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Integrating Ecosystem Services into Impact Assessments: A Process-Based Approach Applied to the Belgian Coastal Zone

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Abstract: Policy makers increasingly acknowledge the importance of considering ecosystem services (ESs) and biodiversity in impact assessment (IA) to reduce ecosystem degradation and halt ongoing losses of biodiversity. Recent research demonstrates how ESs can add value to IA, i.e., by shifting the focus from avoiding negative impacts to creating opportunities, by linking effects on ecological functioning to benefits for society, and by providing a multi-disciplinary framework that allows to consider cross-sectoral effects. However, challenges exist to its implementation in practice. The most commonly used ES models do not consider interactions among ESs. This restricts their capacity to account for cross-sectoral effects. Integrating ESs into IA also increases time investments as they cover a wide variety of disciplines and need detailed information. This paper presents a pragmatic approach that tackles these challenges and may facilitate the inclusion of ESs into IA. The approach focuses on ecosystem processes as the driver of ESs and biodiversity and the basis to evaluate effects of a project. Using the Belgian coastal ecosystem, we illustrate how the approach restricts data needs by identifying the priority ESs, how it improves the coverage of cross-sectoral effects in IA, and how it contributes to a more objective selection of impacts.

Keywords: impact assessment; ecosystem services; marine ecosystem; coastal ecosystem; biodiversity; cumulative effects; scoping; ecosystem processes; cross-sectoral effects

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1. Introduction

Policy makers increasingly acknowledge the importance of integrating biodiversity with ecosystem services (ESs) into impact assessments (IAs). Research has demonstrated how including ESs has the potential to improve traditional IAs and deal with some of its shortcomings [1–5]. One of the main critiques is that the added value for human wellbeing of avoiding environmental impacts is often not clear [6–9], reducing their weight in the decision-making process. ESs are directly expressed in terms of gains for human wellbeing, making the benefits for stakeholders more tangible. Also, IAs typically evaluate on a sectoral basis (e.g., soils, climate, biodiversity, health, . . .) and do not always account for indirect effects (e.g., loss of fisheries production due to poor water quality), cross-sectoral effects, and cumulative effects [8,10,11]. The ES paradigm is based on an integration of all aspects of ecosystem functioning with socioeconomic factors and is thus cross sectoral by definition. Its holistic character supports the inclusion of indirect effects and effects resulting from tradeoffs and synergies among different sectors. It is crucial, herein, to consider not only changes in structural properties but also to evaluate how these affect ecosystem processes [12] and human beneficiaries [4,9,11]. Thus, ESs reflect the functioning of ecosystems as well as the prosperity of human societies [11].

Focusing on the underlying ecosystem processes that produce ESs has increasingly been acknowledged as the key to predicting changes in ESs [13–15] and for more effective biodiversity conservation [16,17]. IAs should evaluate how a project affects processes, and how this ultimately results in changes in ESs and biodiversity values, rather than on assessing merely the current state of the ecosystem. The integration of ESs into IAs can help to integrate perspectives of affected communities, provide more detailed and efficient considerations of impacts, and develop mitigation procedures directed to improve human wellbeing [4,11,18].

However, ESs are often not explicitly implemented in IAs [9]. Certain difficulties may impede the successful integration of ESs in IAs and their usefulness in practice [10]. Two challenges inherent to the concept of ESs are particularly pronounced when including ESs in IAs, which are (1) the large data and expertise requirements to accurately assess ESs [7,19,20] and (2) limited objectivity in the selection of impacts (in this case impacts on ESs) to be included in an IA [21–23]. ES assessments are comprehensive, covering a variety of disciplines, and are therefore resource-, time- and knowledge-intensive. This may cause reluctance to include ESs in IAs as it can be seen as yet another requirement and additional burden on the IA process [10]. In spite of the efforts spent on knowledge integration in recent years, through the development of hands-on instruments, such as InVEST [24], ARIES [25], ECOPLAN-SE [26], application of the ES concept in practice remains challenging [27–29], especially in marine systems where the data is often of poor quality and with low spatial coverage [30,31].

This so-called 'implementation gap' [32] could partly be closed by reducing the number of ESs to be assessed in detail (referred to by [33] as 'priority ecosystem services') in the scoping stage. This can be achieved by selecting a few priority ESs. Yet, complex tradeoffs between several ESs may exist [34], and prioritizations of ESs can diverge substantially based on the cultural and political stakeholder identity [35]. Today, a standardized methodology to identify priority ESs is lacking [21,22]. It is well acknowledged in the ES literature that the selection of ESs is prone to bias [35–38], for example, when ESs with poor information or non-marketable ESs are neglected. This is crucial, especially in IAs, as the outcome of an IA is decisive in project development. A standardized technique for the selection of priority ESs is therefore crucial for an easier integration of ESs in IAs and may consequently enable better informed environmental management decisions. This paper presents an approach to identify potential impacts on ESs in a systematic way. This newly developed procedure serves a more thorough inclusion of cross-sectoral and cumulative impacts in IAs. It aims to be a scoping tool to be used for identifying the most important impacts on ESs to be studied in more detail in an IA. This method is more holistic than classical IA methodologies since it is based on the ecosystem approach which acknowledges processes and interactions among organisms and their environment [39]. The Belgian coastal zone is used as the case study to explain the methodological principles and illustrate its functionalities.

2. Methodology

The approach consists of a stepwise procedure. For each step, the methodological principles are first explained. For the sake of clarity, each step is illustrated with the example of the Belgian coast. Section 3 elaborates on the application of the approach in two hypothetical project proposals.

2.1. The Belgian Coastal Zone

The terrestrial border of the Belgian coastal ecosystem (Figure 1) is delineated by the transition from polder to dunes (up to ~2 km landward from the shore), and the marine limit coincides with the boundary of the Belgian Continental Shelf (~70 km seaward from the shore). The land part (80 km^2 along a stretch of ~70 km coastline) is covered with dunes, both under a protected status as well as dunes used as pasture or private gardens. The area also comprises two zones with tidal flats and marshes, of which one is part of an estuary. The marine zone (3600 km^2) is part of the Southern North Sea and is made up of soft sediments with a series of parallel sandbanks hosting a high benthic diversity as a result of the highly variable topography and sediment composition [40–42].

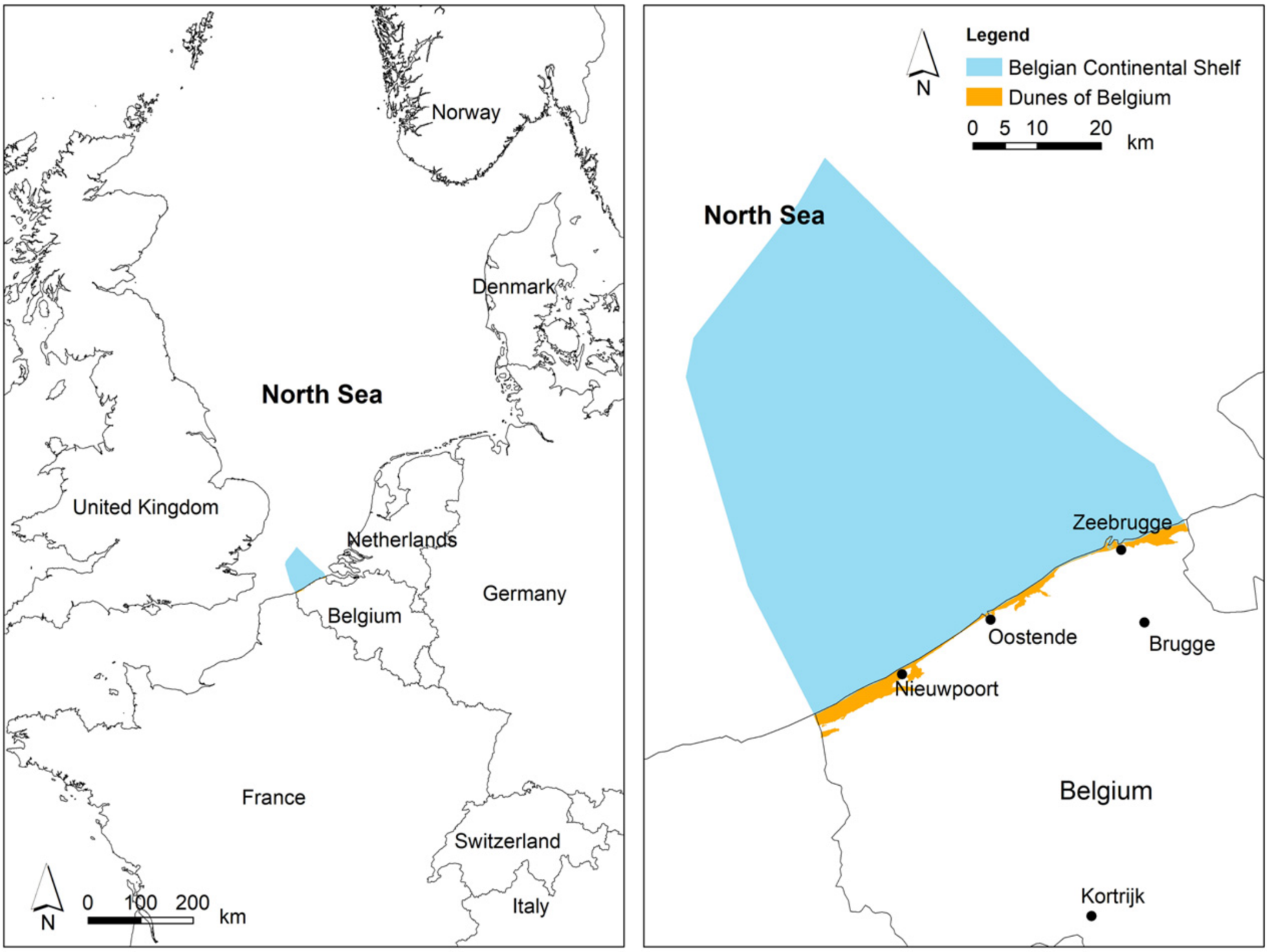

Figure 1. Location of the study area.

2.2. Stepwise Approach

The approach focuses on the key role of ecosystem processes as underlying mechanisms for generating ESs and maintaining biodiversity [12,13,17]—cfr. the ecosystem approach as defined by the Convention on Biological Diversity (CBD) [39]. Ecosystem processes are defined here as changes in the stocks or in the fluxes of products and energy resulting from the interactions among organisms (including humans), between organisms and their abiotic environment, as well as interactions between abiotic structures. Ecosystem processes are directly related to the supply and consumption of ESs and biodiversity assets (Figure 2). These include ecological processes (e.g., primary production, population dynamics) that contribute to the formation of habitats and biodiversity and that are needed to support ecosystem functions (e.g., viable fish population) to provide ESs (e.g., food)—sensu the definition used by The Economics of Ecosystems and Biodiversity study of UNEP [43] TEEB 2012)—and anthropogenic processes that affect ESs and biodiversity (e.g., artificial infiltration of pre-treated sewage water in dunes). Alterations in the rate of a process are caused by changes in pressure parameters. Pressure parameters are measurable variables that describe the changes in the system directly caused by human interventions related to the project which is the subject of the IA (e.g., habitat destruction, changes in flow velocity) or by external stresses. External stresses refer to the changes taking place on larger spatial scales than the ecosystem under study (e.g., effects related to climate change) or the drivers from outside of the ecosystem that affect processes within the ecosystem (e.g., nutrient supply through ocean currents). The design of a project may be driven by the demand for industrial development (including cultural and social activities), demand for ESs, external stresses (e.g., increased need for cooling due to global warming), and/or biodiversity targets. A two-sided arrow between biodiversity and ESs represents the diversity of the relationships between biodiversity and ESs which can be negative and positive [44], although evidence supports a positive effect of biodiversity on ESs in general [45,46], and a negative effect of overconsumption of ESs in biodiversity [47].

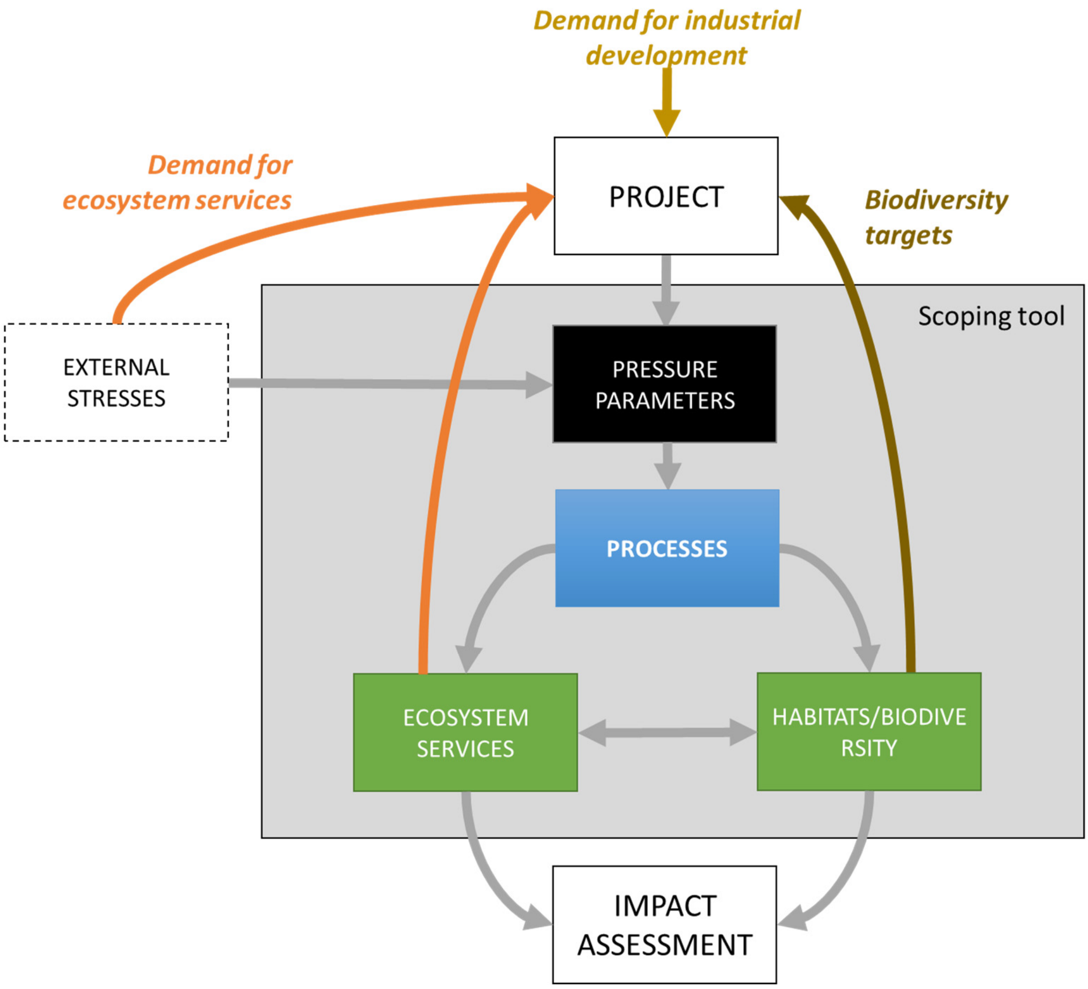

Figure 2. Integration of ESs and biodiversity in IAs based on an assessment of underlying processes.

The approach is described in a stepwise procedure (Figure 3). Steps 1–5 are the preparatory steps to elaborate it at the ecosystem scale (project area and surroundings). These steps require vast knowledge of the ecosystem functioning and the socioeconomic context. In practice, the steps are ideally elaborated in a multidisciplinary setting, involving stakeholders and scientific experts from different fields, which are possibly complemented by the literature. Step 6 concerns its application by IA practitioners.

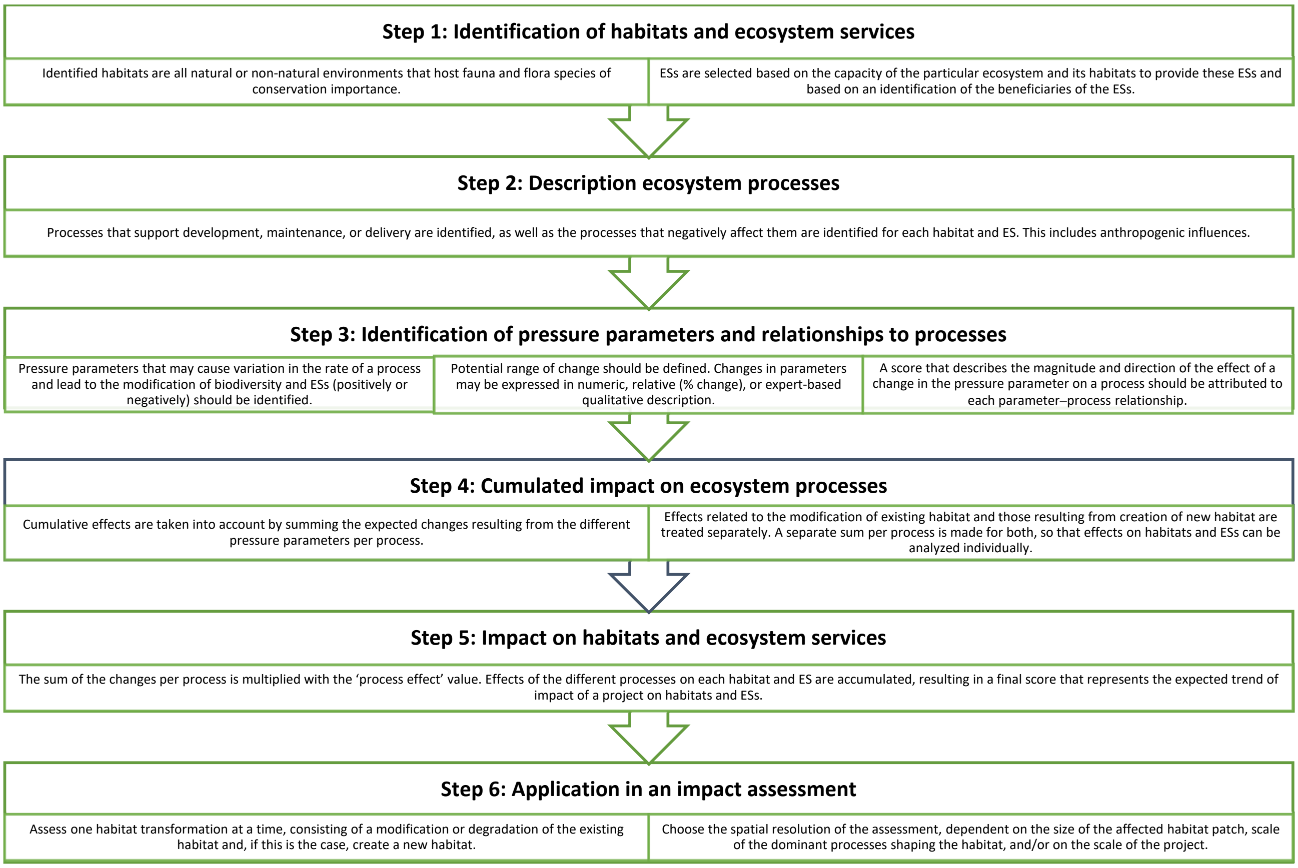

Figure 3. Roadmap of the stepwise approach for the ES integration in IAs.

2.2.1. Step 1: Identification of Habitats and Ecosystem Services

As the first step, the habitats and the relevant ESs in the affected ecosystem need to be identified (Figure 4 matrix 1). Habitats include all natural or non-natural environments that host fauna and flora species of conservation importance. Relevant ESs should be selected based on the capacity of the particular ecosystem and its habitats to provide these ESs, and based on the identification of the beneficiaries of the ESs. The identification of relevant ESs depends on the time scale at which the IA is performed. To be able to account for effects in the long term, it is necessary to bear in mind the future socioeconomic needs and potential changes in use of the ecosystem and its beneficiaries [2,33]. These may alter under climate change, demographic growth, etc. (e.g., expected increase in food production from aquaculture FAO 2020 [48]).

For this case study, the procedure described in Step 2 of [12] was followed to identify the habitats and ESs. The habitats were largely based on the NATURA2000 habitat types and the European habitat classification EUNIS, which distinguishes marine habitats in more detail (Table 1). Artificial reefs (jetties, wind mill foundations, etc.) were included because of their ubiquity, potential ecological values [49], distinct ecological functions, and Ess which they may facilitate [50].

The Common International Classification of Ecosystem Services CICES v4.3 [51] and the marine typology of ESs of [52] were used as the reference frameworks to select relevant ESs. Both lists were first scrutinized by the scientists involved in this project to assess their relevance in the case study area based on their expert judgement. This resulted in a list of 8 ESs, of which 4 were provisioning ESs (agricultural production, fisheries production, aquaculture production, drinking water provision), 3 were regulating ESs (flood protection, climate regulation, water quality regulation), and 1 was cultural ES (recreation). This initial selection was then presented to a mixed group of scientists and stakeholders, representing both natural and social disciplines (Supplementary Information Table S1) who were assumed to have a good understanding of the concept and variety of ESs. They added two additional ESs, i.e., energy production from renewable sources and sediment available for extraction. The time frame for long-term effects was chosen throughout a discussion with the stakeholder and expert panel, i.e., year 2100.

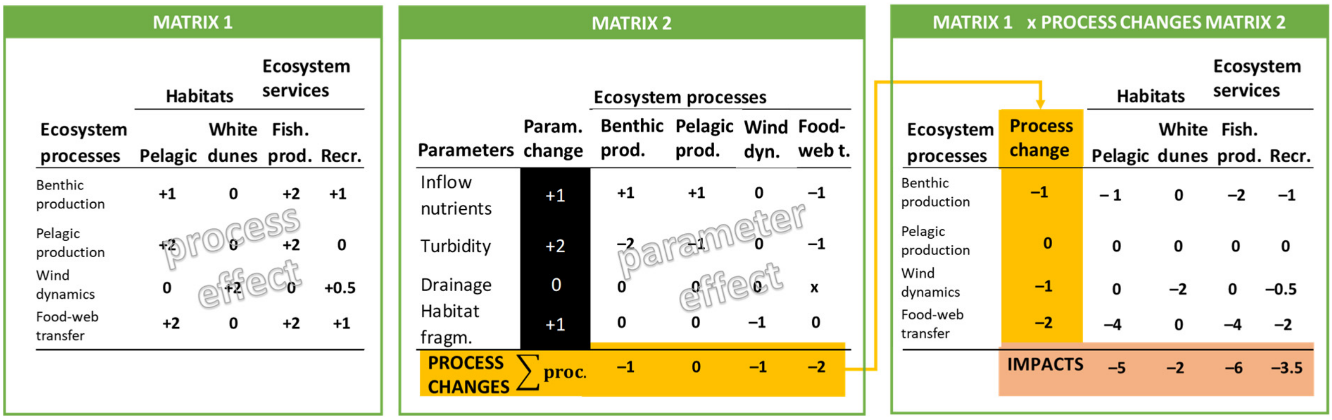

Figure 4. Scheme of the approach using coupled matrices. Matrix 1 = effects of processes on habitats and ES (Steps 1 and 2). Matrix 2 = effects of pressure parameters on ecosystem processes (Steps 3 and 4). For each process in Matrix 1, the value of its effect on a habitat or on an ES is multiplied by the degree of change in the process (Step 5). Black cells: to be filled in to perform an IA (Step 6).

Table 1. Habitats identified in the case study area with indication of their cartographic source (Van der Biest et al. 2020) [12].

Habitat Type	Code EUNIS/NATURA2000	Description
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 sandbank
Submerged sandbanks and foreshore	NATURA2000 1110	Permanently submerged sandbanks at variable depths
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
(Artificial) reefs	NATURA2000 1170	Biogenic reefs formed by dense concentrations of the sand mason worm *Lanice concilega*, or fouling communities on permanently submerged artificial hard substrata
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 and marshes and sandbanks with varying salt gradient
Lower beach and emerged sandbanks	NATURA2000 1140	Sandbanks above low tide and below high tide, including beaches
Upper beach and dune foot	NATURA2000 2110	Part of the beach above high tide where vegetation starts to develop + embryonic dunes
White dunes	NATURA2000 2120	Young, dynamic dunes dominated by dune building species such as marram grass
Grey dunes—herbaceous	NATURA2000 2130, 2150	Dunes fixed by moss or grass, with reduced sand dynamics and increasing soil development
Grey dunes—shrub	NATURA2000 2160, 2170, 2180	Older dunes fixed by shrub and woodland, with important soil development
Dune slacks	NATURA2000 2190	Depressions in the dune landscape which are temporarily or permanently flooded by fresh water

2.2.2. Step 2: Description of Ecosystem Processes

For each habitat and ES, the processes that support their development, maintenance, or delivery are identified, as well as the processes that negatively affect them (Figure 4 Matrix 1). These should include both natural processes as well as anthropogenic processes that may be needed to make use of the ecosystem function and hence produce the ES (e.g., harvesting of fish). The effect that a process has on the habitats and ESs is expressed using a value or a function reflecting the magnitude and direction of the effect ('process effect'). For example, benthic production (process) provides a source of food for part of the pelagic food web (habitat) (+1), and assuming that the largest part of the fisheries' production (ESs) consists of demersal fish, the contribution of benthic production to fisheries is strong (+2).

For this case study, this step is based on and described in detail in Step 4 in [12]. Here, we summarize the main aspects of the procedure. Processes (see Supplementary Information Table S2 for definitions) were identified based on an in-depth literature study and involved experts from natural (biodiversity, water quality, hydrodynamics, etc.) and socioeconomic disciplines (Supplementary Information Table S1), which were determined through several review rounds. In total, 34 processes were distinguished and related to habitats and ESs, resulting in 748 relationships (process–habitat + process–ES) in total (Table 2). The commonly used approach of expert-based scoring to relate habitats to ESs (e.g., [53]) was applied in this case to link processes to habitats and to ESs. A score ranging from −2 to +2 was assigned for the magnitude and the direction of the impact of a process on the occurrence and quality of each habitat and each ES. Processes with multiple and contrasting effects were scored '+/−', corresponding with a value of 0 (when positive and negative effects are expected to be equally large), or the effects were weighed against each other, resulting in one score which takes the differences into account. Scores were assigned based on consensus in smaller groups. When the scores from different groups differed too much, an adjusted score was given. Relationships with low confidence or with low consensus amongst the reviewers were attributed to a lower score '−/0' or '0/+' ($\pm$0.5), respectively, and had potentially negative and potentially positive impacts. This was the case in 3.4% of all relationships.

2.2.3. Step 3: Identification of Pressure Parameters and Relationships to Processes

All pressure parameters that may cause variation in the rate of a process and eventually lead to the modification of biodiversity and ESs (positively or negatively) should be identified. These include environmental parameters (e.g., turbidity, sea level) as well as direct human interventions (e.g., fish harvest). For each pressure parameter, the potential range of change should be defined. Changes in parameters may be expressed in numeric values (e.g., change in °C for sea temperature), relatively (% change), or using an expert-based qualitative description (e.g., moderate increase). Next, a score that describes the magnitude and direction of the effect of a change in the pressure parameter on a process should be attributed to each parameter–process relationship ('parameter effect') (Figure 4 Matrix 2). The unit change of a pressure parameter should be proportionate to its effect on a process and may be different from the unit change in another pressure parameter (e.g., a moderate increase in a process may be caused by a moderate increase in one pressure parameter or by a strong decrease in another parameter). However, the definition of a change in a process should be equal across all pressure parameters, i.e., a strong increase in the rate of a process resulting from a change in one parameter should be as large as a strong increase resulting from a change in another pressure parameter.

For this case study, changes in pressure parameters vary between a strong to moderate increase (+2 or +1), or a moderate or strong decrease (−1 or −2). The scores are not linked with absolute or relative values but are based on expert knowledge (e.g., for air temperature, an increase of 10% should be considered a large increase, while for atmospheric nitrogen deposition, an increase of 10% is considered to be relatively small). Uncertain effects were treated in a deterministic way. Knowledge gaps were highlighted using the symbol "x". The resulting changes in processes vary between −2 and +2 (from a strong negative to strong positive effect of change in the pressure parameter in the process). The relationships between pressure parameters and processes are described using simplified functions (linear and non-linear).

Having a comprehensive list of pressure parameters, the principle of the evaluation framework of the Scheldt estuary [54] was used, which the government uses to monitor and evaluate the ecological state of the Scheldt estuary. This method unravels the functioning of an ecosystem based on a tiered approach, and is developed to evaluate the current state of an estuarine ecosystem in an integrated way. The highest level consists of the major components that describe ecosystem functioning (Figure 5). Each component is split up into several indicators, for which evaluation parameters are identified that allow to evaluate the state of each indicator. Finally, for each evaluation parameter, explanatory variables are identified that explain why the state of an indicator does not meet certain criteria.

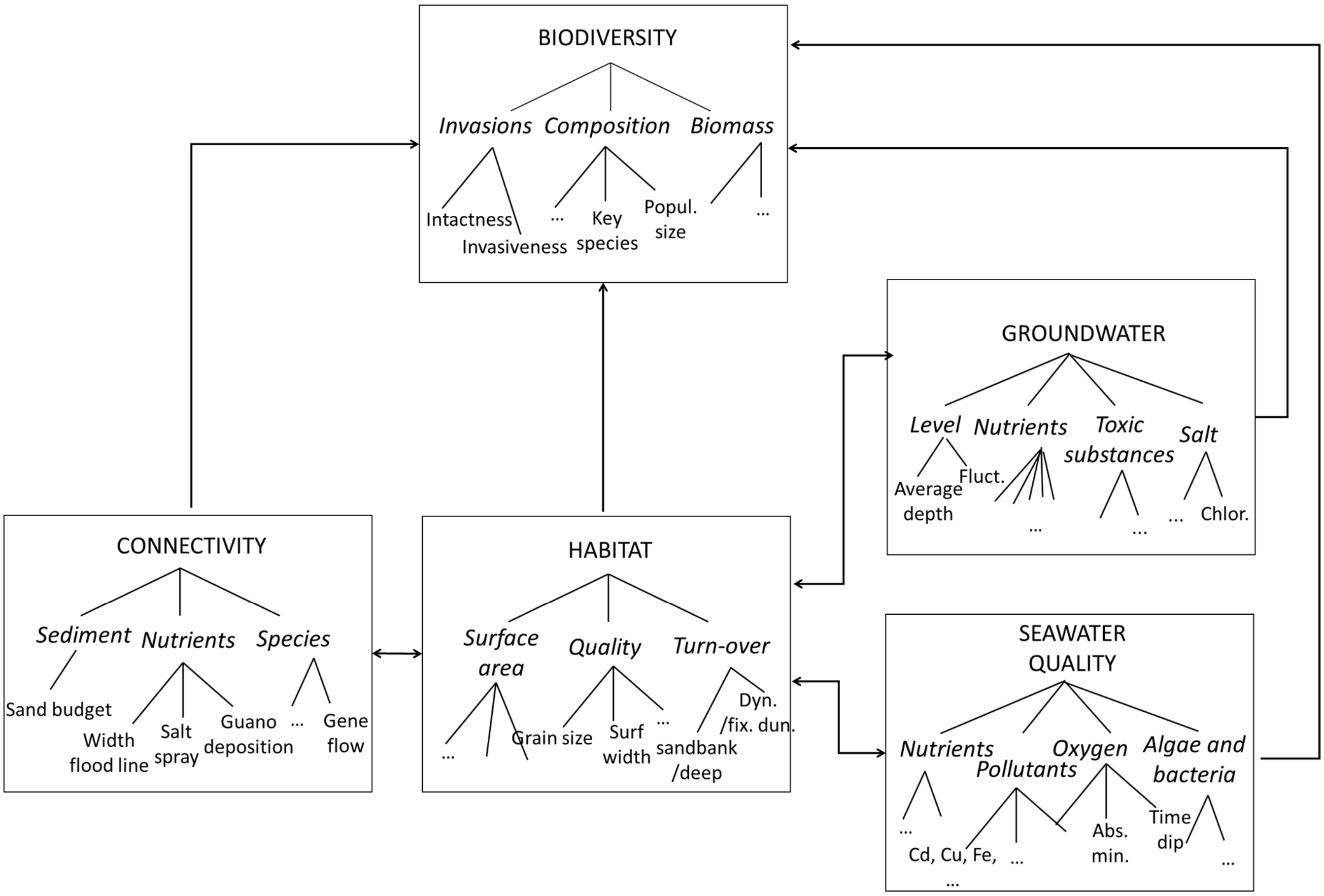

Figure 5. Evaluation framework of the Scheldt estuary (Maris et al., 2014 [54]) applied onto the Belgian coastal zone. Major ecosystem components are in capital letters, indicators are in italics, evaluation parameters are in a small font.

These explanatory variables can also be used to understand how the ecosystem and the ecosystem processes are expected to change in the future, for example, due to the development of a project, and can thus be used as pressure parameters. A change in the inflow of nutrients (pressure parameter) may, for example, explain why pelagic production (process) rates vary. Moreover, the access of pedestrians to the dune foot (pressure parameter) may explain why embryonic dune vegetation cannot be established and why primary dunes are not building up (process). This step was based on an in-depth literature study and involved experts from different disciplines, as described in Step 2.

Table 2. Matrix 1 with process effect scores representing the impacts of processes on habitats and ESs in the Belgian coastal zone. Deep blue: marine processes, brown: terrestrial processes, light blue: processes taking place at sea and on land. Symbology: ++ = +2 (deep green); + = +1 (light green); -- = −2 (red); - = −1 (orange); −/0 and +/0= low confidence or consensus (gold).

		Habitats												Ecosystem Services									
		Pelagic	Gravel Beds	Tidal Flats and Marshes	(Artificial) 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	Agricultural Production	Fisheries Production	Aquaculture Production	Sediment Extraction	Drinking Water Provisioning	Flood Protection	Climate Regulation	Water Quality Regulation	Wind Energy	Recreation and Tourism
Ecological Processes	Hydrodynamics	++	+	+	+	+	++	+	-	-	0	0	0	0	++	++	0	0	--	0	+	++	0
	Morphodynamics	0	-	++	+	++	−/+	++	0	0	0	0	0	0	−/+	−/0	+	0	+	0	0	0	0
	Ecological engineering	+	++	0	++	++	+	0	0	0	0	0	0	0	++	+	−/0	0	+	+	++	0	0
	Benthic production	+	++	++	++	++	++	++	0	0	0	0	0	0	++	0	0	0	0	+	+	0	+
	Pelagic production	++	++	+	+	+	++	+	0	0	0	0	0	0	++	++	0	0	0	+	+	0	−/+
	Transfer	++	++	++	++	++	++	++	0	0	0	0	0	0	++	++	0	0	0	++	++	0	+
	Primary dune formation	0	0	0	0	0	0	0	++	0/+	0	0	+	0	0	0	0	+	++	0	0	0	++
	Large-scale wind dynamics	0	0	−/0	0	0	0	0	0	++	+	-	+	-	0	0	0	-	++	0	+	0	+
	Small-scale wind dynamics	0	0	0	0	0	0	0	0	+	++	0	+	0	0	0	0	0	+	0	+	0	0
	Infiltration	0	0	0	0	0	0	0	0	0	0	++	++	++	0	0	0	++	0	0	+	0	0
	Evapotranspiration	0	0	0	0	0	0	0	0	0/+	0	0	--	-	0	0	0	--	0	-	0	0	0
	Soil development	0	0	0	0	0	0	0	0	-	+	++	+	+	0	0	0	−/+	-	0/+	+	0	0
	Vegetation development	0	0	++	0	0	0	0	++	++	++	++	++	0	0	0	0	0	0	+	0	0	+
	Primary production (land)	0	0	+	0	0	0	0	+	+	+	++	++	0	0	0	0	0	++	++	++	0	0
	Gas emissions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	--	+	0	0
	Denitrification	+	0	+	0	+	+	+	+	0	+	+	+	--	0	0	0	0	0	-	++	0	0
	Population dynamics	++	++	++	++	++	++	++	++	+	++	+	++	−/+	++	−/0	0	0	0	0	0	0	+
Anthropogenic Processes	Sediment extraction	-	--	0	--	-	0	0	0	0	0	0	0	0	-	0	++	0	0	0	0	-	0
	Sediment dumping	-	--	-	--	−/0	-	0	0	0	0	0	0	0	-	-	0	0	0	0	0	0	0
	Bottom disturbing fishing	0	-	0	--	--	0	0	0	0	0	0	0	0	+	0	0	0	0	0	-	0	+
	Pelagic fishing	-	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	+
	Artificial reef formation	−/+	0	0	++	-	-	0	0	0	0	0	0	0	+	++	-	0	+	0	++	0	+
	Artificial infiltration	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	0	++	0	0	+	0	0/+
	Drainage	0	0	0	0	0	0	0	0	0	−/0	−/0	--	++	0	0	0	-	0	--	--	0	0/+
	Water extraction	0	0	0	0	0	0	0	0	0	-	-	--	-	0	0	0	+	0/+	--	--	0	0
	Manuring	-	0	-	0	0	--	-	+	--	--	-	--	++	0	0	0	0	-	-	--	0	0
	Grazing	0	0	-	0	0	0	0	0	0	+	-	+	++	0	0	0	--	0	--	-	0	0
	Cropping	0	0	+	0	0	0	0	0	0	--	--	--	++	0	0	0	--	0	-	0	0	0
	Disturbance by access	0	0	0	0	0	0	0	--	+	0	-	-	0	0	0	0	0	-	0	0	0	++
	Surface hardening	0	0	0	0	0	0	--	--	--	--	--	--	--	0	0	0	--	--	--	--	0	−/+
	Sand nourishing	-	--	0	--	+	-	-	+	+	0	0	0	0	-	0	+	+	++	0	0	0	++
	Nature management	+	++	++	+	+	+	+	++	+	++	+	++	0	++	0	0	+	+	-	+	0	++
	Biological invasions	--	--	--	--	--	--	0	0	0	-	--	-	--	--	--	0	-	-	0/+	0/+	0	−/+
	Noise and visual disturbance	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	−/+

2.2.4. Step 4: Cumulated Impact on Ecosystem Processes

A project causes multiple changes in the environment, and changes in processes are usually the result of changes in multiple pressure parameters. The different effects are considered by summing the expected changes resulting from different pressure parameters per process. From this step onward, the effects related to the modification of an existing habitat and those resulting from creation of a new habitat are treated separately. A separate sum per process is made for both; thus, the effects on habitats and ESs (Step 5) can be analyzed individually. When using a score system, it is not possible to make exact predictions of the absolute or relative change in the processes. The result should rather be interpreted as a general trend.

In this case study, the total sum per process was reduced to a fixed range of −2 to +2, which represents the general trend of the process (strong decrease–moderate decrease–stable–moderate increase–strong increase). Knowledge gaps were not included in this sum; however, the total number of knowledge gaps per process is provided along with the sum.

2.2.5. Step 5: Impact on Habitats and Ecosystem Services

The sum of the changes per process (Step 4) is multiplied with the 'process effect' value (Step 2) (coupling of Matrix 1 and 2 in Figure 4). Changes in the habitats and ESs may result from the changes in multiple processes. Hence, the effects of the different processes on each habitat and ES are accumulated, resulting in a final score that represents the expected trend of impact of a project on habitats and ESs.

The coupling of the matrices is a generic step. No specific elaboration to apply it to this case study is required. Also, an indication of the number of knowledge gaps included in the final result is given here.

2.2.6. Step 6: Application in an Impact Assessment

The approach allows to assess one habitat transformation at a time, consisting of a modification or degradation of the existing habitat and, if this is the case, creation of a new habitat. The user can choose the spatial resolution of the assessment, and this should depend on the size of the habitat patch that is affected, the scale of the dominant processes shaping the habitat, and/or on the scale of the project. Besides the selection of the appropriate scale, the user needs to provide information on the following factors:

- The type of the existing, affected habitat;
- The expected changes in the pressure parameters, as identified in Step 4 (black column in Figure 4), resulting from a modification in the existing habitat;
- The type of a potentially new habitat;
- The expected changes in the pressure parameters, as identified in Step 4 (black column in Figure 4), resulting from the potential creation of new habitat.

The data on the changes in habitat and pressure parameters could largely be extracted from the existing checklists (e.g., scoping checklist of IAs [55]), questionnaires, consultations, or expert judgements (which could be carefully applied).

3. Results

The approach was applied to an explorative study and design of a barrier island and marina in the lee of the jetty of the port of Zeebrugge in the Belgian coastal zone (Figure 6). The main aims of the project are reduce the wave impact on the coastline to protect against the land against floods and to create calm water to enable navigation between the port of Zeebrugge and the port of Antwerp further to the east [56]. Additionally, the island would serve as a habitat for the bird populations in the harbor. In the absence of an ongoing IA for the island, the magnitude of the changes in the pressure parameters was partly derived from the preliminary advisory studies (e.g., [57]) and in part from the judgement of the experts.

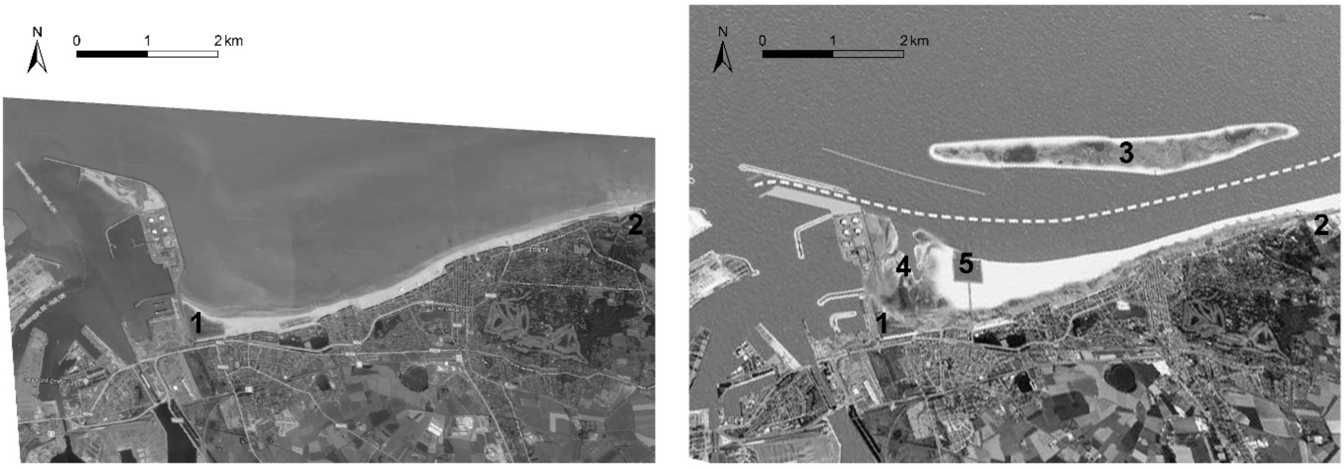

Figure 6. Satellite image of the area today (**left**, Google Maps; map data ©2021 Google) and scenario of artificial barrier island with creation of a marina and tidal flats (**right**, kusteilanden.be 2017 [56]). 1, 2 = existing tidal flats and marshes; 3 = artificial island; 4 = new tidal flats and marshes; 5 = marina.

The construction of the island will have on-site effects at the site of the island and off-site effects along the shoreline, about 1 to 2 km from the island. Also, the marina will have on-site and off-site effects. Due to its illustrative purpose, we present the results of the assessment of the off-site effects of the island and of the on-site effects of the marina.

(a) *Construction of an island—off-site effects*

The off-site effects are related to changing hydrological conditions in the lee of the island and increased shipping traffic. The expected changes in pressure parameters are

- Inflow of pollutants +1 (bilge water, wastewater, oil spills);
- Noise disturbance +1;
- Soil disturbance +1 (anchoring);
- Turbidity +1 (resuspension of fine bottom sediments);
- Disturbance from access +1 (new tidal flats and marshes will be open for public);
- Habitat fragmentation of tidal flats and marshes −2 (improved connectivity due to development of tidal flats nearby existing tidal flat area, see Figure 6);
- Tidal amplitude −1 (buffering of tidal and wave energy by the island);
- Hydrodynamics −2 (buffering of tidal and wave energy by the island);
- Sea level +1 (external stressor related to climate change).

The changes in the pressure parameters are expected to affect the ecological processes of hydrodynamics, morphodynamics, natural reef formation, benthic production, pelagic production, energy transfer, and population dynamics, and the anthropogenic processes of bottom-disturbing fisheries, nature management, biological invasions, access disturbance, and noise disturbance (Table 3).

Trends in the habitats and ESs are represented in Figure 7. The most notable impacts of the project are the development of tidal flats and marshes and the loss of submerged sandbanks and foreshores, which conform with the expectations of the project's developers.

Table 3. Matrix 2 with pressure parameter effect scores for the changes in parameters (black column) related to the construction of the island. Effects on processes are accumulated and the sum per process is standardized to a range of −2 to +2, representing the general trend in the process (light grey). Deep blue: marine processes, brown: terrestrial processes, light blue: processes taking place at sea and on land. Symbology: ++ = +2 (deep green); + = +1 (light green); −− = −2 (red); − = −1 (orange).

		Ecological Processes																	Anthropogenic Processes																
Pressure parameters—expected change		Hydrodynamics	Morphodynamics	Ecological engineering	Benthic production	Pelagic production	Transfer	Primary dune formation	Large-scale wind dynamics	Small-scale wind dynamics	Infiltration	Evapotranspiration	Soil development	GHG	Denitrification	Vegetation development	Primary production (land)	Population dynamics	Sediment extraction	Dumping	Bottom disturbing fishing	Pelagic fishing	Artificial reef formation	Sand nourishing	Artifical infiltration	Drainage	Water extraction	Manuring	Nature management	Intensive grazing	Cropping	Biological invasions	Disturbance by access	Noise and visual disturbance	Surface hardening
Hydrodynamics	**−2**	−2	−2	+1	+1	+1	−1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morphodynamics	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Organic mirco pollution	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residence time	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposition time	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upwelling	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flood freq. (existing flats & marshes)	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tidal amplitude	**−1**	−1	−1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inflow pollutants	**+1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inflow nutrients	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH sea water	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbidity	**+1**	0	0	−1	−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fisheries	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sediment extraction	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand suppletion—new habitat	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Storm surge and frequency	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Sea level	**+1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Gravel beds	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. *Cont.*

		Ecological Processes																	Anthropogenic Processes																
Habitat area—Tidal flats and marshes	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—(Artificial) reefs	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—S. sandb. & foresh.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Estuary	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—L. beach & e. sandb.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—U. beach & dune foot	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat fragmentation—exist. hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat fragmentation—new hab.	**−2**	0	0	+1	+1	0	+1	0	0	0	0	0	0	0	0	0	0	+2	0	0	+1	0	0	0	0	0	0	0	+1	0	0	−1	0	0	0
Nature management—exist. hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nature management—new hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Noise and visual disturbance	**+1**	0	0	o	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+1	0
Soil disturbance (no hab. loss)	**+1**	0	+1	−1	−1	o	0	0	0	0	0	0	0	0	0	0	0	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1	0
Atmospheric nitrogen deposition	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater extraction	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drainage	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artifical infiltration	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Evapotranspiration	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. *Cont.*

		Ecological Processes																	Anthropogenic Processes																
Soil acidification	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manuring	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Disturbance by access (no hab. loss)	**+1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+1	+1	0
Accesibility urban areas	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface hardening	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—White dunes	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Grey dunes—herb.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Grey dunes—shrub	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Dune valleys	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EXISTING HABITAT *Sum processes*	−3	−2	0	−1	1	−1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
	Trend (standardized sum)	−2	−1	0	−1	1	−1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
	NEW HABITAT *Sum processes*	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	1	0	0	−1	0	0	0
	Trend (standardized sum)	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	−1	0	0	0

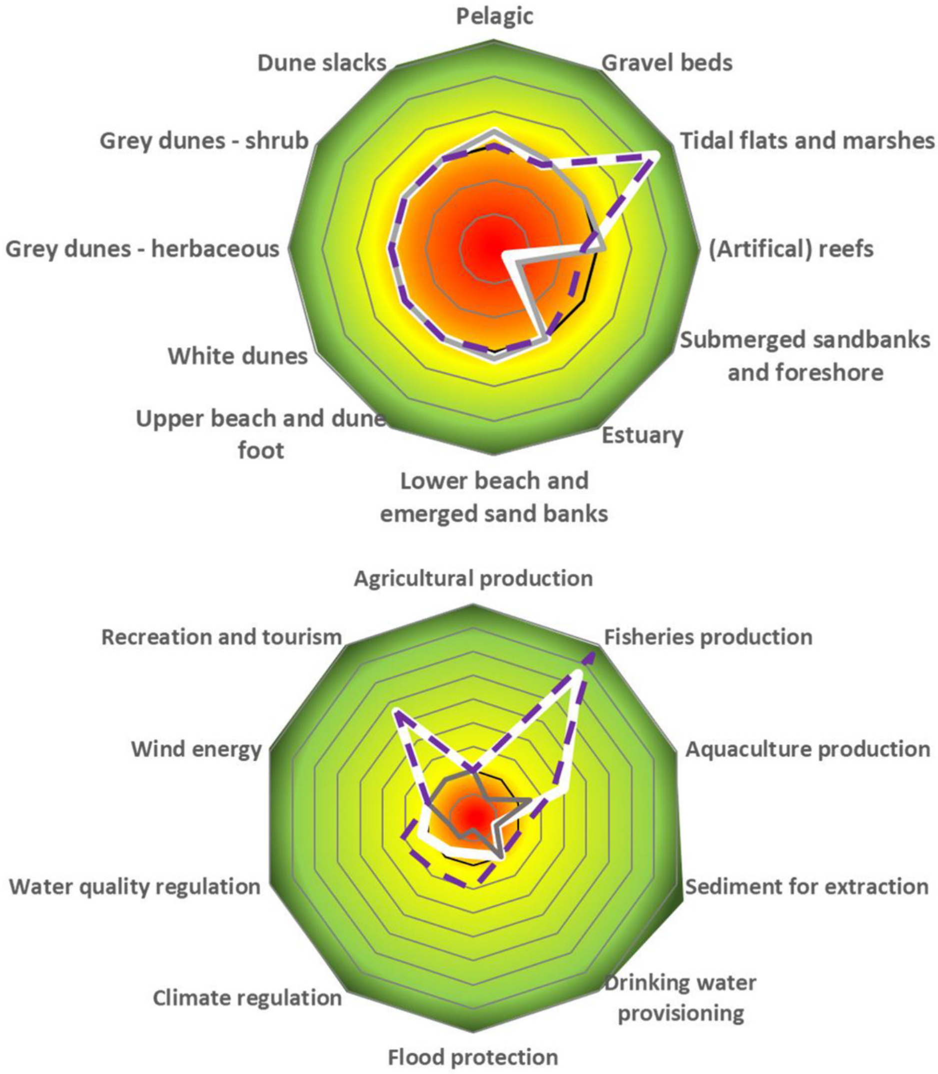

Figure 7. Expected trends in habitats (**top**) and ESs (**bottom**) resulting from off-site effects of the construction of an island. Impacts on existing habitat/ES (grey), on newly created habitat/ES (dashed purple), and the combined effect of both (white). Yellow–green: moderate to strong positive impacts; orange–red: moderate to strong negative impacts; black line: no impacts.

Reduced waves and tidal energy in the lee of the island are expected to improve flood protection because of reduced coastal erosion. On the other hand, submerged sandbanks and foreshores constitute an important source of sand towards the beach and dunes of this zone; hence, their disappearance may negatively affect flood protection. The effect on the production of fisheries is related to the nursery role of structured habitats, such as tidal marshes [58], as well as the impact of connectivity with other marine habitats on population dynamics [59]. Aquaculture production could potentially benefit because of the multiple small positive effects, such as increased pelagic production (more food availability due to a higher benthic production in tidal flats compared to foreshores), enhanced energy transfer, and reduced risk of biological invasions in less fragmented habitats [60]. However, no aquaculture exploitation is currently present in this area. Negative impacts on the available sediment for extraction are caused by a loss of foreshore and submerged sandbanks. In Belgium, sand extraction is only allowed beyond a 12 km distance from the shore [61]; therefore, no impacts are actually expected. Positive impacts on the local water quality result from the nutrient buffering capacity of tidal marshes [62–64]. Climate regulation is also expected to be enhanced due to the storage of organic matter in the soil [65–67]. Benefits for recreation and tourism are a result of several indirect positive impacts of tidal marshes related to biodiversity. These include enhanced opportunities for nature recreation, such as bird watching and increased supply of fish to local markets and restaurants. No knowledge gaps were present in the final outcomes.

(b) *Construction of a marina—on-site effects*

In contrast to the off-site effects, where the habitat modifications result from the changes in the processes, the on-site effects are related to an active destruction of the habitat (foreshore and submerged sandbanks) and the construction of hard structures. Other on-site effects result from the increased shipping traffic and changing hydrodynamic conditions:

- Increase in the surface area of artificial reefs (jetties, floating platforms, . . .) (+2);
- Decrease in the surface area of foreshore and submerged sandbanks (−2);
- High inflow of pollutants +2 in a confined area (bilge water, wastewater, oil spills);
- Soil disturbance +1 (anchoring);
- Turbidity +1 (resuspension of fine bottom sediments);
- Moderate reduction in hydrodynamic energy (−1) because of the already calmer conditions in the lee of the harbor jetty and the island;
- Sea level +1 (external stressor related to climate change).

The changes in pressure parameters are expected to affect the ecological processes of hydrodynamics, morphodynamics, natural reef formation, benthic production, pelagic production, energy transfer, denitrification, greenhouse gas emissions, and population dynamics, and the anthropogenic processes of artificial reef formation, biological invasions and disturbance by access (Table 4).

Trends in habitats and ESs are represented in Figure 8. Most important impacts on the habitats are expected for the pelagic, artificial reefs, and foreshore and submerged sandbanks, and (to a lesser extent) for gravel beds. Impacts on the pelagic food web are related to inflow of pollutants. A reduction in the pelagic production may in turn affect the benthic habitats that strongly depend on the pelagic production of gravel beds. However, no actual impact is expected as gravel beds in the BPNS are found only on offshore sandbanks [68]. The higher production (species colonizing the structures and species benefiting from detritus of these organisms) may have several indirect effects on ESs, such as carbon storage in the predators of the benthic organisms [69] and opportunities for recreational angling. Additionally, the complex structure of sessile communities on the artificial substrata can be highly efficient in water quality processes, such as denitrification [70]. With regard to the production of fisheries, an overall negative trend is expected to occur because of the importance of the shallow foreshore for some of the most important commercial fish species in Belgium, such as sole [71]. No knowledge gaps were identified in the final outcomes.

Table 4. Matrix 2 with pressure parameter effect scores for the changes in parameters (black column) related to the construction of the marina. Effects on processes are accumulated and the sum per process is standardized to a range of −2 to +2, representing the general trend in the process (light grey). Deep blue: marine processes, brown: terrestrial processes, light blue: processes taking place at sea and on land. Symbology: ++ = +2 (deep green); + = +1 (light green); −− = −2 (red); − = −1 (orange).

		Ecological Processes																	Anthropogenic Processes																
Pressure parameters—expected change		Hydrodynamics	Morphodynamics	Ecological engineering	Benthic production	Pelagic production	Transfer	Primary dune formation	Large-scale wind dynamics	Small-scale wind dynamics	Infiltration	Evapotranspiration	Soil development	GHG	Denitrification	Vegetation development	Primary production (land)	Population dynamics	Sediment extraction	Dumping	Bottom disturbing fishing	Pelagic fishing	Artificial reef formation	Sand nourishing	Artifical infiltration	Drainage	Water extraction	Manuring	Nature management	Intensive grazing	Cropping	Biological invasions	Disturbance by access	Noise and visual disturbance	Surface hardening
Hydrodynamics	**−1**	−1	−1	0	0	0	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morphodynamics	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Organic mirco pollution	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residence time	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposition time	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upwelling	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flood freq. (existing flats & marshes)	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tidal amplitude	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inflow pollutants	**+2**	0	0	0	−1	−1	−1	0	0	0	0	0	0	0	0	0	0	−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inflow nutrients	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH sea water	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbidity	**+1**	0	0	−1	−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fisheries	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sediment extraction	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand suppletion—new habitat	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Storm surge and frequency	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Sea level	**+1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Gravel beds	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. *Cont.*

		Ecological Processes																	**Anthropogenic Processes**																
Habitat area—Tidal flats and marshes	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—(Artificial) reefs	**+2**	−1	+1	0	+2	+1	+2	0	0	0	0	0	0	−1	+2	0	0	+2	0	0	0	0	+2	0	0	0	0	0	0	0	0	+1	0	0	0
Habitat area—S. sandb. & foresh.	**−2**	0	0	0	−2	−1	−2	0	0	0	0	0	0	0	0	0	0	−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Estuary	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—L. beach & e. sandb.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—U. beach & dune foot	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat fragmentation—exist. hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat fragmentation—new hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nature management—exist. hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nature management—new hab.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Noise and visual disturbance	**0**	0	0	o	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil disturbance (no hab. loss)	**+1**	0	+1	−1	−1	o	0	0	0	0	0	0	0	0	0	0	0	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1	0
Atmospheric nitrogen deposition	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater extraction	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drainage	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artifical infiltration	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Climate—Evapotranspiration	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. *Cont.*

		Ecological Processes																	Anthropogenic Processes																
Soil acidification	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manuring	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Disturbance by access (no hab. loss)	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accesibility urban areas	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface hardening	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—White dunes	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Grey dunes—herb.	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Grey dunes—shrub	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habitat area—Dune valleys	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EXISTING HABITAT *Sum processes*	−1	0	−2	−6	−2	−2	0	0	0	0	0	0	0	0	0	0	−3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1	0
	Trend (standardized sum)	0	0	−1	−2	−1	−1	0	0	0	0	0	0	0	0	0	0	−1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NEW HABITAT *Sum processes*	−1	1	0	2	1	2	0	0	0	0	0	0	−1	2	0	0	2	0	0	0	0	2	0	0	0	0	0	1	0	0	−1	0	0	0
	Trend (standardized sum)	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

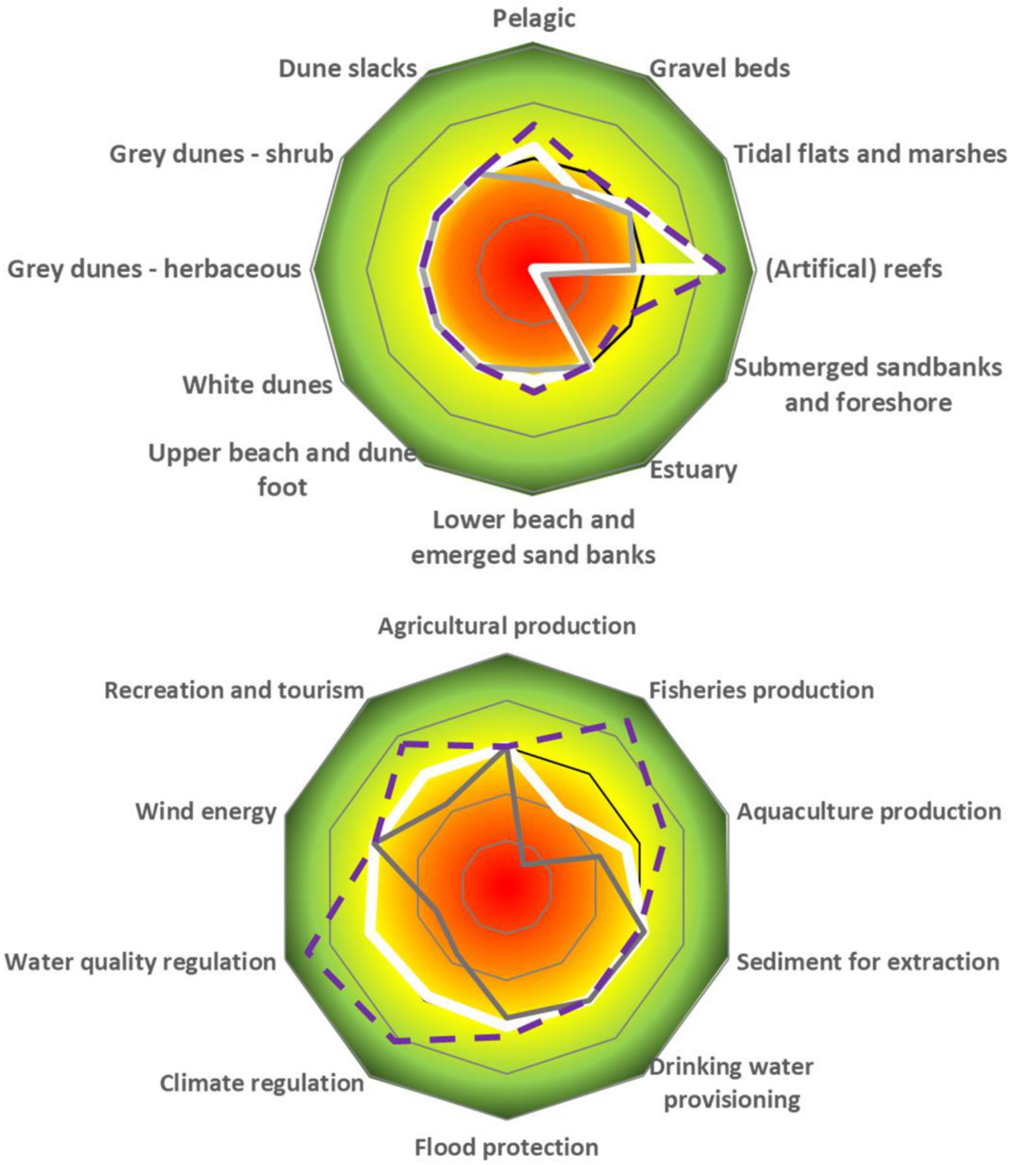

Figure 8. Expected trends in habitats (**top**) and ESs (**bottom**) resulting from on-site effects of the construction of a marina. Impacts on existing habitat/ES (grey), on newly created habitat/ES (dashed purple), and the combined effect of both (white). Yellow–green: moderate to strong positive impacts; orange–red: moderate to strong negative impacts; black line: no impacts.

4. Discussion

4.1. Improved Coverage of Cross-Sectoral Effects in Impact Assessment

Despite progress, there is still a need for new tools to incorporate knowledge of biodiversity and ESs into legislation and spatial planning practices [72], for example, in instruments such as the IA. The presented approach allows for a more comprehensive representation of cross-sectoral and cumulative effects in IAs and provides a way for a meaningful integration of ESz into IAs. By using a generalizable approach, yet by also integrating expert knowledge on the local conditions of the study system to prioritize ecosystem services, our approach makes ES integration into IAs more accessible and efficient. The crux of the approach is to evaluate changes in the processes instead of individual disciplines within an ecosystem (e.g., soil, water, vegetation).

To be able to fully account for cross-sectoral effects, it is necessary to go beyond the assessment of individual disciplines (e.g., soil, water, vegetation) and consider the ecosystem processes that constitute the linkages between ecosystem structures covered by the different disciplines. Today, the focus of IAs is on evaluating impacts per discipline. For example, IAs of offshore wind farms evaluate effects on turbidity within the discipline of 'water'; however, the process of how this leads to the changes in benthic production and habitats in the discipline of 'ecology' (see, e.g., [73]) is mostly not considered. For disciplines such as biodiversity, the underlying processes are of crucial importance, although impacts are often assessed in terms of structural properties such as species' populations [74]. Especially, processes on larger spatial scales [75] or across system boundaries—e.g., the marine and terrestrial system [76]—are often not considered. The inclusion of processes and cross-sectoral effects is said to be rather on an ad hoc basis due to a lack of a systematic approach to identify which effects should be considered. This is why the inclusion of ESs into IAs has been identified as an opportunity to better address cross-sectoral effects [10,77]. This is because ESs provide a more integrated framework, linking the underlying ecosystem processes and structures to the socioeconomic benefits (cfr. ES cascade [78]). A multidisciplinary approach is essential for knowledge integration and for benefitting from the opportunity provided by the ES concept [3,4]. Here, we exemplify how this can be put into practice by using a mixed group of experts and stakeholders from both natural and social disciplines who provided the knowledge on the mechanisms that provide ESs.

Assessing impacts on processes also provides a means to identify cumulative effects (defined here in analogy with the EC definition [55]: "changes to the environment that are caused by an activity/project in combination with other activities/projects"), as changes in processes are usually the result of changes in multiple pressure parameters. For example, the effect of pollutants on benthic production may be limited due to dilution; however, in combination with increased soil disturbance and turbidity, this may affect ESs such as water quality regulation and climate regulation (Figure 8). In some cases, such cumulative effects are included in an IA, by using different methodologies, but this is not always the case. In part, this can be explained by the difficulty to predict cumulative impacts and the lack of consensus on how to perform the evaluation [79], underpinning the need for a more structured approach for identifying relevant cumulative impacts [80]. The presented approach requires the assessor to evaluate the changes in individual pressure parameters and then identifies potential cumulative effects by summing the different changes in a process (Step 4). Hence, potential cumulative impacts are assessed along with other impacts.

To be able to fully account for the cumulative effects, it is necessary to take ecosystem processes into consideration as a first step when delineating the affected area. While the impacts on pressure parameters may be local, the resulting changes in processes may extend beyond the project location and, hence, so do cumulative effects. An appropriate delineation of the study area is therefore crucial to be able to identify cumulative effects [19,75,81].

4.2. Outcomes of this Case Study

The explorative study and design of a barrier island and marina in the lee of the jetty of the port of Zeebrugge in the Belgian coastal zone would result in a number of changes in habitats. Whilst submerged sandbanks and foreshores are lost, a new tidal flat and marsh habitat is created. Further, the marina creation provides a new pelagic artificial reef habitat. The creation of an artificial barrier islands is a practice implemented for coastal protection and beach nourishment. Little scientific literature is found on artificial barrier islands, yet natural barrier islands are important in influencing coastal geomorphology, hydrodynamics, and ecosystem development [82–84]. Human interventions have changed several features, such as their sediment dynamics as well as vegetation development [82,83]. Artificial island creation might thus be expected to impact the same processes and enable marsh development as the results of our case study suggest.

Generally, construction works in coastal areas are associated with the loss of habitats [85,86] and consequent changes in benthic communities [87,88]. Other changes associated with the construction of a marina are the loss of connectivity at the land–water interface, the resuspension of sediments in the water column, and the wave reflection, or refraction and consequential scouring of the sediment bottom [88,89]. Further, introduction of hard structures in predominantly soft sediment environments can serve as the stepping-stones for invasive species [90]. These changes may affect wildlife, fisheries, and water quality [89].

The results of our case study align with these expectations. Processes that are impacted through the changes in the habitat in this case study are hydrodynamics, morphodynamics, reef formation, benthic production, pelagic production, population dynamics, energy dynamics, denitrification, greenhouse gas emissions, fisheries, nature management, biological invasions, noise disturbance, and access disturbance. Some of these processes are linked and may influence each other as well as the delivery of the services of the ecosystem. In this case study, potential positive impacts on fisheries (flatfish) result from a combination of changes in two distinct processes. Benthic biomass production (prey of flatfish) is expected to be higher in fine and organic-rich sediments of tidal flats and marshes compared to coarse and more disturbed unconsolidated sediments [91], such as the ones in foreshores. On the other hand, the development of a new marsh area near an existing one is expected to facilitate interactions between individuals and species from both areas and hence improve the population's dynamics of specialist fish species of marshes (see SI) [92]. The scale of the assessment of fisheries is thus defined by the extent of the underlying processes that affect fisheries, allowing for a more underpinned decision on the scale. However, IAs, as of today, often lack to consider aspects of connectivity at larger spatial scales [93,94]. When connectivity is considered, it is mostly considered from a point of protected species and habitats, while common or commercial species are often ignored [74].

4.3. Facilitating the Inclusion of Ecosystem Services in Impact Assessment

The presented approach offers a way to reduce data and time investments by allowing to select only the key ESs that will be affected by a project and that require a more in-depth (data-driven) evaluation. Existing ES assessment tools that aim to integration their systems into IAs and spatial planning are often created to be as broadly applicable as possible. However, case studies reveal that there is a requirement for a thorough grasp of the local context in order to give appropriate planning support [95]. Whilst the method we describe here is generalizable, the use of expert knowledge ensures proper understanding of the local characteristics of the ecosystem and society. Further, the presented tool herein serves not for the assessment per se, but specifically for the prioritization and selection of a number of ESs to be included into IAs. This would require the tool to be prepared at an ecosystem level (Steps 1–5), prior to its application in IAs (Step 6). The tool should be developed by a multidisciplinary team as it requires profound knowledge of the functioning of an ecosystem and its relationships to ESs. The approach would be most efficient in achieving its goal of facilitating the inclusion of ESs into IAs if the preparatory steps (1–5) are developed in a standardized way, or are institutionally organized on the regional or national scale. Investments of IA practitioners would then be restricted to the expected changes in habitats and in the pressure parameters that affect processes (Step 6), based on information which is gathered in the scoping stage, and a more detailed assessment of the priority ESs that will be affected in the assessment stage. In this case study, the number of ESs that require further analysis could be reduced to 5 (construction of the marina) and 6 (reduced hydrological conditions in the lee of the island) out of 10.

4.4. Unbiased Selection of Impacts

Standardizing an approach, as proposed in this paper, allows us to identify potential effects unbiasedly, without making an a priori selection of impacts that are believed to be (ir)relevant or for which the data is scarce. Following the approach, the pressure parameters that need to be evaluated and that will help to identify potential impacts were identified prior to the IA and in a context independent of the project. The links between the affected pressure parameters and the ecosystem processes, habitats, and ESs are automated prior to the evaluation of the project, allowing for a more comprehensive and underpinned selection of what should be included in the IA. The usage of a matrix approach, in this respect, supports the identification of the gaps within the knowledge. All changing pressure parameters are positioned in relation to each process, and, likewise, all processes to every habitat and ES, thus avoiding potential effects being overlooked and a false sense of certainty in the decision-making process. A sensitivity analysis may help the decision maker to embrace this uncertainty by informing how strong effects with uncertainty would influence the final results.

Recently created ES tools seek to facilitate the use of ES tools in spatial planning and to provide information for a variety of policy sectors. Throughout the scientific literature, there seems to be a preference for certain ESs, whilst others receive considerably less attention. The majority of tools can be used to handle provisioning services as well as regulating services, whilst cultural services are rarely considered, with the exception for recreation [37,96–98]. It is impossible to evaluate every ES when aiming at their integration in IAs, strategic environmental assessments, or life cycle assessments. However, the selection of ESs has conflicting views, since the selection may easily be subject to biases, and methods of ES prioritization are not always clearly defined [35,98].

Tools such as the Ecosystem Service Assessment Support Tool (ESAST) OpenNESS Conceptual Nexus, serve to help with the prioritization of ESs and ES assessment methods [99]. These tools help to frame the case problem that will be addressed, while involving diverse stakeholders and perspectives, before identifying ESs and analyzing ways in which they may be affected by the problem or project at hand. Arguably, these tools have more comprehensive goals than ecosystem services. However, they do not explicitly serve for the integration of ESs into IAs, and are aimed at more broadly viewed ES assessments in diverse socioeconomic contexts. A streamlined ES selection process, as outlined in this paper, will help to overcome these hurdles and biases, and thus enable a smoother integration of ESs into IAs.

4.5. Constraints and Improvements

The presented approach is meant to be an indicative instrument to identify expected impacts that should be assessed in more detail in an IA. It can also be applied in other contexts than in IAs, such as design optimization (e.g., [100]), to inform stakeholders (e.g., in the ENDURE project on dune resilience (https://endure-tool.eu/#slide-0, accessed on 17 October 2023)), or to select priority ESs (e.g., [101]). However, there are also some limitations to this approach. The score-based outcome does not provide information on the precise extent of the impact or on its socioeconomic significance. For example, one of the main purposes of the island is to protect the coast against floods by reducing tidal and wave energy. However, the results (Figure 7) give the impression that the benefits for fisheries production are larger than for flood protection. Due to lack of a common ground for quantifying impacts (e.g., monetary value), the approach does not allow to compare impacts in relative terms and should merely be used to identify which ESs are expected to be impacted and require further detailed analysis.

A methodological improvement that should be explored is the possibility to set thresholds on the impacts of changing pressure parameters on processes, in order for the rate of a process will only be affected at a certain magnitude of the changing parameter. This could make the results more site-specific and refine the assessment of cumulative effects because, in this case, past changes in the environment can be considered. However, this would render the approach more complex and may overshoot its scope of being an indicative instrument.

5. Conclusions

This paper presents an approach for more effective scoping of the impacts on ESs, which enables the selection of impacts to be assessed in an IA to be supported. The approach takes an innovative step by evaluating how a project causes changes in an ecosystem's processes, from which impacts on habitats and ESs are assessed. Based on the case study of the Belgian coastal zone, we showed how the approach (1) allows for a more integrated evaluation of the impacts and identifies the potential cross-sectoral and cumulative impacts on the coastal zone, and (2) provides a structured and objective basis to select what is included in an IA. The approach is applicable to marine and terrestrial environments and, through the assessment of the changes in dynamic processes, is capable of identifying impacts on an ecosystem's services across the marine–terrestrial boundary. The approach is limited in its capacity to compare the resultant impacts in relative terms and is only designed to identify which ESs are expected to be impacted and require further detailed analysis. The paper aims to provide inspiration to further support the integration of ESs into IAs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su152115506/s1, Table S1: Experts and stakeholders involved in Step 1 and 2 of the elaboration of the method on the Belgian coastal ecosystem; Table S2: Definition and interpretation of ecological and anthropogenic processes. Processes are restricted to the marine part (S), the terrestrial part (L) or they take place both in the marine and in the terrestrial part (S/L).

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