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.

1. 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 Bird (1979) and Habitat (1992) 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, unpublished; 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.

2. 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). 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 (on a continuous or discrete value scale, e.g. high, medium and low value). Subzones are defined as subregions within the study area that can 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.

3. 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, UNEP Convention on Biological Conservation, 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, personal communication), 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

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 & Clark (1984), 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,b)
	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,b)
	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)

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 Fig. 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).

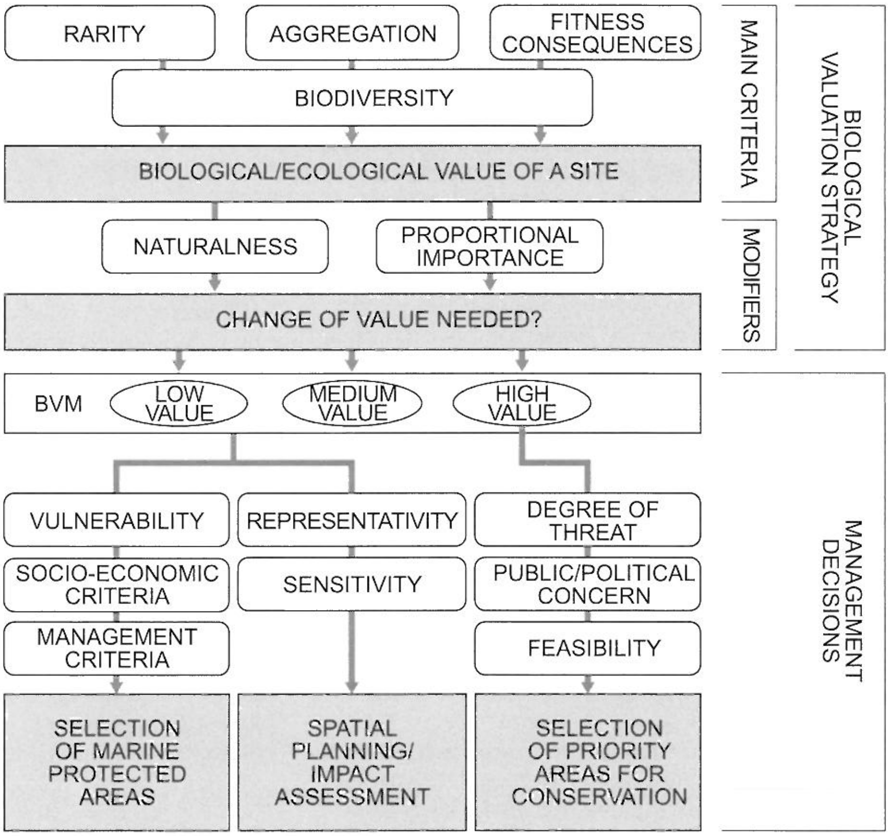

Fig. 1. Conceptual scheme of the biological valuation method and possible future steps in developing decision support tools for managers

3.1. Rarity

Rarity can be assessed on different scales, e.g. national, regional, global. In order to be able to assess the rarity of marine species or communities on 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) 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,b, 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 on 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,b, 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,b) 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,b). 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 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,b).

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 × 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,b)
	Nationally rare species = species occurring in less than 0.5% of the 10 km × 10 km squares within the study area	Sanderson (1996a,1996b); Connor et al. (2004); Lieberknecht et al. (2004a,b)
	Nationally scarce species = species occurring in less than 3.5% of the 10 km x 10 km squares within the study area	
	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.

3.2. 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).

3.3. 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.

3.4. 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 1 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.

3.5. 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,b), 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.

3.6. 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, 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 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) visualized 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.

4. 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 Fig. 1, which shows that, although these following steps should be founded on scientific biological valuation, they cannot be based solely on such criteria.

5. 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.

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Appendix

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?
1	2	3
Rarity	EC Bird Directive (1979); Smith & Theberge (1986); Mitchell (1987); Bergman et al. (1991); HELCOM (1992); Fairweather & McNeill (1993); Norse (1993); Tunesi & 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,b); Connor et al. (2002); OSPAR (2003); Roberts et al. (2003a,b)	Yes, 1st order criterion
(Bio)diversity	Ray (1984); Smith & Theberge (1986); Mitchell (1987); Bergman et al. (1991); HELCOM (1992); Fairweather & McNeill (1993); Norse (1993); Tunesi & Diviacco (1993); IUCN (1994); Chaillou et al. (1996); Sanderson (1996b); Gilman (1997); Hockey & Branch (1997); Brody (1998); Vanderklift et al. (1998); Zacharias & 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 & Günther (2001a); Ardron et al. (2002); Connor et al. (2002); Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Rey Benayas & de la Montaña (2003); Roberts et al. (2003a,b); 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 & Theberge (1986); Mitchell (1987); Fairweather & McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey & Branch (1997); Brody (1998); IMO (1999); Laffoley et al. (2000b); Rachor & Günther (2001a); Connor et al. (2002)	Yes, modifying criterion

Appendix (*continued*)

1	2	3
	Department for Environment, Food and Rural Affairs (2002); Gilman (2002); GTZ GmbH (2002); Breeze (2004); JNCC (2004)	
Proportional importance	Ray (1984); Hockey & Branch (1997); Laffoley et al. (2000b); Connor et al. (2002); Department for Environment, Food and Rural Affairs (2002); Lieberknecht et al. (2004a,b); 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 & 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 & 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,b)	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 & Günther (2001); Connor et al. (2002); GTZ GmbH (2002); Beck et al. (2003); Hiscock et al. (2003); Roberts et al. (2003a,b); Breeze (2004); JNCC (2004)	Yes, under 'aggregation' and 'fitness consequences', 1st order criteria
Productivity	Ray (1984); Smith & Theberge (1986); Mitchell (1987); Fairweather & McNeill (1993); Norse (1993); Chaillou et al. (1996); Brody (1998); Vanderklift et al. (1998); Zacharias & Howes (1998); IMO (1999);	

Appendix (*continued*)

1	2	3
	Rachor & Günther (2001)[a]; BTZ GmbH (2002); Beck et al. (2003); Breeze (2004); JNCC (2004)	
Special features present	Smith & Theberge (1986); Fairweather & McNeill (1993); Norse (1993); Zacharias & Howes (1998); Vanderklift et al. (1998)	
	Tunesi & Diviacco (1993); Beck et al. (2003); OSPAR (2003)	Yes, under 'rarity', 1st order criterion
Uniqueness	UNESCO (1972); EC Bird Directive (1979); Tunesi & Diviacco (1993); Gilman (1997); Brody (1998); Zacharias & Howes (1998); IMO (1999); Rachor & 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 & Branch (1997); Turpie et al. (2000); Beger et al. (2003); Roberts et al. (2003a,b)	No, MPA selection criteria
Representativeness	Ray (1984); Mitchell (1987); Bergman et al. (1991); EC Habitats Directive (1992); Fairweather & McNeill (1993); Sanderson (1996b); Gilman (1997); Hockey & Branch (1997); Brody (1998); Laffoley et al. (2000b); Rachor & Günther (2001)[a]; Ardron et al. (2002); Gilman (2002); GTZ GmbH (2002); Leslie et al. (2003); Roberts et al. (2003a,b); JNCC (2004)	No, MPA selection criteria
Integrity	Ray (1984); Mitchell (1987); IUCN (1994); Brody (1998); IMO (1999); Rachor & Günther (2001)[a]; GTZ GmbH (2002)	
Vulnerability	UNESCO (1972); EC Bird Directive (1979); Smith & Theberge (1986); Mitchell (1987); UNEP (1990); Bergman et al. (1991); EC Habitats Directive (1992); HELCOM (1992);	No, related to 'resilience' criterion which is excluded from final list of

Appendix (*continued*)

1	2	3
	IUCN (1994); Barcelona Convention (1995); Macdonald et al. (1996); Gilman (1997); Hockey & Branch (1997); Brody (1998); RAMSAR COP 7 (1999); Laffoley et al. (2000b); UNEP (2000); Bax & Williams (2001); Rachor & 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,b); Breeze (2004); JNCC (2004)	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,b)	No, management criterion
Protection level	Bergman et al. (1991); Zacharias & Howes (1998)	
International significance	Brody (1998)	
Economic interest	Hockey & Branch (1997); Roberts et al. (2003a,b)	No, socio-economic criterion

[a]Modified and complemented after Salm & Clark (1984), Salm & Price (1995) and Kelleher (1999).