Embedding ecosystem services into the Marine Strategy Framework Directive

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Abstract: The introduction of the Marine Strategy Framework Directive (MSFD) with its focus on an Ecosystem Approach places an emphasis on the human dimensions of environmental problems. Eutrophication has long been recognised as a major problem in Europe's seas but the MSFD marks a shift from management towards specific environmental States toward management largely based on abating nutrient loads towards specifying good environmental stauts and the associated need to manage supply of and demand for marine environmental services. Taking the North Sea as a case study we used a Driver Pressure State Welfare Response (DPSWR) approach to examine the relationships between the eutrophication criteria of the MSFD and the final and intermediate ecosystem services they provide. We valued these ecosystem services where possible in monetary terms in order to examine trade-offs between the benefits derived from the socio-economic drivers that cause eutrophication and the losses of human welfare (economic externalities) the causes of eutrophication. We identify the implications of an ecosystem approach for management and for future environmental research. We conclude the MSFD has the potential to become a social force for sustainable use of the seas , but may also ensure continuation of the status quo.

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Dear Sir or Madam,

Please find attached my article entitled. "A technique for embedding ecosystem services into the Marine Strategy Framework Directive illustrated by eutrophication in the North Sea.."

The purpose of the article is to highlight the new emphasis of the Ecosytem Approach in marine management as mandated by the Marine Strategy Framework Durective. The article demonstrates a method to link the environmental status criteria of the MSFD to ecosystem services and their vales, as such it takes a multidisciplinary in its approach. The article also highlights that management for ecosystem services marks a major paradigm shift in marine management.

I hope it will be considered for publication.

Best Regards

Tim O'Higgins

A technique for embedding ecosystem services into the Marine Strategy Framework Directive: illustrated by the eutrophication in the North Sea.

O'Higgins T.G. Alison Gilbert.

Abstract

The introduction of the Marine Strategy Framework Directive (MSFD) with its focus on an Ecosystem Approach places an emphasis on the human dimensions of environmental problems. Eutrophication has long been recognised as a major problem in Europe's seas but the MSFD marks a shift from management towards specific environmental States toward management largely based on abating nutrient loads towards specifying good environmental stauts and the associated need to manage supply of and demand for marine environmental services. Taking the North Sea as a case study we used a Driver Pressure State Welfare Response (DPSWR) approach to examine the relationships between the eutrophication criteria of the MSFD and the final and intermediate ecosystem services they provide. We valued these ecosystem services where possible in monetary terms in order to examine trade-offs between the benefits derived from the socio-economic drivers that cause eutrophication and the losses of human welfare (economic externalities) the causes of eutrophication. We identify the implications of an ecosystem approach for management and for future environmental research. We conclude the MSFD has the potential to become a social force for sustainable use of the seas , but may also ensure continuation of the status quo.

Introduction.

Growing realisation of the extent of human impacts on global ecosystems and the declining capacity of these ecosystems to provide the services on which we depend (e.g. MEA, 2003; Halpern et al., 2008) has led to the concept of an "Ecosystem Approach" (EA) which may be defined as "*a resource planning and management approach that integrates the connections between land air water, all living things, human beings their activities and institutions*" (Farmer et al., 2012). The approach is based on the recognition of the total dependence of human activities on the ecosystems in which they take place (Boumans et al., 2002). Three main characteristics of an EA include a multisectoral focus; the inclusion of ecosystem services in decision making and the recognition of the tight coupling between social and ecological systems (Tallis et al., 2010). Ecosystem services are defined as "the aspects of ecosystems utilized (actively or passively) to produce human well-being.", ecosystem services "must be ecological phenomena" and "these function or process become services if there are humans that benefit from them" (Fisher et al., 2009). Development of an effective EA requires a multidisciplinary approach incorporating the complexity of ecological and social systems and this multidisciplinary approach represents a relatively new field of research in marine management.

The Marine Strategy Framework Directive (MSFD) (EU, 2008), the environmental pillar of the EU Integrated Maritime Policy is a European Union directive with the aim of "maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean healthy and productive". The directive mandates an Ecosystem Approach (EA) and obliges EU nations to achieve GEnS within member states' EEZs on a regional seas basis by. Introduction of the EA represents a major change in marine environmental management for the EU marking a shift away from a "deconstructing structural" approach of previous environmental legislation towards a more "holistic functional" approach with a focus on marine goods and services (Borja et al., 2010). Eleven descriptors of Good Environmental Status (GEnS) are specified for which targets must be set by each EU member state. The descriptors cover a range of topics, from well-known problems such as those associated with fisheries, invasive species, eutrophication and pollutants to emerging issues including marine energy, noise and marine litter. While some of the GEnS descriptors are already relatively well understood (being the subject of existing European environmental legislation) others are new and have received less scientific attention. Existing regional seas agreements are to be used where possible to harmonise implementation of the directive. The MSFD and achievement of an EA present a major challenge to European scientists and decision makers, in terms of their spatial scale, comprehensive environmental scope and expanded, social-ecological focus (Mee et al., 2008; Atkins et al., 2011). In particular the MSFD presents a challenge in linking traditional metrics of environmental status to the provision of ecosystem services.

The task group for the eutrophication descriptor under the MSFD defined eutrophication as "*a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably* ***degrade ecosystem health and/or the sustainable provision of goods and services****"*(Ferriera et al., 2010). Marine eutrophication has been recognised in Europe's coastal waters for over a century (Adeney, 1908) and has been viewed as a significant problem in Europe since the mid-1980s (Rosenberg, 1985) affecting each of its regional seas, Baltic, Black, North Sea and Mediterranean (Hydes et al., 1999; Gordina et al., 2001, Monecheva et al., 2001 Mee et al, 2005; Pätsch et al., 2010 Savchuk, 2005). The causes of eutrophication, anthropogenic nutrient loading, are linked with the fundamental biological processes of consumption, and excretion and the release of nutrient wastes from either human or from agricultural or industrial sources are its main drivers. The expression of eutrophication varies depending of the physical, chemical and biological conditions in a specific location (Cloern, 2001).

Decades of experience with the monitoring and assessment of eutrophication in the North Sea have highlighted several important challenges for the measurement, monitoring and future management of eutrophication (Hering et al., 2010, Ferriera et al., 2010; 2011) but have also yielded considerable insight into the problem and mean that the ecological characteristics of eutrophication in the area are reasonably well constrained. In the context of the MSFD eutrophication is therefore a well-known and well understood marine management problem and represents an excellent test case for assessment of the implications of an Ecosystem Approach with its expanded social- ecological focus for environmental management and assessment strategies.

The aim of this paper is to develop a framework for the inclusion of ecosystem services into the assessment of environmental status under the Marine Strategy Framework Directive. First we illustrate the framework with respect to a single, well understood descriptor, eutrophication, we then apply the framework to a case study of the North Sea.

Materials and Methods

Study Area

The large human population (~160 million) and intensive agricultural practices in the North Sea's catchment mean that anthropogenic loads to the North Sea are high (EEA, 2005). However oceanic exchange means that anthropogenic contributions to the overall nutrient budget are quite modest. In the relatively poorly-flushed, shallower, coastal and southern North Sea, these sources account for 52% (N) and 41% (P) of all external sources (Vermaat et. al 2008). These areas are susceptible to eutrophication. Anoxic sediments and algal blooms have been observed in the German Bight and parts of the Wadden Sea (Van Es and Ruardij, 1982; Brockmann et al., 1988; Hickel, 1998; Druon et al., 2004; Van Beusekom, 2005); the shallow unstratified southern part of the North Sea is prone to high phytoplankton biomass, hypoxia and nuisance blooms of the foam forming alga *Phaeocystis globosa* (Lancelot et al. 2005; Lancelot et al, 2011). The problem of eutrophication in the North Sea has received extensive academic attention, in terms of modelling of nutrient loading (Skogen et al., 2004; OSPAR, 2008, Lenhart et al., 2010; Los and Blas, 2010); the ecological effects of these loads (Riegman et al., 1990) and the economic costs of remediation (Hoffmann et al, 2005; Nunneri et al., 2007). There have also been considerable management efforts to counteract the effects of eutrophication. Figure 1 provides a visually summary of the spatial distribution of eutrophication in the North Sea.

In the following section we describe a series of three steps designed to allow incorporation of ecosystem services into decision making based on the environmental status criteria of the MSFD. We apply this technique with respect to a single MSFD descriptor eutrophication (descriptor 5) and test its applicability using the North Sea as a case study.

The first step was to characterise the criteria described in the commission decision on descriptors (EU, 2010), this characterisation was based on the Driver, Pressures State Welfare Response (DPSWR) approach, based on Cooper (2012). DPSWR is a systematic framework for addressing environmental problems. The DPSWR components encompass both the human and ecological parts of social-ecological systems and is summarised in Figure 2. Drivers are the economic and social forces that result from government policies, markets and the activities of private industry. Pressures are the ways these drivers place demands upon ecosystems (whether or not these demands can be met in a sustainable manner). State changes are the changes in the ecosystem resulting from the Pressures and these in turn can result in changes to human Welfare through changes in ecosystem service supply.   The Response to a particular problem may be directed towards any of the other elements (D,P,S or W) to achieve a balance between the benefits of economic and social development and the ecosystem costs. Each of the individual subcriteria for a given descriptor were assigned to an information category of the DPSWR according to the definitions given in Figure 2.

Having categorised the criteria the next step was to link these criteria to ecosystem services. Ecosystem services are defined as “the aspect of nature used (actively or passively) to produce human well-being (Fisher et al., 2008. Ecosystem services were classified as either intermediate or final based on Fisher et al. (2009). The ecosystem services related to the MSFD criteria and subcriteria were listed by considering the major chemical physical and biological processes associated with the criteria and their direct and indirecect relations to human well-being, the identification of services also relied on reference to existing list of ecosystem services including O’Higgins and Roth (2010) and Saunders et al. (2010).

The third step was to provide a means of evaluating and intercomparing ecosystem services. In this study we chose economic valuation of ecosystem services based market values where available. Where ecosystem services did not have market values, non-market values estimated based on benefits transfer, a technique whereby economic values for a particular good or service from one study site are transferred to those of another study site. In order to avoid double counting final ecosystem services only were valued.

We tested the framework described above by application to the eutrophication descriptor of the MSFD taking the North Sea as a case study.

Estimates of current values of selected ecosystem services were calculated and converted to values in €(2010) using the Consumer Price Index. The economic value of carbon burial by the North Sea ecosystem was based on estimates of carbon export to deep waters by the shelf sea pump in Bozec et al. (2006). Estimates of the value of carbon storage were based on European Union allowance of €16.80/tC/yr (www.pointcarbon.com).

Values for Willingness to Pay for recreation in European nations (reported in WTP/individual/yr) were taken from a global meta-analysis of recreational values, Ghermandi et al. (2011) for the UK a mean of European WTP values was used. WTP values for visitors to coastal sites were multiplied by the number of visitors in North Sea coastal area hotels and campsites in 2010 based on Nomenclature of Territorial Units for statistics (NUTS) level 2 data (Eurostat, 2012). These data were further disaggregated to immediate coastal areas at the NUTS level 3 data level assuming that number of visitors at proportional to the number of hotel beds in each territorial unit. WTP for residents at the NUTS2 level was obtained by multiplying the national WTP from Ghermandi et al. (2011) by the NUTS level 2 population data for 2010 (Eurostat, 2012).

The data for price for each fish species was taken from <http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/data/database>. The main source of data is the obligatory reporting from national authorities and gathered through collections of fishing log-books, landing declarations and sales notes. Catch data were taken from ICES FishStat database and included ICES areas IIIa, Iva, IVB,IVc,IV,d,IVe (the Greater North Sea, fom the English Channel to the Northern North Sea). Data for three years (2007-2009) were averaged to give a mean annual catch and price.

RESULTS

Table 1 summarises the eutrophication criteria from the commission decision on descriptors and relates them to the qualitative assessment parameters of the OSPAR comprehensive procedure (OSPAR, 2005). Figure 3 shows a conceptual model of eutrophication (based on Ferriera et al., 2012) but contained within the DPSWR framework. The model highlights the social as well as ecological aspects of the system and illustrates the location of the MSFD eutrophication criteria within that framework. All the eutrophication criteria in the Commission Decision on descriptors (EU, 2010) measure specific aspects of ecosystem disturbance or integrity. Taken in combination the criteria for eutrophication provide a comprehensive overview of marine flora. They encompass the changes in the chemical environment causing eutrophication (criteria 5.1.1. and 5.1.2) as well as the abundance and composition of marine microflora (criteria 5.2.1, 5.2.4) and macroflora, both algae and macrophytes (criteria 5.2.3, 5.3.1) and their consequences for light transmission (5.2.2) and oxygen concentrations in the water column (5.3.2). All eight eutrophication indicators are measurements of ecosystem state and therefore are readily linked to ecosystem services. However the links between environmental states and ecosystem services are not explicit in the criteria themselves.

Figure 4 illustrates the links between the eutrophication criteria and some intermediate services; final services and benefits. The relationships between individual eutrophication criteria and the supply of ecosystem services vary in complexity. There are reasonably direct links between some criteria; the final services they provide and benefits. For example the abundance of opportunistic and perennial seaweeds (criteria 5.2.1 and 5.3.1) is a final service where there is a commercial harvest of species (e.g. for alginates, fertiliser or as an input to biomass digestion processes) and there are clear resulting marketed benefits. There is also a relatively simple link between increasing chlorophyll concentrations (5.2.1), decreased water transparency (5.2.2) the quality of bathing waters and the benefits these provide to humans. In the North Sea, shifts in species composition of phytoplankton (5.2.4) may also be related to the provision of bathing water, since there are annual outbreaks of the nuisance algal species *Phaeocystis globosa* which form foam.

The criteria also affect human welfare in indirect ways, acting as intermediate services. For example seaweeds (5.2.3, 5.3.1), seagrasses (5.3.1) and dissolved oxygen concentration (5.3.2) all play roles in the provision of habitat an intermediate service which contributes to the final service of fish and shellfish production (which in turn have commercial as well as recreational benefits). There are also well known feedbacks between chlorophyll concentrations, transparency and macroflora which further complicate the relationship between the ecosystem and the final services it supplies. Chlorophyll concentration (5.2.1) is a proxy for marine primary production which plays a vital role in the biogeochemical cycling of atmospheric gases, the production of oxygen and the fixation and burial of carbon these fluxes of elements to and from the atmosphere represent an essential final service providing life support for terrestrial animals (including humans), both in terms of generating an oxygenated atmosphere (by production of oxygen through photosynthesis) and in regulation of climate (through burial of carbon) as such these services may be said to have primary values. Primary production also forms the basis of marine food webs, and can be viewed as an intermediate service contributing to the final services of *any aspect* of a particular marine food web which is valued by humans for its use or for its existence.

The intermediate and final services related to the eutrophication descriptor result in four distinct benefits, the regulation of oxygen in the atmosphere, recreational uses, commercial harvest of species and maintenance of a habitable planet through climate regulation (Figure X). For supply of breathable air the benefits are currently plentiful and free and therefore their marginal values will be infinitesimally small (Sagoff, 2009).

Values of Willingness to Pay for coastal recreation by visitors and residents of coastal areas in the Greater North Sea are summarised in Table 2. The estimated aggregated total for all north Sea coastal areas was €23,346m

The mean annual tonnage of commercially landed fish 2007-2009 was 5,436,679t with a mean value of €1,977.5m. Over 50% of the commercial value was due to the catch of just seven species. Figure 5 shows the mean annual value of commercial catch in each of the ICES subdivision. Table 3 shows the value of the main commercial species of the greater North Sea by ICES division.

Based on Bozec et al. (2006) the annual export to the deep Atlantic of carbon from the North Sea is 1.83 $X 10^6$ tonnes C y^{-1} with a nominal market value of €30.8m annually.

Discussion

Our estimates of economic values of the benefits of the selected ecosystem services range by three orders of magnitude, from tens of billlions for recreation to tens of millions for carbon burial. Despite the overwhelming value of the recreational benefits when compared to the other services evaluated, our understanding of how these benefits are related to levels of eutrophication and other ecosystem processes is incomplete. We aggregated WTP values based on numbers of individuals living in or staying in hotels and campsites in coastal “Territorial Units” adjacent to the North Sea. In reality WTP values are likely to decline gradually with distance from the resource and availability of alternatives (Schaafsma et al., 2012). Philippart et al. (2007) have suggested positive relationships between nutrient loads and food web components in the North Sea including estuarine birds which could increased recreational values with increasing nutrient loads. The amount of recreational bathing occurring in the North Sea either by visitors or residents is likely to be lower than in other European seas due to the temperature of the sea itself, a factor which may not be represented in the annual values we have used based on the meta-analysis of Ghermandi et al. (2011). The shallow, well mixed nature of the southern north sea results in a degree of natural turbidity such that high water clarity might not play as a large a role in coastal recreation values as it does in other systems, such as the Baltic or Mediterranean which are naturally less turbid and changes in recreational values for the North Sea may therefore be less sensitive to water transparency and eutrophication than other areas.

More reliable estimates of economic value are presented for commercial fisheries. However separating the effects of anthropogenic pressures on the state of fisheries is challenging, given that multiple pressures such as fishing and nutrient loading have increased concurrently (Caddy, 2000) and that other climatological and ecological processes also play a role in determining species biomass and composition and distribution (Colijn et al., 2002; Engelhard et al., 2011). Changes in primary productivity affect the productivity of higher trophic level species, and can alter the ratio of pelagic to demersal fisheries increased primary production can have a positive effect on fisheries landings (Hondorp et al., 2010). Sole is the major commercial species of value in the Southern North sea (Table 2) and decreases in productivity of flat fishes, sole and plaice have been associated with reduced nutrient loads (Rijnsdorp et al. 2004). The long term value of the fisheries relies on the effective management of the stocks. Under the MSFD, fisheries are to be managed under Maximum Sustainable Yeild (EU, 2010) but this maximum yield may be increased with increasing productivity.

Our estimate of the value of carbon burial from the north sea is based on single snapshot in time based on a multi-annual dataset combined to produce a box model of carbon flux (Bozec et al., 2006). The OSPAR target reductions in nutrients supply of 50% are predicted to reduce primary production by between 25% - 45% in some locations (Lenhart et al., 2010). The current levels of carbon exported for burial to the deep North Atlantic from the North Sea (1.8 x 10^6t.y^{-1}) is approximately equal to the 2.7% of the amount of carbon extracted annually as crude oil (IEA, 2011). At this rate it would take the North Sea shelf sea pump 37 years to mitigate the carbon produced by current annual oil extraction. Assuming a constant proportion of Net Primary Productivity is exported under different levels of eutrophication. A reduction in net primary productivity by 40% an upper bound for predictions through achievement of the OSPAR nitrogen reduction targets (Lenhart et al., 2010) would result in an increase of this timescale for mitigation of annual extraction to 61 years However the time taken to mitigate the carbon added to the atmosphere through extraction and use of crude oil from the North Sea over the last 40 years is in the order of millennia which indicates that the natural process of carbon burial in the North Sea (even if augmented by eutrophication) does not have a practical role to play in mitigation of climate change.

Considered together these estimates of ecosystem service values for the North Sea might help focus management priorities. For example our estimates suggest that managing ecosystem services to safe-guard recreational activities while maintaining fisheries could be a sensible management option whereas management toward carbon burial with the aim of mitigating climate change would clearly not be a sensible choice. These value estimates also highlight major knowledge gaps in particular with respect to human recreational uses of the North Sea and how these uses might change with nutrient loading but also regarding the effects of increased primary production on the sustainable yield of fisheries within the North Sea.

In order to support decision making an understanding of marginal changes in ecosystem service values is required. Figure 4 illustrates idealised trajectories for bathing water supply, fish production and primary production with increasing nutrient supply, the order of magnitude of the services is based on our analysis of the North Sea. The idealised trajectories shown for supply of each service with increasing eutrophication differ in their direction. Primary production (and correspondingly carbon burial) increase with increasing primary production and at high levels of nutrient loading this may become light limited. Fish production also increases to a certain extent with nutrient loading as plant biomass and thus the availability of food to higher trophic levels increases. By contrast bathing water supply is likely to decrease as primary production and nutrient load increase. Identifying the point where the benefits of the abatement, for recreation, commercial fisheries and carbon burial of equal the costs of abatement can in theory therefore identify the best strategies for the management of multiple ecosystem services. Despite the number of criteria for eutrophication under the MSFD and the complexity of interactions between them they relate either directly or indirectly to a relatively small number of final ecosystem services and benefits. Balancing the anthropogenic pressures and the state changes they cause to maximize ecosystem service production is central to an ecosystem approach. For eutrophication at least, this management paradigm is at odds with previous management approaches (such as that of the WFD) which sought to manage towards reference states.

The framework we have developed to facilitate the inclusion of ecosystem services into the MSFD criteria for decision making has allowed us to identify and categorise the ecosystem services associated with a single descriptor in the MSFD and to link these services to benefits. In our worked example, the valuation of the ecosystem services was the least robust part of the process entailing many uncertainties and lacking the dynamism on which real world decision might be made this lack of non-market valuation data to support coastal and marine decisions, has been recognised by many others (Pendleton, 2008; O'Higgins et al., 2010; Raheem et al., 2012). When assessing non-marketed values, it may be the case that the specific value for a given for an individual's WTP for a given marginal change in ecosystem service is less important than the number of individuals making up the "economic jurisdiction" of given service (Bateman, 2012; Jordan et al., 2012); the development of reliable, accurate and transferable distance decay models for WTP is a prerequisite for application of non-market valuation studies to real-world management. Understanding the mixture of recreational activities and their relation to environmental quality is a more fundamental challenge.

Though monetary valuation is a useful tool for communication with decision makers, monetary valuation of services is not the only, or necessarily the best, way of quantifying the values humans hold for the environment, and it is not always possible appropriate or useful to place monetary values on ecosystem services. Practical alternatives to monetary valuation of ecosystem services do exist, Multi-Criteria-Analysis (MCA) allows multiple ecosystem services to be considered in tandem and relative weights to be assigned without the requirement for economic valuation, and its potential in gathering spatially explicit location-specific value data in the marine environment is beginning to emerge (Alexander et al., 2012).

CONCLUSIONS

For an EA, understanding the links between the natural and social systems is essential, and the MSFD will fail as an instrument of EA if these considerations are not incorporated. We have presented a simple framework to facilitate the inclusion of ecosystem services into the management of the MSFD environmental status criteria. We have identified links between the environmental status criteria for eutrophication and the ecosystem services they provide in the North Sea.

Identifying the effects of eutrophication on ecosystem services represents a scientific challenge. The North Sea example highlights a number of areas where data are insufficient to support an ecosystem approach based on the valuation of ecosystem services. There is lack of ecological knowledge about the effects of eutrophication on the dynamics of the shelf-sea pump and carbon burial. The relationships between environmental state of the North Sea and patterns of human recreation are not understood, while our analysis suggests there are extremely high values for recreation, it is currently not known how these values might change with changing environmental state. Similar complex linkages will be present for each of the eleven descriptors contained within the MSFD and identifying these linkages and how they relate to human welfare is a useful first step toward an ecosystem approach. Understanding the complexity of the linkages between ecological processes will require new measurements of the social aspects and novel approaches to modelling which incorporate both natural and social sciences (see Tett et al. 2011).

The MSFD represents more than simple shift in the spatial jurisdiction and ecological scope of the WFD and the OSPAR common procedure, it demands an Ecosystem Approach which must incorporate social as well as ecological dimensions into decision making. The experience of eutrophication measuring and monitoring gained through the legislative processes of the WFD and OSPAR has resulted in an improved understanding of eutrophication in the North Sea. The philosophical approach to management under the MSFD marks a major change in direction, recognising human and ecological processes as an integrated system and seeks to manage ecosystem services provided by the environment sustainably for the benefit of mankind.

In the Anthropocene (Zalsiewicz et al.,2008) where human driven processes dominate the planet and a time when humans are exceeding planetary boundaries for sustainability (Rockström et al., 2009) return to pristine conditions is not a realistic option. The MSFD and EA represent an opportunity to extend the environmental management focus beyond the existing ecological quality objectives of the WFD, the return to a pristine status toward the recognition of the integral role of humans in the environment and the role of environmental management in the construction of sustainable societies. Within the European Union, which contributes disproportionately to exploitation of the global environment, decision makers, society, and researchers have an obligation to extend their vision beyond academic and sectoral boundaries and to engage with the solutions to the problems of a rapidly changing planet. Identifying threatened forms of natural capital which limit economic development or exceed the carrying capacity of the earth is the essential role of the ecosystem approach (Sagoff, 1995). In the case of the eutrophication descriptor of the MSFD this would mean quantifying the capacity of Europe's regional seas to absorb our wastes and the ecological and social costs and benefots of these processes. The study of ecosystem services is not about assigning economic values to nature, though this can be a useful means of identifying trade-offs, it is about understanding how our activities affect the capacity of the environment to sustain our lifestyles.

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Table 1: Comparison of MSFD eutrophication criteria and relevant WFD biological and physico-chemical quality elements.

	MSFD Criteria	WFD Biological/ Physico- chemical quality	OSPAR qualitative assessment parameters
5.1	**Nutrient levels**		**Category I the causative factors:**
5.1.1	Nutrient concentration in the water column	Nutrient concentrations	the degree of nutrient enrichment with regard to inorganic/organic nitrogen· with regard to inorganic/organic phosphorus· with regard to silicate
5.1.2	Nutrient ratios (silica, nitrogen and phosphorus), where appropriate		
5.2	**Direct effects of nutrient enrichment**		**Category II. the direct effects of nutrient enrichment:**
5.2.1	Chlorphyll concentration in the water column	Phytoplankton biomass	i.phytoplankton:· increased biomass (e.g. chlorophyll a, organic carbon and cell numbers)· increased frequency and duration of blooms · increased annual primary production
5.2.2	Water transparency reglated to increase is suspended algae where relevant	Transparency	ii. macrophytes, including macroalgae: • increased biomass • shifts in species composition (from long-lived species to short-lived species, some of which are nuisance species) • reduced depth distribution
5.2.3	Abundance of opportunistic macroalgae	Composition of macroalgal taxa	iii. microphytobenthos:
5.2.4	Shift in floristic composition sucha s diatom to flagellate ratio, benthic to pelagic shifts as well as blooms events of nuixance/toxic algal blooms (eg cyanobacteria) caused by human activities	Composition and abundance of phytoplankton, frequency and intensity of blooms	
5.3	**Indirect effects of nutrient enrichment**		**Category III. the indirect effects of nutrient enrichment**
5.3.1	Abundance of perennical seaweeds and seagrasses (e.g. fucoids, eelgrass and Neptune grass) adversly impacte by decreasing in water transparecy	Taxonomic composition of angiosperms	i.organic carbon/organic matter· increased dissolved/particulate organic carbon concentrations· occurrence of foam and/or slime· increased concentration of organic carbon in sediments (due to increased sedimentation rate)
5.3.2	Dissolved oxygen i.e, changes due to increased organic matter decompositin and size of the area concerned	oxygen balance	ii.oxygen:· decreased concentrations and saturation percentage· increased frequency of low oxygen concentrations· increased consumption rate· occurrence of anoxic zones at the sediment surface (“black spots”) iii.zoobenthos and fish:· mortalities resulting from low oxygen concentrations
			iv.benthic community structure:· changes in abundance· changes in species composition· changes in biomass v.ecosystem structure: structural changes

Table 2: Main North Sea commercial fisheries species, mean ananual value of the fishery (€) by ICES areas. The main species for each ICES area is shown in bold.

	IIIa	IVa	IVb	IVc	Ivd	Ive
Atlantic mackerel - *Scomber scombrus*	1,389,589	**223,320,585**	556,142	262,678	3,755,673	528,518
Common sole - *Solea solea*	5,721,067	25,250	41,423,724	**92,093,281**	**48,188,891**	8,233,441
Norway lobster - *Nephrops norvegicus*	**40,385,307**	81,828,438	47,678,312	108,066	13,618	133,980
Atlantic herring - *Clupea harengus*	14,675,505	70,566,486	20,295,766	1,544,725	13,603,157	145,161
Common shrimp - *Crangon crangon*	0	0	**78,327,811**	35,953,541	1,965,966	38,448
European plaice - *Pleuronectes platessa*	13,827,645	1,802,201	58,627,940	20,614,196	5,478,884	1,495,263
Saithe(=Pollock) - *Pollachius virens*	6,079,398	77,779,738	2,852,495	18,454	29,870	5,885
Great Atlantic scallop - *Pecten maximus*	0	6,842,393	6,415,514	158,918	30,267,833	**35,466,835**

Table 3: Value of coastal recreation in the North Sea based on Willingness to Pay values from the meta-analysi of Ghermandi et al. (2011), visitor and resident data from Eurostat.

Country	WTP (€2010)	Visitors (m)	Residents (m)	Value(€2010)
Belgium	148.09	2.42	1.16	503,560,394
Denmark	152.20	3.14	5.55	1,187,332,591
France	169.09	15.94	12.46	4,465,107,012
Germany	106.29	4.59	7.66	1,172,198,257
Nethrelands	148.34	11.69	8.29	2,768,214,035
Norway	206.42	2.51	3.29	1,087,641,657
Sweden	110.01	8.45	3.26	1,231,203,483
UK	175.49	44.56	21.09	10,930,801,361
Total		44.56	62.77	23,346,058,791

Figure_1
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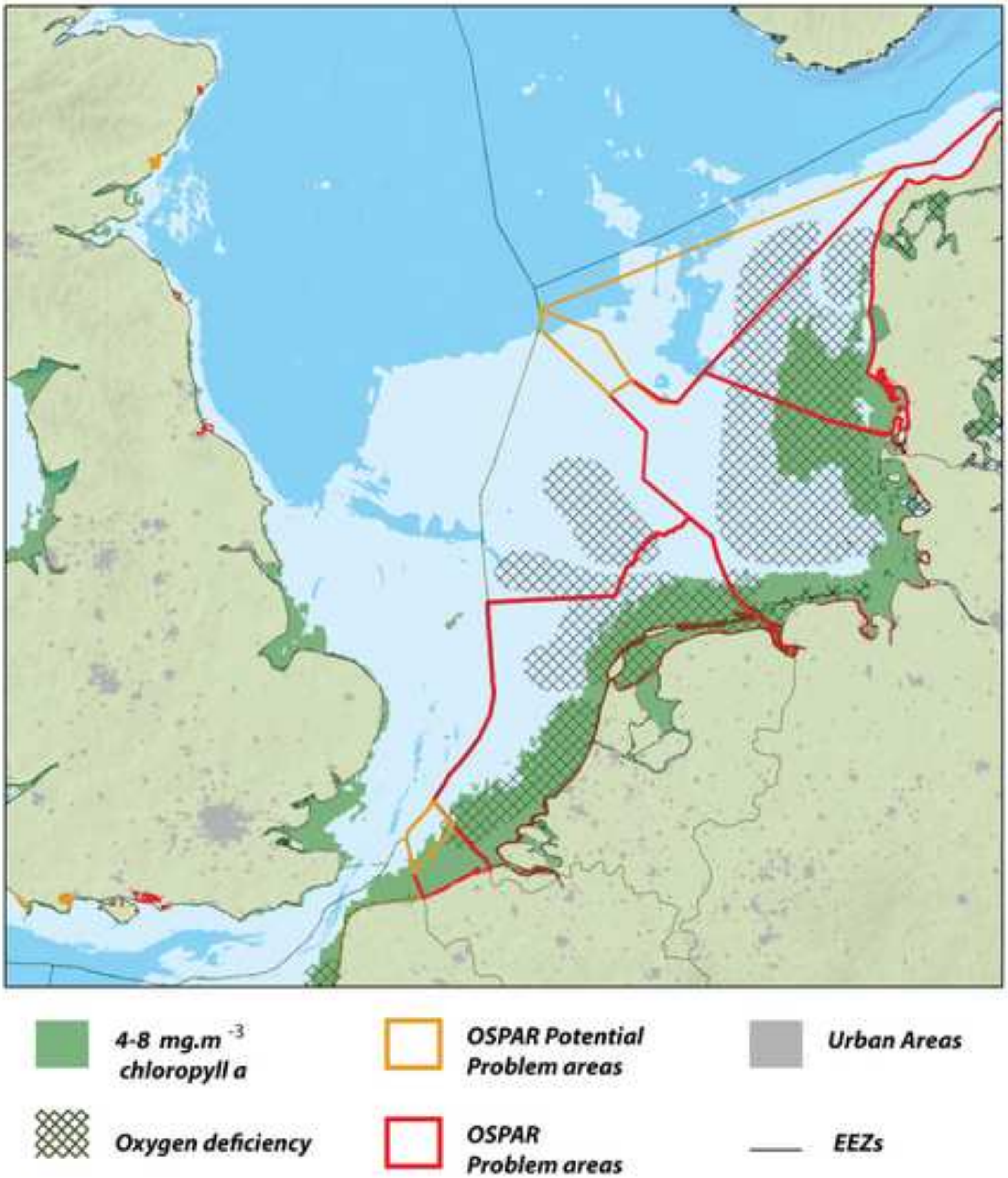

Figure 1: Map of the North Sea showing chlrophyll growing season mean annual chlorophyll (2008) derived from MERIS using the case 2 algorithm. Areas which have experienced oxygen deficientcy (OSPAR, 1992); OSPAR potential problem and problem areas; national EEZs and urban areas.

Figure_2
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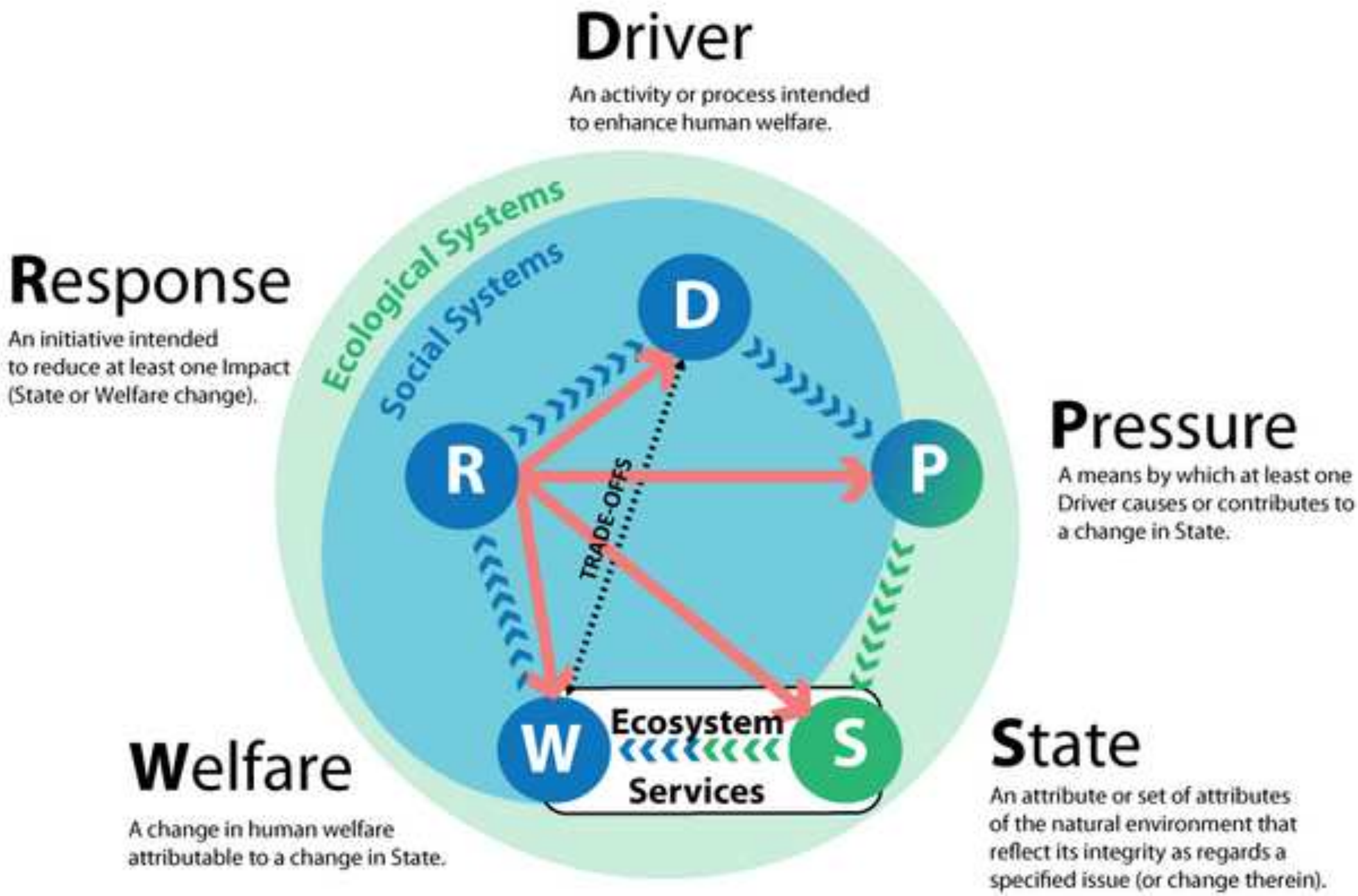

Figure 2: The DPSWR framework indicating social (blue) and ecological (green) elements of the system and the link between changes in environmental state and human welfare through ecosystem services.

Figure_3

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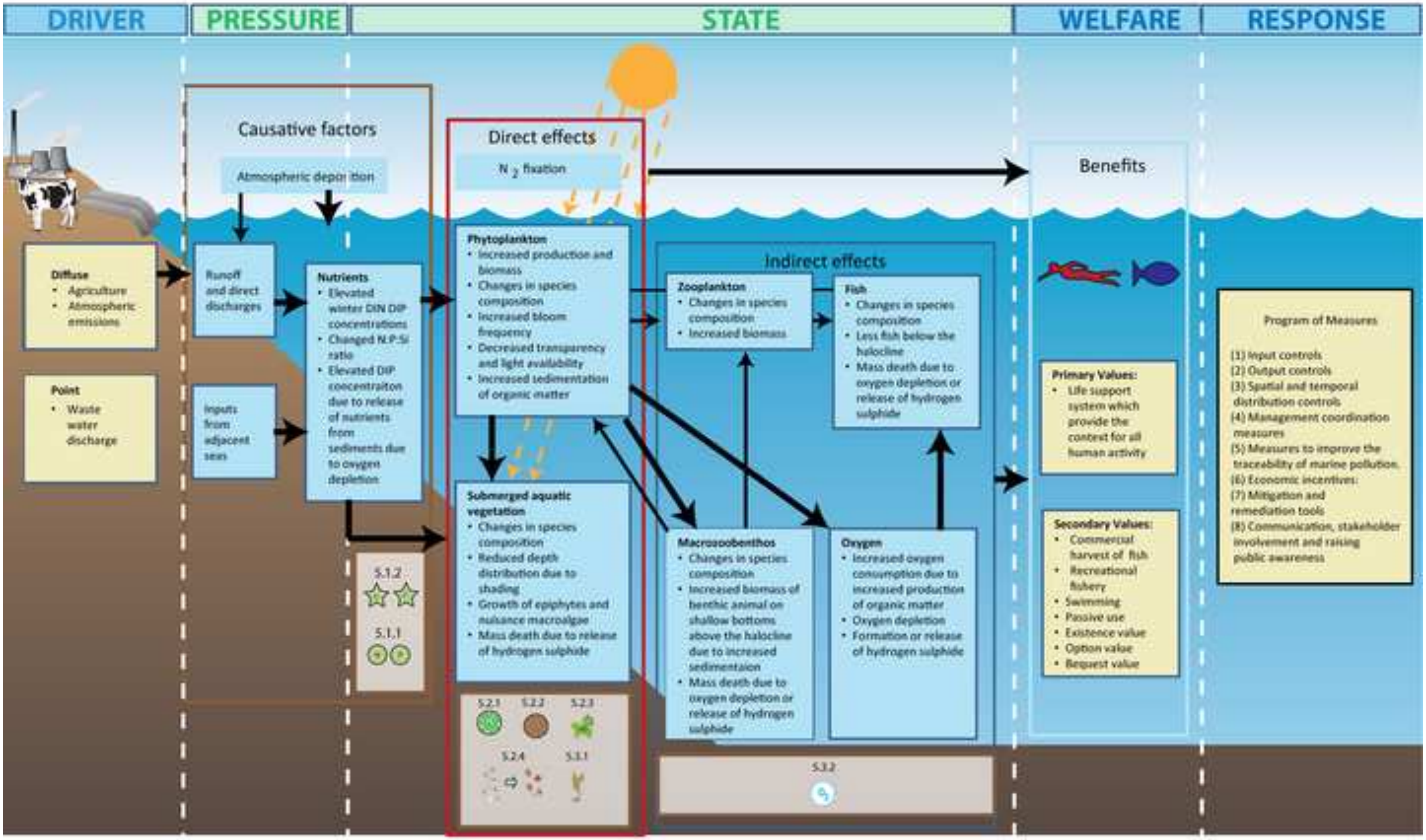

Figure 3: Conceptual diagram of eutrophication (after Ferriera et al., 2012) within the DPSWR framework, indicating social and ecological elements of the system. The numbered symbols indicat the MSFD criteria for eutrophication as see table 1.

Figure_4
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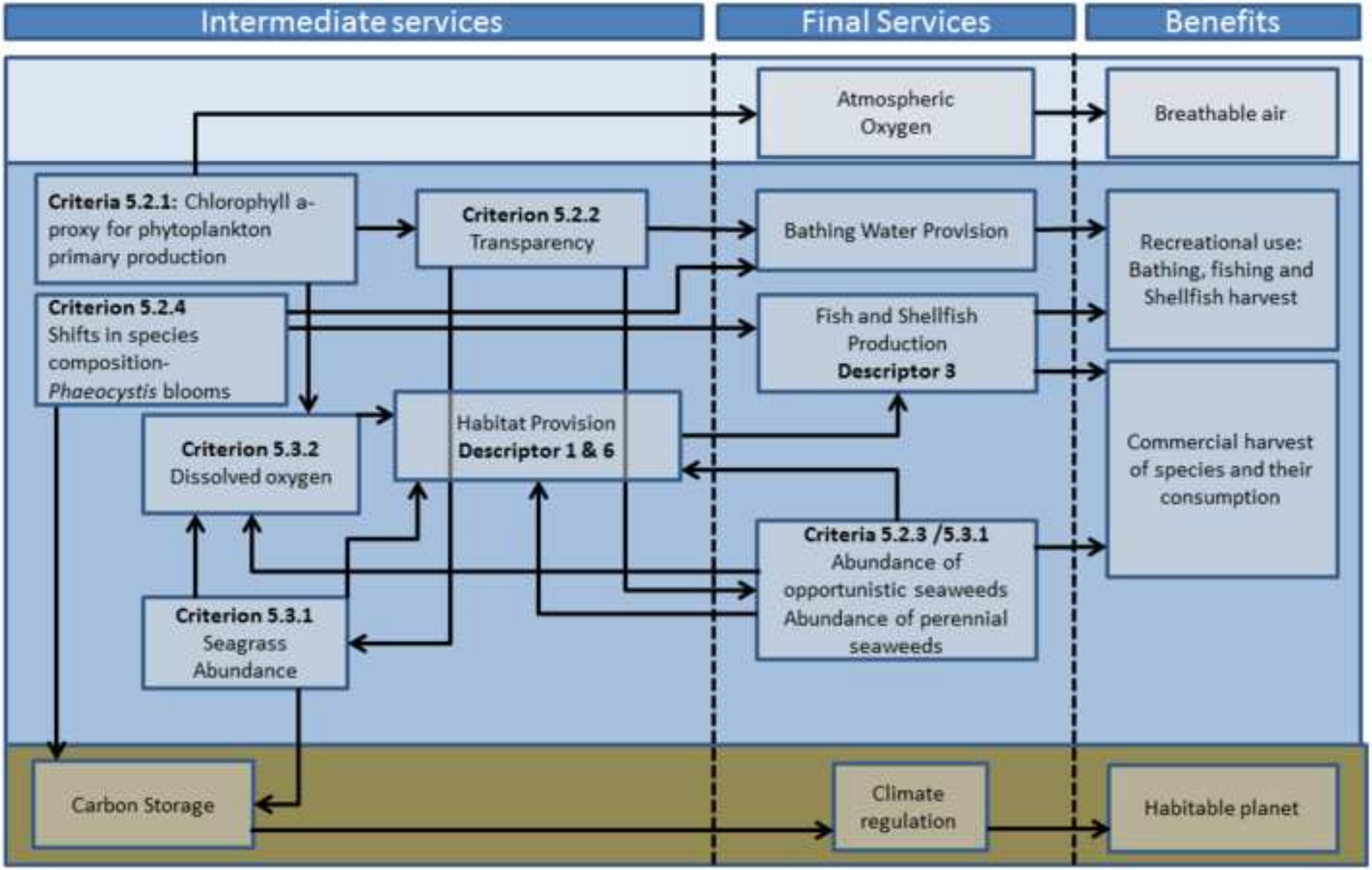

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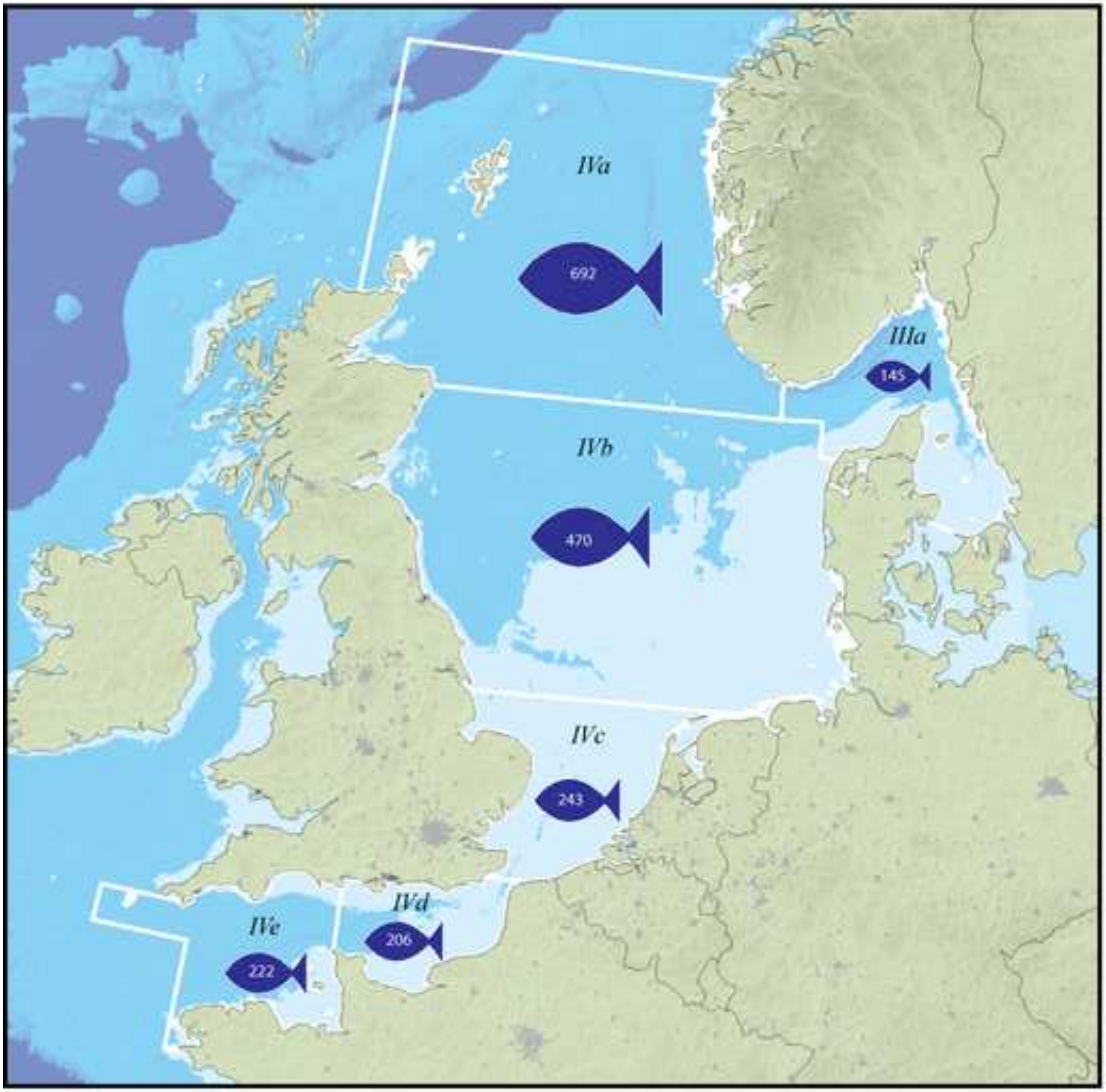

Figure_6
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