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Aligning biodiversity conservation and ecosystem services in spatial planning: focus on ecosystem processes

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Abstract

Although the consideration of socio-economic demands with biodiversity conservation is now high on the environmental policy agenda, it is not yet standard practice in spatial planning. This is argued to be related, amongst others, to a lack of awareness among stakeholders and practitioners of the underpinning role of ecosystem functioning and biodiversity to support human well-being. Meanwhile, there is mounting critique on the absolute focus of biodiversity conservation on static properties such as species and habitats. The establishment of more ecologically sensible objectives that include ecosystem processes besides species and habitats is put forward as a more effective way of environmental conservation. Methodological approaches increasingly consider ecosystem processes. However, the processes that are included mostly relate to aspects of biodiversity such as dispersal and productivity, and rarely do they include abiotic mechanisms that underlie biodiversity. We here report on the development of a method that integrates two principles which we identify as key to advance the integration of ecosystem services with biodiversity conservation in planning practice: (1) consider the variety of ecosystem processes, biotic as well as abiotic, that support biodiversity and ecosystem services, and (2) link the ecosystem processes to biodiversity and to socio-economic benefits to identify the common ground between seemingly conflicting objectives. The methodology uses a stepwise approach and is based on an extensive review of available knowledge on ecosystem functioning, expert consultation and stakeholder involvement. We illustrate how the methodology supports the setting of strategic goals to accomplish a healthy coastal ecosystem in Belgium, and exemplify how this may affect spatial plans. The aim of this paper is to demonstrate how including processes opens opportunities to align biodiversity and ecosystem services and how this increases chances to provide long-term benefits for biodiversity and human well-being. The paper may provide inspiration to advance current spatial planning approaches.

Keywords

Natural dynamics; ecosystem approach; marine ecosystem; stakeholders; synergies, trade-offs

1. Introduction

Given the fast growth of the world population, safeguarding the necessary space to protect biodiversity and ensuring natural processes is a major challenge worldwide for spatial planning both on land and at sea. Over the past decades, different concepts have been established that aim to find compatibilities between nature conservation and socio-economic development. The ecosystem approach (CBD, 2004), marine spatial planning (MSP) and ecosystem-based management (McLeod et al., 2005) all focus on combining biodiversity conservation and sustainable and equitable use rather than on isolated, sectoral objectives such as individual species/habitats or economic benefits. In recent decades, the notion of ecosystem services (ES), which connects aspects of ecosystem functioning to human well-being and underlines the dependency of humans on ecosystems, gained a lot of attention. Highlights are the publications of the Millennium Ecosystem Assessment (MEA) in 2005 and The Economics of Ecosystems and Biodiversity (TEEB) in 2010, and the foundation of the Intergovernmental Panel on Biodiversity and ES (IPBES) in 2012. Although they have contributed to increasing awareness on the contribution of nature to human well-being, conservation and spatial planning are still often focused on achieving sectoral objectives (Liu et al., 2015; Ortiz-Lozano et al., 2017; Pires et al., 2018) and true integration of ES with biodiversity is not yet standard practice (Guerry et al., 2015).

Biodiversity conservation has long focused on the preservation of individual species (assemblages) and habitats (Jepson, 2016). However, ecosystems evolve through biophysical interactions and complex ecological processes taking place on spatial and temporal scales beyond the boundaries of a single habitat. It is increasingly recognized that conservation efforts are more successful if also ecological processes are considered (Klein et al., 2009; Bennett A.F. et al., 2009; Magris et al., 2014; Perring et al., 2015; Watson et al., 2016; Pettorelli et al., 2018). Likewise, research in ES has shown that decision-making based solely on structural properties such as land use and habitat can result in strongly adverse effects (Eigenbrod et al., 2010; Van der Biest et al., 2015) and calls for a consideration of ecosystem processes (Kremen et al., 2005; Nicholson et al., 2009; Rieb et al., 2017).

Conservation approaches that take into account processes often only consider biotic processes such as dispersal and succession (Tulloch et al., 2016; Pires et al., 2018), while abiotic processes tend to be underrepresented (e.g. Edwards et al., 2010; Berglund et al., 2012; D'Aiola et al., 2017). Ockendon et al. (2018) identify the inclusion of the variety of natural processes, both biotic and abiotic, as an essential progress towards biodiversity and landscape restoration. Especially when integrating ES, the role of including biotic and abiotic processes becomes more prominent as they are the driving mechanisms for these benefits (Kremen et al., 2005; Nicholson et al., 2009; Haines-Young and Potschin, 2010; Rieb et al., 2017). Management of ecosystem processes thus constitutes a key approach for both biodiversity and ES optimization (Reyers et al., 2012; Liu et al., 2015; Perring et al., 2015; Truchy et al., 2015).

Recent work that integrates ES with biodiversity is often based on co-occurrence mapping of high values for both objectives (Martínez-Harms et al., 2015; Schröter and Remme, 2016; Hermoso et al., 2018; Hou et al., 2018). However, this may result in conflicts between competing objectives (Egoh et al., 2010), without providing guidance on how to deal with these trade-offs. In some cases, a distinction is made between biodiversity-compatible and non-compatible ES (e.g. Hermoso et al., 2018) and win-wins for both (e.g. Naidoo et al., 2008; Lanzas et al., 2019). Mostly provisioning ES are considered not to be compatible with biodiversity and with other ES (Rodríguez et al., 2006; Raudsepp-Hearne et al., 2010). This requires an a priori decision on how trade-offs will be dealt with in planning, leaving opportunities for multifunctionality and for turning trade-offs into synergies (Maes et al., 2012) underexplored. A more clear representation of the underlying processes that cause the trade-offs and information on the different links of these processes to ES and biodiversity values is needed to advance the integration of ES with biodiversity in spatial planning.

We here report on the development of a method that integrates two principles which we identify as key to advance the incorporation of ES with biodiversity conservation in spatial planning: (1) consider the variety of ecosystem processes (biotic and abiotic) that support biodiversity and production of ES and (2) link the ecosystem processes to biodiversity and to socio-economic benefits to identify the common ground between these seemingly conflicting objectives. By considering ecosystem processes in early stages of spatial planning, the method aims to support the development of spatial plans that safeguard long-term benefits to biodiversity and ES.

We illustrate its use in light of the development of a future vision for the Belgian coastal ecosystem which is an intensively used area with high pressures on remaining important biodiversity values and show how this may affect spatial planning using two detailed examples.

2. Methodology

2.1. Study area

The methodology is explained using the case-study of the Belgian coastal ecosystem. The terrestrial limit is formed by the transition from polder to dunes, and the marine limit coincides with the boundary of the Belgian part of the North Sea (Fig. 1). The land part (80 km²) is dominated by dunes under a protected status as well as degraded dunes used as pasture or private gardens. The dunes are intersected at two places by estuaries with tidal flats and marshes. The marine zone (3600 km²) is part of the Southern North Sea and the seafloor is mainly made up of soft sediments with a series of parallel sand banks hosting a high benthic diversity as a result of the variable topography and sediment composition (Degraer et al.,2008; Vanden Eede et al., 2014). Densely urbanized areas are left out from the study as management of open space is the main purpose of the application in the case-study. The relatively small size and high population density create intensively used land- and seascapes and jeopardize remaining biodiversity values. Several developments are taking place which will further increase spatial claims or change the ecosystem (Douvere et al., 2007; Vanden Eede et al., 2014; Van de Velde et al., 2014) such as blue growth initiatives (e.g. aquaculture, marine biotechnology) and harbor developments.

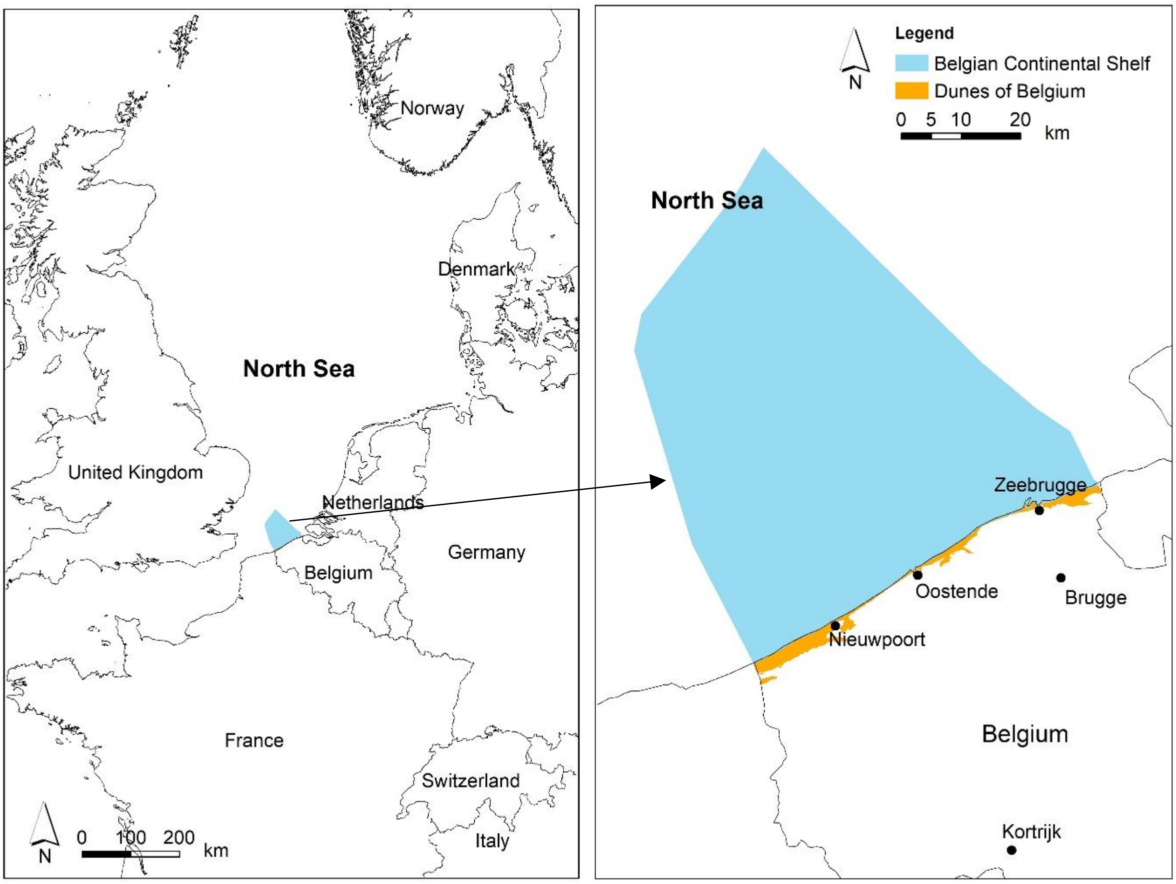

Fig. 1 – Location of the study area consisting of a marine part (continental shelf) and a dune part

2.2. Stepwise approach

Central in the approach is the focus on ecosystem functioning as the motor of a healthy ecosystem (cfr. the ecosystem approach by CBD, 2004). A well-functioning ecosystem can be defined as a system which has the ability to maintain its structure and processes over time in the face of external stress (CBD, 2004). Ecosystems are characterized by structural properties and shaped by underlying processes that allow them to adapt to changes. Ecosystem processes are here defined as changes in the stocks or in the fluxes of products and energy resulting from interactions among organisms (incl. humans), between organisms and their abiotic environment as well as among abiotic parameters. Ecosystems consist of different habitats, which the Convention of Biodiversity defines as "essential to the concept of biodiversity conservation, where the aim is to conserve natural habitats supporting the preservation of the ecological processes which underpin ecosystem function”. Ecosystem services likewise result from structural characteristics and underlying ecological processes that form these structures (Haines-Young & Potschin, 2010). As processes are the drivers of both biodiversity and ES (Nicholson et al., 2009), they enable to integrate objectives for biodiversity and for ES. This is the key rationale of the proposed methodology which is described as a stepwise procedure (Fig. 2).

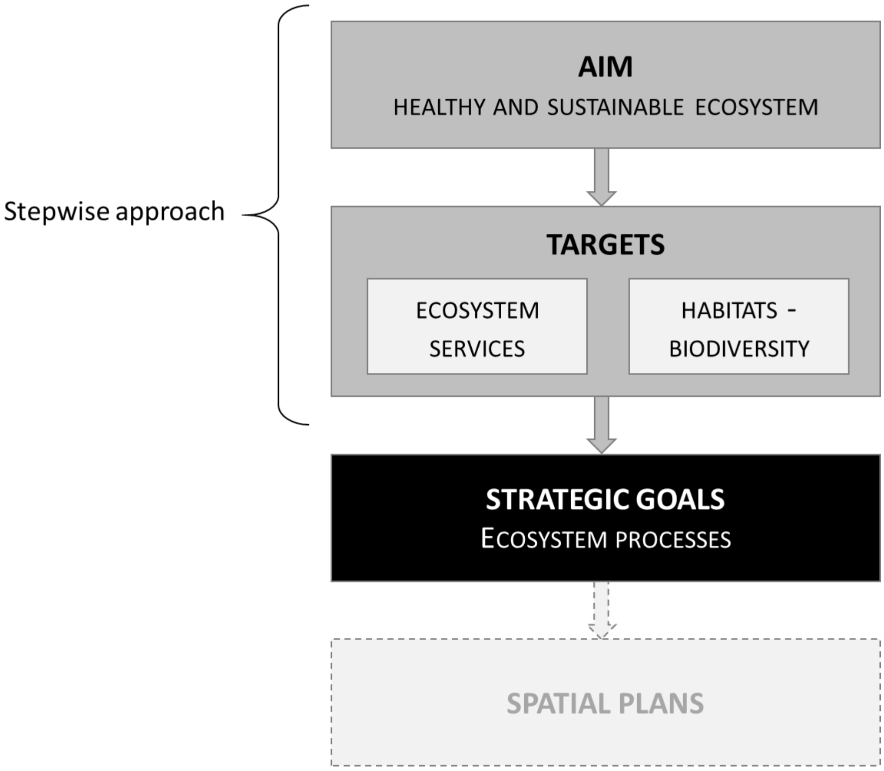

Fig. 2 – Schematized overview of the rationale of the proposed methodology. The stepwise approach supports in the creation of a future vision described by a series of strategic goals. These strategic goals can be used as guidance in the development of actual spatial plans.

2.2.1. Step 1: Set term and identify external drivers of change

The first step consists of setting the time scale by which the aim of a healthy ecosystem and associated goals should be accomplished and identifying the external drivers of change. External drivers of change refer to processes taking place on large temporal and spatial scales beyond the boundaries of the ecosystem under consideration, and which are difficult to control by governance only on the local scale and within the established term. Both the targeted time frame and the drivers of change will influence future socio-economic demands (Step 2) and the capacity of the ecosystem to provide certain ES and to develop habitats and maintain biodiversity goals.

For the low-lying Belgian coast where protection against floods is a major challenge, it was opted to set the time scale at 2100, which corresponds to the long-term climate change scenario of the Intergovernmental Panel on Climate Change (IPCC, 2014). Following external drivers of change were identified: (1) effects of climate change related to more winter rainfall, warmer and drier summers, ocean acidification due to increased CO_2-uptake (Van der Aa et al., 2015) and sea level rise; and (2) demographic growth (FPB-FOD, 2015). Although an increase in population size in the coastal zone is expected, the spatial demand for housing is considered not to increase because of restrictions related to building in dune areas and a tendency to urban infill in Flanders.

2.2.2. Step 2: Identify habitat and ecosystem services targets

In a second step, the habitats and relevant ES are identified. Habitats include all natural or non-natural environments that host species of biodiversity conservation importance or wild fauna and flora species. In some ES classification frameworks, biodiversity is included as an ES, e.g. in the category of non-use values or option values (Gómez-Baggethun et al., 2014). However, biodiversity is not always positively correlated with ES (Mace et al., 2012), and the benefits of biodiversity-related non-use values or option values to human well-being are not always tangible (Small et al., 2017). Participatory spatial planning solely to support ES may thus lead to adverse effects on biodiversity. Therefore, biodiversity is included as a target aside ES in this methodology.

Habitats can be identified based on biodiversity targets of conservation frameworks for which they provide opportunities. These include habitats occurring naturally in the ecosystem and non-natural habitats with important biodiversity values, as well as habitats that are expected to occur in the future, for example because of active management or environmental changes. The scale on which habitats are defined should be such that variable effects of processes between habitats (see Step 3) can be distinguished. If a process has mixed effects within one habitat, it is recommended to divide it into separate habitats.

Relevant ES are selected based on the capacity of the particular ecosystem and its habitats to provide these ES and based on socio-economic demands. As the aim of the method is to develop a strategic vision for the future, it is important not only to consider today's capacity and demand for ES, but also future potential demands and needs which may alter under the external drivers of change identified in Step 1. An ES is considered to be relevant if its economic or social value is (expected to become) high, or if it is specific to the ecosystem (e.g. fisheries production in marine ecosystems).

For the case study, the identification of habitats was largely based on the NATURA2000 habitat types and the European habitat classification EUNIS which distinguishes in more detail marine habitats. Twelve habitats were identified (Table 1) of which distribution and total surface area were derived from monitoring data and existing cartographic information (Van der Biest et al., 2017b). Artificial marine structures (jetties, ship wrecks, groynes, wind turbine foundations, ...) were additionally included because of their ubiquity, potential ecological values (Perkol-Finkel et al., 2012), distinct ecological functions and ES they may facilitate (Wetzel et al., 2014). A large differentiation was applied to dune ecosystems in which processes related to sand dynamics and soil development strongly influence species assemblages (Brunbjerg et al., 2015) and ES (Van der Biest et al., 2017a).

*Table 1 – Habitats identified in the development of a strategic plan for the Belgian coastal ecosystem, with indication of their approximated total surface area in the Belgian coastal zone (km²) and cartographic source. * the definition of the habitat is based on the definition of EUNIS or NATURA2000 and complemented with additional criteria in this study*

Habitat type	**Code EUNIS/NATURA2000**	**Description**	**Surface area**

			(km²)
Pelagic	EUNIS A7	The water column of the Belgian part of the North Sea	-
Gravel beds	EUNIS A5.13, A5.14, A5.15	Accumulation of loose grind and pebbles at the edge of a sand bank	max. 526.2
Submerged sandbanks and foreshore	NATURA2000 1110	Permanently submerged sandbanks at variable depths	524.8
Tidal flats and marshes	NATURA2000 1140, 1310, 1320, 1330	Habitats of fine sediment in the tidal zone above low tide and below spring tide, ranging from bare flats to densely vegetated on the least frequently flooded parts	1.3
(Artificial) reefs *	NATURA2000 1170	Biogenic reefs formed by dense concentrations of the sand mason worm *Lanice concilega* (NATURA2000) or fouling communities on permanently submerged artificial hard substrata	141.4
Estuary	NATURA2000 1130	Downstream part of a river that discharges in the sea and is subject to tidal forces and characterized by a salt gradient, including tidal flats	0.4

		and marshes and sand banks with varying salt gradient	
Lower beach and emerged sand banks	NATURA2000 1140	Sand banks above low tide and below high tide, including beaches	1.7
Upper beach and dune foot	NATURA2000 2110	Part of the beach above high tide where vegetation starts to develop + embryonic dunes	1.2
White dunes	NATURA2000 2120	Young, dynamic dunes dominated by dune building species such as marram grass	3.1
Grey dunes – herbaceous	NATURA2000 2130, 2150	Dunes fixed by moss or grass, with reduced sand dynamics and increasing soil development	5.8
Grey dunes – shrub	NATURA2000 2160, 2170, 2180	Older dunes fixed by shrub and woodland, with important soil development	9.1
Dune slacks	NATURA2000 2190	Depressions in the dune landscape which are temporarily or permanently flooded by fresh water	0.9

Relevant ES were identified using the Common International Classification of Ecosystem Services CICES v4.3 (EEA, 2016) as reference framework. Additionally, marine-specific ES that were not included in

CICES were selected from the marine typology of ES of Böhnke-Henrichs et al. (2013). An initial selection of the most relevant ES was made based on the expected demand now and by 2100. From this list, the ES whose consumption does not threaten ecosystem functioning and sustainability were not retained (e.g. several cultural ES such as spiritual value and health benefits), since the overall aim is a strategic vision for a healthy and sustainable ecosystem. This resulted in a list of 8 ES, of which 4 provisioning ES (agricultural production, fisheries production, aquaculture production, drinking water provisioning), 3 regulating ES (flood protection, climate regulation, water quality regulation) and 1 cultural ES (recreation). This preliminary list was proposed to a multidisciplinary group of experts (detailed in Supplementary Information Table S2) who added 2 provisioning ES (renewable energy production and sediment supply), so in total 10 ES were considered.

2.2.3. Step 3: Prioritize ecosystem services and habitats

Next, the ES were given a weight for their anticipated demand in the ecosystem within the defined time frame and taking into account the external drivers of change (Step 1). A variety of methods exists to assess socio-economic priorities, but stakeholder involvement is strongly recommended (Keune et al., 2015). Depending on local conditions and on the goal of application of the method, habitats can be considered equally important or they can also be attributed a weight. A weight can for example be attributed based on the biological value of the habitat (number of (rare) species, particular species, etc.), its desired surface area, etc. In the case study, a group of stakeholders (see Supplementary Information Table S3) was invited to individually give a score of 1 (not important) to 10 (extremely important) to each ES, reflecting what they believe are the socio-economic benefits the coastal ecosystem will need to provide by 2100. The final priority score per ES was calculated as the average of all respondents (Table 2). The different habitats were considered equally important (weight [10]) since the overall aim is a healthy ecosystem.

Table 2 – Priority scores attributed to ES by stakeholders (average, minimum and maximum of all respondents)

	ES	Priority score (average)	Min	Max
Provisioning	Agricultural production	1	0	8
	Fisheries production	7	2	8
	Aquaculture production	3	3	9
	Drinking water provisioning	5	1	10
	Renewable energy from wind	8	5	9
	Sediment supply	6	0	7
Regulating	Flood protection	10	7	10
	Water quality regulation	8	2	10
	Climate regulation	3	3	10
Cultural	Recreation	9	6	10

2.2.4. Step 4: Describe ecosystem processes

For each habitat and ES, the processes are identified that contribute to their development, maintenance or delivery. Natural processes are essential for the development and the functioning of the ecosystem and the production of ES. Anthropogenic processes also have an impact on ecosystem functioning (positive or negative), but they are, in contrast to natural processes, not essential for the development and maintenance of a sustainable ecosystem. Most of the anthropogenic processes are directly or indirectly related to the demand and consumption of ES. Only those processes should be included that have a significant contribution to or impact on the identified habitats and ES, and that do not fall under external drivers of change (Step 1). A score is assigned that expresses the magnitude and direction of the impact of a process on the occurrence and the quality of a habitat or the provision of an ES, referred to as the impact score. This can be based on quantitative information such as derived from models or measurements, or expert judgment when no quantitative data is available. Contrasting effects of processes (positive and negative effects on a habitat or ES) should be avoided as much as possible, to prevent loss of information when combining them into a single score. This can be done in several manners: 1) Divide into narrower defined habitats when parts react differently to disturbance or provide different ES (e.g. tidal areas into vegetated tidal marshes and non-vegetated tidal flats). 2) Subdivide ES that affect habitats in different ways (e.g. pelagic fisheries has less impact on the seabed than benthic fisheries; fish production can accordingly be split into benthic and pelagic fisheries). 3) Specify processes to more detail when the general process is important for different and/or conflicting reasons in habitats (e.g. greenhouse gas emissions can be split into different types of emissions: nitrous oxide production reduces the amount of nutrients in the ecosystem and impacts climate regulation, whereas methane production is only related to climate regulation). Alternatively, positive and negative effects can be weighed against each other resulting in a single overall score that takes differences into account. Uncertain processes regarding effect sizes are either merely identified but not included; the range of the expected effects can be provided; or the weight of the expected effect can be corrected based on its probability.

For the case study, an extensive literature and model review was performed (Van der Biest et al., 2017b) to gain insight into the processes. Based on this review, a preliminary impact score was attributed to each relationship process-habitat and process-ES by the project partners. This score was either derived from quantitative data found in literature, based on descriptive literature, or using expert judgment in case no literature was available. The impact scores for the processes (described in Supplementary Information Table S1) on habitats and ES were synthesized in an impact matrix (Table 3, Table 4). Each of these preliminary scores was then presented to a group of experts from multiple disciplines (natural and socio-economic sciences, see Supplementary Information Table S2) who adapted the score based on their own knowledge and expertise. The scores were adapted based on consented discussions within the group of experts.

Processes with multiple and contrasting effects were given a score +/- with a numeric value of 0 (positive and negative effects are expected to be equally large), or the effects were weighed against each other resulting in a single overall score which takes the differences into account. Uncertain relationships were included by attributing the lowest possible score for the anticipated direction of the influence (± 0.5).

Table 3 – Impact matrix of the impacts of processes on habitats and ES in the Belgian coastal zone. Dark blue: marine processes, brown: terrestrial processes, light blue: processes taking place at sea and on land. Definitions of the processes are found in Supplementary Information

		HABITATS													ECOSYSTEM SERVICES										
		Pelagic	Gravel beds	Tidal flats and marshes	(Artifical) reefs	Submerged sandbanks and foreshore	Estuary	Lower beach and emerged sand banks	Upper beach and dune foot	White dunes	Grey dunes - herbaceous	Grey dunes - shrub	Dune slacks	**HABITAT SUM**	Agricultural production	Fisheries production	Aquaculture production	Sediment supply	Drinking water provisioning	Flood protection	Climate regulation	Water quality regulation	Wind energy	Recreation and tourism	**ECOSYSTEM SERVICES SUM**
	Priority score	-	-	-	-	-	-	-	-	-	-	-	-		***1***	***7***	***3***	***6***	***5***	***10***	***3***	***8***	***8***	***9***	
ECOLOGICAL PROCESSES	Hydrodynamics (HD)	++	+	+	+	+	++	+	-	-	0	0	0	**7**	0	++	++	0	0	--	0	+	++	0	**24**
	Morphodynamics (MD)	0	-	++	+	++	-/+	++	0	0	0	0	0	**6**	0	-/+	-/0	+	0	+	0	0	0	0	**14.5**
	Ecological engineering (EE)	+	++	0	++	++	+	0	0	0	0	0	0	**10**	0	++	+	-/0	0	+	+	++	0	0	**43**
	Benthic production (BeP)	+	++	++	++	++	++	++	0	0	0	0	0	**13**	0	++	0	0	0	0	+	+	0	+	**34**
	Pelagic production (PeP)	++	++	+	+	+	++	+	0	0	0	0	0	**10**	0	++	++	0	0	0	+	+	0	-/+	**31**
	Transfer (T)	++	++	++	++	++	++	++	0	0	0	0	0	**14**	0	++	++	0	0	0	++	++	0	+	**51**
	Primary dune formation (DUNE)	0	0	0	0	0	0	0	++	0/+	0	0	+	**3.5**	0	0	0	0	+	++	0	0	0	++	**43**
	Large-scale wind dynamics (LW)	0	0	-/0	0	0	0	0	0	++	+	-	+	**2.5**	-	0	0	0	-	++	0	+	0	+	**31**
	Small-scale wind dynamics (SW)	0	0	0	0	0	0	0	0	+	++	0	+	**4**	0	0	0	0	0	+	0	+	0	0	**18**
	Infiltration (IF)	0	0	0	0	0	0	0	0	0	0	++	++	**4**	++	0	0	0	++	0	0	+	0	0	**20**
	Evapotranspiration (ET)	0	0	0	0	0	0	0	0	0/+	0	0	--	**-1.5**	-	0	0	0	--	0	-	0	0	0	**-14**
	Soil development (SOIL)	0	0	0	0	0	0	0	0	-	+	++	+	**3**	+	0	0	0	-/+	-	0/+	+	0	0	**0.5**
	Vegetation development (VEG)	0	0	++	0	0	0	0	++	++	++	++	++	**12**	0	0	0	0	0	++	+	0	0	+	**12**
	Primary production (land) (PP)	0	0	+	0	0	0	0	+	+	+	++	++	**8**	0	0	0	0	0	0	++	++	0	0	**2**
	Gas emissions (GHG)	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	--	+	0	0	**2**
	Denitrification (DEN)	+	0	+	0	+	+	+	+	0	+	+	+	**9**	--	0	0	0	0	0	-	++	0	0	**11**
	Population dynamics (POP)	++	++	++	++	++	++	++	++	+	++	+	++	**22**	-/+	++	-/0	0	0	0/+	0	0	0	+	**26.5**
ANTHROPOGENIC PROCESSES	Sediment extraction (SED)	-	--	0	--	-	0	0	0	0	0	0	0	**-6**	0	-	0	++	0	0	0	0	-	0	**-3**
	Sediment dumping (DUM)	-	--	-	--	-/0	-	0	0	0	0	0	0	**-7.5**	0	-	-	0	0	0	0	0	0	0	**-10**
	Bottom disturbing fishing (BeF)	0	-	0	--	--	0	0	0	0	0	0	0	**-5**	0	+	0	0	0	0	0	-	0	+	**8**
	Pelagic fishing (PeF)	-	0	0	0	0	0	0	0	0	0	0	0	**-1**	0	+	0	0	0	0	0	0	0	+	**16**
	Artificial reef formation (ARF)	-/+	0	0	++	-	-	0	0	0	0	0	0	**-1**	0	+	++	-	0	+	0	++	0	+	**42**
	Artifical infiltration (AIF)	0	0	0	0	0	0	0	0	0	0	0	+	**1**	+	0	0	0	++	0	0	+	0	0/+	**23.5**
	Drainage (DRA)	0	0	0	0	0	0	0	0	0	-/0	-/0	--	**-3**	++	0	0	0	-	0	--	--	0	0/+	**-20.5**
	Water extraction (EXTR)	0	0	0	0	0	0	0	0	0	-	-	--	**-4**	-	0	0	0	+	0/+	--	--	0	0	**-13**
	Manuring (MAN)	-	0	-	0	0	--	-	+	--	--	-	--	**-11**	++	0	0	0	0	-	-	--	0	0	**-27**
	Grazing (GRZ)	0	0	-	0	0	0	0	0	0	+	-	+	**0**	++	0	0	0	--	0	--	-	0	0	**-22**
	Cropping (CRP)	0	0	+	0	0	0	0	0	0	--	--	--	**-5**	++	0	0	0	--	0	-	0	0	0	**-11**
	Disturbance by access (TR)	0	0	0	0	0	0	0	--	+	0	-	-	**-3**	0	0	0	0	0	-	0	0	0	++	**8**
	Surface hardening (PAV)	0	0	0	0	0	0	--	--	--	--	--	--	**-12**	--	0	0	0	--	--	--	--	0	-/+	**-54**
	Sand nourishing (NOUR)	-	--	0	--	+	-	-	+	+	0	0	0	**-4**	0	-	0	+	+	++	0	0	0	++	**42**
	Nature management (NAT)	+	++	++	+	+	+	+	++	+	++	+	++	**17**	0	++	0	0	+	+	-	+	0	++	**52**
	Biological invasions (INV)	--	--	--	--	--	--	0	0	0	-	--	-	**-16**	--	--	--	0	-	-	0/+	0/+	0	-/+	**-31.5**
	Noise and visual disturbance (DIS)	--	--	--	--	--	--	--	--	--	--	--	--	**-24**	0	0	0	0	0	0	0	0	0	-/+	**0**

Table 4 – Score and numeric value per type of impact of processes on habitats and ES.

Score	Type of impact	Numeric value
--	important negative impact	-2
-	moderate negative impact	-1
-/0	relationship is uncertain, rather negative impact is expected	-0.5
0	no relationship	0
+/-	positive and negative effects are expected to be equally large	0
0/+	relationship is uncertain, rather positive impact is expected	0.5
+	moderate positive impact	1
++	important positive impact	2

2.2.5. Step 5: Identify synergies, trade-offs and conflicts

Per habitat and ES (Step 4) the impact score of a process is multiplied with the priority score for the habitat or ES (Step 3). Per process a sum is made of its effects on habitats and of its effects on ES, resulting in two (weighted) sums: 1) ES sum, which is a proxy for the degree to which the process contributes to (multiple) ES and 2) habitat sum, which is a proxy for the degree to which a process contributes to the development or maintenance of (multiple) habitats that host species of conservation importance or wild fauna and flora. Both sums are plotted relative to each other in an XY-diagram (Fig. 3). The graph shows a trend of multi-functionality from the bottom left to the top right (blue arrow). Processes in the upper right corner mostly create synergies between ES and habitats. In the lower left corner are processes that mostly cause conflicts between ES and habitats.

Trade-offs occur when (1) a process has negative impacts on habitats but positive on ES (upper left) or (2) a process has negative impacts on ES but positive on habitats (lower left).

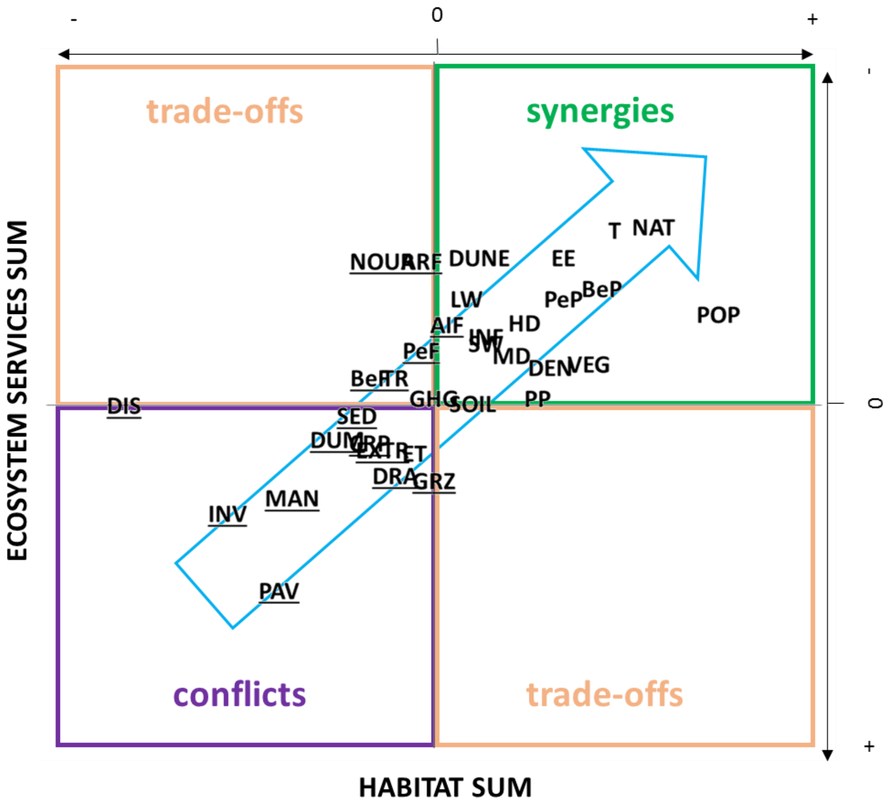

Fig. 3 – Step 5 applied to the Belgian coastal zone. Habitat sum and ES sum represent the contribution of the processes to resp. habitats and ES. Underlined: anthropogenic processes, not underlined: ecological processes. Blue arrow: degree of multi-functionality. See Table 3 for abbreviations.

2.3. Setting strategic goals

The ranking of the processes according to their multifunctionality and the identification of trade-offs, synergies and conflicts (Fig. 3) supports the process of setting goals to accomplish a healthy ecosystem. For the case study, 8 strategic goals were identified and 2 main backbones to which these goals are linked (Fig. 4, 5). Together these goals are the key elements that describe the vision for a healthy ecosystem.

A first set of goals was defined for the processes (hereafter abbreviated and written in italics; see Table 3 for abbreviations) in the far top-right corner which create mostly synergies between biodiversity and ES. Many of these processes are related to **transport of sediment** (*HD, MD, LW, SW*) or **dynamic biotic processes** (*BeP, PeP, POP, VEG, PP, T*). Transport of sediment in the sand-dominated ecosystem of the Belgian coastal zone is a key driver of diversity at sea and in the dunes (Provoost et al., 2011). Natural erosion and sedimentation processes create variation in topography, grain size, turbidity and hence vegetation and benthic biomass producing heterogenic landscapes that drive biodiversity at the landscape scale (Gingold et al., 2010; Hewitt et al., 2010; Brunbjerg et al., 2014, 2015). Also many ES depend on sediment dynamics. Sand transport is crucial to create new dunes (*DUNE*) and, in combination with vegetation development, maintain a **resilient coast** which is able to adapt to external stress such as sea level rise (Van der Biest et al., 2017a). Sedimentation also is an important underlying mechanism of carbon and nutrient **buffering in intertidal soils in estuaries and tidal marshes** (Adams et al., 2012; Fagherazzi et al., 2013). Biotic processes and fluxes are crucial to create and sustain **diversity**, and to develop the self-regulating capacity of ecosystems via ecological engineering (*EE*) and reef development, which is the driver of ES such as water quality regulation (*DEN*) (Adams et al., 2012; Fagherazzi et al., 2013; Chambers et al., 2017; Erikkson et al., 2017), climate regulation (*GHG*) (Adams et al., 2012; Fagherazzi et al., 2013; Howard et al., 2017), coastal stabilisation and safety (*EE, DUNE*) (van Leeuwen et al., 2010; Borsje et al., 2011) and fish production (*BeP, PeP*) (Koenig et al., 2000; Rabaut et al., 2013). Hence, providing **space for dynamic processes** and **connectivity** are defined as the two backbones of the future vision to which all other goals can be linked. Management should primarily focus on sustaining and enhancing these to safeguard ES and biodiversity.

The debate on formulating recommendations for the processes that create trade-offs and conflicts was more challenging. For these processes a choice needed to be made whether to accept trade-offs, avoid these processes or minimize negative impacts by restricting or adapting the process. Many anthropogenic processes are located in the upper left corner, illustrating the potential multi-functionality of certain anthropogenic interventions and – depending on the location along the habitat axis – benefits for some habitats. For example, nourishing of beaches creates opportunities for the development of young, embryonic dunes and for multiple ES (artificial reef formation provides benefits for water quality regulation through the filtering capacity of fouling communities). However, regular sand nourishing at the same site negatively impacts benthic communities and thus trade-offs with other habitats (Martin et al., 2005). Adaptation to reduce trade-offs is possible by 1) decreasing the consumption of the ES so that the process reduces in intensity, frequency or geographical extent or (2) search for alternative forms, location or timing to produce the ES. For example, beach recreation may involve trampling of embryonic dunes (*TR*), hampering the development of dunes with *Amophila arenaria* which host a high endemic diversity and allow to develop a **resilient coast** in view of sea level rise. Access to the most critical areas could be restricted by creating (temporary) no-go zones, while in less fragile zones access could be allowed.

Very few processes have only positive effects on habitats and negatively affect ES (lower right corner), underpinning the dependence of human well-being on ecosystem functioning. Drinking water provisioning, flood regulation, climate regulation and water quality regulation are ES that are most affected by anthropogenic pressures. This is in line with conclusions from other studies that regulating ES present highest trade-offs with provisioning services (Bennett E.M. et al., 2009; Howe et al., 2014), to which most of the anthropogenic processes are linked.

Urbanisation (*PAV*) **should be minimized** as it poses a threat to a healthy ecosystem: less space is available, sedimentary and biotic processes get interrupted, habitats fragmented and disturbed by noise (*DIS*). **Biological invasions** (*INV*) post important threats to local biodiversity and should be controlled to avoid potential drastic changes in ecosystem functioning (Ehrenfeld et al., 2010) and ES (Vilà and Hulme, 2017). Based on our approach, we recommend drastic changes in coastal zone management in light of climate change, i.e. to develop strategies to **advance or retreat rather than to maintain the current line**.

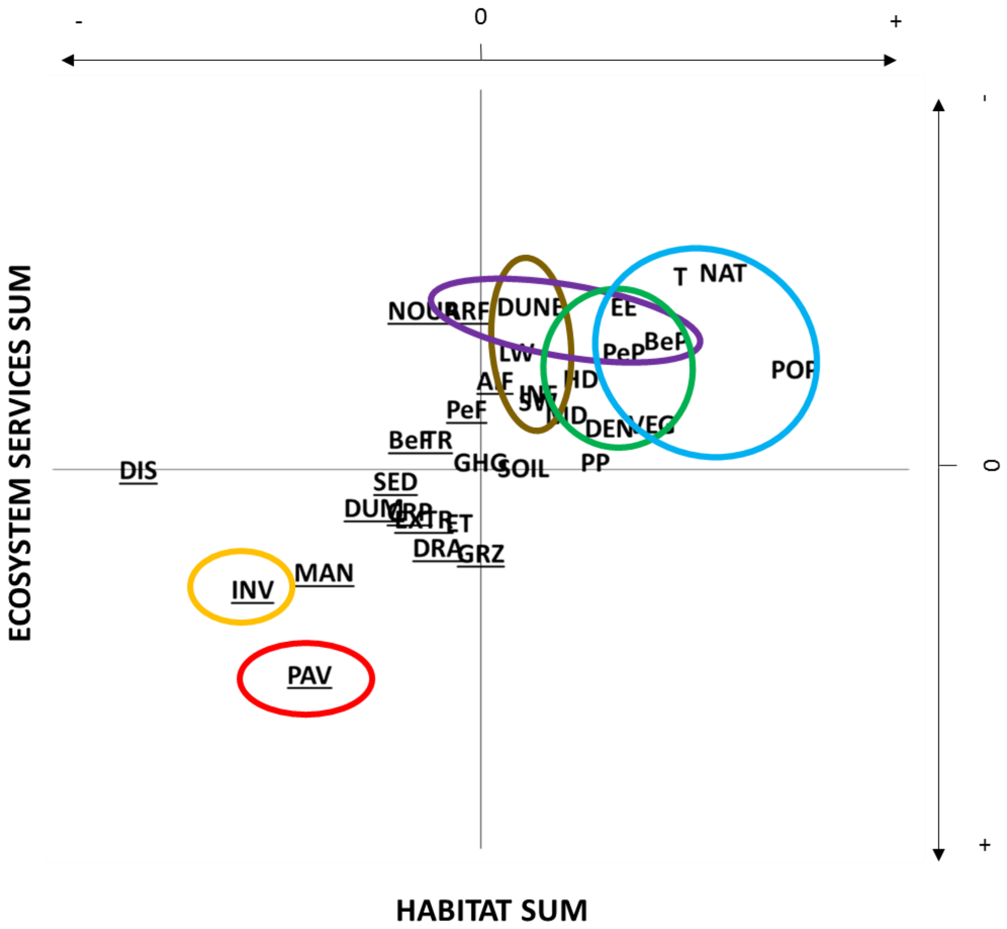

Fig. 4 – Illustration of how the strategic goals are deduced from the ranking of processes in Fig. 3. Underlined: anthropogenic processes, not underlined: ecological processes. Ovals represent groups of processes that are essential to achieve the strategic goals.

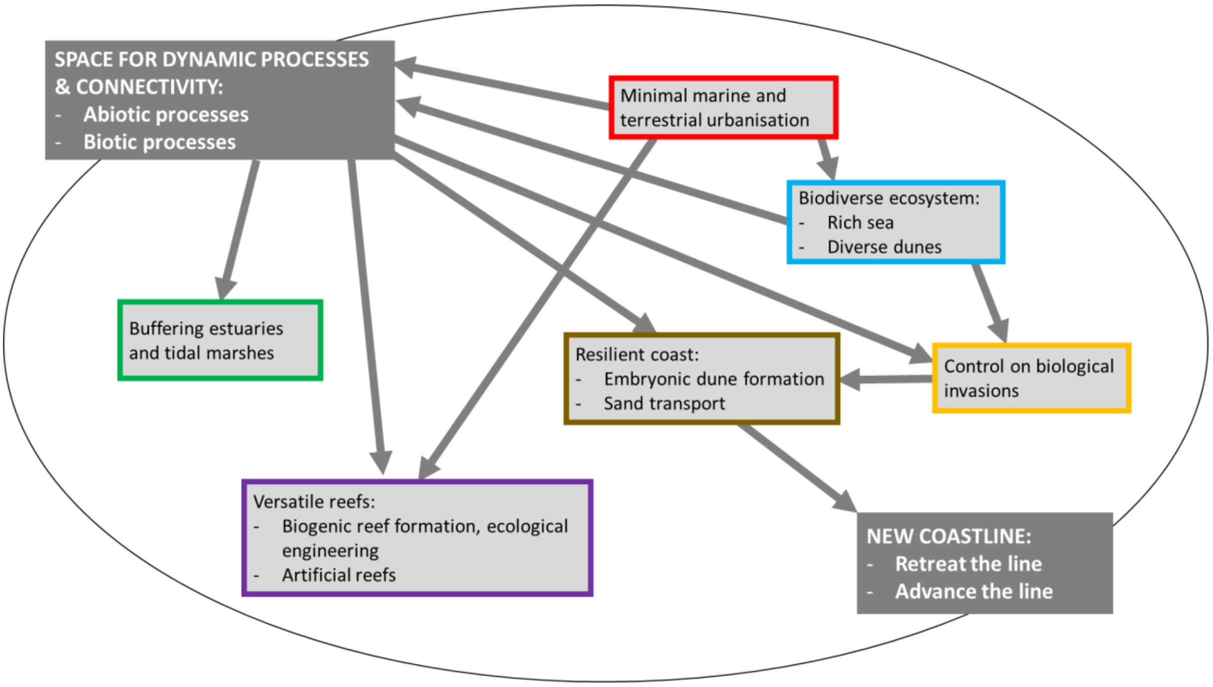

Fig. 5 – Scheme of the vision on a sustainable coastal ecosystem for the Belgian coastal zone indicating how key goals are connected to each other.

3. Illustration of impacts on spatial planning: two show-cases

We illustrate how the methodology could lead to different outcomes in spatial planning using two examples. This step from translating strategic goals into concrete spatial plans or management measures does not fall within the scope of the methodology itself as it requires a much more elaborated process including scenario development, advanced participatory trajectory, financing mechanisms, legal considerations, … (Ehler and Douvere, 2009). The two examples that are demonstrated here have the purpose to show the merits of including processes and integrating biodiversity and ES in spatial planning, which the methodology supports by providing an approach to create a shared vision as guidance in the development of the actual management plan.

First, we demonstrate the effect of including ES on the spatial allocation of target habitats. Second, we show how including processes can change the range of target habitats and scale requirements for long-term habitat maintenance.

3.1. Example of including processes: restoration of sand transport

Hard engineering structures along the shoreline have originally been constructed to protect the coast against erosion (e.g. dykes, groynes). However, a collateral effect of such structures is that they block supply of sand from the sea to the beach and from the beach to the dune. As sea level rises, the capacity of the dune to protect the hinterland against flooding will gradually reduce as the dune is not able to grow without sand supply (Temmerman et al., 2013; Van der Biest et al., 2017a). Typical habitats and species of the shoreline dunes also depend on this sand dynamic (Howe et al., 2010; Brunbjerg et al., 2014; Keijsers et al., 2015). In Belgium, one of the few remaining dynamic dune areas has been protected as nature reserve since 1957 (‘Westhoek’, Fig. 6). Embryonic and shifting dunes are European habitat targets (H2110, 2120) for the area and they depend on sand dynamics. However, today the area is still largely cut off from the beach by the presence of a dike, resulting in a domination of fixed dunes with moss, grass and shrub. Nature management to protect the target habitats is now dominated by active removal of fixating vegetation.

The presented methodology highlights the need to restore the natural process of sand transport between sea, beach and dune to support the target habitats of young dunes in a sustainable way. This safeguards long-term benefits for biodiversity and human well-being, as the young dune habitats and species are kept viable by regular sand burial and the dune can regain its natural capacity to protect against flooding as sea level rises. In the latest nature management plan, removal of the obstructing dike along the entire zone where H2110 and H2120 are target habitats has been included as a measure for a more efficient and long-term restoration of these dynamic habitats and of the natural capacity of the dune to protect against flooding.

This example shows that explicitly considering processes besides protection of species and habitats in spatial planning provides additional arguments to convince decision-makers for spatial rearrangement of habitats and artificial structures. Especially when the benefits for human well-being of these processes are made explicit, arguments for process restoration can become even more convincing.

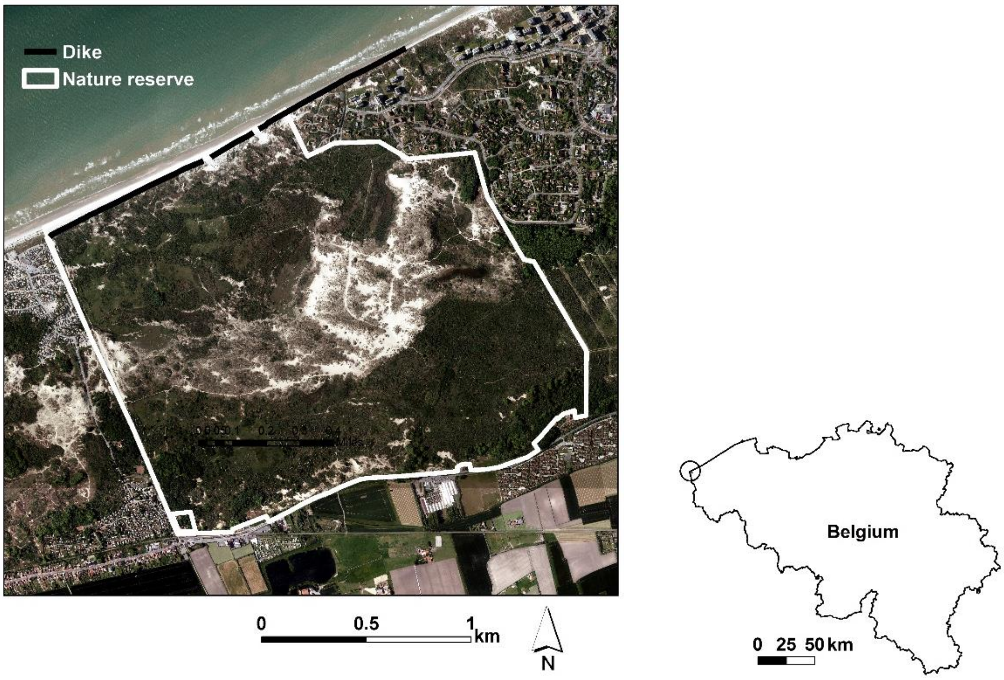

Fig. 6 – Aerial photograph and location of the Westhoek nature reserve (Belgium) with indication of the dike. White zones: dynamic, bare dunes; patchy, light brown-green vegetation: dynamic, marram grass dunes; dark green zones: densely vegetated, fixed dunes.

3.2. Example of including ecosystem services: Belgian MSP 2020-2026

In Belgium, the first true MSP was adopted in 2014. The plan document which areas can be used for different types of activities and tries to reconcile the spatial impact of the multiple users to one another to optimally protect the marine ecosystem (Van de Velde et al., 2014). Although the MSP did not add extra areas for nature conservation to the already existing protected areas, it aimed to improve the coordination of activities with disturbing effects on the ecosystem by specific measures in subzones within the protected areas. For example, bottom disturbing activities are limited to protect and restore biogenic (*Lanice concilega* aggregations) and geogenic reefs (gravel beds) in 4 delineated areas within the 'Vlaamse Banken' nature reserve (Vanden Eede et al., 2014). While the MSP mentions the potential of future developments at sea for additional nature creation outside the boundaries of protected areas (e.g. value of artificial reefs within wind farms to attract fish and other animals), it is not compulsory for obtaining a license for the construction of infrastructure for these activities (Van de Velde et al., 2014).

In 2019, a preliminary draft for a new MSP was presented (FOD Leefmilieu, 2019). In comparison with the first MSP, more attention is paid to multifunctional use of space, naturalness and ES, and they are even defined as the key principles for the development of all new activities in the Belgian part of the North Sea. For these key principles, a recommendation is included in the MSP, which aims to improve habitat development and biodiversity also outside the boundaries of the special protected areas. Each new activity anywhere in the BPNS should be evaluated based on its potential for multifunctionality and working-with-nature in function of nature protection or development. Additionally, one zone outside the boundaries of the special protection areas is delineated where measures should be taken to ensure sea-floor integrity, allowing to enhance biodiversity and provision of ES.

Legally binding actions included to accomplish the second MSP are the restoration of the biodiverse gravel beds and research for the restoration of oyster reefs in designated zones both inside and outside the boundaries of the protected areas. The second MSP explicitly mentions the exceptional value of these habitats not only for biodiversity but also for several ES (e.g. water quality regulation: Jansen

(2012), Rose et al. (2015), van der Schatte Olivier et al. (2018); carbon sequestration: van der Schatte Olivier et al. (2018), Filgueira et al. (2019) and nursery function for fisheries production: Peterson et al. (2003), zu Ermgassen et al. (2016)), in contrast to the first MSP that considers nature conservation only from the perspective of biodiversity support. The second MSP not only targets to avoid negative effects from bottom-disturbing activities but also aims to stimulates active habitat restoration. Another addition that can (partly) be ascribed to the consideration of ES, is the inclusion of a criterion for multifunctionality and working-with-nature. Although the criterion is not legally binding, the MSP explicitly states that all new activities within the BPNS should strive to comply with the working-with-nature principle, i.e. to create added for the ecological, the physical and the societal system by making use of the natural processes and/or stimulate nature development (FOD Leefmilieu, 2019).

4. Discussion

The main objective of the methodology is to support in the creation of a shared vision that guides in the long term development of a region. The method is intended to be applied in early, strategic stages of spatial planning. Its primary focus is to build understanding among different stakeholder groups and find support for solutions that balance biodiversity conservation and socio-economic goals (McKenzie et al., 2014). The output of the method can be used in later stages of the planning process to facilitate the negotiation of compromise on specific actions and measures as part of a spatial plan. The method identifies the key processes that should be considered in spatial planning besides structural properties. This makes the methodology also useful to define additional criteria in spatial prioritization of conservation areas making it more likely that they guarantee long term benefits for ES and biodiversity (e.g. Klein et al., 2009).

4.1. Guidance in finding common ground

Starting from an inventory of scientific knowledge on how ecosystem processes underlie the development of ES and biodiversity values, the methodology identifies (i) the key ecosystem processes that support both conservation values and socio-economic demands, and (ii) the processes that result in conflicts between both objectives. Processes are thus represented as the mechanisms that link biodiversity and socio-economic demands, allowing to find common ground or to balance trade-offs. Explicitly considering the production mechanisms of biodiversity and ES and emphasizing the common ground between both objectives provides more guarantee for long-term benefits to biodiversity of conservation efforts and spatial planning than solely considering structures (Klein et al., 2009; Arkema et al., 2015; Manea et al., 2019). The methodology explicitly takes into account the multiple consequences of trade-offs and ranks the underlying processes that cause the trade-off accordingly: the position of the process along the blue arrow Fig. 3) gives information on the degree to which a process creates multiple benefits or trade-offs. For example, pelagic fishing (PeF) is located relatively high along the arrow, indicating that in the Belgian coastal zone pelagic fisheries creates multiple additional benefits such as opportunities for recreation associated with visits to the local fish mines and fish restaurants. However, PeF also has some negative impacts on habitats, but these can be reduced to a minimum by proper management of the ecosystem, or even turned into opportunities for synergies (Maes et al., 2012). For example, artisanal fishing causes less impact on biodiversity due to reduced catch efficiency and usage of more sustainable fishing techniques. Allowing limited fisheries in certain zones can also reduce pressure in intensively exploited fishing areas elsewhere, creating opportunities for biodiversity at these sites.

Focusing on the underlying production mechanisms that produce the trade-offs instead of on (seemingly conflicting) end goals changes the subject of the spatial planning debate. Processes are prioritized by ordering them according to a degree of multifunctionality, based on the sum of the multiple effects they have on ES and on habitats. This shifts the debate on choosing over priorities from a focus on conflicts between sectors to a common goal of multifunctionality (Egoh et al., 2012; Hermoso et al., 2018). It also facilitates communication among stakeholders as (1) sectors are not explicitly targeted in the discussion, (2) potential co-benefits are also taken into account and may compensate minor negative effects (Egoh et al., 2010; Hermoso et al., 2018) and (3) benefits for human well-being of biodiversity conservation are made explicit (Albert et al., 2019). A more comprehensive overview of the multiple roles that processes play in supporting biodiversity and ES provides a more solid basis to balance trade-offs (Mastrangelo et al., 2014). Sand transport can for example be negatively experienced by local people when sand is blown into gardens or on agricultural fields. However, it is an important underpinning process for multiple ES such as flood prevention and recreation, and it is the underlying mechanism that resets ecological succession and promotes diversity of plants and arthropods (Brunbjerg et al., 2015). This is shown by the location of the process of sand dynamics in Fig. 3. In spite of the negative impacts of sand blowing, the process is located far along the arrow of multifunctionality in the upper-right corner of the graph. It is indeed argued that there is a lack of transparent information and awareness among stakeholders and spatial planners of the underpinning role of ecosystem processes and biodiversity to support human well-being (Ortiz-Lozano et al., 2017), and that this may explain why integration of ES and biodiversity is yet to be operationalized in everyday decision-making (Guerry et al., 2015; Dick et al., 2018; Saarikoski et al., 2018).

4.2. Including biotic and abiotic processes

The need to incorporate ecological processes in spatial planning has been highlighted by many recent studies (e.g. Bennett A.F. et al., 2009; Klein et al., 2009; Hughes et al., 2012; Syrbe and Walz, 2012; Watson et al., 2016; Kukkala and Moilanen, 2017; Rieb et al., 2017; Lanzas et al., 2019), but often only biotic processes are taken into account (Lawler et al., 2015; Tulloch et al., 2016; Ockendon et al., 2018; Pires et al., 2018; Albert et al., 2019). Especially when integrating ES into conservation planning it becomes important to also explicitly consider abiotic processes, as some ES are more strongly controlled by physical processes than by biological processes (Hooper et al., 2005; Midgley, 2015). For example, services related to water flow (e.g. drinking water supply, flood regulation) are primarily driven by abiotic processes (e.g. infiltration, hydrodynamics). Lawler et al. (2015) explain how including abiotic drivers allows to more explicitly take into account global changes in conservation efforts that may result in changes in species composition. However, studies where restoration of abiotic processes is targeted together with biodiversity conservation are scarce and mostly restricted to floodplains (e.g. Schiemer, 1999; Rood et al., 2003; Maris et al., 2004; Beauchard et al., 2014; Oosterlee et al., 2018). By following the ecosystem approach (CBD, 2004), the method unravels the development of biodiversity values and ES in a systematic way. This provides a more structural and objective approach for selecting the processes that need to be considered and is an essential change associated with the transition from sectoral towards more holistic approaches to spatial planning. In the case study of the sandy coastal ecosystem of Belgium, the method identifies processes related to sand dynamics (MD, SW, HW) as having a crucial role in providing ES and in maintaining biodiversity (Fig. 4). However, in Belgium coastal zone planning traditionally focused on stabilizing the coastline with hard structures such as dikes and groynes that reduces sand dynamics. This can partly be explained by a lack of awareness of the underlying role of sand dynamics for several ES and biodiversity among different stakeholders (Nordstrom et al., 2015).

4.3. Methodological approach

The structure of the presented approach is comparable with the DPSIR framework (Drivers-Pressures-State-Impact-Response) and other frameworks that link human activities to ecological processes and

ES. However, the presented framework starts from an analysis which processes are essential to create ES and habitats and from there defines targets to stimulate ES and habitats, in contrast to the DPSIR framework which starts from an identification of driving forces and pressures that have a negative effect on the ecosystem processes. The difference thus lies in a focus on avoiding negative impacts (DPSIR) versus a focus on creating opportunities by stimulating processes (presented framework). Although the presented framework also includes anthropogenic processes, most of them being similar to pressures in DPSIR, and negative impacts on the ecosystem, it explicitly identifies which processes are beneficial. This framework also allows to include processes that can be stimulated by human intervention and result in benefits for ES and habitats (nature-based solutions), but that are not necessarily under threat by human activities.

An important limitation of the method is related to knowledge availability. The relationships between the processes and the habitats and ES are now expressed using expert-based scores and thus strongly depend on the knowledge of the involved experts, and of the knowledge available for a certain ecosystem. The Belgian coastal ecosystem is one of the most intensively monitored and studied coastal ecosystems in the world. Applying the method may be more challenging in other areas where less knowledge is available.

Also, more complex relationships such as non-linear effects of processes and interactions between processes that reduce or increase the impact of a process on a habitat or ES are not included. This is related to the usage of coupled matrices that are not capable of dealing with feedback loops. Petri-nets (Rova et al. 2019) or causal loop diagrams (Dambacher et al. 2002) can be a potential solution to account for more complex relationships.

5. Conclusion

The main aim of this paper is to demonstrate how including biotic and abiotic ecosystem processes opens opportunities to find common ground between seemingly conflicting objectives of biodiversity conservation and socio-economic demands. The paper present a stepwise methodology to support the early, more strategic stages of spatial planning and guides in the creation of a shared vision among different stakeholders. The application of the methodology on the Belgian coastal zone shows how explicitly considering ecosystem processes in spatial planning is more likely to safeguard long-term benefits for biodiversity and human well-being than taking only structural properties into account. The paper aims to provide inspiration to advance current approaches for integrating biodiversity and ES in spatial planning.

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KVDB, BD, TS, TV, DB, TY and PM developed the method. KVDB wrote the manuscript, PM, DB, TS, TY and BD contributed critically.

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