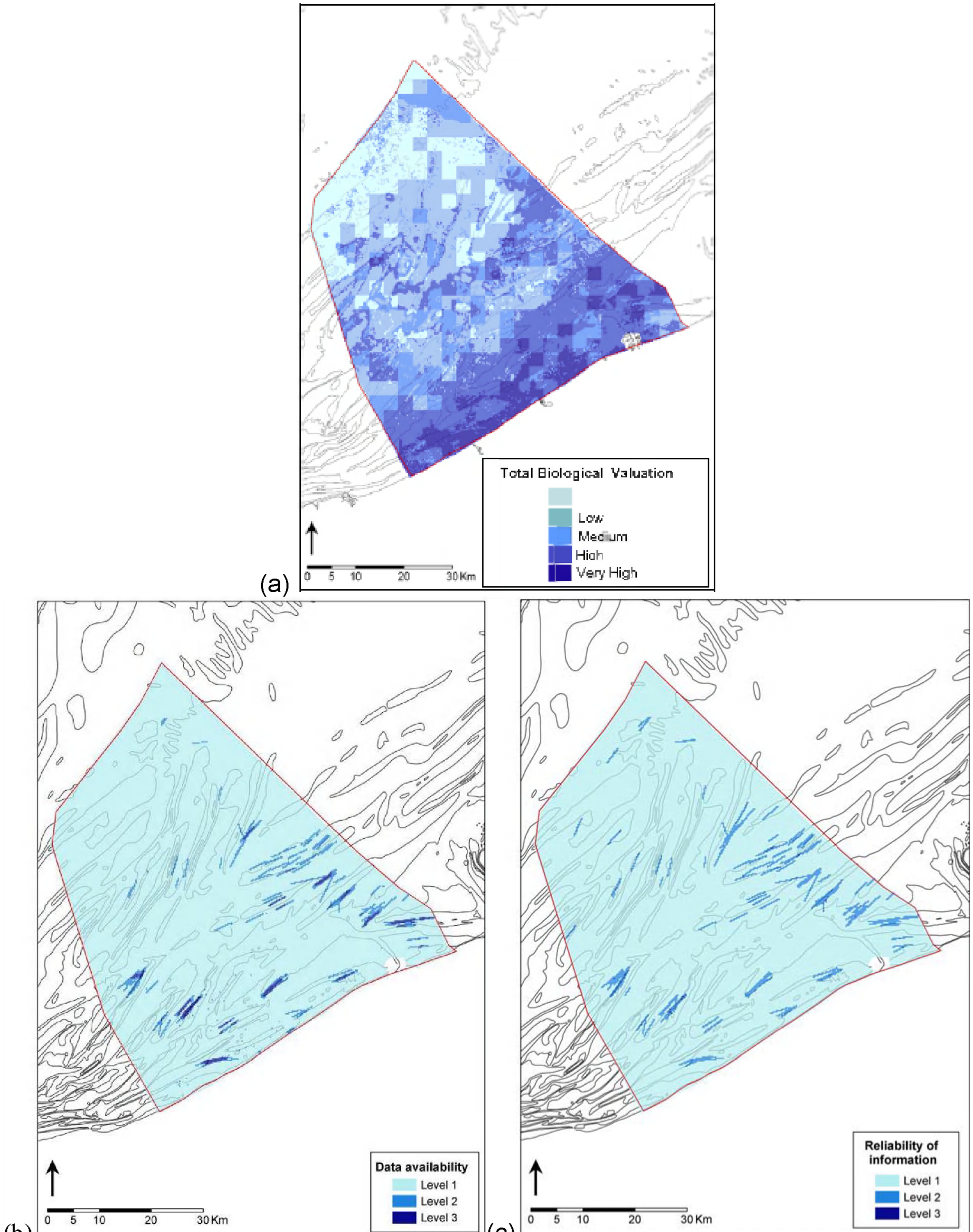

Fig 1: (a) Marine biological valuation map of the BPNS, (b) Data availability map, (c) Reliability of information map (Derous *et al.*, in prep.).

A detailed explanation of the application of the valuation protocol is given by Derous *et al.* (submitted). A dynamic atlas at the project website (http://www.vliz.be/bwzee) allows an in-depth view of the total value of each subzone, as well as the biological value for each of the ecosystem components.

This paper investigates the implementation of the European Habitats and Birds Directives in the BPNS and the implications of the Marine Strategy Directives for the BPNS. The results of these implementations are also compared to the results of the application of the marine biological valuation protocol to see whether there is agreement between the areas designated or proposed according to these Directives and the biologically highly valuable areas determined. As the different Directives all aim at the conservation of the areas which are most valuable from their point of view, agreement with the valuation map of the BPNS can be expected, although this is not necessarily the case. Next to that the classification methodology proposed by Belgium and other European countries for the implementation of the WFD was applied to data from the Belgian coastal zone and compared to the results of the valuation exercise.

Implementation of the European Directives in the BPNS

A. Study area

The BPNS comprises the southwestern part of the North Sea and has a total surface area of 3600 km² (0.6% of total North Sea surface area). The BPNS has a maximum depth of 46 m and is characterized by a continuous variation between deep (swale) and shallow (sandbank) areas. Based on their orientation and depth, four sandbank systems can be distinguished: Coastal Banks (parallel to the coastline, 0-7 km from coast), Flemish Banks (SW-NE direction, 10-30 km from coast), Zeeland Banks (parallel to coastline, 15-30 km from coast) and Hinder Banks (SW-NE orientation, 35-60 km from coast). These sandbanks are the result of sedimentation around hard cores in the underlying substrate (as cited in Van Lancker *et al.*, 2005; Maes *et al.*, 2005). The depth of the tops of the sandbanks varies between 0 and more than 10 m at low water. At spring tide, the top of some of the Coastal Banks are exposed during low water (Haelters *et al.*, 2004).

From a hydrodynamic point of view, the tidal current velocities reach their maximum value during flooding (NE) in the near coastal zone and along most of the Flemish Banks region. The maximum current velocity in the ebb direction (SW) occurs along the Hinder Banks and

along some of the swales of the Flemish Banks. High currents of up to 1.6 m/s have been modeled at the mouth of the Westerschelde estuary, running in a SE-NW direction. The strong tidal currents and wave action are responsible for high dynamics in the sandbank systems (erosion and sedimentation), but although the sediment is constantly moving most sandbanks and swales remain stable. The seabed is mostly covered by soft sediments, except for some gravel deposits in the northern part of the BPNS. The BPNS is intensely used by man in terms of resource extraction (aggregate extraction, fisheries,…) and space occupation (shipping, gas pipes, military activities, tourism and recreation,…), which urges the need to implement protected areas in this area to decrease the impacts on the environment and preserve its biodiversity (as cited in Van Lancker *et al.*, 2005; Maes *et al.*, 2005).
The high diversity, both in topography and in sedimentology and hydrodynamics, of the BPNS makes it an ideal test case for the purposes of this contribution.

B. European Birds and Habitats Directive

The Annexes of the Bird and Habitats Directives give clear guidelines on which species and habitats need to be protected. Table 1 gives a list of marine habitats provided by Annex I of the Habitats Directive.

Table 1: Marine habitats listed in Annex I of the Habitats Directive.

EU Code	Habitat name
Open sea and tidal areas	
1110	Sandbanks which are slightly covered by sea water all the time
1120	*Posidonia* beds
1130	Estuaries
1140	Mudflats and sandflats not covered by sea water at low tide
1150	Coastal lagoons
1160	Large shallow inlets and bays
1170	Reefs
1180	Submarine structures made by leaking gases
Other rocky habitats	
8330	Submerged or partially submerged sea caves

The types of habitat that take priority include shallow sandbanks (specific definition of habitat 1110 according to the Directive: sandbanks with permanent shallow covering of seawater – rarely more than 20 m below MLLWS). This is the only habitat of Annex I which occurs in the BPNS, which urges that the shallow sandbanks are to be protected as a priority in this part of the North Sea. Annex II of the Habitats Directive gives the species whose habitats, essential for the existence and/or reproduction of these species, need to be considered as SACs when they should occur in a MS' territory. Species belonging to this Annex are species which are believed to be endangered, fragile and/or rare and need to be protected for these reasons. Marine species listed in Annex IV of the same Directive are species whose habitats are not explicitly to be protected in SACs, but still need some form of protection under the provisions of Article 12 of the Habitats Directive. Table 2 shows that only a few Annex II and IV species occur in this area and that these are all fish or sea mammal species. It should be mentioned that data on the distribution of sea mammals, like the common seal *Phoca vitulina*, in the BPNS are very sparse. It could be possible to identify preferred feeding areas for certain sea mammal species. However, it should always be considered whether these areas are essential to the life and reproduction of the species, and consequently whether they should be considered as possible SACs. Where sites cannot be identified, further special measures may be required to ensure the conservation of these species. In the case of the BPNS, the limited knowledge on the sites with most sightings of marine mammals was integrated in the selection of the SACs. The two fish species mentioned in table 2 are estuarine species which were sampled as vagrants in the BPNS and should therefore not be considered when selecting SACs.

After analysis of all available biological data of the BPNS (including fish, seabirds and sea mammals and different benthos groups) and consultation of different panels of biological experts, the Federal Authorities proposed and designated two SACs in the BPNS, one large area of 17000 ha, comprising the western Coastal Banks area ("Trapegeer Stroombank" area, indicated as area H1 on Figure 2), and one smaller area in the Vlakte van de Raan (area H2 on Figure 2). Area H1 was chosen because of its high diversity of Bivalvia, the occurrence of habitat 1110 and its importance for seals (mainly *Phoca vitulina*). Next to that, the shallow coastal area is important as spawning and nursery area for the *Crangon crangon* and some fish species (e.g. *Pleuronectes platessa* and *Solea solea*). Area H2 was designated based on its importance for *Podiceps cristatus*, *Larus minutus*, several tern species and the occurrence of seals. The specific location of the SAC was also chosen to complement the Dutch SAC of the Westerschelde and Voordelta (Dienst Continentaal Plat, 2005). Although bird species should not be considered when implementing the Habitats Directive, some bird species were taken into account during the Belgian selection process in order to complement the SPAs selected under the Birds Directive and to establish a coherent NATURA 2000 network in the Belgian marine waters.

A number of bird species occurring in the BPNS satisfy the criteria from the Birds Directive (Table 2) and so the sites which are crucial for their existence in this area need to be protected. The marine species (and their habitats) that need protection pursuant to Annex I of the Birds Directive are *Sterna sandvicensis*, *Sterna hirundo* and *Sterna albifrons* (Haelters *et al.*, 2004). The other Annex I species mentioned in table 2 (*Gavia stellata, Gavia arctica, Sterna paradisaea and Larus melanocephalus*) have been observed in the BPNS in densities which are negligible when considering its beogeographical population and the designation of sites for the maintenance of these species would therefore not be meaningful.

Other species reached the 1% biogeographical population limit (article 4 (2) and Annex II of the Birds Directive) in the BPNS during the period 1992-2002: *Podiceps cristatus*, *Larus minutus*, *Melanitta nigra* and *Stercorarius skua*. *Stercorarius skua* occurs widely distributed in the BPNS, which does not allow indicating concentration sites for this species. Table 2 shows that some other species also reached this 1% limit, being *Larus fuscus*, *Larus argentatus* and *Larus marinus*, but as these species are mainly foraging on beaches, breakwater and in inland areas and are only spotted at sea during migration from one feeding area to another, no crucial sea areas can be designated (Haelters *et al.*, 2004). Based on interpretations of data for the selected bird species from ship-based surveys during the period 1992-2002 three important bird areas were proposed (Haelters *et al.*, 2004): (1) area of the west coast (off Koksijde and De Panne) from the low water line up to 6 NM, (2) an area on the middle coast (off Middelkerke-Bredene) from the low water line up to 6 NM in the western part and between 1.5 and 6 NM in the eastern part of the area and (3) an area enclosing the front part of the harbour of Zeebrugge (Figure 3). These areas were later proposed and implemented as SPAs (respectively areas SPA1, SPA2 and SPA3 on Figure 2) under the EU Birds Directive by the Federal Authorities, after transposing them into well-delineated areas. Area SPA1 is an important site for Sandwich Tern and Great-crested Grebe, while area SPA2 is a crucial site for the life and reproduction of Common Scoter, Great-crested Grebe, Common Tern, Sandwich Tern and Little Gull and area SPA3 is important for Common Tern, Little Gull and Little Tern (Dienst Continentaal Plat, 2005). Parts of areas SPA1 and SPA2, which have a depth of less than 6 m at low water, are already designated as the Ramsar area 'Flemish

Banks' (Kuijken, 1972; 1976). This designation was mainly based on the high densities of *Melanitta nigra* in this zone (Haelters *et al*., 2004).

Table 2: List of Annex I habitats and Annex II and IV species of the Habitats Directive and Annex I and II species of the Birds Directive, occurring in the BPNS (Cattrijsse & Vincx, 2001; Haelters *et al*., 2004). (*) indicates bird species which are very rare in the BPNS, whose densities are negligible to its biogeographical population or which cannot be defined as marine bird species. No SPAs should be designated for these species as they are no regular residents at the BPNS.

Common name	Scientific name	Habitat Directive	Bird Directive
Sea mammals			
Grey Seal	*Halichoerus grypus*	II	
Common Seal	*Phoca vitulina*	II	
Harbour Porpoise	*Phocoena phocoena*	II, IV	
Atlantic white-sided Dolphin	*Lagenorhynchus acutus*	IV	
White-beaked Dolphin	*Lagenorhynchus albirostris*	IV	
Sea birds			
Red-throated Diver	*Gavia stellata*		I (*)
Black-throated Diver	*Gavia arctica*		I (*)
Arctic Tern	*Sterna paradisaea*		I (*)
Sandwich Tern	*Sterna sandvicensis*		I
Common Tern	*Sterna hirundo*		I
Little Tern	*Sterna albifrons*		I
Mediterranean Gull	*Larus melanocephalus*		I (*)
Great Northern Diver	*Gavia immer*		I (*)
Slavonian Grebe	*Podiceps auritus*		I (*)
Balearic Shearwater	*Puffinus mauretanicus*		I (*)
Cory's Shearwater	*Calonectris diomedea*		I (*)
Storm Petrel	*Hydrobates pelagicus*		I (*)
Leach's Storm-petrel	*Oceanodroma leucorhoa*		I (*)
Bar-tailed Godwit	*Limosa lapponica*		I (*)
Ruff	*Philomachus pugnax*		I (*)
Red-necked Phalarope	*Phalaropus lobatus*		I (*)
Smew	*Mergus albellus*		I (*)
Pied Avocet	*Recurvirostra aboceta*		I (*)
Golden Plover	*Pluvialis apricaria*		I (*)
Gull-billed Tern	*Gelochelidon nilotica*		I (*)
Black Tern	*Chlidonias niger*		I (*)
Great-Crested Grebe	*Podiceps cristatus*		Art 4 (2)
Common Scoter	*Melanitta nigra*		II + Art 4 (2)
Little Gull	*Larus minutus*		Art 4 (2)
Lesser black-backed Gull	*Larus fuscus*		II + Art 4 (2)
Herring Gull	*Larus argentatus*		II + Art 4 (2)
Great black-backed Gull	*Larus marinus*		II + Art 4 (2)
Great Skua	*Stercorarius skua*		Art 4 (2)
Fish			
Twaite Shad	*Alosa fallax*	II	
River Lamprey	*Lampetra fluviatilis*	II	
Habitats			
Shallow sandbanks	Sandbanks slightly covered by sea water all the time	I	

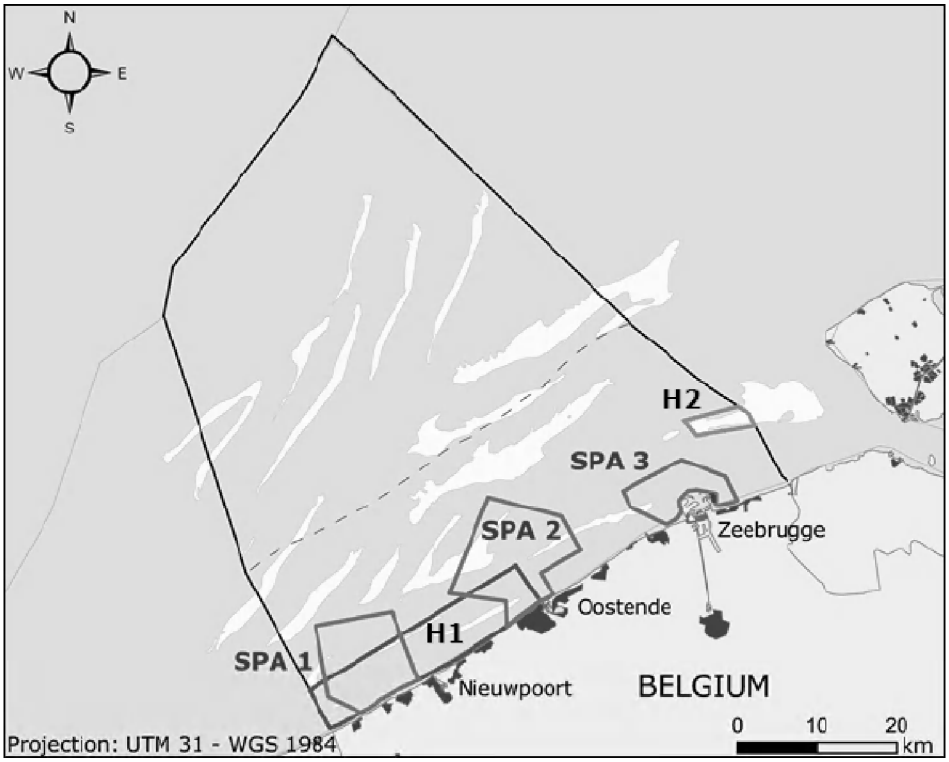

Fig. 2: The designated Birds (V1, V2 and V3) and Habitats (H1 and H2) Directive areas in the BPNS (reproduced from *www.mumm.ac.be and* Dienst Continentaal Plat, 2005).

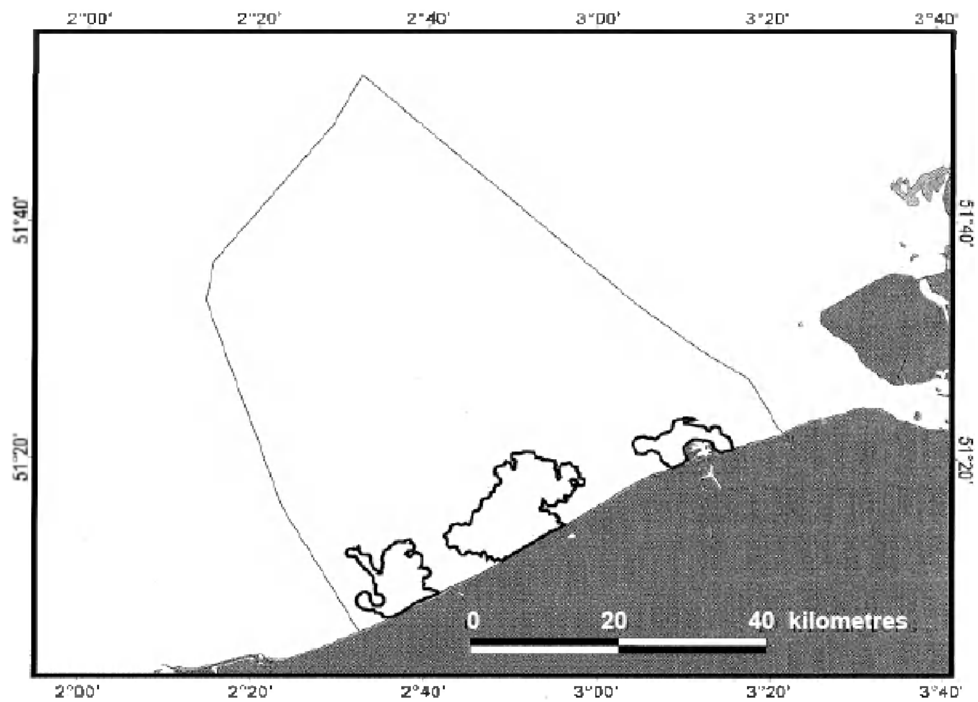

Fig. 3: The selected important bird areas for the BPNS (Haelters *et al.*, 2004).

C. European Water Framework Directive

The implementation of the WFD in the Belgian coastal waters (defined as the surface waters up to 1 nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured) was done by investigating the reference conditions and a classification tool. This section describes the outcome of the classification tool that was used for macrobenthos and compares its results with the outcome of other European classification methods using the same data. The comparability between the different methods is tested on a temporal dataset (1995-2003) from a slightly organically enriched station and on a spatial dataset (2002) from an impacted area nearby the harbour of Ostend. At both locations the near-shore shallow muddy sand habitat (*Abra alba* community) (Van Hoey *et al.*, 2005) is found. The samples were taken with a Van Veen grab (0.1m²) and sieved on a 1 mm sieve.

The ecological status of the macrobenthos of this habitat was evaluated with six available classification methods: the Spanish m-AMBI, the Danish Quality Index (DKI), the UK Infaunal Quality Index (IQI), the Portugese m-AMBI, the Norwegian Quality Index (NKI) and the Dutch–Belgian BEQI (Benthic Ecosystem Quality Index).

- The Spanish M-AMBI method (Borja *et al.*, 2004; Bald *et al.*, 2005; Muxika *et al.*, 2006) includes the use of the multivariate PCA technique with AMBI (Muxika *et al.*, 2006; Borja *et al.*, 2000), species richness and Shannon's diversity as structural parameters. The EQR is calculated on the basis of a Factor Analysis, including the distance of a location to two virtual 'high' and 'bad' quality status locations. High ecological status is determined after excluding all opportunistic species from samples with high AMBI scores. Bad status equals an AMBI of 7, H' of 0 and species richness of 0. This determines a trend line and the assessment samples are scored according to their distance to bad status.

- The Portuguese m-AMBI method used the same technique (Factor Analysis) as the Spanish, but used besides AMBI and Shannon's diversity also the Margaleff index.

- The Danish method is a multi-metric approach which combines the AMBI, the Shannon-Wiener diversity index and a factor to compensate for low densities and species numbers.

  $$DKI = ((1 – (AMBI/7)) + (H/H_{max}))/2 * ((1 – (1/N)) + (1 – (1/S)))/2$$

  Where *H* the Shannon-Wiener index with log base 2, H_{max} the reference value that H can reach in undisturbed conditions, *N* the number of individuals and *S* the number of species.

- The UK method (Borja *et al.*, 2007; Prior *et al.*, 2004; Miles *et al.*, in prep.) uses a multi-metric index, combining AMBI, Simpson's diversity, abundance and number of taxa.

  $$IQI = (((0.38 * AMBI^{IQI}) + (0.08 * (1 - \lambda')^{IQI}) + (0.54 * S^{IQI\ 0.1})) – 0.4)/0.6$$

  where $AMBI^{IQI}$ = (1 – (AMBI BC/7))/(1 – (AMBI BC/7))^{MAX}, *AMBI BC* = AMBI biotic coefficient, $(1 - \lambda')^{IQI}$ = (1 - λ')/(1- λ'^{MAX}), *λ'* = Simpson's index, S^{IQI} = S/S^{MAX} and *S* is the number of taxa.

- The Norwegian method uses the AMBI, the number of individuals and the diversity index SN (combination of number of species and individuals).

  $$NKI = 0.5 * (1 – AMBI_{63}/7) + 0.5 * (SN_{63}/2.7) * (N/N + 5))$$

  where *SN* = ln(S)/ln(ln(N)), S the number of species and N the number of individuals

- The BEQI method assesses the ecological status at the habitat level by evaluating four parameters: density, biomass, number of species and similarity (Bray-Curtis similarity) (Escaravage *et al.*, 2004; Van Damme *et al.*, 2007; Van Hoey *et al.*, 2007). The EQR is assessed relative to a pre-defined reference situation. Reference conditions and class boundaries for these parameters are based on permutation calculations. The reference values are calculated per habitat over increasing sampling surface. This allows the estimation of the reference values for any given sampling surface. The reference for a 1 m² sampling surface is based on a set of 2000 artificial random samples out of the reference dataset. Out of the randomisation procedure, a 5th percentile value is selected for each parameter as the value that has to be reached to achieve 'good' ecological status (Escaravage *et al.*, 2004; Van Hoey *et al.*, 2007). For the Belgian coastal waters, not enough biomass data are available, so this parameter was not taken into account when determining the EQR.

The classification according to the Spanish, Danish, British, Portuguese and Norwegian was done at the sample level (Borja *et al.*, 2007) while in the BEQI approach all samples are clustered per habitat type to give an overall habitat classification. To be able to compare the results of the BEQI approach with the other classification methods, the latter results were averaged per habitat. This way of habitat or water body level assessment has been accepted at the NEA-GIG benthos intercalibration workshop in Lisbon (February 2007) in anticipation of the final acceptance of the habitat/water body level assessment methods, which are currently in development in other European countries. This analysis delivers 23 assessment cases (22 cases from the temporal dataset and 1 from the spatial dataset), which are used to test the comparability between the different methods at the habitat level (Figure 4).

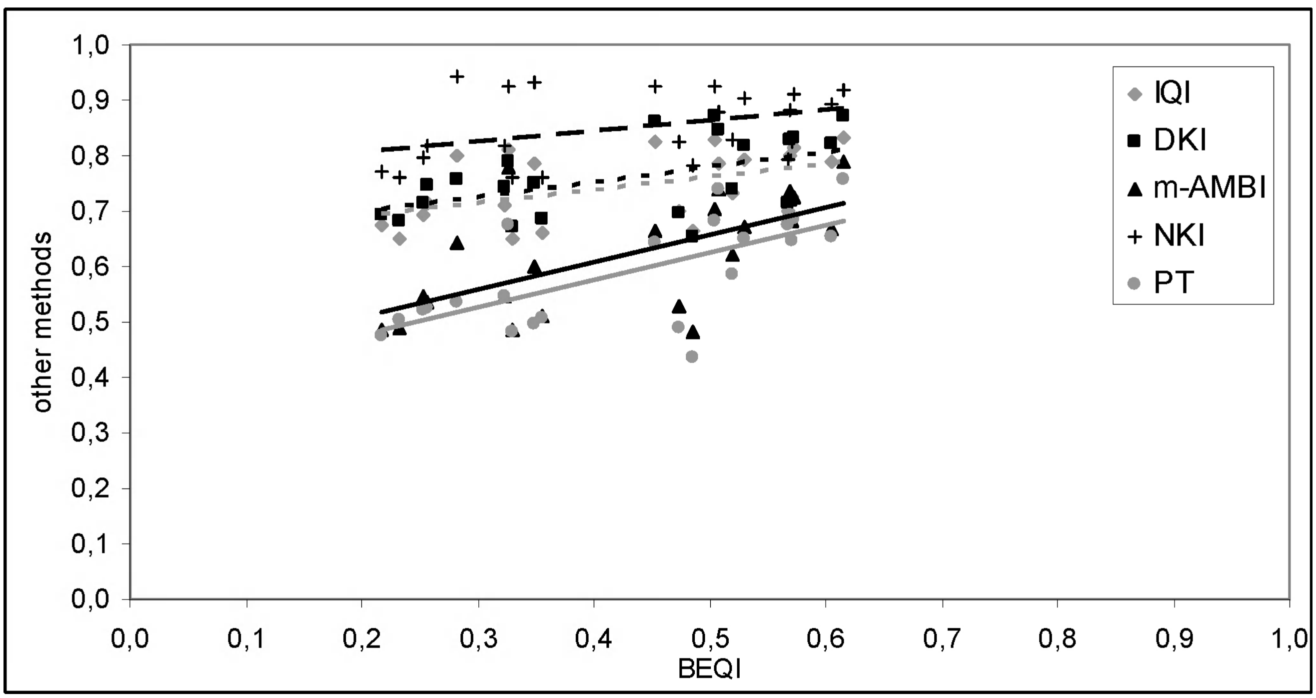

Fig. 4: Comparison of the Ecological Quality Ratio (EQR) obtained with the Benthic Ecosystem Quality Index (BEQI) approach against the other classification methods.

Through the use of the average of the EQRs of the samples per habitat, the comparison of the percentage of agreement best includes the precautionary principle. Therefore, the average of the standard deviations of the sample's EQR of each method has been taken into account. A small deviation from the class boundaries of less than the 0.05 (IQI, NKI, BEQI) or 0.06 (DKI, m-AMBI, PT) EQR units, is not considered as a real misclassification. The EQR boundaries of the status classes of the different classification methods were determined for each method separately and were intercalibrated (Borja *et al.*, 2007) to maximise agreement between the different statuses (Table 3). For m-AMBI, NKI and PT the comparability is acceptable, because in most cases the same or no more than one class difference is observed (90.9 or 95.5%) (Table 4). The lowest comparability is observed with the IQI and especially the DKI, which were both less precautious than the other methods. This is an acceptable level of agreement, bearing in mind the different approaches between the BEQI and the other methods and the inherent variability of the biological data. In all cases, the BEQI classifies the habitat more precautious than the others. However, to be too precautious is not a problem in general. The comparability at the level of the habitat/water body, which gives acceptable results in this first phase, can be improved in a later phase, when every country has its definitive assessment method at the habitat/water body level.

Table 3: Ecological Quality Ratio (EQR) boundaries used to define ecological quality status (moderate, good and high) in the six classification methods.

	EQR		
Methodology	**Moderate**	**Good**	**High**
Spain – M-AMBI	< 0.53	0.53 – 0.77	0.77 – 1.0
Portugal – M-AMBI	< 0.58	0.58 – 0.79	0.79 – 1.0
Denmark – DKI	< 0.58	0.58 – 0.67	0.67 – 1.0
UK – IQI	< 0.64	0.64 – 0.75	0.75 – 1.0
Norway – NKI	< 0.81	0.81 – 0.92	0.92 – 1.0
BE/NL - BEQI	< 0.60	0.60 – 0.80	0.80 – 1.0

Table 4: The percentage of cases in which a certain class difference is found between the BEQI and the other international methods.

Class difference	IQI	DKI	M-AMBI	NKI	PT	Total
-4	0	0	0	0	0	0
-3	4.3	17.4	0	0	0	4.3
-2	26.1	43.5	8.7	8.7	4.3	18.3
-1	43.5	30.4	52.2	47.8	47.8	44.3
0	26.1	8.7	39.1	43.5	47.8	33.0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
Equal or 1 class	69.6	39.1	91.3	91.3	95.7	77.4

D. European Marine Strategy

As this European Directive is still in its developmental phase, it has not been implemented in the BPNS yet. When the Directive comes into force, Belgium will have to develop a Marine Strategy for its part of the Marine Sub-Region 'Greater North Sea, including the Kattegat and the English Channel' (part of Marine Region 'North East Atlantic Ocean'). The development of such Marine Strategy comprises four major steps: (1) an initial assessment phase, with determination of good environmental status, (2) the establishment of environmental targets, (3) the establishment of monitoring programmes and (4) the development of a programme of measures to improve or maintain the environmental status. The initial assessment should comprise an analysis of the essential characteristics and current environmental status, taking into account the list of elements from Annex II of the proposed Directive (biological elements given in Table 5). Next to the assessment of the status of these environmental elements, Member States should make an analysis of the predominant (human) pressures and impacts on the characteristics of those waters as well as investigate the economic and social implications and the cost of degradation of the marine environment of the different human uses. The determination of a set of characteristics for good environmental status should be based on the generic qualitative descriptors, criteria and standards which will be given in Annex II of the proposed Directive, two year after the Directive has entered into force (CEC, 2005). These qualitative descriptors should be easy measurable variables for the environmental characteristics given in Table 5, allowing explaining natural and human-induced variability.

Table 5: Environmental characteristics to be taken into account in the initial assessment according to the proposed European Marine Strategy and generic descriptors to be investigated when determining good environmental status (reproduced from CEC (2005) and RPA (2005)).

Environmental characteristics		
Physical and chemical features	Bathymetry Temperature	Currents Salinity
Habitat types	Predominant habitats Habitats identified under EU legislation or international conventions	Special areas
Biological elements	Biological communities associated with habitats: - phyto- and zooplankton (typical species, variability, productivity) - invertebrate bottom fauna (species composition, biomass, productivity, variability) - fish (abundance, distribution, age/size structure) Marine mammals (population dynamics, range, status) with special emphasis on species protected under EU Habitats Directive or international agreements	Seabirds (population dynamics, range, status) with special emphasis on species protected under EU Birds Directive or international agreements Other species protected under EU legislation or international agreements (population dynamics, range, status) Non-indigenous, exotic species (occurrence, abundance, distribution)
Other features	Nutrient enrichment or cycling (currents and sediment/water interactions)	Chemical pollution state (chemicals, sediment contamination, hot spots, health issues)

Comparison of the current implementation of European Directives with the results of biological valuation

A. Relevance of biological valuation for the implementation of the Habitats and Birds Directives

When the SACs and SPAs designated under the Habitats and Birds Directive are plotted on the total BVM of the BPNS (Figure 5a), it can be seen that all areas are located within the 20 meter coastal strip. This is an area which is generally assessed as having a high to very high biological value, although patches of lower values occur in the coastal zone as well. Higher values are found in the nearshore zone of the western part of the coastal strip diverging slightly to a more offshore zone in the east (Vlakte van de Raan and above). The SACs H1 and H2 were chosen after consulting experts on different ecosystem components (macro- and epibenthos, fish, seabirds and sea mammals) and investigating habitat data, while the BVM was developed after detailed analysis of all available biological data. No data on sea mammal species could be integrated due to the unavailability of representative data. Area H1 also contains an area which receives protection under the RAMSAR Convention. It can be concluded that SACs H1 and H2 seem to overlap relatively well with some of the biologically highly valuable areas in the coastal zone of Belgium, when the total valuation map (Figure 5a) is considered. However, when the valuation map for macrobenthos is investigated (Figure 5b), the high values in the western coastal zone are coverd by area H1, while one of the largest valuable areas in the eastern coastal zone will not be protected by the chosen SACs. It could be recommended to propose other priority areas under the Habitats Directive located outside the coastal zone, for instance the area above the Vlakte van de Raan or the sandbank complex of the Thornton bank (mid-eastern part of BPNS), which also revealed a high biological value.

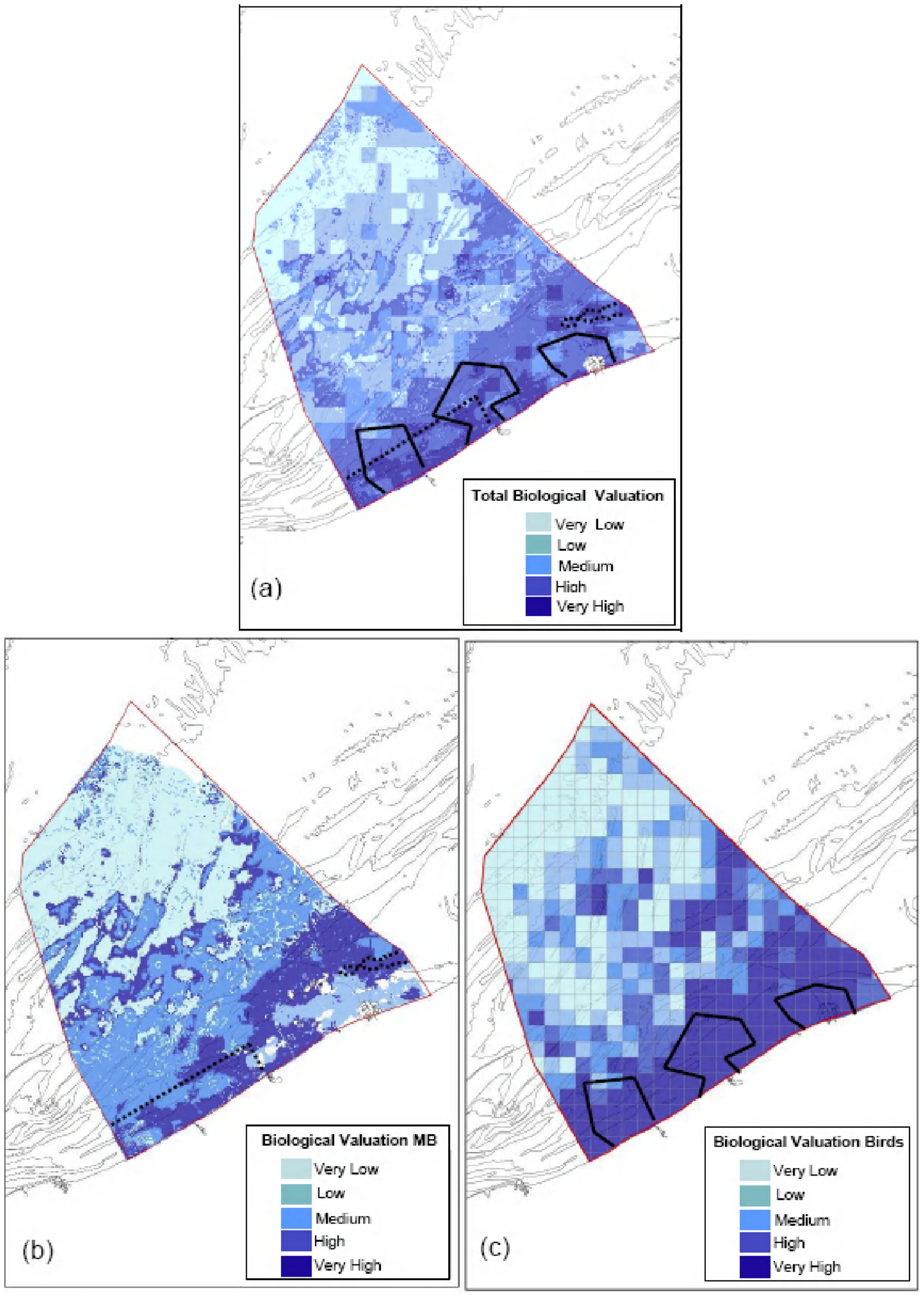

Fig. 5: (a) Total biological valuation map, (b) macrobenthic valuation map, (c) bird biological valuation map with overlying designated Special Protection Areas (full lines) and Special Areas of Conservation (dotted lines).

As the location of the SPAs under the Birds Directive was based only on ornithological criteria from the Annexes, these can best be compared to the valuation using the birds BVM (Figure 5c). Again, the coastal zone shows the highest values for birds and SPA1, SPA2 and SPA3 are all located within this high to very high valued zone. This high value for seabirds in the coastal zone can not only be explained by the presence of nesting areas near the coast, because the seabird counts were adjusted with correction factors to account for this ‘distance to the coast’ bias and it is also known that the coastal zone (with its high variety of shallow sandbanks and swales) is a major feeding area for many seabird species. No areas offshore have been proposed as Birds Directive areas yet, although some spots could be identified using the birds BVM. It should be emphasized that the bird valuation integrates data on all seabird species and does not solely investigate data on threatened species or species for which more than 1% of their biogeographical population is located in the BPNS, as is the case for the selection of SPAs (Table 6). The information from the birds BVM therefore gives a realistic picture of the intrinsic biological value of the different subzones of the BPNS for every bird species.

To be able to answer the assessment questions for the marine biological valuation of seabirds, seabird species were split into two categories, being regularly occurring (or common) and rare species (Derous *et al.*, in prep.). Only the common species were used to answer the assessment questions on density and aggregation, while all species were used to calculate the species richness assessment question. This means that common bird species will dominate the valuation as they are included in more assessment questions. Table 6 shows which common species were included in the valuation protocol of seabirds and also indicates the species which were used for the SPA selection. When the distribution data of the species, which were used for the valuation but not for the SPA selection, are investigated, it is seen that most of these species are widely distributed on the BPNS, which does not allow the selection of important bird areas. Only the Black-headed Gull and the Great Cormorant occur aggregated, but as their aggregation areas are also located in the coastal area, the inclusion of information on these species during SPA selection would not result in the selection of additional areas.

It can be concluded that, while the selection method for SPAs differs from the valuation methodology, no striking differences can be observed between the resulting maps (Figures 2 and 5c). The highly valuable area around the Thornton bank can be explained by the fact that the bird counts in this area were done after finalisation of the SPA selection. Also, SPA selection divided all data in 10 classes instead of the 5 classes used in the biological valuation, resulting in three segregated proposed areas in the coastal zone, which can not be distinguished using the 5 class division of the valuation. The agreement between both methodologies suggests that marine biological valuation can be used to select additional (offshore) SPAs in the future.

Table 6: Comparison of species included in SPA selection and in marine biological valuation (Common = regularly occurring species, rare = species occurring in less than 1% of the grid cells).

SPA selection	Marine biological valuation
Annex I species	
Sandwich Tern	Sandwich Tern (common)
Common Tern	Common Tern (common)
Little Tern	Little Tern (rare)
	Red-throated Diver (common)
	Black-throated Diver (rare)
	Arctic Tern (rare)
	Mediterranean Gull (rare)
Art 4 (2): 1% biopopulation	
Great-crested Grebe	Great-crested Grebe (common)
Little Gull	Little Gull (common)
Common Scoter	Common Scoter (common)
	Great Skua (common)
	Lesser black-backed Gull (common)
	Herring Gull (common)
	Great black-backed Gull (common)
Other common species	
	Kittiwake (common)
	Common Guillemot (common)
	Common Gull (common)
	Northern Gannet (common)
	Northern Fulmar (common)
	Razorbill (common)
	Black-headed Gull (common)
	Great Cormorant (common)

B. Relevance of biological valuation for the implementation of the Water Framework Directive

To compare the results of the classification of the Belgian coastal waters according to the different international methods (m-AMBI, IQI, DKI, NKI, PT, BEQI) with the results of the biological valuation, the coordinates of the two assessment areas (slightly organically enriched station and the area nearby Ostend) used for the WFD classification are linked to the appropriate subzones (GIS grid cells) of the valuation. Also, the ecological status classes are translated into numerical values (bad-1, poor-2, moderate-3, good-4, high-5) to be comparable with the value classes of the valuation (very low-1, low-2, medium-3, high-4, very high-5). The ecological statuses of the areas are averaged to allow comparison with the biological value of the grid cell.

Because the total biological value is based on seabirds, epibenthos, demersal fish and macrobenthos and the classification methods only include macrobenthos, only the macrobenthic biological value is used. The macrobenthic biological value for the area nearby the harbour of Ostend was 1 (very low) in 7 cases and 2 (low) the remaining 15 cases. The ecological status, determined by the BEQI method is poor (2), while all other classification methods classify the habitat as having a moderate (3) to good (4) status. At the slightly organic enriched station the ecological status is evaluated as moderate (BEQI) to good (other methods) by the different classification methods, whereas the macrobenthic value is evaluated as low.

This comparison shows that in this case the biological value is mostly lower than the ecological status. In most classification methods, the EQR is based on the sensitivity of species (AMBI) or on diversity (Shannon-Wiener, Simpson, number of species, Margaleff index), which are two indicators chosen for their ability to detect changes in the macrobenthos which can be related to human impacts. The BEQI approach has the same goal, but it also incorporates density and a community parameter (similarity), next to a diversity indicator. This seems to make its results more comparable with the outcome of the biological valuation. Macrobenthic biological value is determined by another set of indicators (density, aggregation of species, rarity of species, presence of ecologically significant species, species richness and community parameters), which give an idea of the intrinsic value for macrobenthos in a certain grid cell (relatively to the other grid cells of the BPNS). The use of these difference sets of evaluation indicators, related to the different objectives of both methods, probably explains the different outcome of both analyses.

C. Relevance of biological valuation for the future implementation of the Marine Strategy Directive

During the development of the marine biological valuation concept and protocol, it was attempted to incorporate as much of the biological characteristics as possible, according to Annex II of the future Marine Strategy Directive (Derous *et al.*, 2007; submitted). The protocol is flexible so that information on every marine ecosystem component can be integrated in the valuation. The assessment questions of the protocol relate to different aspects of these ecosystem components (e.g. density, species richness, biomass, community structure, significant species and productivity).

Table 7: Physical and chemical characteristics which should be included in the assessment of the environmental status according to the future Marine Strategy Directive and their corresponding assessment questions from the valuation protocol.

Annex II of Marine Strategy Directive	Assessment questions for biological valuation
Physical and chemical characteristics:	
Bathymetry	Complex topography or seabed morphology
Temperature Salinity	Distinctive oceanographic features (with respect to temperature, salinity, stratification, anoxia)
Currents	Distinctive oceanographic processes (upwelling, gyral systems, nutrient retention, entrainment, natural erosion or deposition, unique tidal systems,…)
Not required by Annex II	Substrate diversity Significant geological processes
Special features:	
Nutrient enrichment or cycling	Nutrient cycling Distinctive oceanographic processes (upwelling, gyral systems, nutrient retention, entrainment, natural erosion or deposition, unique tidal systems,…)
Chemical pollution status	Not included in valuation protocol

Characteristics which are not included in the valuation protocol are invasive or exotic species and the threat status of species, because these are related to human impacts which should not be included when determining the intrinsic value of a site. Descriptors dealing with the assessment of the human pressure on the marine environment are also excluded from the valuation protocol. Physical and chemical characteristics and special features are also not explicitly included in the assessment, although some of the assessment questions at the ecosystem level relate to these characteristics, because they have direct implications for the biological communities related to them (Table 7). By incorporating information on these human-related descriptors as overlying layers on the marine BVM it should be possible to integrate all information and to implement a Marine Strategy for the Sub-Region under consideration. So, the development of a BVM for a given area can be a first step in the implementation of the future Marine Strategy Directive.

Discussion

A. Habitats and Birds Directive

While some highly valuable areas in the coastal zone of the BPNS seem to be included in the designated SACs and SPAs, other highly valuable areas are not protected under the Habitats or Birds Directive yet. The overlap of highly valuable areas and the selected SACs and SPAs can be explained by the fact that most criteria from the Directives were investigated and, where possible, incorporated during the initial selection of the valuation criteria. Nevertheless, biological valuation does not take into account the threat status of a species, although this can be related to 'rarity' which is one of the valuation criteria. If future conservation areas have to be selected under these Directives, the BVMs could be used as a starting point for the investigation of suitable sites. Although the BVMs show integrated information on different ecosystem components, it is still possible to investigate the underlying data for separate species on which these values were based. Such species information could also be useful for the selection of Habitats and Birds Directive areas, when information on the presence or density of certain threatened species, listed in the Annexes, is needed.

Investigation of the Habitats and Birds Directives learned that, whereas the species scope of the Birds Directive is already comprehensive for the marine environment, it should be recognized that the present Annexes of the Habitats Directive have limited focus on marine species and habitat types, especially those that occur in the offshore marine areas (European Commission, 2007). Although this has led to problems with the identification of relevant SACs in the past (Rachor & Gunther, 2001), it was an important first step towards protecting the marine environment and implementing the NATURA 2000 network in marine waters (European Commission, 2007). The selection of SPAs and SACs in the BPNS confirms this limited applicability of both Directives in offshore marine areas, as only coastal areas were selected. Although the selected set of bird species used for the selection of SPAs was limited, they appeared to function as umbrella species for seabirds in the selection of important coastal areas. Because the marine biological valuation protocol incorporates additional information on other species and other characteristics (e.g. aggregation, species richness), this protocol could be used in the future for the selection of additional areas, for instance in more offshore areas. The listing of additional marine habitat types and species in the Annexes in the near future could provide a legal basis for extending the scope of the marine network.

This work will probably be done in the framework of the Marine Strategy, where the Commission has proposed the development of a rational approach for the full implementation of NATURA 2000 at sea with a view to consider potential adaptations to the Annexes of the Habitats Directive.

B. Water Framework Directive

The relative high level of agreement between the some of the NEAGIG methods and the BEQI classification suggests that these multi-metric approaches used, considering the highest values as reference, may be a valid approach (Borja *et al.*, 2007). Other authors also stated that the complementary use of different indicators or methods based on different ecological principles is highly recommended in determining the environmental quality of a system (Dauer *et al.*, 1993; Salas *et al.*, 2004). Univariate indices, like diversity or eveness, have the disadvantage of reducing a great amount of information into a single summary index. It is also possible to find the same values for diversity for disturbed and undisturbed communities at different localities, which makes it difficult to distinguish changes produced by natural factors from those produced by anthropogenic ones (Warwick & Clarke, 1993; Muniz *et al.*, 2005). Conversely, multivariate or multi-metric methods are more sensitive in detecting community changes (Warwick & Clarke, 1991), although their results are less easy to be interpreted by non-scientists (Muniz *et al.*, 2005).

The major benefit of the BEQI classification method is the fact that it takes sampling size into account, which is not done by the other NEAGIG methods. A possible drawback of the BEQI method however, could be that reference conditions have to be determined for every system separately. Better agreement between the BEQI results and the NEAGIG classification could possibly be attained by adjusting the class boundaries of the BEQI classification and removing outlier data from the Belgian dataset. The classification of the Belgian coastal zone also indicated that the amount of samples taken in this area is too low to allow for a reliable ecological status assessment. A better monitoring network for the different habitat types should be selected, which will allow a thorough investigation of the ecological status of the area. This is also one of the steps that Member States need to take when implementing the WFD in their coastal waters.

Comparison of the classification outcome with the results from the biological valuation of macrobenthos shows little agreement, except slightly for the BEQI results. As the classification methods are designed to assess the ecological status, related to the level of human impact, of the macrobenthos in the coastal zone, it is not surprising that applying this methodology gives other results than assessing the intrinsic biological value, where no anthropogenic influences are considered. Macrobenthic valuation is based on assessment questions related to species richness, aggregation of species, ecologically significant species, density, rare species and community parameters, which are all assessed for each subzone relatively to the other. If the subzones, corresponding to the assessment samples used in the classification, receive a low score for these assessment questions compared to other subzones, their values will be low. For instance, relative low densities found in a subzone will result in low scores for some of the assessment questions (e.g. aggregation or density), while low densities are considered as a sign of relative low human impact in the subzone, which would give a higher ecological status according to the classifications.

C. Marine Strategy Directive

The marine BVMs could provide valuable information for the implementation of the future Marine Strategy Directive. Comparison of the environmental characteristics, which have to be investigated to determine the environmental status under this future Directive, with the assessment questions from the protocol for valuation, show a lot of similarities (both at the biological and at the physical level). Nevertheless, several environmental characteristics of the Marine Strategy Directive relate to anthropogenic use (or its absence) and as this human factor was deliberately excluded from the biological valuation protocol, there is no total overlap of assessment questions and qualitative descriptors. When information on human pressures and indicators translating these pressures into impacts on the environment is provided as overlying maps on top of the BVM of the BPNS, it could be possible to assess the environmental status of the different subzones of the BPNS in the future. Such detailed information is already available for some of the human activities going on in the Belgian marine waters (Maes *et al.*, 2005), but such assessments will still ask a lot of work in the future.

Conclusions

Relative good agreement was found between the SPAs designated under Birds Directive and the high valuable areas for birds in the BPNS and the marine biological valuation protocol therefore seems to be a suitable guiding tool for future implementation of such areas. Most of the criteria or species considered in the Birds Directive are also investigated during valuation, although information on seabird species which are not considered as priority species for conservation is also included in the valuation, giving a more realistic picture on the biological value of the BPNS for every bird species. The SACs selected under the Habitats Directive are located in areas which show relatively medium to high biological values on the total BVM, while other highly valuable areas (especially for the macrobenthos) seem to be excluded from the selection. The situation of medium valued areas in the SACs can be explained by the fact that biological valuation gives a more patchy result of values (as subzones are scored relatively to each other), while under the Habitats Directive it is more logical to select large, undivided areas like area H1, which can be managed more easily. The fact that a range of biological values is present in the SACs will also increase the biological diversity which is conserved, which is one of the major aims of the Habitats Directive.

As the classification methods and the biological valuation protocol are designed for their own purposes, it is obvious that the results of applying them to the same dataset can give different results. When the biological values for macrobenthos are compared to the ecological status scores for the same grid cells, major dissimilarities are noticed. This is mainly due to the fact that both values/scores are determined after integration of (partly) different parameters. Next to that, the classification methods are developed to assess the anthropogenic stress on the coastal ecosystem and habitats of Belgium while the biological valuation method is designed to determine the intrinsic biological value of the coastal zone (without reference to human use), which could explain the differences in values and scores for the two methods. It is therefore recommended to use both methodologies parallel to each other, depending on the purpose of the investigation. The BEQI approach agreed well with most other European classification methods, developed for the implementation of the WFD, and should be applied in the future to new datasets to investigate its general applicability and comparability.

Marine BVMs could be used a baseline map for the implementation of the future European Marine Strategy Directive, as the protocol incorporates most of the biological and physical characteristics required by the Directive. To be more useful in the future, the BVM of the BPNS should be updated with information on other marine ecosystem components, like plankton and sea mammals, as these components need to be considered for the implementation of the Marine Strategy. It stays questionable of course, if the inclusion of information of highly mobile and scarce sea mammal species, like the harbour porpoise, is relevant for the development of valuation maps, as chance then plays a very important role. Next to these baseline BVMs, maps with information on human activities and the pressures and impacts they have on the environment should be provided as overlying layers, to be able to assess the environmental status of an area.

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Chapter 6

General Discussion and Conclusions on the Applicability of the Protocol for Marine Biological Valuation For Marine Management

Abstract

Decision support tools used for marine management purposes should fulfill several conditions to be easily applicable and sufficiently reliable. Marine biological value is a multi-metric ecological indicator developed to be able to capture the intrinsic value of a certain area by integrating all available biological data. The indicator was screened against several guidelines for the assessment of the quality of ecological indicators for marine management, developed by the Environmental Protection Agency (EPA). This evaluation shows that the determination of marine biological value can significantly contribute to marine management decisions concerning spatial planning. The protocol for biological valuation is relatively straightforward, which makes it easy to apply to new marine areas, and is also flexible enough to allow the integration of different quantities of biological data without decreasing its reliability. The marine biological valuation maps, developed for certain case study areas, were also used to screen past management decisions and direct future spatial planning possibilities. A conceptual scheme is developed for guidance in the use of marine biological valuation for different management actions and policy questions.

Keywords: Marine management, biological valuation, decision support tool, ecological indicators

Introduction

The marine biological valuation map (BVM) is a highly usefull baseline layer for the development of an objective and scientifically-sound spatial structure plan of a marine area. Marine BVMs hold a warning system to avoid threatening human activities in areas with a high biological value. Next to its direct merit as a warning system during spatial planning, the development of an integrated biological and ecological database of a marine area should also be seen as a major contribution to marine management as currently most marine biological data are stored in different institutes and it can be difficult to obtain an integrated picture on the available data without such collated databases. Marine biological valuation also aids in the translation of scientific data to managers, policy makers and the public at large. Alhough the end product of a biological valuation is a map showing the integrated value for each subzone within a study area, the methodology is transparent and allows the interested user to see how this value is determined or what the underlying valuation maps are. The approach is also flexible and allows for easy inclusion of newly gathered data in the database.

Evaluation of biological value as ecological indicator

Chapter 1 indicated that although a wide range of ecological indicators is available, no integrative, system-level indicators exist that give an indication of the state of the environment (Dale & Beyeler, 2001). Due to the variety of environmental issues, the complexity of environmental data, and the necessity for management decisions, many types of indicators have been developed for different purposes. They can reflect biological, chemical and physical aspects of ecological condition, and have been used to characterize status, track or predict change, identify stressors or stressed systems, assess risk, and influence management actions. Because ecological indicators are so diversified, development and selection of successful ecological indicators has become a relatively complex process (Kurtz *et al.*, 2001).

Marine biological value can be seen as an ecological indicator that gives an idea of the status (or intrinsic value) of the ecosystem by integrating the available biological information on different organizational levels of biodiversity (from the species op to the ecosystem level) and for different ecosystem components (Derous *et al.*, 2007). As such it can be described as a multi-metric, integrative, system-level biological indicator to assess the state of the marine environment.

The Environmental Protection Agency's Office of Research and Development has prepared a technical guidance to assist with the development and selection of ecological indicators for use in specific monitoring programs. The guidance can be used for indicator evaluation and specifies 15 guidelines, organized in four phases that are functionally related and allow users to focus on four fundamental questions (Table 1) (Jackson *et al*., 2000; Kurtz *et al*., 2001):

1. Phase 1: Conceptual relevance – Is the indicator relevant to the assessment question (management concern) and to the ecological resource or function at risk?

2. Phase 2: Feasibility of implementation – Are the methods for sampling and measuring the environmental variables technically feasible, appropriate and efficient for use in a monitoring program?

3. Phase 3: Response variability – Are errors of measurement and natural variability over time and space sufficiently understood and documented?

4. Phase 4: Interpretation and utility – Will the indicator convey information on ecological conditions that is meaningful to environmental decision-making?

Table 1: Overview of the evaluation guidelines for ecological indicators, as developed by EPA's Office of Research and Development (reproduced from Kurtz *et al*., 2001).

Phase 1: Conceptual relevance	
Guideline 1	Relevance to the assessment
Guideline 2	Relevance to ecological function
Phase 2: Feasibility of implementation	
Guideline 3	Data collection methods
Guideline 4	Logistics
Guideline 5	Information management
Guideline 6	Quality assurance
Guideline 7	Monetary costs
Phase 3: Response variability	
Guideline 8	Estimation of measurement error
Guideline 9	Temporal variability (within-season)
Guideline 10	Temporal variability (within-year)
Guideline 11	Spatial variability
Guideline 12	Discriminatory ability
Phase 4: Interpretation and utility	
Guideline 13	Data collection objectives
Guideline 14	Assessment thresholds
Guideline 15	Linkage to management action

In the next section, the indicator 'marine biological value' is evaluated according to the different EPA guidelines.

Guideline 1: Relevance to the assessment

It should be demonstrated in the concept that the proposed indicator is responsive to an identified assessment question and will provide information useful to a management decision. For aggregated indicators, the relevance of each sub-indicator to the management objective should be identified. In addition, the indicator should be evaluated for its potential to contribute information as part of a suite of indicators designed to address multiple assessment questions. The ability of the proposed indicator to complement indicators at other scales and levels of biological organization should also be considered.

Evaluation: The indicator "marine biological value" was developed in response to the assessment question "What is the relative biological value of the subzones of the Belgian part of the North Sea?". This question was posed by Belgian policy makers and would help them in establishing a marine spatial plan that is able to balance socio-economic aspects against biological value when suitable locations for present uses and future developments need to be selected. When developing the methodology to assess the indicator the geographical scope was enlarged to make the indicator applicable to any marine area. Next to that, marine biological valuation not only aims at locating the subzones with the highest biological value, but also those with medium and low biological value. As such, the indication of the marine biological value of each subzone can be used as a warning system to avoid new developments in subzones with high value or to facilitate provision of a greater-than-usual degree of risk management during spatial planning activities in these subzones. Each of the sub-indicators, which are investigated through the use of the assessment questions (see Chapter 3), capture a specific aspect of the intrinsic biological value of a site and give a realistic picture of the total biological value when they are integrated. Biological value also integrates available data from different ecosystem components, at different organizational levels of biodiversity (from the species to the ecosystem level), which enables to assess the integrative biological value at the system-level. By doing so, no complementary biological indicators need to be applied to answer the assessment question posed above. By integrating the biological value indicator with indicators on the socio-economic value of the goods and services provided by marine biodiversity and human impact indicators, it could be possible to answer other assessment questions, like "Where should efforts for the conservation of marine biodiversity and ecosystem functioning be maximized?" or "How can certain marine areas be used in a more sustainable way?". As the criteria described in the Annexes of the European

Habitats and Birds Directive for the implementation of SACs and SPAs were also included in the initial review of ecological valuation criteria (Chapter 2A), it is also possible to use marine biological valuation for this purpose (Chapter 5). Integration of biological value with indicators on human pressures and physical indicators could also enhance the future implementation of the proposed European Marine Strategy Directive (Chapter 5).

Guideline 2: Relevance to ecological function

> *It must be demonstrated that the proposed indicator is conceptually linked to the ecological function of concern. If the link is indirect or if the indicator itself is particularly complex, ecological relevance should be clarified with a description or conceptual model. A conceptual model is recommended, for example, if an indicator is comprised of multiple measurements or if it will contribute to a weighted index.*

Evaluation: Marine biological value is a multi-metric indicator composed of different sub-indicators, which give an idea of the intrinsic biological value of a marine area when they are integrated. The conceptual framework of marine biological valuation is given in Figure 1.

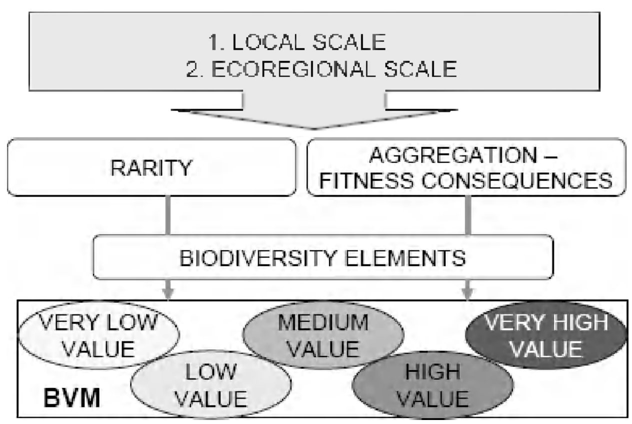

Fig. 1: Concept of marine biological valuation (Derous *et al.*, 2007).

This concept shows that marine biological value is determined by relating selected valuation criteria (rarity and aggregation-fitness consequences) to all elements of biodiversity, as visualized in the 'marine ecological framework of biodiversity' of Zacharias & Roff (2000). These relations are given in the form of assessment questions which assess one of the sub-indicators of biological value (Chapter 3). It should be repeated that biological valuation does not take into account anthropogenic influences on the environment and as such the indicator "biological value" does not give an idea of the effects of human impacts on marine biodiversity (Chapter 2A).

Guideline 3: Data collection methods

Methods for collecting all indicator measurements should be described. Standard, well-documented methods are preferred. If multiple methods are necessary to accommodate diverse circumstances at different sites, the effects on data comparability across sites must be addressed. Expected sources of error should be evaluated. Methods should be compatible with the monitoring design of the program for which the indicator is intended.

Evaluation: The marine biological valuation protocol is developed in such way that it is applied to data which are already available for a certain area. Data which are available in most cases are standard abundance, species richness, presence/absence or biomass data, which are all collected with standard sampling and analyzing methods (Chapter 4). As subzones within a study area are valued relatively to each other, results should not be compared across different areas, as boundaries for each of the value classes will differ in each of the areas. Sources of error could be introduced in the application of the protocol when samples for a certain parameter are collected with different sampling gear, when samples are analyzed in different ways or when data treatment procedures have changed over years. This should always be documented in the description of the quantity and quality of the data that were available for the valuation of the study area and can also be reflected in the determination of the "data availability" level for each subzone. This data availability label reflects the number of samples, replicates, observations or counts, which were available for the determination of the biological value of a subzone, and is therefore an estimate of the reliability of the value estimate (Chapter 3).

Guideline 4: Logistics

The logistical requirements of an indicator can be costly and time-consuming, and these should be evaluated to ensure the practicality of indicator implementation, and to plan for personnel, equipment, training, and other needs. A logistical plan should be prepared that identifies requirements for field personnel and vehicles, training, travel, sampling instruments, sample transport, analytical equipment and laboratory facilities and personnel. The length of time required to collect, analyze and report the data should be estimated.

Evaluation: As the application of the marine biological valuation protocol to a certain area does not imply the collection of new monitoring data, but rather uses the ones which are already available, the use of the indicator does not impose costs concerning field sampling and data processing. The analysis of the available data however will still take some time as first the data should be organized in an integrated database and then the appropriate assessment questions need to be selected and translated into mathematical algorithms which can be applied to the database (Chapter 3). The application of the protocol is relatively straightforward; the length of time from data collection to the visualization of the biological value on maps is on the order of a few months (depending on the quality and quantity of available data and their division over different biological institutes). All case studies described in Chapter 4 were valuated by scientists with a background in marine biology, which is a minimal requirement for this type of analysis. Next to that the scientists should have good knowledge of the biological and ecological characteristics of the area they will be valuating, or they should consult experts who have this knowledge.

Guideline 5: Information management

> *Requirements for management of information should be identified for data processing, analysis, storage and retrieval, and data documentation standards should be developed. Compatibility with other systems should also be considered, such as the internet, established federal standards, geographic information systems, and systems maintained by intended secondary data users.*

Evaluation: Information management was thoroughly addressed during the valuation project and one of the aims was to disseminate the data to the public. All available data were gathered in an integrated relational Microsoft Access database, where every sample received a unique code. The case study areas were divided into subzones (grid cells) by using a Geographic Information System (ArcView) and all samples were coupled to their corresponding subzone in Access. In addition to the data sets, the database contains metadata files that describe methods, contacts, sampling years and other information pertinent to the data. The valuation of the case study areas was visualized by producing biological valuation maps, which were created with GIS. A user-interface for the total biological valuation map and the underlying valuation maps per ecosystem component and per assessment question is available on the internet to ensure their efficient use by end-users (http://www.vliz.be/bwzee). So, the hardware and software required would be a high-end PC with Access and ArcView installed.

Guideline 6: Quality assurance

> *For accurate interpretation of indicator results, it is necessary to understand their degree of validity. A quality assurance plan should outline the steps in collection and computation of data, and should identify*

the data quality objectives for each step. It is important that means and methods to audit the quality of each step are incorporated in the monitoring design.

Evaluation: After integration of the data, a quality check on the data was performed by analyzing the species list of each of the ecosystem components to see whether synonyms or misclassified species occurred in the lists. These were omitted from the analysis. As the valuation was done by using available data, no quality control of the initial sampling and sample treatment and analysis of the different monitoring programs can be performed. One drawback of the development of the protocol as it stands now, is the fact that no sensitivity analysis was performed to assess the reliability of the valuation and to assess which assessment questions or ecosystem components have the largest impacts on the outcome of the valuation. Also the scoring system, and especially the choice of division into five classes, should be statistically analysed. This is something which should be investigated in the future.

Guideline 7: Monetary costs

Estimates of all implementation costs should be evaluated. Cost evaluation should incorporate economy of scale, since cost per indicator or cost per sample may be considerably reduced when data are collected for multiple indicators at a given site. Costs of a pilot study or any other indicator development needs should be included if appropriate.

Evaluation: The only costs that should be taken into account for the application of this indicator to a certain study area, are the costs of scientific personnel for the data analysis and costs for hard- and software. No costs for sampling gear and personnel or laboratory treatments need to be taken into account, unless no biological data would be available for a certain area and new samples have to be taken, which is a very unrealistic. As the application of the valuation protocol should only take some months of work, the corresponding cost should be relatively small.

Guideline 8: Estimation of measurement error

The process of collecting, transporting, and analyzing ecological data generates errors that can obscure the discriminatory ability of an indicator. Variability introduced by human and instrument performance must be estimated and reported for all (sub-)indicator measurements.

Evaluation: While the parsing of overall variance into specific components (i.e. measurement error) is essential to the estimation of trends, biological valuation is more concerned with the estimation of intrinsic value. Measurement error was not evaluated specifically as only already available data were used. All sub-indicators were measured with standard methods and equipment, for which information on measurement errors is available in the literature. Measurement errors can be introduced into the data from three primary sources: collection of the sample, handling and preservation of the sample, and activities in the laboratory. In the field, variability in the sample would be associated with the volume of grabs, incorporation of water in the sample, and human error associated with sieving, preservation or observation mistakes (e.g. seabird and sea mammal countings). In the lab, errors could occur in the storage and sorting samples, in the identification and enumeration of species, in the use of laboratory equipment, and in the input of the data in databases. Although the magnitude of variability in the indicator that is associated with these sources of measurement error was not quantified, some potential measurement errors could be minimized by averaging data from replicate samples. Some errors due to the use of different sampling techniques could be eliminated by only using data which were gathered with the same technique, as was done for macrobenthos data from the Belgian part of the North Sea (BPNS) (Chapter 4). Also, measurement errors will be minimal due to the standardized methods employed and the fact that only data from monitoring programs, executed by trained personnel and under quality control requirements, should be used for marine biological valuation.

Guideline 9: Temporal variability (within-season)

> *The available data for indicator assessment can be obtained from different sampling campaigns, ranging over different years and seasons. Within-field season variability should be estimated and evaluated. In some cases, indicators are applied only within a particular season, time of day, or other window of opportunity when their signals are determined to be strong, stable, and reliable. This optimal time frame, or index period, reduces temporal variability considered irrelevant to the objectives of the indicator assessment. The use of an index period should be defended and the variability within the index period should be estimated and evaluated.*

<u>Evaluation:</u> Within-season variability was mostly not investigated during the biological valuation of the case study areas and all species data for the same grid cell from different seasons were averaged. This was done to have a minimal loss of data, available for the valuation. Biological valuation maps therefore have a medium-term reliability and should be updated after a period of time (several years) to reflect the medium-term variability of the biological value. For some case study areas, like the Isles of Scilly, it was very difficult to obtain a large dataset for certain ecosystem components, so it was decided to use all data for

the analysis, which allowed for a better coverage of valued grid cells. Also, when data need to be extracted from literature sources, information on the season (or month) of sampling is usually not indicated, which disables the analysis of within-season variability. As a test case, within-season variability was evaluated for the BPNS. This was done for epibenthos and demersal fish data, where only data from the most relevant season (i.e. season where the average density of the species was highest) were used for the valuation. A similar procedure was used for seabird data of the BPNS, where only data were retained from the months in which the average density was at least 25% of the value of the month with the maximal density. Such in-depth variability analysis is only possible when a large dataset is available for the valuation exercise, which was the case for the BPNS (Chapter 4). Although within-season variability could not be examined for each of the selected case study areas, it is necessary to exclude such temporal variability from the analysis if possible. This will enhance the reliability of the valuation and could indicate stronger and more stable value trends.

Guideline 10: Temporal variability (across years)

> *Indicator responses may change over time, even when ecological condition remains relatively stable. Observed changes in this case may be attributable to weather, succession, population cycles or other natural inter-annual variations. Estimates of variability over years should be examined to ensure that the indicator reflects true trends in ecological condition for characteristic that are relevant to the assessment question.*

Evaluation: Marine biological value integrates data from samples (or observations), taken during several years in diverse monitoring programs or other measuring campaigns. Unless these monitoring programs investigated time series over several years, samples were usually not taken at the same sampling stations. When such time series are available, the protocol for marine biological valuation indicates that these data should be averaged to get one value per sampling stations. In this way, anthropogenic and natural variations in parameters over years are smoothed. Most case study valuations described in Chapter 4 use datasets which range over a 10 year period. Because the marine environment is a highly dynamic and open system and because different ecosystem components show a high variation (e.g. benthic communities) valuation maps have to be updated after a certain period of time to reflect the most recent value status of the study area. However, due to high sampling intensity needed to update marine biological valuation maps, these maps cannot be updated frequently enough to reflect real interseasonal or interannual differences in value. So, only maps based on data from a longer time period, giving a summary of the medium-term variability in value, can be developed.

Guideline 11: Spatial variability

> *Indicator responses to various environmental conditions must be consistent across the region under observation if that region is treated as a single reporting unit. Locations within the reporting unit that are known to be in similar ecological condition should exhibit similar indicator results. If spatial variability occurs due to regional differences in physiography or habitat, it may be necessary to normalize the indicator across the region, or to divide the reporting area into more homogeneous units.*

Evaluation: As marine biological valuation is not designed to assess the biological status of an area against some environmental conditions or human pressures, it is not possible to evaluate biological value of subzones against a certain gradient to test its consistency in similar ecological conditions. All subzones (or gridcells) within a study area are treated as equivalent units that are valued relatively to each other. So, only the range in values across subzones determines the boundaries of the value classes of a study area. This can be seen as a normalization of the indicator across the study area. The total biological value of a subzone is determined after integration of the data which are available for that subzone and different subzones can be valued based on different amounts or types of data. This could potentially lead to over- or underestimation of the biological value, when the score of a certain subzone is extremely low or high (due to an extreme low quantity of data for that subzone) in comparison to the other subzones.

Guideline 12: Discriminatory ability

> *The ability of the indicator to discriminate differences among sites along a known condition gradient should be critically examined. This analysis should incorporate all error components relevant to the program objectives, and separate extraneous variability to reveal the true environmental signal in the indicator data.*

Evaluation: No condition gradient can be established for marine biological value (see guideline 11) and as such it is difficult to assess the discriminatory ability of the indicator. Differences among subzones are discriminated based on comparisons between the subzones (relative valuation strategy). Subzones receive a higher value if they score higher on certain assessment questions than other subzones (Chapter 3). Because of this relative valuation it can be assured that subzones, which are classified in the same value class, scored similarly for the same sub-indicators and have the same “status”.

Guideline 13: Data quality objectives

The discriminatory ability of the indicator should be evaluated against data quality objectives and constraints. It should be demonstrated how sample size, monitoring duration and other variables affect the precision and confidence levels of the reported results, and how these variables may be optimized to attain stated assessment goals.

Evaluation: The protocol for marine biological valuation specifies that reliability scores should be determined for each of the biological values. Reliability should be assessed at two different levels: the “data availability” score should give an indication of the amount of data (number of samples/observations, replicates, sampling stations) that were available for each subzone and the “reliability of information” score should indicate how many assessment questions could be answered per subzone (as this gives and idea of the number of sub-indicators and ecosystem components that could be assessed). The higher these two scores are for a subzone, the more reliable their estimated value will be. Marine biological valuation maps should therefore never be used without simultaneous consultation of these two reliability maps (Chapter 3 and 4).

Guideline 14: Assessment thresholds

To facilitate interpretation of indicator results by the user community, threshold values or ranges of values should be proposed that delineate acceptable from unacceptable ecological condition. Justification can be based on documented thresholds, regulatory criteria, historical records, experimental studies, or observed responses at reference sites along a gradient. Thresholds may also include safety margins or risk considerations. Regardless, the basis for threshold selection must be documented.

Evaluation: Threshold selection (or the choice of value class boundaries) is based on the range of scores obtained for each (sub-)indicator (Chapter 3 and 4). The range of the scores is divided by five to get five value classes (very low, low, medium, high, very high). High and very high values, accompanied with a high reliability score, indicate that the user should be careful when they want to implement new developments in these subzones, because these subzone are important for a number of ecosystem components and for different ecosystem functions.

Guideline 15: Linkage to management action

> *Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. Policy makers and resource managers must be able to recognize the implications of indicator results for stewardship, regulation or research. An indicator with practical application should display one or more of the following characteristics: responsiveness to a specific stressor, linkage to policy indicators, utility in cost-benefit assessments, limitations and boundaries of application, and public understanding and acceptance.*

<u>Evaluation:</u> The indicator "biological value" is extremely valuable for marine spatial planning, where past and future site selections for human uses, which are mostly based on socio-economic aspects, need to be weighted against the biological value at these sites. Marine biological valuation is a tool to call attention to areas with particularly high ecological or biological significance. By determining whether subzones have a high or low intrinsic value within a certain study area, it facilitates the provision of a greather-than-usual degree of risk aversion in management of activities in these subzones. Biological value can not be used to assess its responsiveness to a specific stressor as the indicator was not developed to be used in impact assessments and only gives an idea of the intrinsic biological value of an area (Chapter 2A). The value of the indicator lies in its applicability across geographic areas (Chapter 4) and its ability to provide local assessments of biological value. When marine BVMs are revised after a certain period of time, changes in the biological value can be evaluated in the framework of management actions which were implemented in time that elapsed between the development of the maps. Because the indicator value is determined on a relative scale, it can be applied to every region without the need of reference data sets or fixed class boundaries.

Evaluation of past management actions with respect to biological valuation

As described in guideline 15 of the EPA guidance document, an indicator with practical application should be able to provide information to support a management decision or to assess the success of past decisions. Here, the BVMs of the BPNS and DPNS are compared with some management decisions which were recently made for this area.

The Royal Decree of 17 May 2004 declared which area within the Belgian Exclusive Economic zone (EEZ) could be used for the implementation of future concession zones for windmill parks. The choice of this area was mainly made based on socio-economic and physical factors (e.g. distance to the coast, interference with already existing activities in the EEZ, connection to the electricity net at the coast, visibility from the coast, the wind availability, water depth and composition of the seabed). Two locations within this area have already been claimed by C-Power and these are situated on the Thornton Bank (Figure 1). During the preparation phase of the Royal Decree, biologists were also consulted to see whether the selected area did not interfere with subzones of high biological value. At that time, no integrated marine BVMs existed, so the decision makers could only rely on the expert judgement of selected scientists. No particularly high biological value could be linked to the area or parts of it, based on this consultation. However, as can also be seen on Figure 1, the application of the biological valuation protocol to the BPNS showed that the Thornton Bank and the area north of it seem to harbor a high biological value. This example shows that it would have been worthwhile to postpone the installation of the Royal Decree until more integrated biological information was available. Although this does not necessary mean that the installation of the windmills will lower the biological value of this area, based on the precautionary principle, the information of the BVM could have suggested to avoid this area and select another areas with a lower biological value, if this was socio-economically viable as well. Still, the BVM can be used for the future selection of concession zones for windmills within this larger area, as several low value subzones are available as well. Two other concession areas have recently been allocated to Eldepasco and Belwind, and these consortia are now preparing environmental impact assessments. Eldepasco plans to build a windmill farm on the Bank zonder Naam, north of the C-power concession area, and Belwind has selected the Blighbank, north of the Bank zonder Naam, to build its windmills on. Especially this last concession area seems to be located in an area which has a lower biological value.

In 2005, the harbor of Oostende asked permission for the aquaculture of blue mussel (*Mytilus edulis*) in four different sites (indicated as Z1 to Z4 on Figure 1). Area Z4 overlaps with the area for windmill parks and should allow for the simultaneous culture of Bivalves around the bases of the windmills. Areas Z1 to Z3 are smaller and are associated with smaller structures (radar tower or measurement post). Conform the Law for protection of the marine environment in sea areas under Belgian jurisdiction (20 January 1999), an environmental impact assessment (EIA) for this activity was performed and the competent Minister has approved the permission for the production of Bivalves in these four zones. Analysis of sites Z1, Z2 and Z3 on the marine BVM shows that sites Z1 and Z2 are situated in areas with a high biological value, while site Z3 is located in an area of rather low to medium biological value.

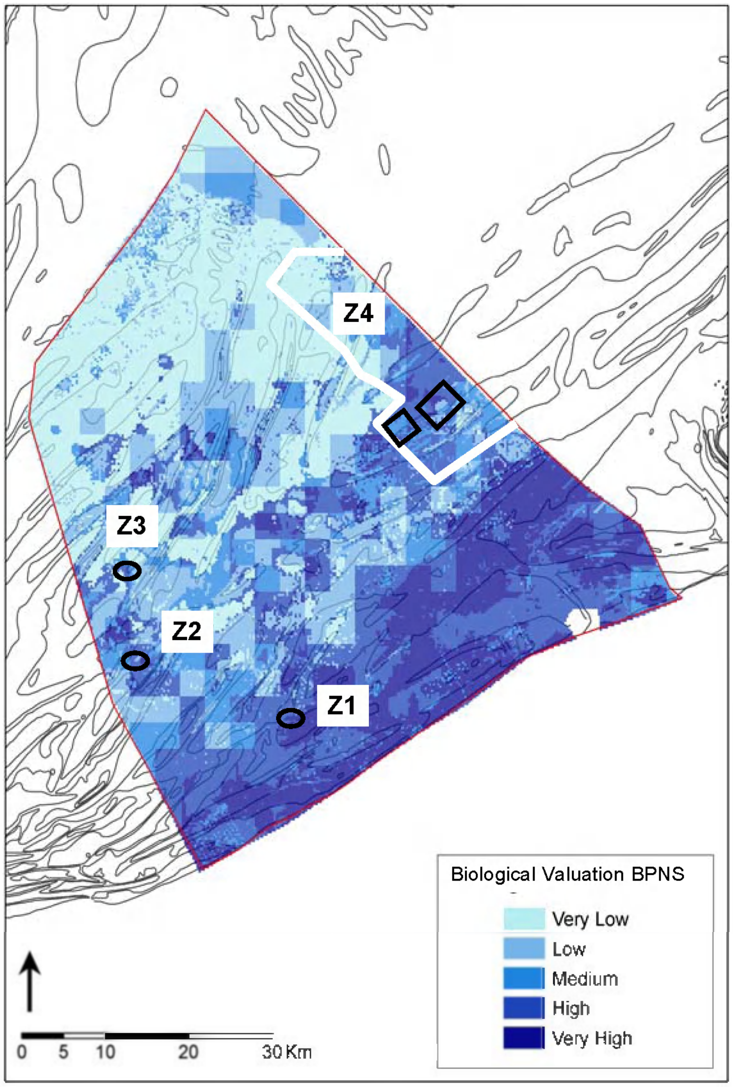

Fig. 1: Belgian concession zone for offshore windmill farms (Z4) with indication of the approved windmill zones for C-POWER (black squares within Z4) and the four zones for production of Bivalves (Z1-Z4) (reproduced from MUMM website www.mumm.ac.be).

Detailed investigation of the valuation maps of the different ecosystem components (see Appendix 1 of Chapter 4) learns that the high value of site Z1 is mostly influenced by the high value for seabirds and the medium to high value for macrobenthos, while the high value of site Z2 is due to a combination of high values for demersal fish and epibenthos. Different impacts of the aquaculture of Bivalves in marine ecosystems were determined in the EIA of this proposal, both at the scale of the ecosystem (influence on material in suspension, influence on primary production, influence on secondary production and competition with zooplankton, change of the natural nutrient fluxes, transfer of material from the planktonic to the benthic food web and organic enrichment of sediments) and at a more local scale (accumulation of mussel shells around the culture, presence of fouling community, attraction of birds, fish and parasites, outbreaks of diseases, loss of equipment) (MUMM, 2005). It seems likely that these effects could lead to changes in the biological value, although this can only be investigated by revision of the maps after the sites have been operative for some time. The effect on biological value could be both negative (decrease of value due to organic enrichment of the seabed or diseases) and positive (increase of value due to aggregation of fish and seabirds around the structures). If the BVM of the BPNS would have been available at the time of the EIA, this information could have been used in the decision making phase and it could have been advised to select two other sites, which are located in areas with a lower biological value. To conclude, BVMs can only be used as a warning signal during EIAs and further investigation of the impacts of a marine activity (by applying criteria such as vulnerability) will be necessary.

The Netherlands are planning to build a new port and industrial zone on the North Sea (Maasvlakte 2 project in the northern part of the Voordelta area). This will lead to the loss of a part of the southern shallow coastal area. Because this coastal zone is known for its high biological significance (Lindeboom *et al.*, 2005) and also contains an area which is designated under the European Habitats Directive, measures need to be taken to compensate for this loss. Physical compensation, by means of the creation of a similar surface area in the North Sea through depolderisation, is impossible, but EU guidelines also allow compensation by means of quality improvement of another part of the North Sea coastal ecosystem. Because one seeks for a quality improvement of 10%, the compensation area needs to be larger than the part that is lost. The study of Lindeboom *et al.* (2002) investigated which areas are suitable as potential compensation areas and concluded that an area in the Voordelta (Figure 2) is a realistic option to compensate for the marine natural values which will be lost due to the development of Maasvlakte 2. Comparison of the location of this future compensation area with the marine biological valuation map of the Dutch part of the North Sea (DPNS), indicates that the compensation area overlaps with subzones which received a medium to high biological value. The data availability map (Figure 9 in Chapter 4) however only showed a low to medium level of data available for the value assessment. Contrary to this, the ‘reliability of information’ label (Figure 9 in Chapter 4) for this subzone indicated medium to high reliability, which means that although the amount of data to base the value on was rather low, information on several ecosystem components is integrated for this subzone. This renders the overall reliability of the estimated value of the subzones within the proposed marine reserve area relatively high. The chosen area for the compensation area therefore seems to be ideal from a biological value point of view. The fact that this area will comprise subzones that are important for a number of ecosystem components can only be seen as beneficial. The fact that this area was assessed to have a medium to high biological value, relatively to the other subzones of the DPNS, could indicate that the quality status of the area is already good, which could decrease the management measures that will need to be taken to attain the 10% quality improvement in the compensation area.

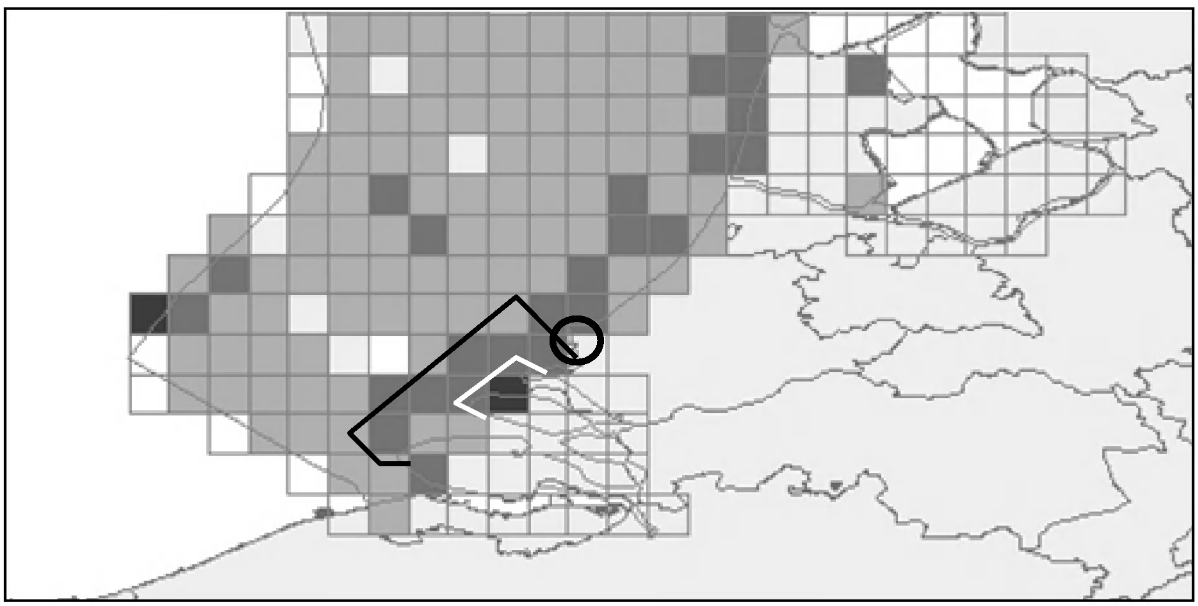

Fig. 2: Part of the BVM of the DPNS, with indication of the Voordelta area (black lines), the location of Maasvlakte 2 (circle) and the area in which the marine nature reserve will be located (white lines). (www.rijkswaterstaat.nl).

Conceptual framework for the applicability of marine biological valuation for marine policy and management

The present thesis described a protocol for biological valuation in marine environments. Due to increasing socio-economic pressures on the marine ecosystem, managers and policy makers require baseline maps showing the biological value of different subzones within an area. Such integrated biological information should be analyzed complementary to socio-economic aspects when new developments at sea are planned or when past management decisions are evaluated, and is thus essential for sustainable spatial planning (Chapter 1). Figure 3 provides a conceptual overview of the different parts of this thesis and can also be used to assess the applicability of the protocol for marine biological valuation. Next to that, the flow-chart gives an overview of the management issues, which can not be answered directly by the developed valuation protocol and for which additional information is needed.

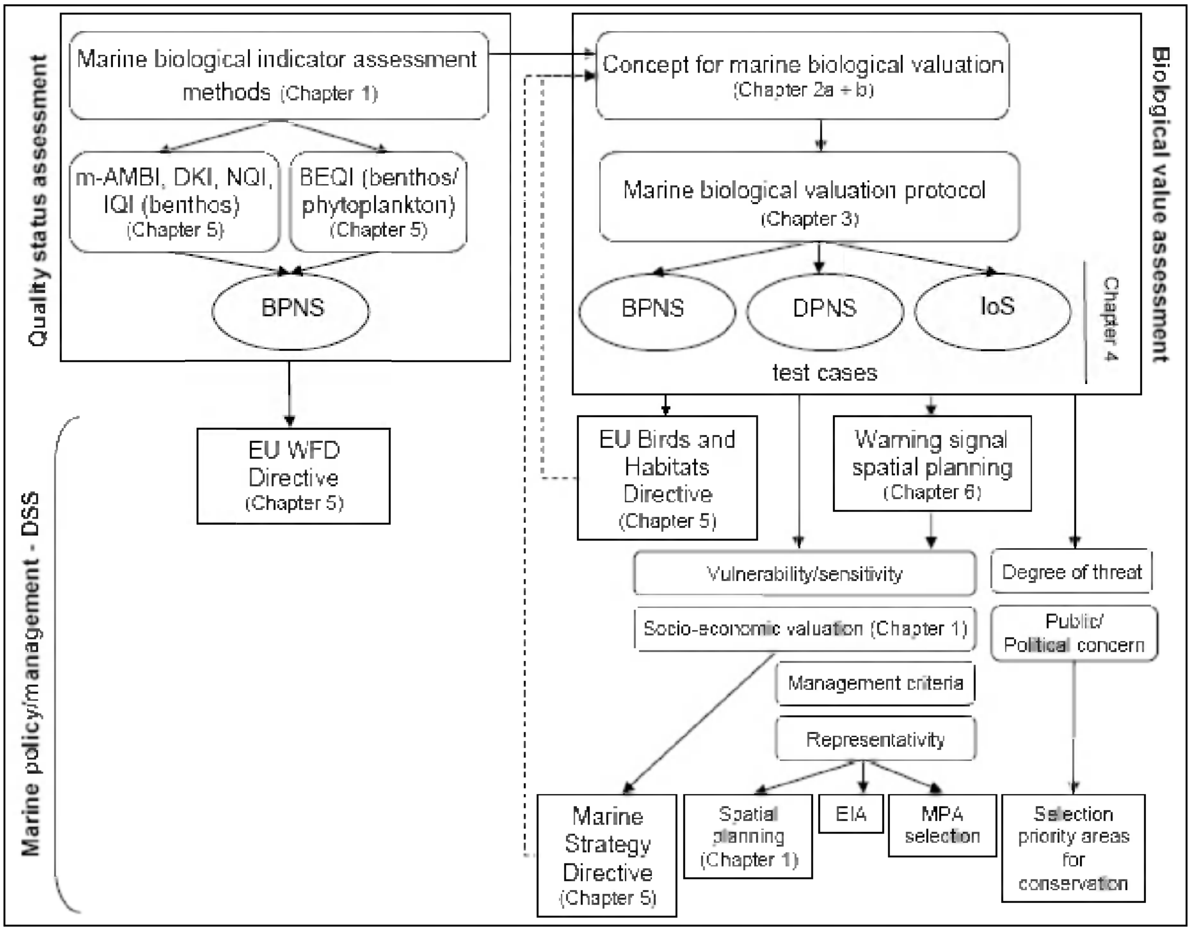

Fig. 3: Conceptual overview of the applicability of marine biological valuation for marine policy and management (EIA = environmental impact assessment, MPA = marine protected area, WFD = Water Framework Directive).

The thesis developed a concept for marine biological valuation around a selected set of valuation criteria which can be related to all organizational levels of biodiversity (Chapters 2A and 2B). This general framework allows for the integration of available biological data on different levels and for different ecosystem components, which results in one indicator estimate of the intrinsic biological value at a certain place. The valuation criteria were selected after a thorough review of existing ecological criteria from literature and (inter)national legislation (including the European Directives which are relevant for marine waters). This approach was chosen so that previous efforts on this matter were not neglected but integrated in the valuation concept.

A detailed and straightforward protocol was built around this valuation concept (Chapter 3) and was applied to three different test case areas (BPNS, IoS and DPNS), which differed in geographical scale, amount and quality of available data and human pressure on the environment (Chapter 4). The applicability of the valuation protocol for marine policy was also investigated by analyzing the scope of different European Directives (Habitats and Bird Directive, Water Framework Directive and (future) Marine Strategy Directive) and by comparing implementation efforts in the BPNS for these Directives with valuation results. While marine biological valuation seems to be a valuable tool for future implementations of the Birds and Habitats Directive, additional information is needed for full implementation of the Marine Strategy Directive. The aim of the Water Framework Directive (WFD) is to assess the ecological status of coastal waters, with respect to anthropogenic impacts, and this cannot be evaluated with the valuation protocol, whose objectives are too different. Other ecological indicators were evaluated for the implementation of the WFD in Belgian coastal waters (Chapter 5). The final chapter of this thesis evaluated the applicability of "marine biological value" as a multi-metric ecological indicator and assessed its use in marine management by screening past management decisions in the light of the developed biological valuation maps to see how the protocol could provide targeted advise to management in the future (Chapter 6).

Conclusion: Strenghts and Weaknesses of the developed biological valuation concept and protocol

This thesis focused on the development and application of a biological valuation protocol that can be used as a decision support system for marine management. Two key issues will be discussed below: (a) the contribution of the developed protocol to marine management, and (b) recommendations for future refinement of the methodology to increase its applicability and scientific acceptability.

A. Contribution of the marine biological valuation to marine management

In this thesis, a scientifically sound concept for marine biological valuation was developed. Because this concept was conceived during two international workshop with experts from different countries and with different backgrounds in marine ecology, we feel that the produced concept can be regarded as acceptable for a wider scientific community. While previous assessment methods or biological indicators mainly focussed on biological structures of marine biodiversity, the valuation method presented in this thesis incorporates all organizational levels of marine biodiversity, including both structures and functions/processes. This is a major benefit of the valuation concept and allows for a system-level biological assessment, based on the ecosystem approach, of the marine environment.

The protocol for marine biological valuation provides clear steps towards the development of biological valuation maps. This makes the valuation methodology highly transparent to its users and should therefore be preferred to expert judgement, which is highly subjective and untransparent, during management decisions. The protocol is also very flexible and enables easy incorporation of new data and subsequent valuation. As shown in Chapter 4, the protocol can be applied to areas with varying amounts of data, and can even be used when only qualitative occurrence data are available. This illustrates the applicability of the methodology.

To what extent can the developed methodology be used by marine managers?

Marine biological valuation maps are baseline maps describing the intrinsic biological value of subzones within a study area. The maps are constructed by integrating all available biological data of the area. They can be considered as warning systems for marine managers who are planning new, potential threatening activities at sea, and can help to indicate conflicts between human uses and a subzone’s high biological value during spatial planning. As such, they enable marine managers to adopt the precautionary principle during their decisions.

Anyone who wants to apply the methodology to a certain marine area with respect to marine management, should clearly state beforehand what marine biological value means and for which purposes the obtained valuation maps can be used. It is crucial that managers or stakeholders understand what the maps present and how they should be interpreted. If not, the risk exists that the valuation maps are used for things they were not designed for. The maps always should be used simultaneous with the reliability maps, so that managers get an idea of the amount of data on which the valuation was based.

As shown in Chapter 5, the marine biological valuation protocol could be used for the implementation of the Habitats or Birds Directive. The information provided by the maps and the underlying data could enhance the future selection of new NATURA 2000 sites.

Another major benefit of the development of marine biological valuation maps, is the fact that the creation of such maps asks for the integration of all available biological data. These data, which are in most cases distributed over different institutes or even different countries, are then gathered in integrated databases. This could certainly enhance future biological assessments or projects, even if they are not related to biological valuation, by reducing the time and money needed to extract these data from different databases and/or literature sources.

The biological valuation concept and protocol seems to agree well with the criteria which are described in documents concerning the future Marine Strategy Directive. This could mean that biological valuation could be a first step towards the implementation of this Directive in the future.

For which management issues can the developed methodology not be used?

As already stated in the previous chapters, it should be emphasized that the biological valuation maps give no information on potential impacts that an activity could have on a certain area, since criteria like vulnerability or resilience are deliberately not included in the valuation concept.

The development of decision support tools for the selection of marine protected areas could build on the valuation methodology by adding criteria like representativeness, integrity or socio-economic value to the framework. Since these criteria are not incorporated in the valuation concept, managers should avoid using the valuation maps for conservation purposes. The fact that a certain area receives a high biological value through this methodology does not necessarily mean that this area should be protected. Additional analyses should be performed for this purpose.

B. Recommendations for future work

When starting the project on marine biological valuation, the expectations of the outcome were high. We intended to design a concept and protocol that was objective, transparent and scientifically acceptable. The methodology also had to be applicable to any marine area, regardless of the amount and quantity of the biological data which were available. Applying the methodology would then lead to maps showing the biological value of all marine ecosystems. Although the developed methodology already fulfils a lot of the criteria mentioned above, it should be recognised that producing biological valuation maps for each marine environment is still utopic. The methodology certainly needs further refinement and testing before it can and will be used as a decision support system for marine management. Some recommendations for future improvement of the methodology are described here.

Although the protocol for marine biological valuation tries to exclude all subjectivity, some subjective steps in the protocol can still be recognised. For instance, no final scoring system has been proposed in the protocol, which still allows future users of the valuation protocol to select the scoring system, whose outcome best suits their own hypotheses. In the future, more tests with different scoring systems need to be performed to see how the scoring system and the division into value classes influences the valuation outcome of the different subzones. To have better agreement with the EU Water Framework Directive, a similar integration method (assigning the total ecological status similar to the lowest score of its constituent ecosystem components, cf. the “one out, all out” principle) could be proposed for marine biological valuation. This could further increase the adoption of the precautionary principle in marine management. Another step in the protocol where subjectivity cannot be excluded at this moment, is the selection of ecologically significant species. At this moment, only fragmentary literature sources to identify such species is available, especially on case study level, which forces the user to base this selection on expert judgement of scientists with experience with the marine environment and the ecosystem components under consideration.

Following this statements about the exclusion of subjectivity, a general sensitivity analysis on the valuation protocol should be performed. A statistical analysis, identifying the assessment questions or ecosystem components that have the largest influence on the outcome of the valuation should be identified and solutions should be developed to decrease this bias to a minimum. Also questions can be raised whether it makes sense to treat all ecosystem components equally. Mobile components such as seabirds or marine mammals, whose populations can be dependent on conditions occurring elsewhere, are now getting the same weight as sessile benthic groups. Next to that, it should be evaluated whether the inclusion of very fragmentary data with a low distribution over a case study area should be included in the valuation. The inclusion of such focalised data can introduce a bias in the total valuation or the estimation of the reliability of the results.

Another crucial point for further refinement of the methodolgy is the provision of uniform guidance in the selection of grid cell size for the delineation of the grid sizes. The selection of grid sizes should be ecologically meaningful for the ecosystem component under consideration. Also, the potential use of extrapolation and interpolation techniques or predictive modelling should be investigated to see how these tools could enhance the development of valuation maps with a higher coverage.

Until now, all case study areas which have been biologically valuated were relatively small local areas. No tests on a regional level, as suggested by de adapted concept of marine biological valuation (Chapter 2B), have been performed. This is definitely something which should be explored in the future, especially to place the local values into a broader, regional perspective. This could also be useful for the implementation of European Directives, like the Habitats or Birds Directive, which clearly emphasize the importance of a regional viewpoint on biological importance (especially in the framework of the NATURA 2000 network). It could also be worthwile to see how the developed methodology performs in transitional waters or coastal areas (e.g. dunes, beaches). One aspect which could complicate the use of the methodology in for instance estuarine systems, is the fact that these systems are naturally impoverished due to their inherent high variability in physico-chemical conditions, leading to reduced abundance and biomass. This could result to cases where these naturally stressed environments are given a low biological value estimate, compared to marine environments (so-called Estuarine Quality Paradox as introduced by Elliott & Quintino (2007)).

ANNEX A: IDENTIFICATION, DEFINITION AND QUANTIFICATION OF GOODS AND SERVICES PROVIDED BY MARINE BIODIVERSITY: IMPLICATIONS FOR THE ECOSYSTEM APPROACH

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Abstract

This paper identifies and defines ecosystem goods and services provided by marine biodiversity. Case studies have been used to provide an insight into the practical issues associated with the assessment of marine ecosystem goods and services at specific locations. The aim of this research was to validate the definitions of goods and services, and to identify knowledge gaps and likely difficulties of quantifying the goods and services. A validated theoretical framework for the assessment of goods and services is detailed, and examples of the goods and services at a variety of case study areas are documented. These results will enable future assessments of marine ecosystem goods and services. It is concluded that the utilisation of this goods and services approach has the capacity to play a fundamental role in the Ecosystem Approach, by enabling the pressures and demands of society, the economy and the environment to be integrated into environmental management.

Keywords: Marine biodiversity, Goods and services, Ecosystem Approach, Environmental management

Introduction

To ensure environmental decision making is sustainable, efficient and equitable it is essential that all social, economic and environmental impacts of a development, both short and long term, are identified and measured (Daily *et al.*, 2000). The need for this holistic approach is increasingly apparent in environmental policy and is implicit in the Ecosystem Approach. This approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. The term ‘Ecosystem Approach’ was first applied in a policy context at the Earth Summit in Rio in 1992, where it was adopted as an underpinning concept of the Convention on Biological Diversity. It now plays an integral part in environmental policy, for example it was endorsed by the World Summit on Sustainable development in Johannesburg in 2002, and is implicit in the European Water Framework Directive, the approach to halt the loss of biodiversity by 2010 as agreed in Gothenburg by the European Union Heads of Government, and the Ramsar Convention (Laffoley *et al.*, 2004).

One method of ensuring the integration of social, economic and environmental demands and pressures, as required by the Ecosystem Approach, is to utilise the concept of ecosystem goods and services. Goods and services are defined as ‘‘the direct and indirect benefits people obtain from ecosystems’’. Assessing ecological processes and resources in terms of the goods and services they provide translates the complexity of the environment into a series of functions which can be more readily understood, for example by policy makers and non-scientists. Describing the environment in this way also enables a true understanding of exactly what is being gained and lost when exploitation and development takes place (Holmlund & Hammer, 1999; Borgese, 2000; Weslawski *et al.*, 2006). Research on ecosystem goods and services began in the late 1960’s and this area has developed rapidly in the last decade. However, despite many studies identifying, defining and classifying goods and services (Costanza *et al.*, 1997; Pimentel *et al.*, 1997; Ewel *et al.*, 1998; Moberg & Folke, 1999; de Groot *et al.,* 2002; Millenium Ecosystem Assessment, 2003), little research has been undertaken to assess if this approach is realistic or useful in management terms.

To address this issue this paper aimed firstly to identify and define the goods and services provided by marine biodiversity. Lewan & Söderqvist (2002) argue ecosystem services can be difficult to understand, and as such this paper aimed to present goods and services in a concise fashion with user friendly definitions. The focus is on marine biodiversity as the majority of the literature on goods and services has tended to be biased towards the terrestrial environment. In addition, biodiversity issues are playing an increasingly significant role in all areas of marine environmental policy (Sheppard, 2006; Defra, 2002; 2006). The term biodiversity has many different definitions (Sheppard, 2006), but as far as possible in this paper it is used to refer to richness and composition at species and functional type levels. However, goods and services accruing from living organisms are sometimes used as a proxy for those accruing from biodiversity, especially where information is not available. The provision of all the goods and services is linked to biodiversity, although the exact mechanism and quantification of this linkage is not discussed in this paper; further information on these linkages have been documented by Beaumont *et al.* (2006), Worm *et al.* (2006) and Balvanera *et al.* (2006).

Case studies have been used to provide an insight into the practical issues associated with the assessment of goods and services at specific locations. The aim of this research was to validate the list and definitions of goods and services, to investigate where goods and services are present, what form they take, the gaps in our knowledge and likely difficulties encountered when quantifying the goods and services. Quantification of the goods and services at the various case study sites was beyond the scope of this study. It was anticipated that providing a wide range of examples of the goods and services, at a variety of case study areas, would improve the overall understanding and definitions of the goods and services provided by biodiversity within the context of marine ecosystems.

Methodology

The study of goods and services crosses many disciplines, thus to facilitate this research a two day inter-disciplinary workshop, sponsored by the EU Network of Excellence: Marine Biodiversity and Ecosystem Function (MarBEF), was hosted by the Marine Biological Association, Plymouth, UK. At this workshop twenty one experts from a variety of disciplines adapted and refined previously defined approaches to goods and services (Holmlund & Hammer, 1999; Moberg & Folke, 1999; de Groot *et al.*, 2002; Millenium Ecosystem

Assessment, 2003), with the aim of identifying and defining the goods and services provided specifically by marine biodiversity. The results of this workshop are described below.

Working groups of experts attempted to collate secondary data on the provision of the goods and services at seven case study sites. Comparatively well studied sites were selected to provide good spatial and ecological variability including deep water sites, off-shore islands, small coastal areas, and reduced salinity habitats and encompassed a spectrum from near pristine to heavily impacted sites. The locations of the seven case study sites are detailed in Figure 1. Experts tried to identify readily available data that could be used to quantify the goods and services in the case study areas. Sources included the World Wide Web, peer reviewed and grey literature, published books, personal communications and expert opinion. The case study areas are briefly described below, as are the results of the investigation of their goods and services.

A. Atlantic frontier

The Atlantic Frontier comprises the waters at the edge of the continental shelf from the west of the Shetland Islands south to the Rockall Trough. It has a seafloor ranging from 200–2000 m water depth, opposing current streams of up to three knots, a strongly stratified water column varying in temperature by as much as 10°C and strong down-slope variations in sediment type.

B. Banco D. João de Castro, Azores

The sea mount Banco D. João de Castro is located in the Azores Archipelago between the islands of São Miguel and Terceira. The sea mount rises from an ocean bottom of 1000 m deep, its surface is at a depth of 13 m. From 13 to 45 m depth the ecosystem of Banco D. João de Castro is predominantly based on solar energy, but below that the ecosystem is based upon chemical energy as found at the sea mounts Menez Gwen and Lucky Strike also in the Azores waters.

C. Isles of Scilly

The Isles of Scilly is an archipelago of five inhabited islands and over 300 smaller islands, islets and rocks, 43 km WSW of the western extremity of the Cornish peninsula, mainland UK. The total area delimited by these islands is approximately 95km^2 and much of this area is shallow sea. Marine habitats on the islands include intertidal rocky and sandy shores with a wide range of exposure, sublittoral sands, seagrass beds, kelp beds and rocks.

D. Belgian part of the North Sea

The studied area is part of the southern bight of the North Sea and is characterized by a complex system of sandbanks which are virtually parallel with the coast, some of which emerge from the water at very low tides. The surface area of the Belgian part of the North Sea is 3600 km^2 (=0.5% of total surface area of North Sea), and the maximum water depth is 46 m.

E. Flamborough Head

Flamborough Head is situated on the north-east coast of England and comprises of cliffs, platforms, gullies, chalk reefs, sea caves and ledges, which provide habitat for many marine species including algae, invertebrates, fish, and birds. The Flamborough Head European Marine Site (EMS) covers an area of 6470 ha, with subtidal depths reaching 40 m within the site.

F. Gulf of Gdańsk

The Gulf of Gdańsk is in the south-east of the Baltic Sea enclosed by a large curve of the shores of Gdańsk Pomerania in Poland, and Kaliningrad Oblast of Russia. The maximum depth is 118 m, and surface water salinity is 8.28 PSU. The total surface area of the Gulf of

Gdańsk is 4296 km^2 and its volume is 236 km^3. Sandy bottom biotopes dominated by macrophyte vegetation mainly occur in the sheltered Puck Bay, There are also areas of stony (near the coastline) and muddy (deeper part) bottom covered with macrophytes and algae.

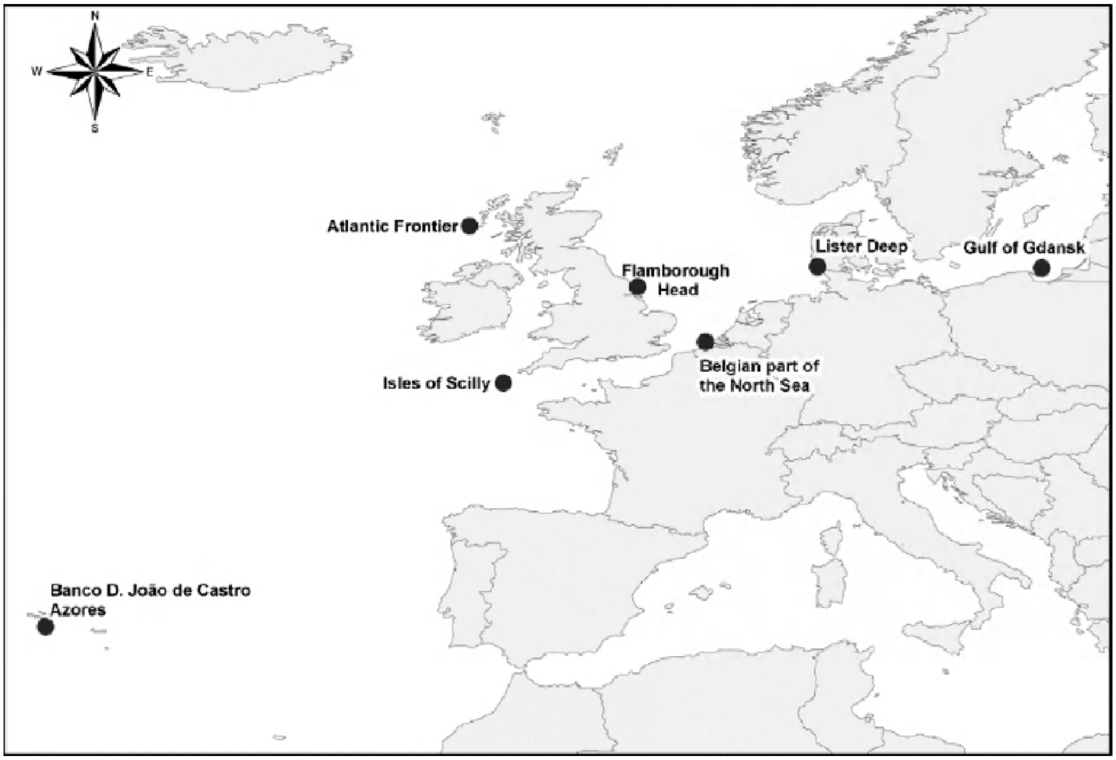

Fig. 1: Location of the seven case study sites.

G. Lister Deep

Lister Deep is a tidal inlet with surrounding mud flats of the Wadden Sea located in the border area between Denmark and Germany of the North Sea. Lister Deep covers about 400 km^2. Water exchange between the deep and the open North Sea takes place through a 2.8 km-wide tidal channel. 33% of the area belongs to the intertidal zone, 57% to the shallow subtidal (<5 m depth) and 10% to deeper tidal channels. The marine habitats include sandy and muddy tidal flats as well as sea grass and mussel beds.

Results

A. Goods and services provided by marine biodiversity

Many different methods of categorisation of goods and services have been defined (Costanza *et al.*, 1997; Pimentel *et al.*, 1997; Ewel *et al.*, 1998; Moberg & Folke, 1999; Holmlund & Hammer, 1999; de Groot *et al.*, 2002; Millenium Ecosystem Assessment, 2003, Hein *et al.*, 2006). The over-arching classification applied here follows the Millenium Ecosystem Assessment (2003) and Hein *et al.* (2006) and divides goods and services into four categories:

• Production services are products obtained from the ecosystem.
• Regulating services are the benefits obtained from the regulation of ecosystem processes.
• Cultural services are the nonmaterial benefits people obtain from ecosystems.
• Supporting services are those that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

Within each category a range of goods and services has been identified (Table1). Previous lists of goods and services have not included the less tangible benefits which are derived from the environment (Brito, 2005). As such, a small deviation from previous categorisations is the inclusion of the category ‘‘Option use value’’, with the accompanying service of future unknown and speculative benefits. This is the benefit associated with an individual’s willingness to pay to safeguard the option to use a natural resource in the future, when such use is not currently planned. In other words, it is the value of being able to change one’s mind, and of keeping one’s options open.
Hein *et al.* (2006) propose that option value is associated with all the categories, however, an option value for a specific service cannot be calculated, as this implies an expectation that this service will be used, and any expected future use is properly part of direct/indirect use, not option value.
There is some debate associated with the definition and concept of option value, as detailed further by Hanemann (1989) and Walsh *et al.* (1984), but option value can only be properly calculated for the whole ecosystem, not for the individual goods and services.

Table 1: Goods and services provided by marine biodiversity.

Category		Good or service
Production services	1	Food provision
	2	Raw materials
Regulation services	3	Gas and climate regulation
	4	Disturbance prevention (flood and storm protection)
	5	Bioremediation of waste
Cultural services	6	Cultural heritage and identity
	7	Congnitive benefits
	8	Leisure and recreation
	9	Feel good or warm glow (non-use benefits)
Option use value	10	Future unknown and speculative benefits
Over-arching support services	11	Resilience and resistance (life support)
	12	Biologically mediated habitat
	13	Nutrient cycling

1. Food provision

Definition: The extraction of marine organisms for human consumption.

Plants and animals derived directly from marine biodiversity provide a significant part of the human diet. Fisheries in particular, and the accompanying employment, provide a significant example of the importance of this function.

2. Raw materials

Definition: The extraction of marine organisms for all purposes, except human consumption.

A wide variety of raw materials are provided by marine biodiversity for a variety of different uses, for example, seaweed for industry and fertiliser, fishmeal for aquaculture and farming, pharmaceuticals and ornamental goods such as shells. The provision of raw materials results in significant employment opportunities. This category does not include dredge materials, oil or aggregates as these are not supported by living marine organisms.

3. Gas and climate regulation

Definition: The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms.

The chemical composition of the atmosphere and ocean is maintained through a series of biogeochemical processes. The maintenance of a healthy, habitable planet is dependent on processes such as the regulation of the volatile organic halides, ozone, oxygen and dimethyl sulphide, and the exchange and regulation of carbon, by marine living organisms. For example, organisms in the marine environment play a significant role in climate control through their regulation of carbon fluxes, by acting as a reserve or sink for CO_2 in living tissue and by facilitating burial of carbon in sea bed sediments. The capacity of the marine environment to act as a carbon sink will be affected by changes in marine biodiversity.

4. Disturbance prevention (flood and storm protection)

Definition: The dampening of environmental disturbances by biogenic structures.

Living marine flora and fauna can play a valuable role in the defence of coastal regions. The presence of organisms in the front line of sea defence can dampen and prevent the impact of tidal surges, storms and floods. This disturbance alleviation service is provided mainly by a diverse range of species which bind and stabilise sediments and create natural sea defences, for example salt marshes, mangrove forests and sea grass beds (Huxley *et al.*, 1992; Davison & Hughes, 1998).

5. Bioremediation of waste

Definition: Removal of pollutants through storage, burial and recycling.

A significant amount of human waste is deposited in the marine environment. Waste material can be organic, such as oil and sewage, as well as inorganic, comprising a huge variety of chemicals. Through either direct or indirect activity, marine living organisms store, bury and transform many waste materials through assimilation and chemical de and re-composition. For example, the bioturbation activity (reworking and mixing of sediments) of mega-and macro-faunal organisms within the seabed can bury, sequester and process waste material through assimilation and/or chemical alteration. These detoxification and purification process are of critical importance to the health of the marine environment.

6. Cultural heritage and identity

Definition: Benefit of biodiversity that is of founding significance or bears witness to multiple cultural identities of a community.

There is benefit associated with marine biodiversity for example for religion, folk lore, painting, cultural and spiritual traditions. Human communities living by and off the sea often attach special importance to marine ecosystems that have played a founding or significant role in the economic or cultural definition of the community. This identification may be associated with a strong economic interest in the extraction of the site but as economic significance decreases the community may attach increased symbolic values to the preservation of the site. For example a mussel bed may long have lost its economic significance while the symbolic importance may be high. This valuation should be distinguished from the economic importance of revitalised and commercialised cultural heritage which is included below under the heading Leisure and recreation.

7. Cognitive benefits

Definition: Cognitive development, including education and research, resulting from marine organisms.

Marine living organisms provide stimulus for cognitive development, including education and research. Information ‘held’ in the natural environment can be adapted, harnessed or mimicked by humans, for technological and medicinal purposes. Current examples of the use of marine information include: the study of microbes in marine sediments to develop economical electricity in remote places (Chaudhuri & Lovley, 2003); the inhibition of cancerous tumour cells (Self, 2005); the use of *Aprodite* sp. spines to progress the field of photonic engineering, with potential implications for communication technologies and medical applications (Parker *et al.*, 2001); the development of tougher, wear resistant ceramics for biomedical and structural engineering applications by studying the bivalve shell (Ross & Wyeth, 1997).

In addition, marine biodiversity can provide a long term environmental record of environmental resilience and stress. The fossil record can provide an insight into how the environment has changed in the past, enabling us to determine how it will change in the future. This is of particular relevance to current concerns about climate change. Bio-indicators, such as changes in biodiversity, community composition and ecosystem functioning, are also beneficial for assessing and monitoring changes in the marine environment caused by human impact. Ecophysiological responses of marine organisms to the changes in their environment, defined as biomarkers, can provide significant information for development of early warning systems for environmental degradation (Walker *et al.*, 2001).

8. Leisure and recreation

Definition: The refreshment and stimulation of the human body and mind through the perusal and study of, and engagement with, living marine organisms in their natural environment.

Marine biodiversity provides the basis for a wide range of recreational activities including: (sea) bird watching, rock pooling, beachcombing, sport fishing, recreational diving, and whale-watching. The provision of this service results in significant employment opportunities.

9. Feel good or warm glow (non-use benefits)

Definition: Benefit which is derived from marine organisms without using them.

Bequest value: The current generation places value on ensuring the availability of biodiversity and ecosystem functioning to future generations. This is determined by a person's concern that future generations should have access to resources and opportunities. It indicates a perception of benefit from the knowledge that resources and opportunities are being passed to descendants.

Existence value: This is the benefit, often reflected as a sense of well being, of simply knowing marine biodiversity exists, even if it is never utilised or experienced, people simply derive benefit from the knowledge of its existence (Hageman, 1985; Loomis & White, 1996).

The considerable importance which the wider public attach to maintaining diverse marine life is revealed through their interest in marine based media presentations, such as the "Blue Planet". In addition, articles on cold water corals frequently appear in the media (http://news.bbc.co.uk/1/hi/sci/tech/3719590.stm, 2004), despite the fact the majority of the general public will never see a cold water coral, they are interested in them and benefit from their existence.

10. Future unknown and speculative benefits

Definition: Currently unknown potential future uses of marine biodiversity.

Potential future uses of marine biodiversity have an option use value. This paper has explored current uses of marine biodiversity, option value reflects the importance of more uses being discovered in the future. The biodiversity may never actually be exploited, but there is benefit associated with retaining the option of exploitation. Any expected future use is not option value, but would belong under cognitive benefits.

11. Resilience and resistance (life support)

Definition: The extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping to alternate states (Hughes *et al.*, 2005).

Healthy ecosystems with high biodiversity can have greater resilience to natural or anthropogenic impacts (Hughes *et al.*, 2005). However, high biodiversity alone does not necessarily lead to improved resilience. It is necessary to have a range of species that respond differently to various environmental perturbations to enhance resilience and/or resistance. For example, if all species within a functional group respond similarly to anthropogenic pressures, such as over fishing and pollution, increased biodiversity will not alleviate these pressures.

12. Biologically mediated habitat

Definition: Habitat which is provided by living marine organisms.

Many organisms provide structured space or living habitat through their normal growth, for example, reef forming invertebrates, meadow forming sea grass beds and marine algae forests. These ‘natural’ marine habitats can provide an essential breeding and nursery space for plants and animals, which can be particularly important for the continued recruitment of commercial and/or subsistence species. Such habitat can provide a refuge for plants and animals including surfaces for feeding and hiding places from predators. Living habitat plays a critical role in species interactions and regulation of population dynamics, and is a pre-requisite for the provision of many goods and services.

13. Nutrient cycling

Definition: The storage, cycling and maintenance of nutrients by living marine organisms.

The storage, cycling and maintenance of a supply of essential nutrients, for example nitrogen, phosphorus, sulphur and metals, is crucial for life. Nutrient cycling encourages productivity, including fisheries productivity, by making the necessary nutrients available to all levels of the food chains and webs. Nutrient cycling is undertaken in many components of the marine environment, in particular within seabed sediments and salt marshes in shallow coastal waters and in the water column in deeper, offshore waters.

B. Assessing goods and services at seven case study sites

Data availability on goods and services at the case study sites was very varied in quality and quantity. Table 2 presents an overview of the results of the case studies. If the good or service is detailed as “present” this indicates that this good or service has been recorded at the case study area and that some information is available on the extent and method of provision, but it could not be quantified. Conversely, the term “not present” indicates that the data available suggests that the good or service is not present at the site. The term "unknown" is used when there is no information available on the good or service. Full details of the case study areas can be found in Appendix 1. Quantitative information in the form of monetary value was generally available for food provision, but these figures tended to be underestimates of the benefits as the monetary values often did not include revenue and employment created through the fish processing industry, retail sales, exports, and unreported catches (e.g. illegal fishing and recreational fishing). Some quantitative data was available for raw materials and leisure and recreation, but this was minimal and also tended to represent only a small portion of the total service.

Table 2: Overview of provision of goods and services at case study areas.[6]

Good/service	Case study area						
	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdansk	Lister Deep
Food provision	+	€	+	€	+	+	+
Raw materials	+	?	+	?	+	€	?
Gas and climate regulation	+	?	+	+	+	+	+
Disturbance prevention	0	0	0	0	0	+	?
Bioremediation of waste	+	?	+	+	+	+	+
Cultural heritage and identity	?	?	?	+	+	+	+
Cognitive benefits	+	+	+	+	+	+	+
Leisure and recreation	+	0	+	+	+	+	+
Feel good or warm glow	+	+	+	?	+	?	+
Future or speculative values	+	+	?	?	?	+	?
Resilience and resistance	?	+	+	?	?	?	?
Biologically mediated habitat	+	?	+	+	+	+	+
Nutrient cycling	+	+	+	+	+	+	+

The remaining goods and services could not be quantified from the available information. Of the regulation services, gas and climate regulation and bio-remediation were perceived to be of considerable importance at most sites, but there was very little data available on these services. Disturbance prevention was only considered to be of importance in the Gulf of

[6] 0: good or service not present in the study area, +: good or service present in the area, but not quantifiable in monetary terms, €: good or service present in the study area and quantifiable in monetary terms, ?: unknown whether the good or service is present in the case study area.

Gdańsk, and was not considered to be significant at any of the other sites, but this will probably not be the case at all coastal areas.

There was no information available on the service cultural heritage and identity at three of the sites: the Atlantic Frontier, the Isles of Scilly and the Banco D. Joãode Castro. This is due to a poor understanding of this service and very limited information availability. It may not be a true indication of the importance of this service. Leisure and recreation, cognitive benefits, and feel good or warm glow were all considered to be of importance at most sites.

The specific information provided on all the cultural services was very varied, and this possibly stemmed from a difficulty in understanding the exact nature of these services.

Future unknown and speculative benefits were considered to be important at four of the sites, and were classed as "unknown" at the remaining sites. This is indicative of the difficulty of defining, understanding and quantifying this service. The supporting services, biologically mediated habitat and nutrient cycling, were considered to be of importance at most sites. There was very little information on the service of resilience and resistance which was expected, as again this service is very difficult to define. Indeed, there was considerable confusion about precisely what this service was, thus quantifying it was likely to prove problematical.

Conclusions and discussion

This paper identifies and defines the goods and services provided by marine biodiversity, and presents an exploratory attempt to describe these goods and services at case study sites using only secondary data that was readily available. The case studies indicate that the list of goods and services is comprehensive, and that the majority of the definitions were workable and realistic. The definitions of the services cultural heritage and identity, resilience and resistance, and future or speculative values require further research as some confusion was noted about the precise meaning of these services.

The goods and services approach is a reductionist method, but the benefits arising from marine biodiversity are entirely dependent on the state of the whole ecosystem.
The sum of the parts of the system is less than the value of the whole system, and the different goods and services provided are intrinsically connected. Individual services can also provide additional benefit when examined in the context of the other services with which they coexist at wider scales (spatial or temporal) rather than the scale of investigation (e.g. those of our individual case study sites). The exploitation of services can have negative, positive or neutral impacts on the other services. Thus, although this classification of services breaks the environment down into specific components, the inter-dependency of these components, and overall value of the environment should be remembered. In addition, it is sometimes easy to forget that species do not actively endeavour to provide any goods and services. The provision of goods and services is merely a consequence of living organisms natural functioning.

The case study sites are well studied and have more data available than most marine areas. Even so, using present knowledge quantifying all the goods and services at any given site, in a comparable way, would be impossible. This indicates the difficulties likely to arise in applying the Ecosystem Approach. If environmental, social and economic concerns are to be integrated into an Ecosystem Approach to environmental management, policy makers need to be able to quantify the provision of goods and services, on a before and after, site specific basis to get a true idea of the impact of a development or human activity. To choose between management options, the values of the associated goods and services must be quantifiable and comparable. Given the short time scales associated with most environmental policy and management decisions it is unlikely that this would be possible.

Limited knowledge should not, however, be used as an excuse to delay the implementation of the Ecosystem Approach (Laffoley *et al.*, 2004). Despite the difficulties of quantifying all the goods and services it is still valuable to think about the importance of marine biodiversity in these terms since biodiversity generally, and marine biodiversity in particular, is a complex concept (Sheppard, 2006). Defining ecosystem processes and resources in terms of goods and services translates the complexity of marine biodiversity into a series of functions, which can be more readily understood, for example by policy makers and non-scientists.

As data is not available to quantify all of the goods and services, their assessment at a given site is likely to be biased towards those goods and services that are more data rich, such as food provision and recreation. There is a risk of assuming no data equates to no benefit. In the past this bias has contributed to the over exploitation, and resultant degradation, of the environment. The provision of goods are often given priority over services, as services cannot be seen or held, often do not yield immediate market value, and are generally more difficult to quantify. Services are, however, fundamental to providing humanity with a healthy and habitable planet, and are thus just as critical to human welfare as tangible goods. Utilising a goods and services framework reduces the likelihood that environmental managers will overlook certain goods and services when making a decision, and defining services alongside goods should raise their profile in environmental decision making. Adaptive management is required which utilises the available data within the context of the uncertainties, limitations and gaps in our knowledge.

The results of this study highlight knowledge gaps which should be addressed if an Ecosystem Approach to environmental management is to be successfully adopted. The disparity in data availability of goods versus services and the lack of availability of data to quantify services is less surprising if one considers that the ecosystem goods and services approach is adapted from a commonly used methodology of economists. Economists are accustomed to gathering data concerning benefits that accrue to man, primarily as valuation data. Natural scientists such as ecologists are only beginning to view ecosystem functioning in terms of its direct and indirect benefits to people. Whilst the benefits clearly exist, natural scientists are only just beginning to explore how to collect tangible data that can quantify them in a comparable way. Ecosystem services are a summary of complex interrelations of functions performed by a large variety of organisms at a range of spatial and temporal scales. The challenge is to model these functions in such away that data can be made available to quantify the services, or alternatively to find proxies for or indicators of these interrelated functions. Services such as resilience and resistance play a fundamental role in the continued delivery of all other goods and services, but little is known about the contribution of biodiversity to this service. Time and resources should be devoted to the fundamental services rather than the already well understood goods and services. At a more holistic scale, there are still large gaps in our understanding of goods and services including, inter-dependences, inter-variability, and vulnerabilities.

This research provides a validated theoretical framework for the quantification of ecosystem goods and services, including a wide range of examples from a variety of case study areas. It is intended that these results will enable and encourage future assessments of goods and services. The utilisation of this goods and services approach has the capacity to play a fundamental role in the Ecosystem Approach, by enabling the three pillars of society, the economy and the environment to be integrated into environmental management. However, the continued development of this approach must be undertaken in a cohesive manner. Established frameworks of goods and services should be applied to enable comparison between studies. Ideally a database of marine case studies and values should be collated, to again enable comparison between studies, and also allow benefit transfer of values which will reduce the time and resources required to undertake a study.

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Appendix 1: Provision of goods and services at case study areas[7]

Good/Service	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdańsk	Lister Deep
Food provision	Deep water fisheries have developed in last decade and include: black scabbardfish, blue ling, leafscale gulper shark, greenland halibut, orange roughy, roundnose grenadier	The value of registered fisheries is 1.5 Million € per year	There are 30 registered shellfish boats, potting or using large mesh (12.5 in.) fixed nets for crabs and lobsters, employing about 50 persons. There is only one small (8 m) trawler	Belgian sea fishing industry (both catches inside and outside) in 2002: landings: 25,810 tonnes (23,445 tonnes demersal fish/106 tonnes pelagic fish/2259 tonnes shellfish) profit: 91,911,000 €	Four main fishing methods: trawling, netting, potting and lines, to catch white fish, salmon and sea trout, and shellfish. There is also a developing sea bass fishery using pair trawling techniques	Total landings of commercial fishes (cod, herring, flat fishes, roach and others) in the Gulf of Gdańsk were 19067 tonnes in 2001. Seasonal freshwater fishery e.g. eel, pike perch and perch	Professional licensed fishery for mussels and cockle at a low level. Low scrimp trawling activity in the German part of the deep
Raw materials	The Portuguese dogfish and the leafscale gulper shark are valued for their liver oils, particularly squalene which are used in lubricants, as cosmetic bases and in the pharmaceutical industry	Unknown	Dried marine organisms are used in arts and crafts which are sold locally, and in arts and crafts lessons. Kelp is occasionally used locally as fertiliser	Unknown	Bait digging occurs on the shores from Sewerby to Flamborough Head. Fossil collection takes place at Sewerby and the South cliffs	The value of the Polish amber market is estimated to be in the region of 20 million €. Empty mussels are collected by people walking on the beach	Unknown
Gas and climate regulation	Sink for global carbon	Unknown	Bioturbators in the sediment will affect sediment-water fluxes of carbon and degradation and storage of carbon	Low density of phytoplankton and no macroalgae present so low impact on gas and climate regulation	Kelp forests act as a source and/or a sink for CO_2	Oxygen production and carbon sink by marine plants. DMS production by microplankton. Benthic organisms influence carbon circulation	High productivity of the ecosystem will affect carbon circulation
Disturbance prevention	Not present	Not present	Not present	Not present	Not present	Along coastline, macrophytes and macroalgae influence coastal erosion. Rhizomes and roots stabilize the sediment and leaves can reduce wave energy (unpublished data)	Marine biodiversity have an influence on sedimentation though the extent is unknown
Bioremediation of waste	Since 1982 no waste is dumped at sea, but contaminants will be washed off the land. Bioturbator activity will bury dilute and recycle contaminants	Unknown	Marine organisms bio-remediate waste that derives from sewage and agricultural run off. There is no industrial pollution on the Islands	This is a high energy area with great turbidity and sediment bedload transport, the organisms are capable of withstanding waste compounds, including organic matter from rivers, and redistributing them	Marine biodiversity is believed to be affected by, and play a role in processing a variety of wastes, including outputs from the distilling, brewing and food industries and sewage treatment works	Filtration by micro- and macro-organisms reduces the numbers of suspended particles, increasing water transparency. Bioturbation, is provided by macrofauna including polychaete worms, priapulids and bivalves	High productivity, deposition and filtering capacity. Although Eutrophication and pollution negatively impact marine species
Cultural heritage and identity	Unknown	Unknown	Unknown	Traditional shrimp fisheries take place which attracts some tourists	The site is a designated stretch of Heritage Coast and is internationally important for wildlife. This creates a special interaction between people and the environment	Local society (Cassubia) is strongly connected with the sea through culture, folklore, legends, and fisheries festivals. Local old traditionally run companies (maszoperie)	Local identity is connected to the sea. Historical evidence of the co-existence of humans and marine animal populations is present in landscape and society

[7] This analysis for the Belgian part of the North Sea (BPNS) should be seen as a preliminary exercise, done in 2004 at a European workshop. Further investigation is necessary to determine the actual provision of goods and services in the BPNS.

Appendix 1 (continued)

Good/Service	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdańsk	Lister Deep
Cognitive benefits	Research on impact of deep water trawls on the seabed and coral banks. Long-term environmental datasets exist (e.g. PAP and Rockall Trough) which are valuable, as they show evidence of large-scale change in diversity over time	The annual investment on research at this site by the Department of Ocean Sciences of Azores University is between 3000 and 10 000 Euros	This is a pristine location for research and education e.g. by Plymouth Marine Laboratory, EU projects and universities. Local schools use the shoreline for educational purposes. Regular diving expeditions to record subtidal marine life. This is a monitoring location for English Nature and the Joint Nature Conservation Committee	Few field trips at sea by universities and secondary schools, mostly education on the beach and dunes. The area has been explored by scientists (e.g. biologists, geologists, hydrologists), and there is good knowledge of various ecosystem components. Scientific data from the area is frequently used by international scientists	The habitats are a resource, used by schools and universities for education and research. Statutory monitoring is undertaken by authorities in relation to public health issues, specific surveys and national programmes	Importance in educational events, including use by schools, universities, technical universities, and local educational initiatives	The habitats and biodiversity of the Wadden Sea area is important for schools, universities and all kinds of educational activities. The area is intensively researched through more than 100 years
Leisure and recreation	Whale watching	Due to its distant position the demand for recreation is minimal	Tourism accounts for 85% of the Isles of Scilly economy, including sea angling, seal watching, scuba diving and bird watching	Diving, angling, Beach fisheries with bottom set gill nets, bird watching	Bathing, walking, bird watching, angling, rock-pooling, boating/canoeing, diving, day-trip cruises, rock pools and the Royal Society for the Protection of Birds reserve at Bempton Cliffs	Sea-bird watching, sea angling, recreational diving (35% of fishermen with fishing boats organize boat trips for recreational fishing). Limited by poor bathing water quality	Tourism is a major part of the economy on Romo and Sylt. Activities include bird watching, recreational fishing, hunting, seal watching and beachcombing
Feel good or warm glow	Articles on the Darwin mounds and cold water corals frequently appear in the media, despite the fact the majority of the general public will never see a cold water coral	There is a major interest in the videos and reports produced about this site	There is a local branch of the UK based Wildlife Trust charity within the Islands	There is no knowledge available of the public's point of view on this subject. Few people know what biodiversity exists at this site	Feel good values are considered likely to be positive because of its outstanding natural features	Not many people realize that there is marine biodiversity present in the site	Major interest in the conservation and restoration of ecosystem on local, national and international levels
Future unknown or speculative values	Poor knowledge of environment, thus it is likely that there are unknown habitats and species (≥50% species in any deep sea samples are new)	Possibilities for scuba diving	Unknown	Unknown	Unknown	The cold brackish waters may have produced unique genetic forms, so potentially considerable future value	Unknown
Resilience and resistance	Research provides an insight into environmental resilience and stress in the deep sea, but role of biodiversity unknown	High concentration of biodiversity that sustains, with other sea mounts and islands, the resilience of the surrounding ocean	In their pristine state they provide a reservoir for European biodiversity	Unknown	Unknown	Unknown	Unknown

Appendix 1 (continued)

Biologically mediated habitat	The coldwater coral and mass occurrence of large demosponges provide nursery and refugia for many deeper water species	Unknown	Extensive seagrass and sublittoral kelp beds. Encrusting epifauna on many of the rocky surfaces. Habitat modifying bioturbators are present in the sand	Epibiota associated with wrecks provide refugia for other organisms. *Lanice conchilega* reefs (protruding tubes) also provide refugium	Significant kelp forests (*Laminaria hyperborea*) near shore, and forests of *Laminaria saccharina* with red algal undergrowth in near shore	Seagrasses beds especially within the Puck Bay are used as refuge, nursery as well as feeding grounds by fish including commercial and protected species and sea-birds	Important refugia for birds and nursery for fish
Nutrient cycling	Physical upwelling and biological cycling by phyto and zoo plankton	The remoteness from emissions sources of nitrogen, phosphorus and sulphur leads to a negligible role of the biodiversity in nutrient cycling	Bioturbators that facilitate nutrient cycling are abundant in the sediments	High recycling due to high productivity, owing to anthropogenic inputs from the river Scheldt. High inputs of nitrogen from rivers and atmosphere result in *Phaeocystis* algal blooms	Flamborough Front is the boundary of the northern and southern North Sea and communities differ noticeably during the summer creating a very productive, nutrient-rich environment	Twenty three percent of nitrogen load, and 34% of phosphorous load are retained in system All of the retained phosphorus and a small part of the nitrogen is buried in the bottom sediments. The majority of the nitrogen was denitrified and removed from the system	High productivity results in high recycling. Import of nutrient from the North Sea due to tidal water exchange and from rivers

LIST OF ABBREVIATIONS

A	Abundance data
A-F	Aggregation-Fitness consequences
AL	Algae
AMBI	Azti Marine Biotic Index
AONB	Area of Outstanding Natural Beauty
BCI	Benthic Condition Index
BDNZ	Belgisch Deel van de Noordzee
BEQI	Benthos Ecosystem Quality Index
BHI	Biological Health Index
B-IBI	Benthic Index of Biotic Integrity
BOPA	Benthic Opportunistic Polychaetes Amphipods Index
BPI	Benthic Pollution Index
BPNS	Belgian Part of the North Sea
BQI	Biological Quality Index
BVM	Biological Valuation Map
BWK	Biologische Waarderingskaart
CEC	Commission of the European Communities
CITES	Convention on International Trade in Endangered Species of wild flora and fauna
CMS	Convention on the conservation of Migratory Species of wild animals
DEFRA	Department for Environment, Food and Rural Affairs
DENS	Density
DFO	Department of Fisheries and Oceans
DKI	Daske Kvalitet Indeks
DPNS	Dutch Part of the North Sea
DPSIR	Driver-Pressure-State-Impact-Response
DSS	Decision Support System
EB	Epibenthos
EBSA	Ecologically and Biologically Significant Area
EEI	Ecological Evaluation Index
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
ENCORA	European Network on Coastal Research
EPA	Environmental Protection Agency

EQI	Ecofunctional Quality Index
EQR	Ecological Quality Ratio
ERI	Ecologic Reference Index
F	Fish
FHI	Fish Health Index
FSI	Feeding Structure Index
G&S	Goods and Services
GIS	Geographic Information System
H	Hard sediments
HB	Hyperbenthos
HELCOM	Helsinki Commission
I2EC	Coastal Endofaunic Evaluation Index
IBI	Index of Biotic Integrity
IBN	Integraal Beheerplan Noordzee
ICES	International Council for the Exploration of the Sea
IMARES	Marine Research and Ecosystem Studies
IoS	Isles of Scilly
IQI	Infaunal Quality Index
ITI	Infauna Trophic Index
IUCN	International Union for the Conservation of Nature
JNCC	Joint Nature Conservation Committee
MaB	Macrobenthos
MACRODAT	Macrobenthos Database
MARBEF	Marine Biodiversity and Ecosystem Functioning
MeB	Meiobenthos
MPA	Marine Protected Area
NDNZ	Nederlands Deel van de Noordzee
NQI/NKI	Norwegian Quality Index
O	Occurrence data
P	Plants
PCA	Principal Components Analysis
PP	Phytoplankton
PRC	Principal Response Curves
R	Rarity

RTR	Infauna Ratio-to-Reference
RWS RIKZ	Rijkswaterstaat – Rijksinstituut voor Kust en Zee
S	Soft sediments
SAC	Special Area of Conservation
SB	Seabirds
SM	Sea mammals
SPA	Special Protection Area
SPR	Species Richness
TRIX	Trophic Index
UK BAP	United Kingdom Biodiversity Action Plan
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WFD	Water Framework Directive

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