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Marine biological valuation of the shallow Belgian coastal zone: A space-use conflict example within the context of marine spatial planning

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ABSTRACT

The Belgian coastal zone hosts a complex of space- and resource-use activities with a myriad of pressures. Specifically at the beaches, predictions on sea-level rise, storms and flood risk from the North Sea have led to several big coastal defence projects. Management of sandy beaches is therefore a multifaceted and complex endeavour, where the interests of several stakeholders need to be combined and where biodiversity should be taken into account.

In this study, the biological value of the shallow Belgian coastal zone was derived based on a detailed and integrated dataset (1995–2011) of all available ecological information on macrobenthos, epibenthos, hyperbenthos and birds. The 67 km Belgian coastline was divided into an across-shore intertidal and shallow subtidal subzone, and into along-shore subzones of 250 m for benthic components and 3 km for birds. The intrinsic biological value of each subzone was then calculated using the biological valuation method, and the pertained score, ranging from *very low* to *very high*, was plotted accordingly in order to obtain a marine biological valuation map.

Following trends were detected: (1) a strong mosaic pattern of biological value along the coastline; (2) a clear lack of (benthic) data at the eastern part of the Belgian coast; (3) a rather *high* biological value in around 70% of the shallow subtidal subzones, compared to the intertidal part; and (4) a *high/very high* biological value in intertidal zones located immediately to the east of the harbours of Nieuwpoort, Oostende and Zeebrugge.

A detailed analysis of protected areas and areas under coastal flood risk indicated that biological valuation maps are very promising management tools for local decision-makers as they allow for an early integration of 'natural/ecological values' in policy implementation.

1. Introduction

Marine and coastal waters are sensitive habitats that support high levels of biodiversity and provide many essential ecosystem goods and services (Costanza et al., 1998; de Groot et al., 2002; Beaumont et al., 2007, 2008). The escalating crisis in these ecosystems, from biodiversity loss and transformed food webs to marine pollution and warming waters, has been recognized to increasingly undermine the ocean's capacity of providing goods and services and maintaining resilience to stressors and changes (Worm et al., 2006). This crisis is in large part a failure of integrated governance (Crowder et al., 2006; Crowder and Norse, 2008). In Belgium for instance, legal jurisdiction concerning coastal management is shared between the Flemish Government (landwards from the mean low water level; MLW) and the Belgian State (seawards from the MLW). Such 'multi-level government' structure

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(Cliquet, 2001; De Ruyck et al., 2001; Cliquet et al., 2007) most often results in conflicting priorities and overall lack of clarity in the implementation of relevant policies at the coastal zone (Commission of the European Communities, 2007). It fails to provide a comprehensive integrated coastal management whereas ecosystems, natural resources, and human activities have place-based characteristics and an inherent spatial and temporal dimension (McLeod et al., 2005; Crowder and Norse, 2008), increasing the need for a spatial and temporal perspective.

During the last decade, marine spatial planning (MSP) has gained considerable importance in establishing ecosystem-based management in the marine environment. Already implemented in a few countries on a preliminary basis, including Belgium, its aim is to attain not only consensus in sea-use management among distinct sectors, but also and most importantly to maintain the ecosystems' integrity and services through the conservation of marine biodiversity (Douvere, 2008; Pomeroy and Douvere, 2008; Douvere and Ehler, 2009; Ehler and Douvere, 2009). Biodiversity can be valued under several approaches and scales (Noss, 1990; Oksanen, 1997; Costanza, 1999; Balvanera et al., 2006; Granek et al., 2009). In fact, the objectives behind each approach are directly linked with the respective definition of the term 'value' (Derous et al., 2007a). Valuing ecosystems socio-economically by estimating the benefits they provide to society, accruing to ecosystems' goods and services, is an increasingly common practice in literature (Pearce and Moran, 1994; Costanza, 1999; de Groot et al., 2012). Under an ecosystem-based management approach however, biodiversity should also be valued intrinsically, independently of its potential usefulness for human beings (Wilson, 1986; Ghilarov, 2000).

The present work focuses on marine biological valuation (BV). This spatial tool provides an integrated view on nature's intrinsic value, within a certain time frame (Derous et al., 2007a, 2007b). By compiling all available biological and ecological information for a selected study area, and allocating an integrated intrinsic biological value to the subzones within the study area, biological valuation maps (BVMs) are produced. These maps facilitate the provision of a greater-than-usual degree of risk aversion in the management of activities as they are a tool for calling attention to areas which have particularly high ecological or biological significance (Derous et al., 2007a). Therefore, they can be used as reliable and meaningful baseline maps for spatial planning, marine policy and management approaches (Derous et al., 2007a, 2007b; Pascual et al., 2011). Hitherto, marine biological valuation has been performed in different European subtidal coastal waters (Derous et al., 2007c; Forero Parra, 2007; Rego, 2007; Vanden Eede, 2007; Weslawski et al., 2009; Pascual et al., 2011) including the Belgian Part of the North Sea.

The general objectives of this paper are: (1) to analyse the spatial structure of the intertidal and shallow subtidal Belgian coastal zone using the marine BV method; and (2) to explore the applications of BV for an ecosystem-based approach to MSP of two space-use conflicts at the Belgian coast, being flood protection, by means of beach nourishment, and nature conservation.

2. Material and methods

2.1. Study area

The Belgian natural coastline (Fig. 1) is entirely composed of sandy beaches. However, the ecological continuum expected in this type of ecosystem, from the intertidal zone to the foredunes, is disrupted by stone groins and concrete dykes (De Ruyck et al., 2001), as a response to coastal flood risk (Speybroeck, 2007; Roode et al., 2008). Previous research on the Belgian coastal ecosystem (Speybroeck et al., 2008) suggested a zonation scheme delimitating three main zones along the tidal range: (i) the *supralittoral zone*, the area above the high water line influenced by sea water, represented by embryonic dunes, the dry beach area, and the drift line; (ii) the littoral or *intertidal zone*, the area comprised between high water and low water lines; and (iii) the *infralittoral or shallow subtidal zone*, represented by the subtidal foreshore as the seaward continuation of the beach profile until a depth of 4 m below MLW. The subdivision of the shallow Belgian coastal zone follows this ecological zonation, focussing specifically on the intertidal and the shallow subtidal zones, and is defined by a landward boundary that follows the high water mark obtained by LIght Detection And Ranging (LIDAR) observations of the Belgian coast in 2011 (data provided by the Agency for Maritime and Coastal Services: Coastal division) and a seaward boundary for the shallow subtidal foreshore of 1 nautical mile from the zero depth (0 m) bathymetric line, instead of the legal 4 m depth (Fig. 1). The width of the subzones was chosen as fixed distances of 250 m for benthic components (463 subzones) and wider distances (Fig. 1) of 3 km for birds (42 subzones), as these are highly mobile species (Derous et al., 2007c) .

2.2. Databases

For the biological valuation of the shallow Belgian coastal zone, all available relevant data in the intertidal and shallow subtidal zones during the period 1995–2011 were gathered (see Table 1 for references and sampling locations). On the Belgian beaches, research focuses on benthos and birds. The methodology was therefore applied on the benthic and bird ecosystem component, allowing for the integration of the remaining ecosystem components (e.g. meiobenthos, dune vegetation, insects, sea mammals …) when reliable and compliant scientific data becomes available. The use of different sampling gears defines a differentiation among the benthic organisms: (i) macrobenthos – sampled with Van Veen grabs and/or quadrats and sieved over 1 mm; (ii) epibenthos – sampled with 1 mm mesh size trawl nets (or push nets) over the bottom; and (iii) hyperbenthos – sampled with 5 mm mesh size trawl nets (or push nets), approximately 1 m above the bottom. The birds were counted on the beach, during early morning. The sampling strategy used for each ecosystem component was always the same. All datasets included geographical coordinates, sampling gear used and area sampled. Species richness data (number of individuals per species and per sample) were standardized into densities (number of individuals per m^2).

2.3. Biological valuation protocol

2.3.1. Method application

The purpose of marine biological valuation is to provide an integrated view on nature's intrinsic non-anthropogenic value of the subzones, relative to each other within a study area (Derous et al., 2007d). Unlike the previous applications of the protocol (Derous et al., 2007c; Forero Parra, 2007; Rego, 2007; Vanden Eede, 2007; Weslawski et al., 2009; Pascual et al., 2011), the procedure used in this study was based on the *R* script for marine biological valuation, which has been recently developed by the Flanders Marine Institute (VLIZ), in Oostende, Belgium (Deneudt et al., Unpublished results). R is open-source software for statistical computing and graphics. The protocol is flexible and subject to specific adaptations for each application. Therefore, each of the steps used for this valuation of the Belgian beaches will be explained in the following subsections.

The *R*-script for marine biological valuation guarantees general data quality control on several levels, i.e. geographical coordinates,

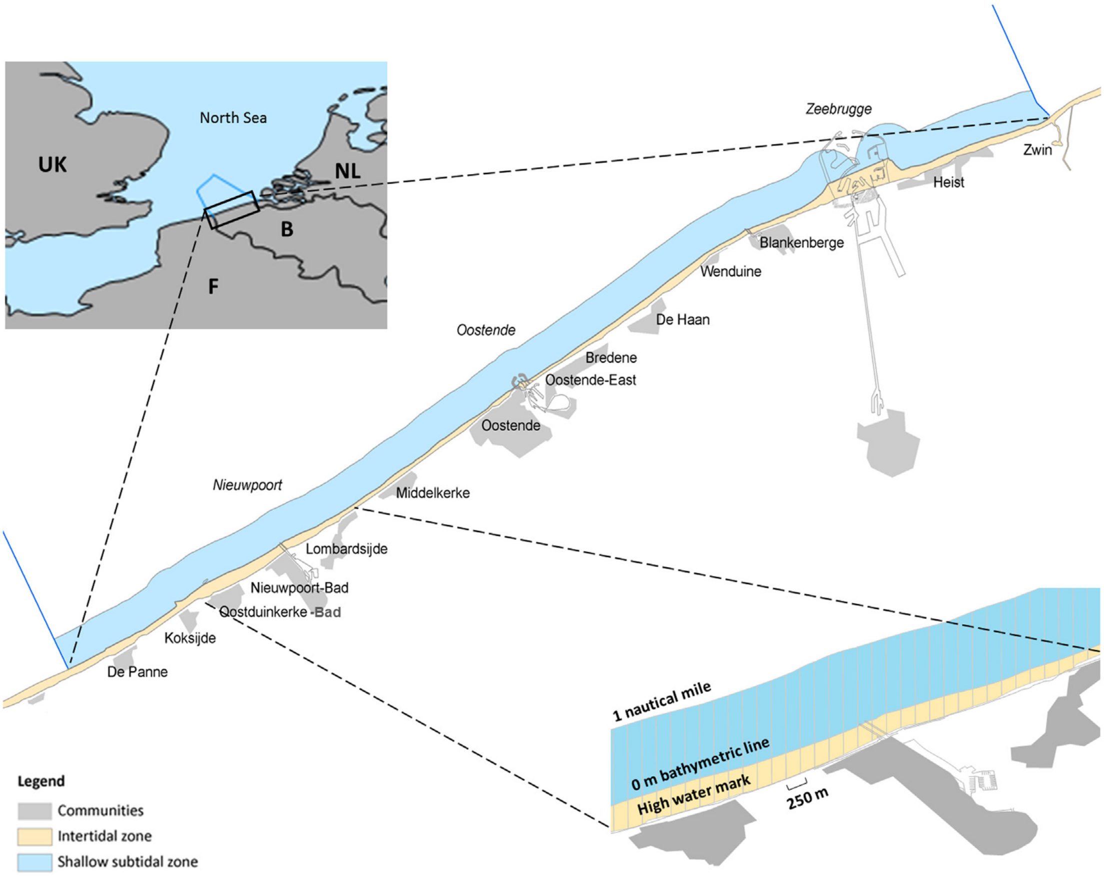

Fig. 1. Study area of the shallow Belgian coastal zone, with a distinction between the intertidal (light brown) and shallow subtidal zone (blue) and a detail showing the subdivisions performed for biological valuation (i.e. for benthic components). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

dates, time, and taxonomy based on the World Register of Marine Species (WoRMS). The set of assessment questions (Table 2) relates the available biological data to the valuation criteria, being rarity and aggregation-fitness consequences, and to a specific organizational level of biodiversity. The valuation criteria were proposed by Derous et al. (2007a), after an extensive literature review and selection based in part on the framework for identification of Ecologically Significant and Biologically Significant Areas

Table 1
References used for the integrated database per ecosystem component. Restricted to data collected in intertidal and shallow subtidal zones of the Belgian coast (mainly from unpublished data of Marine Biology, Ghent University).

Year of collection	Sampling location	Reference
Macrobenthos		
1995	De Panne, Bray-Dunes and Koksijde	De Neve, 1996; Mouton, 1996
1997	De Panne ('De Westhoek'), Schipgatduinen, Koksijde, Paelsteenpanne, Ijzermonding, Lombardsijde, Raversijde, Spinoladijk, Vosseslag, Blankenberge, Fonteintjes, Zeebermduinen, Zeebrugge-bad, Baai van Heist, Heist, 'Zwin' and VNR 'Zwinduinen en -polders'	Volckaert, 1998; Speybroeck et al., 2005b
2001	Knokke-Heist, Blankenberge, Wenduine, Oostende, Westende, Oostduinkerke, De Panne, Koksijde and Zeebrugge	De Backer, 2001; Boulez, 2002
2002, 2004, 2006, 2008, 2009, 2011	Lombardsijde, Nieuwpoort-Bad, Bredene, Koksijde-Oostduinkerke, Oostende (Centrum, Oosteroever, Vaargeul), Wenduine, Blankenberge, Mariakerke	Beach Nourishment Project[a]
Epibenthos		
2001	Koksijde	Buyle, 2002
2003	De Panne ('De Westhoek'), Ijzermonding, VNR 'Zwinduinen en -polders', Spinoladijk, Fonteintjes, Raversijde, Zeebermduinen, Schipgatduinen, Zeebrugge-bad, Baai van Heist, Paelsteenpanne	Speybroeck et al., 2005b
Hyperbenthos		
1997	Lombardsijde	D'Hondt, 1999
2001	Koksijde	Buyle, 2002
2003	De Panne ('De Westhoek'), Ijzermonding, VNR 'Zwinduinen en -polders', Spinoladijk, Fonteintjes, Raversijde, Zeebermduinen, Schipgatduinen, Zeebrugge-bad, Baai van Heist, Paelsteenpanne	Speybroeck et al., 2005b
Birds		
2003 and 2004	De Panne ('De Westhoek'), Ijzermonding, VNR 'Zwinduinen en -polders', Fonteintjes, Raversijde, Zeebermduinen, Schipgatduinen, Zeebrugge-bad, Baai van Heist, Paelsteenpanne	Speybroeck et al., 2005b

[a] Beach nourishment project: Speybroeck et al., 2003; Welvaert, 2005; Van Ginderdeuren et al., 2007; Vanden Eede et al., 2008; Vanden Eede and Vincx, 2010, 2011.

Table 2
Set of assessment questions (Derous et al., 2007c).

Assessment question	Categories of species
Is the subzone characterized by high counts of many species?	All species
Is the abundance of a certain species very high in the subzone?	All species
Is the abundance of rare species high in the subzone?	Rare species
Is the subzone characterized by the presence of many rare species?	Rare species
Is the species richness in the subzone high?	All species
Is the abundance of ecologically significant species high in the subzone?	Ecologically significant species
Is the abundance of habitat-forming species high in the subzone?	Habitat-forming species

(DFO, 2004) and expert judgement (Derous et al., 2007d). Biodiversity is not included as a separate valuation criterion, but linked to one or more of the selected valuation criteria using the 'marine ecological framework' created by Zacharias and Roff (2000).

The assessment questions are based on several 'categories of species', such as *all* species, *rare* species, *ecologically significant* species and *habitat-forming* species (Table 2) giving differential value to some species categories. Species richness (all species) is calculated as the mean species richness per sample, location and subzone. Some sensibility to sampling effort bias cannot be excluded when using this calculation but it remains limited as the sampling method is uniform per ecosystem component and the species richness is calculated per sample. Derous et al. (2007c) determined the criteria on rare species, by their percentage of occurrence in the samples, i.e. appearing in less than 5% of the studied subzones. However, this threshold can be changed if properly justified as is the case when a limited number of subzones hold data. For example, if only 10 subzones have data, rare species would be species occurring in less than half a subzone. Naturally this cannot be determined. Since the protocol was designed to be flexible and aims at offsetting the relative differences between subzones as much as possible, the threshold in this study was elevated to 10%. Therefore, rare species were defined as those appearing in less than 10% of the studied subzones. Habitat-forming species (HFS) and ecologically significant species (ESS) were selected based on expert judgement, supported by the extensive literature existent on the role of such species dwelling the Belgian coast and continental shelf (HFS: Hiittel, 1990; Rasmussen et al., 1998; Callaway, 2006; Rabaut et al., 2007; Van Hoey et al., 2008; Rabaut et al., 2010; ESS: Van Hoey et al., 2004; Van Hoey et al., 2007b). It should be noted that subjectivity cannot be totally excluded. A list of selected HFS and ESS, and the rationale behind this selection can be found in Annex I – A.

The assessment questions for each of the ecosystem components need to be translated into mathematical algorithms (see Annex I – B). Solving these algorithms yields a numeric answer to each assessment question, corresponding to a score translated into a semi-quantitative classification system of five value classes: *very low, low, medium, high* and *very high* BV. If there is no data to answer a specific question for a certain subzone, it is labelled as 'not available' (NA). An example of the scoring process described above can be seen in Annex I – C. The scores for all assessment questions are added together per subzone, though separated for different ecosystem components. Each assessment question has been attributed an equal weight in the total score. The results are then illustrated in a biological valuation map (BVM) per ecosystem component.

The reliability of the assessed values for each subzone is noted with an attached label, perceptible in the final map (low, medium, high). Such label can either display the amount and quality of the data used to assess the value of a certain subzone (data availability) or it displays how many assessment questions could be answered per subzone given data availability (reliability of information). For example, when a certain question cannot be answered for one or more subzones, these subzones are scored on the basis of the remaining questions that could be answered, decreasing the completeness of the information and the reliability of the scoring. When certain subzones lack data for one or more ecosystem components, these are valued based on the final score for the remaining available ecosystem components, being less reliable than subzones valued based on all of the ecosystem components. An example of how data availability and reliability of information have been incorporated into the protocol can be seen in Annex I – C. These reliability labels and the BVMs should be consulted simultaneously as they allow us to identify knowledge gaps.

The total biological value of the subzones is determined by averaging the intermediate values for the different ecosystem components. An example of how to perform the final scoring is given in Annex I – C. The results of the BV are then presented on a final BVM, where each subzone is assigned a colour corresponding to its resulting biological value. Both reliability and availability labels of each subzone are displayed on the BVM by using different colours or fillings.

2.3.2. *Using BV for solving space-use conflicts*

Once a final BVM map of the shallow Belgian coastal zone was obtained, its applications were investigated. For the flood risk scenario at the Belgian coast, information regarding extremely vulnerable areas (that are highly likely to undergo coastal defence activities in the near future) was transformed into a spatial layer (see Annex I – D) which was displayed along with the final BVM and with a map depicting the ten delimited Belgian coastal areas covered by Provincial Spatial Implementation Plans (PSIPs) (Annex I – D).

For the nature conservation scenario, the final BVM was displayed together with the existing protected areas at the shallow Belgian coastal zone, under European (RAMSAR, Birds & Habitat Directive combined in the Natura 2000 Network – Special Areas of Conservation & Special Protection Areas) and National/Flemish legislation (marine and nature reserves, and protected dunes) (see Annex I – E). Data were obtained from the interactive coastal atlas of the Flemish Region (Maelfait and Belpaeme, 2009).

3. Results

3.1. *BVMs per ecosystem component*

The BVMs for birds, macrobenthos, epibenthos, and hyperbenthos can be seen in Annex II – Figs. 1, 2, 3 and 4 respectively. The reliability indices, data availability and information reliability, per ecosystem component are depicted in the maps of Annex III – Figs. 1, 2, 3 and 4. Information reliability was maximal (*high*) for all subzones with data, meaning the chosen assessment questions for each ecosystem component could be answered in every subzone with data. Table 3 shows the number of subzones with data per ecosystem component. It is clear that the ecosystem component 'macrobenthos' delivers the highest amount of data for the total valuation. Data availability correlation with the valuation scores was checked through a Pearson correlation (Table 3) and no correlation was detected.

3.2. *Integrated BVM*

Fig. 2 shows the final BVM for the shallow Belgian coastal zone. The mosaic-like variability of scores is apparent and can also be seen in the BVM of macrobenthos (Annex II – Fig. 2). There is a clear

Table 3
Number and percentage (%) of subzones with data, out of the total number of subzones per ecosystem component; Pearson correlation (r), with corresponding coefficient of determination (r^2) between data availability and biological valuation scores per ecosystem component.

Ecosystem component	Total number of subzones	Number of subzones with data (%)	R	r^2 (%)
Macrobenthos	463	124 (27%)	−0.40	0.16 (16%)
Epibenthos	463	11 (2%)	0.73	0.53 (53%)
Hyperbenthos	463	14 (3%)	0.16	0.03 (3%)
Birds	42	10 (24%)	0.30	0.09 (9%)
Total valuation	463	216 (47%)	0.21	0.04 (4%)

difference in the amount of data collected to the west of Oostende if compared to the east and around 70% of the shallow subtidal subzones with data scored *medium*, *high* or *very high*. Moreover, high biologically valued intertidal zones are not necessarily bordered by high biologically valued shallow subtidal zones and vice versa. Both final reliability indices, information reliability and data availability, are mapped together in Fig. 3. Most subzones displayed *medium* to *high* information reliability and have a *low* or *medium* data availability. *High/very high* biological values are consistently found in intertidal zones located immediately to the east of the three prominent Belgian harbours (Fig. 4).

3.3. Using BV for solving space-use conflicts

The final BVM was displayed along with areas under coastal flood risk (Annex I – D) and along with the PSIPs. Since the PSIPs only cover the intertidal part of the Belgian beaches, the maps in Fig. 5 and Annex IV only show the biological value of the intertidal area. Fig. 5 focuses on the harbour areas as they have been given high priority for coastal defence in the current Integrated Master Plan for the Flemish coast (Mertens et al., 2008) and the areas just east of the harbours seem to attain a *high/very high* biological value (Fig. 4). Areas for which no spatial plan exists, e.g. the beach of Lombardsijde, are commonly addressed as blank or undesignated areas (Fig. 5a). Areas sensible to coastal flood (in red) but lacking biological data (no colour) were identified within almost all of the PSIPs (Fig. 5c). Areas sensible to coastal flood and displaying *high/very high* biological value were also identified (Fig. 5a and c and Annex IV – Figs. 1–6).

Considering the nature conservation scenario, all protected areas in the shallow Belgian coastal zone are displayed together with the final BVM (Annex I – E). Detailed maps of the most important protected areas are shown in Fig. 6. Overall *low* BV scores for De Panne and 'De Westhoek' (Fig. 6a) and the *medium* intertidal value and *low* subtidal value for 'Zwin' (Fig. 6c) were certainly lower than expected. Lombardsijde beach area of the Flemish nature reserve 'IJzermonding' gets a *medium/high* intertidal score and a *very high* shallow subtidal score (Fig. 6b). The Flemish nature reserve 'Baai van Heist' (Fig. 6c) attained a *very high* BV.

4. Discussion

4.1. Integrated BVM of the shallow Belgian coastal zone

According to Table 3, data used in this biological valuation covered almost half of the total study area (47%), with the ecosystem component 'macrobenthos' delivering the highest amount of data for majority of subzones and for the total valuation. Most observed trends of the integrated BVM can be explained by taking a closer look at the BVM of macrobenthos (Annex II – Fig. 2). A simple correlation test was performed in order to check if the amount of data obtained in each subzone would be influencing the valuation score (Table 3). Although a relatively higher r^2 was obtained for epibenthos (0.53), overall r^2 values were low and showed no strong correlation between the variables. The datasets used for epibenthos and hyperbenthos were incorporated into the final valuation although they won't deliver reliable results as data availability and spatial coverage (merely 3% of the study area) are unsatisfactory (Annex I and II – Fig. 3 and 4, respectively).

Firstly, the mosaic-like variability of scores was apparent in both the final BVM (Fig. 2) as well as in the BVM of macrobenthos (Annex II – Fig. 2). This can be explained by the irregular and patchy distribution of sediments in the coastal zone due to minor across-

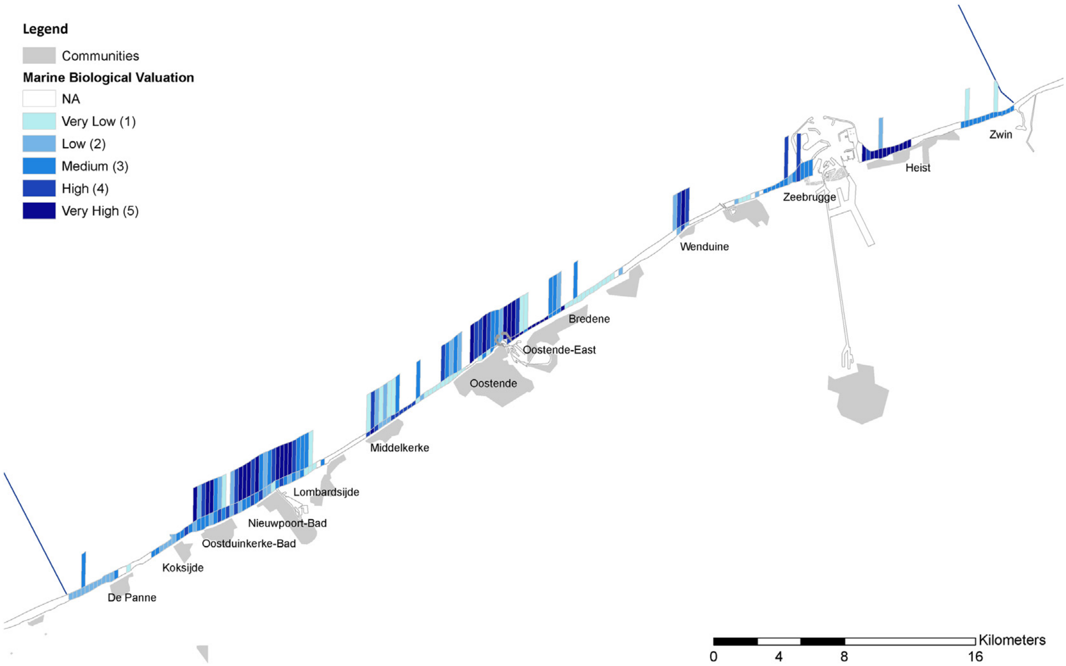

Fig. 2. Final biological valuation map for the shallow Belgian coastal zone (NA: not available). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

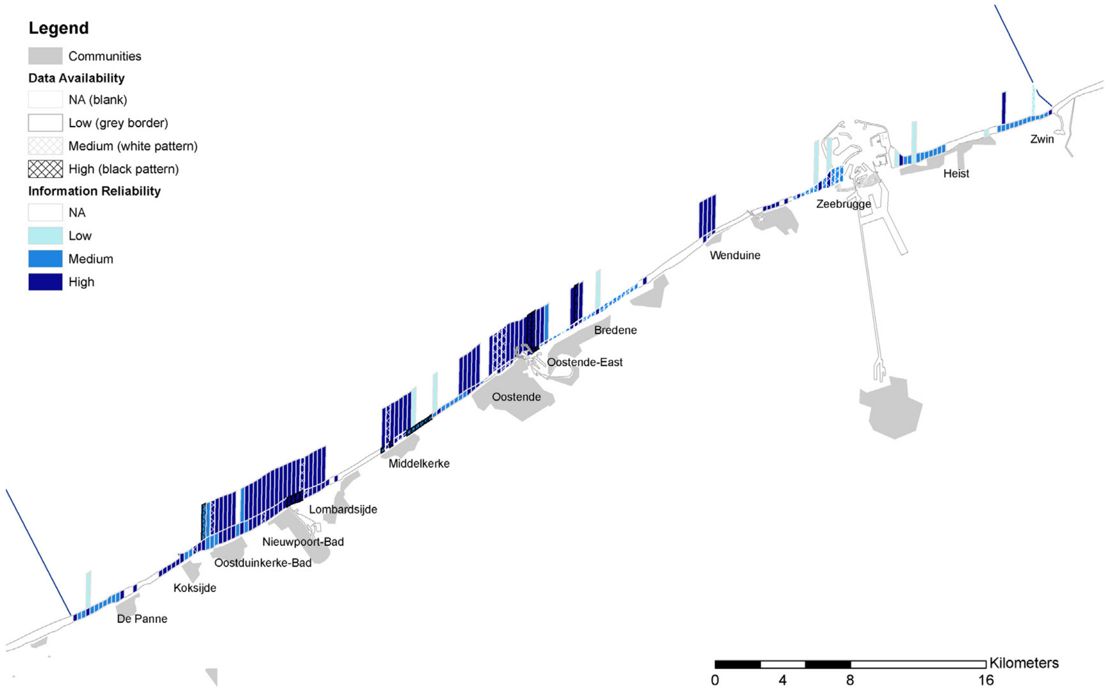

Fig. 3. Final map depicting information reliability and data availability for the shallow Belgian coastal zone (NA: not available). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

shore and along-shore morphodynamic and morphological differences (Degraer et al., 2003; Van Hoey et al., 2004). Combined with the diverse topography of the Belgian coastal zone, this creates a wealth in habitats supporting a high capacity for varied benthic species assemblages (Van Hoey et al., 2004). Secondly, there was a clear difference in the amount of data collected to the west of Oostende compared to the east. Information at the eastern part of the Belgian coast was much scarcer, even for areas of great

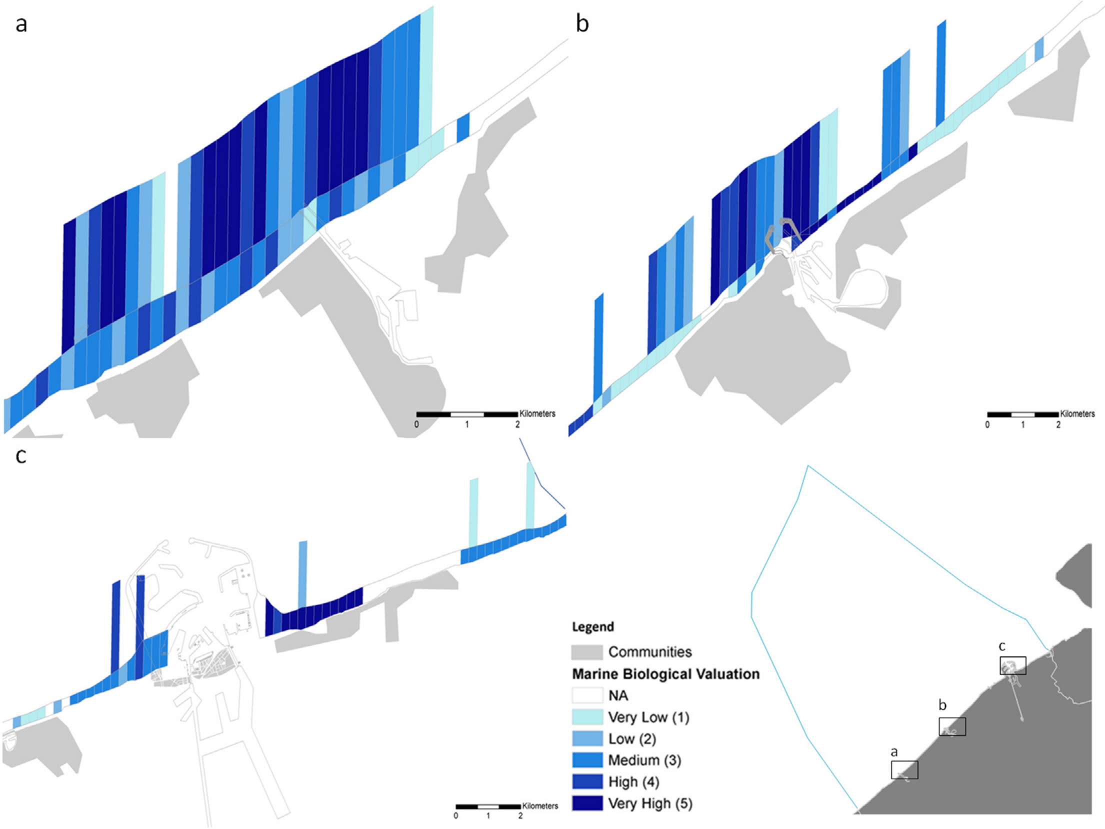

Fig. 4. Detailed information on the biological value of areas located at the east side of the main harbours at the Belgian coast (NA: not available): (a) Nieuwpoort (Lombardsijde); (b) Oostende (Oostende-East); (c) Zeebrugge (Baai van Heist). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

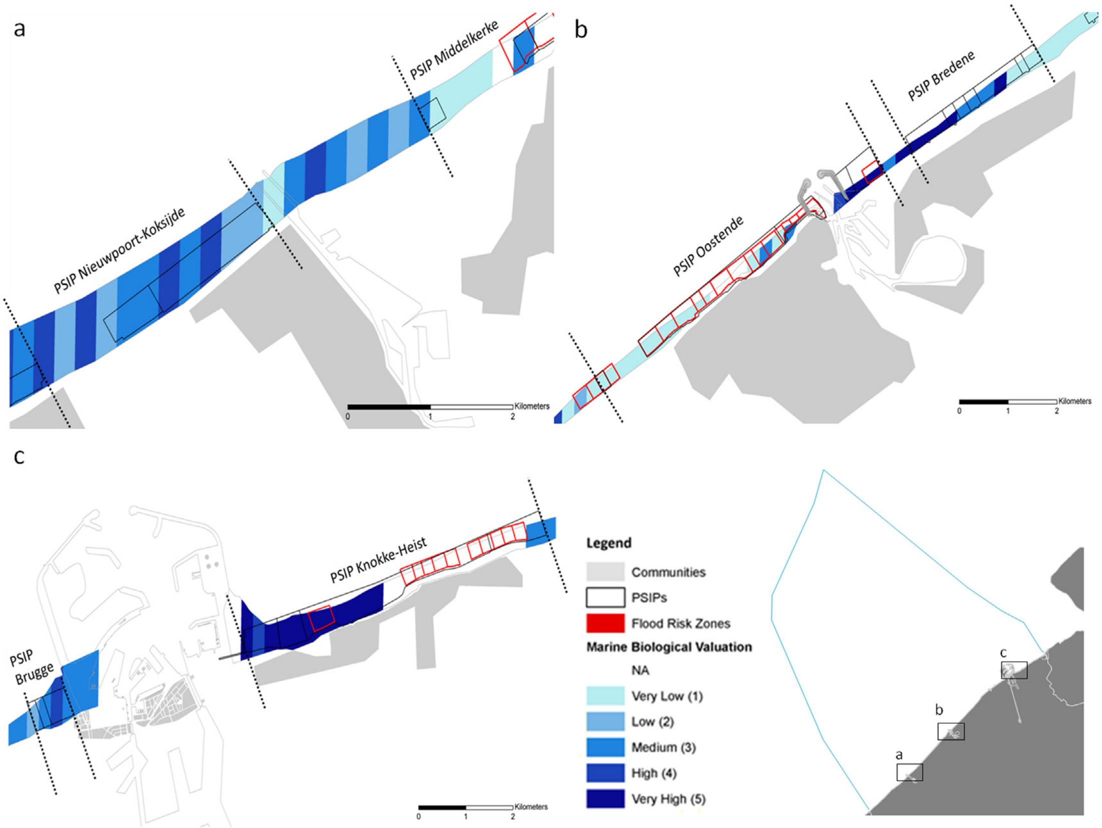

Fig. 5. Detailed map with biological value scores of intertidal areas located at the east side of the main harbours at the Belgian coast, inside Provincial Spatial Implementation Plans (PSIPs). Red indicates areas with coastal flood risk (NA: not available). The dashed lines mark the boundaries of each PSIP: (a) Nieuwpoort (Lombardsijde); the beach of Lombardsijde (green rectangle) falls inside an undesignated area as it is not covered by any PSIP (Maes and Bogaert 2008); (b) Oostende (Oostende-East); (c) Zeebrugge (Baai van Heist). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

ecological importance such as 'Baai van Heist' or 'Zwin'. This is easily explained since the largest clusters of data (Lombardsijde, Nieuwpoort-Bad, Bredene, Koksijde-Oostduinkerke, and Oostende) were gathered during sampling campaigns in the framework of environmental assessments for beach nourishment projects, which are located mostly westwards of Oostende. Thirdly, around 70% of the shallow subtidal subzones with data scored *medium*, *high* or *very high*. These high values were obtained through questions related to Aggregation-Fitness consequences. Due to specific abiotic conditions, species richness and abundance of benthic organisms (Dewicke et al., 1998), shallow Belgian coastal waters are indeed known as nursery areas for a series of epibenthic macro-crustaceans and flatfish species (Rabaut et al., 2010). However, for the question on ESS, higher values were mostly found in the shallow subtidal, suggesting that the ESS selected (Annex I – A) were perhaps not equally capturing intertidal and shallow subtidal communities. For example, although the *Abra alba* community is extremely important in subtidal waters (Van Hoey et al., 2005, 2007a), the emphasis given to this species by naming it an ESS might have caused an underestimation of the overall ESS scores for intertidal subzones. Finally, high biologically valued intertidal zones were not necessarily bordered by high biologically valued shallow subtidal zones and vice versa. Although there seems to be a gradual transition in macrobenthic assemblages from the lower intertidal to the shallow subtidal zone (Defeo and McLachlan, 2005; Speybroeck et al., 2008), the differences in these assemblages between both zones are substantial enough to lead to different scores by applying the same assessment questions.

Reliability of information apprises the level of certainty of the obtained BV scores, whereas data availability pinpoints subzones with more or less sampling effort, indicating where future surveys should be undertaken (Pascual et al., 2011). Hence, increasing reliability and sampling effort leads to a higher level of certainty of the final BV scores. The assessment questions chosen aimed at addressing data integrated in this valuation. Most subzones displayed *medium* to *high* information reliability and have a *low* or *medium* data availability (Fig. 3).

4.2. Using BV for solving space-use conflicts

4.2.1. Coastal defence

In addition to the trends previously discussed, *high/very high* biological values were consistently found in intertidal zones located immediately to the east of the three prominent Belgian harbours (Fig. 4). The major wind-driven and tidal currents and waves at the Belgian coast have a southwest-northwest direction (van der Molen and van Dijck, 2000; Speybroeck et al., 2008). As a consequence, current-induced erosion causes depletion of sediments to the west of these hard structures and sediment deposition at the east side, in a kinematic process already described and commonly addressed in coastal geophysics (Deronde et al., 2004). The east side of these prominent hard structures (also referred to as lee-side) is a sheltered area where hydrodynamics are less intense and sand deposition occurs. Hence, it creates a wealth in soft-bottom habitats and proper environmental conditions for benthic colonization, which goes in accordance with the observed pattern.

The spatial correlation between the final BVM and the PSIPs (Annex IV – Figs. 1–6) showed that areas for which no spatial plan exists are commonly addressed as blank or undesignated areas (Bogaert and Maes, 2008) and as such cannot be legally considered

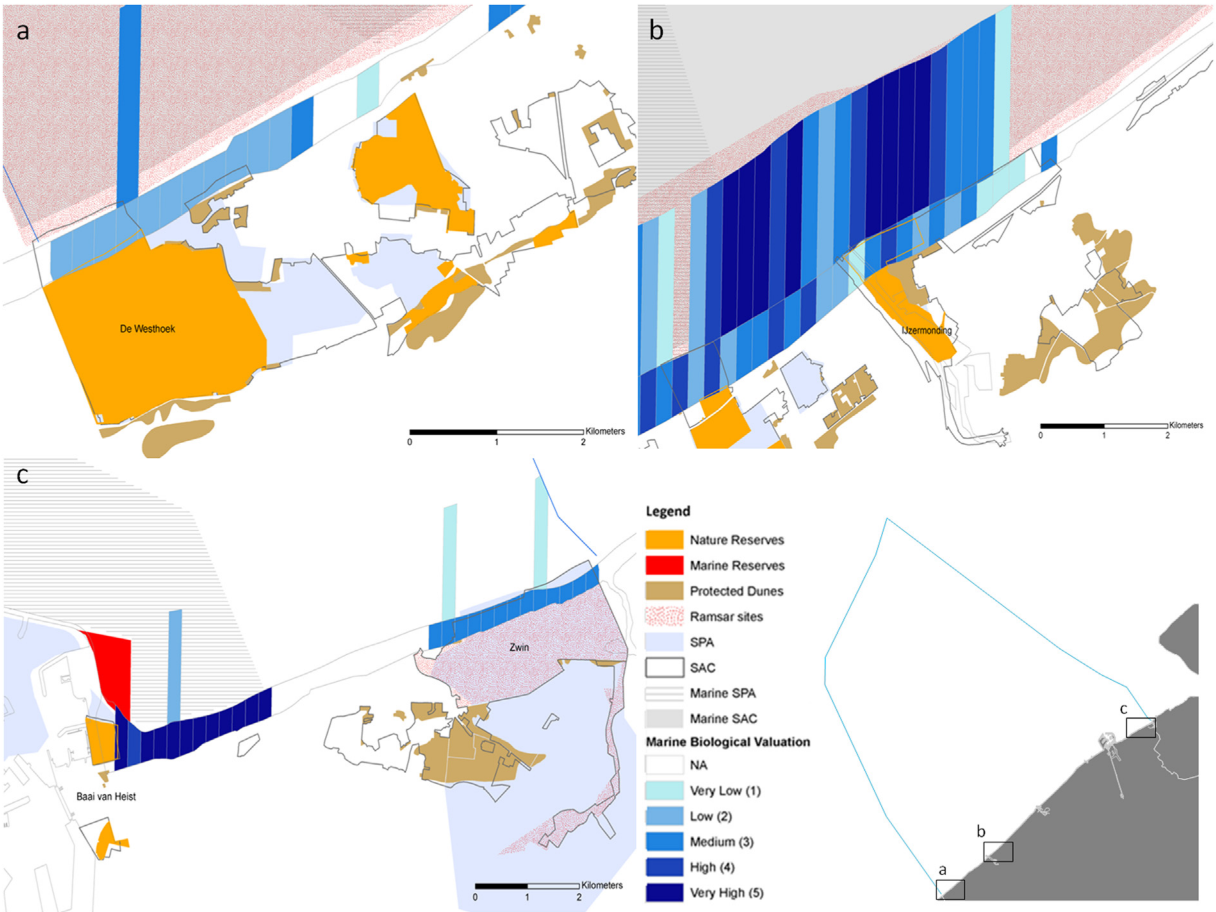

Fig. 6. Detailed information on the biological value of protected areas located at the shallow Belgian coastal zone (NA: not available; SPA: Special Protection Area (Birds Directive); SAC: Special Area of Conservation (Habitats Directive)): (a) 'De Westhoek' (De Panne): only low intertidal scores were obtained despite its ecological importance; (b) Nature Reserve IJzermonding (Lombardsijde): very high valuation scores were obtained for the subtidal waters adjacent to Lombardsijde beach, providing a visual support for the extension of the reserve seawards; (c) Zwin: an overall medium score, whereas intertidal subzones located near Baai van Heist have high/very high scores. For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

under the scope of coastal spatial management. Lombardsijde beach, part of the nature reserve 'IJzermonding' (Figs. 5a and 6b), is an undesignated area but its *high/very high* BV scores emphasize the importance of a full-coverage coastal network of PSIPs, leaving no room for undesignated areas. Areas sensible to coastal flood (in red) but lacking biological data (no colour) are identified within almost all of the PSIPs, e.g. the beach zone between Knokke-Heist and Zwin (Fig. 5c). Areas sensible to coastal flood and displaying *high/very high* biological value are also identified (Annex IV – Figs. 1–6), e.g. Middelkerke (Fig. 5a), Oostende Oosteroever (Fig. 5b) and Knokke–Heist (Fig. 5c). If coastal defence activities are to be performed in these areas, appropriate mitigation or compensation measures should be drafted. This stresses the need for acquiring more relevant biological data at the unstudied areas with high coastal flood risk. Some critical steps for an ecologically good practice of beach nourishment should be taken, particularly in areas of *high/very high* BV, such as: (1) selection of nourishment techniques in respect to local natural values; (2) selection of nourishment sand based on the sediment composition of the targeted area (grain size); (3) avoiding drastic alteration of the beach slope; (4) execution of nourishment activities during periods of low beach activity of birds or other mobile organisms; and (5) favouring the selection of smaller, phased projects as opposed to a single, wide project (Peterson et al., 2000; Speybroeck et al., 2006).

An alternative nourishment solution, known as foreshore nourishment, involves the implementation of parallel sandbanks along the entire coast just at the submerged foreshore. These sandbanks constantly supply sand to the beach zone after progressive tidal regimes (Misdorp and Terwindt, 1997). However, intertidal communities are much more adapted to extreme sudden changes in environmental conditions than subtidal ones (Speybroeck et al., 2005a), making them relatively more resilient to anthropogenic interventions such as beach nourishment. Additionally, habitat continuity from the low intertidal zone to the foreshore (Degraer et al., 1999) is disrupted by these sandbanks, hindering repopulation of the low intertidal zone by subtidal organisms. The *high/very high* BV obtained for most shallow subtidal zones along the Belgian coast (Fig. 2) further stresses the need for caution when contemplating coastal defence measures such as foreshore nourishment. Overall, it can be concluded that these results highlight the potential usefulness of BVMs for coastal and marine spatial planning in Belgium, particularly as baseline maps underlying a solid decision-support system (Fig. 7).

4.2.2. Nature conservation

The BV protocol has achieved good results as a tool for the implementation of the Habitats and Birds Directives in the Belgian Part of the North Sea (Derous et al., 2007d) and as a framework to assess the ecological quality status of waters, under the European Water Framework Directive (Pascual et al., 2011). It could also be used as a baseline map for the implementation of the European Marine Strategy Directive, as the protocol incorporates most of the

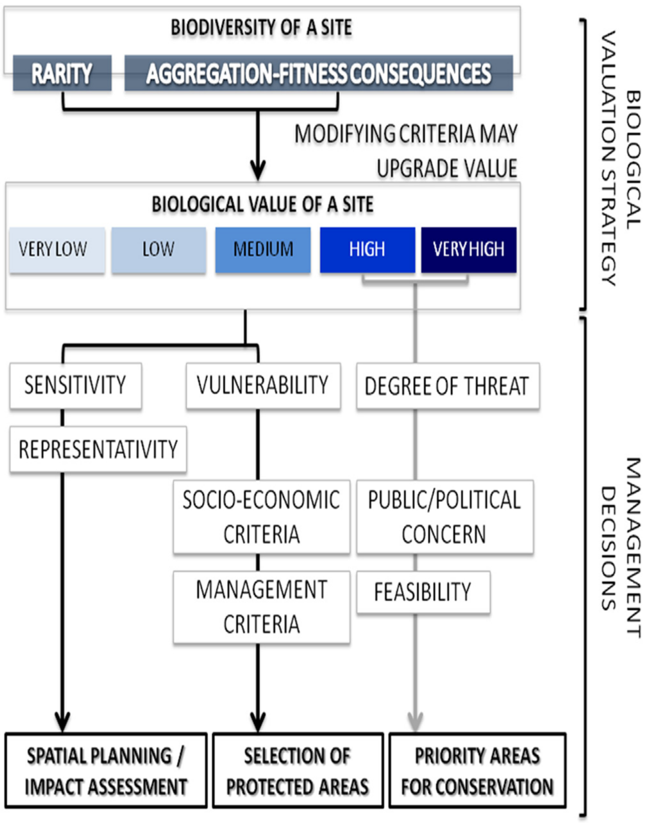

Fig. 7. Overview of the biological valuation concept and possible future steps to develop decision-support management approaches (adapted from Derous et al., 2007c). For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.

biological and physical characteristics required by the Directive (Derous et al., 2007d). To stress the usefulness of the BV protocol as support tool for the proposal of new or the extension of already existing protected areas, the integrated coastal BVM was displayed alongside the main protected areas at the Belgian coast (Annex I – E). It is clear that not all areas with some kind of protection status have a high ecological value, as defined with the BV method.

For the area of De Panne, both the birds and macrobenthos BVM showed a *low* BV (Annex II – Fig. 1 and 2) leading to overall *low* BV scores (Fig. 6a). Nevertheless, the ecological importance of De Panne and the grey dunes of 'De Westhoek' have been widely acknowledged in literature (Bonte et al., 2004; Provoost et al., 2004; Vandenbohede and Lebbe, 2004) and the latter is even a reserve considered to be properly managed from an ecological perspective (De Ruyck et al., 2001; Houston, 2003). However, literature also allocates the ecological importance of both areas to the ecosystem components vascular plants and terrestrial arthropods. Since there was insufficient data for these components and subtidal information is nonexistent, they were not included in this analysis. As such, no significant conclusions regarding the biological value of De Panne and 'De Westhoek' can be made.

High data availability in the Lombardsijde beach area of the Flemish nature reserve 'IJzermonding' supports a *medium/high* intertidal score and a *very high* shallow subtidal score (Fig. 6b). Unfortunately, the beach of Lombardsijde is an undesignated area on the PSIPs since it falls under military jurisdiction. It was proposed for special management plans in 2000 given its high ecological importance (Herrier and Van Nieuwenhuyse, 2005). The *very high* shallow subtidal scores of Lombardsijde beach justify and underline the ecological importance of extending the beach reserve seawards (Fig. 6b) by providing a straightforward and visual message to support this advice (Van Nieuwenhuyse, 2003).

The Flemish nature reserve 'Baai van Heist' (Fig. 6c) attained a *very high* BV due to the birds' valuation. This was expected, as the development of the harbour of Zeebrugge in the 1980s created vast areas of sandy, sparsely vegetated and relatively undisturbed coastal areas (Speybroeck et al., 2008), mimicking natural processes and attracting a great number of coastal breeders (Stienen and Van Waeyenberge, 2002; Stienen and Van Waeyenberge, 2004; Stienen et al., 2005). In fact, the distribution of species such as *Sterna albifrons* (Little tern) is now almost exclusively limited to this area and adjacent beaches (Courtens and Stienen, 2004; Stienen et al., 2005).

Protected under various legislations and directives, 'Zwin' is one of the most important protected areas of the Belgian coast (Fig. 6c). Its ecological relevance is related not only to its role as a breeding/feeding/aggregation site for birds but also to the presence of rare and important species (Devos, 2008; Herrier and Leten, 2010; Charlier, 2011; BirdLife, 2013). The *medium* value obtained for 'Zwin' (Fig. 6c) was certainly lower than expected. The value is strongly influenced by the results for the birds, suggesting that the birds' data are not covering the real situation. The *low* score for the shallow subtidal subzone of 'Zwin' (Fig. 6c) was only valued on the basis of epi- and hyperbenthos, scoring very *low* and *low*, respectively. Although little can be discussed for these components separately, previous literature suggested a decline of species richness and abundance for hyperbenthic communities under estuarine influence (Dewicke et al., 2003). Being in such proximity to the Scheldt estuary, this might very well be the case for 'Zwin' but without a better spatial coverage of data, this remains a mere speculative conclusion.

Clearly, more comprehensive datasets need to be incorporated in future biological valuations of the Belgian coast, particularly for the beach of De Panne and the 'Zwin' area.

4.3. BV as tool for EB-MSP at the Belgian coast?

Since the marine and coastal environment is very complex, several indicators have been designed to reduce the number of measurements and parameters that normally would be required to give an exact representation of the state of this environment. An indicator in ecology and environmental planning is defined as a component or a measure of environmentally relevant phenomena, e.g. pressures, states and responses, used to depict or evaluate environmental conditions or changes or to set environmental goals (Heink and Kowarik, 2010). Indicators thus require detailed knowledge of what the natural state of a system should be, why the system is in a particular state, and which value-based criteria are necessary for applying the 'good' or 'bad' label (Mee et al., 2008). In general, indicators have to be SMART (specific, measurable, achievable, realistic and time-bounded) to allow for an apparent signal when they have been met, and when management measures have been successful. In moving towards a more functional approach, the need for indicators of overall health of the system still increases, at the expense of indicators of single aspects of the biota, e.g. species richness and biomass (Borja et al., 2010). Marine biological value is a multi-metric, integrative, system-level ecological indicator developed to be able to assess the intrinsic value of a certain area by integrating all available biological data on different organizational levels of biodiversity (from the species up to the ecosystem level) and for different ecosystem components (Derous et al., 2007d).

The BVMs of the shallow Belgian coastal zone give a good overview of the biological value of the intertidal and shallow subtidal subzones of the study area. As for most marine and coastal environments worldwide, the data available for this work addresses biological structures at the species/population and community levels. To incorporate more levels of biodiversity (Zacharias and Roff, 2000), larger and more comprehensive datasets are needed on a global scale. Incorporating data on beach meiofauna, terrestrial arthropods and vascular plants could permit a more integrative and sound valuation of the coastal zone by addressing the beach ecosystem as a continuum from shallow subtidal waters to the foredunes. However, these ecosystem components are either only scarcely researched or restricted to the foredunes. In the latter case, this would hinder a good relative comparison between all studied zones (foredunes, intertidal and shallow subtidal zones) which is why these ecosystem components were not included. Although the BVMs only have a medium-term reliability, the necessary high sampling intensity restrains a frequent update of BVMs after a relevant period of time (several years). A recalculation every five years seems appropriate given the amount of new data that can be gathered within that time frame. For the moment being, it is impossible to reflect real inter-seasonal or inter-annual differences in biological value. Only maps based on data from a longer time period, giving a summary of the medium-term variability in value, can be developed (Derous et al., 2007d), as has been attempted in this study.

In future research, limitations on data coverage can be overcome by mapping biophysical characteristics (Young et al., 2007) and subsequent habitat modelling based on, for example, grain size (Van Hoey et al., 2004; Degraer et al., 2008; Willems et al., 2008), resulting in a sound extrapolation of benthic data to presently unsampled subzones. More ecologically meaningful results can also be achieved by including data regarding biological processes and functions, e.g. the presence of migratory routes or overall productivity of a subzone, and by drafting new or different assessment questions, based on the ecological knowledge of the study area.

In conclusion, BV can be a valuable tool within the scope of EB-MSP at the Belgian coast as it allows for the integration of 'nature' at an early stage of policy implementation, for both coastal flood risk and nature conservation space-use conflicts. BVMs underly management and policy decisions in a clear, efficient, transparent and objective way, significantly attenuating conflicts and enabling a transparent involvement of stakeholders (Pomeroy and Douvere, 2008; Fleming and Jones, 2012). Within an integrative decision-support system for spatial planning, BVMs should be further considered together with other criteria related to socio-economic and political/legal preconditions (Derous et al., 2007c) (Fig. 7).

4.4. Limitations and caveats of BV

The protocol followed in this work reflects the reasoning behind the development of the BV tool, and no fundamental changes to the original assessment questions and concept definitions (Derous et al., 2007a) have been undertaken.

When first applied to the Belgian Part of the North Sea, species richness per subzone was corrected by applying a logistic regression analysis in which besides sampling effort (in terms of area surveyed), the distance to the coast and mean depth were also taken into account (Derous et al., 2007c). However, the BV protocol used here did not yet foresee for such correction, especially since distance to coast and mean depth would be irrelevant factors to be considered in the intertidal and shallow subtidal zone. For future applications, a correction for sampling effort differences among subzones could be designed and applied for questions related to species richness.

The relationship between the spatial coverage of data gathered and the number of subzones strongly influences the selection for rare species in the BV protocol. Rare species in BV are defined as species appearing in less than 5% of the studied subzones (Derous et al., 2007d), but this can be changed if properly justified. Since only a limited number of subzones per ecosystem component actually had data (Table 3), with the exception of the macrobenthic component, this resulted in a conflict within the selection of rare species. Rarity thresholds smaller than 10% were automatically returning areas equal to a fraction of a subzone (less than one subzone itself), causing errors in the calculation of the score. A 10% threshold for rarity was chosen in this work to overcome this rather technical constraint of the protocol. Possible adjustments of the protocol are changing the calculation steps or changing the approach to the selection of rare species (Pascual et al., 2011). Clearly, further attention regarding this matter is fundamental to the successful improvement of the BV protocol.

We highlight that misinterpretations could occur when the BVM is used without consultation of the reliability and availability maps as the underlying maps depict the results of each assessment question separately per ecosystem component, the documentation of the valuation process or the integrated database.

5. Conclusions

The application of the biological valuation framework (Derous et al., 2007a, 2007b) for the shallow Belgian coastal zone was feasible and required minor adjustments. Spatial coverage and overall data availability were satisfactory and allowed for significant trends and patterns to be observed. Although the Belgian coast is entirely composed of sandy beaches, there is indeed biological diversity among distinct subzones. Spatial information on the intrinsic biological value of a given subzone within areas covered by PSIPs and/or within coastal flood risk areas was presented in a straightforward manner, potentially enabling stakeholder's involvement. Similarly, BVMs provided a strong visual support for the extension of some already existing nature reserves and for the high amount of data needed to allow for significant conclusions regarding the biological value of other reserves. For spatial planning, BVMs should be used along with other criteria defined within a sound decision-support system (Derous et al., 2007c). Important limitations to the applicability of this BV protocol have been identified, mostly related to the threshold for selection of rare species and the approach to calculating species richness. Notwithstanding, the potentialities of this integrative tool should not be underestimated. Further research on the applications of BV to coastal areas is still required to perfect and fine-tune the tool, enhancing the robustness of its results and consequently strengthening its application within spatial management strategies towards an integrative, ecosystem-based management of coastal areas worldwide.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2014.04.022.

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