Geography and Sustainability 1 (2020) 256–265

Contents lists available at ScienceDirect

Geography and Sustainability

journal homepage: www.elsevier.com/locate/geosus

Prespective

Ecosystem services of the Baltic Sea: An assessment and mapping perspective

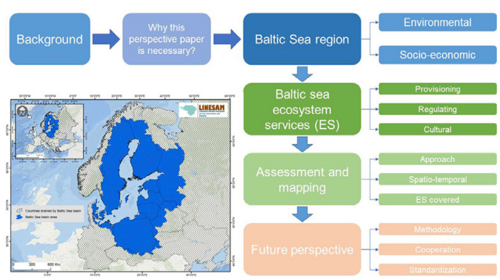
Miguel Inácio[a], Donalda Karnauskaitė[a], Eglė Baltranaitė[b], Marius Kalinauskas[a], Katarzyna Bogdzevič[a], Eduardo Gomes[a], Paulo Pereira[a,*]

[a] Environmental Management Laboratory, Mykolas Romeris University, Vilnius, Lithuania
[b] Marine Research Institute, Klaipeda University, Klaipeda, Lithuania

HIGHLIGHTS

- Ecosystem service (ES) assessment and mapping in the Baltic Sea are mainly qualitative.
- A collaborative effort between the Baltic countries is essential.
- It is necessary to standardize the practices regarding ES in the Baltic Sea.
- Hydrodynamic and ecologic models will increase the quality of the ES assessed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 October 2020
Received in revised form 17 November 2020
Accepted 17 November 2020
Available online 23 November 2020

Keywords:
Collaborative effort
Ecological modeling
Marine ecosystem services
Cultural
Provisioning
Regulating

ABSTRACT

The Baltic Sea is essential for marine ecosystem services (MES) provision and the region's socio-economic dynamics. It is considered one of the busiest and most polluted regional seas in Europe. In recent years a collective effort in enforcing European and regional environmental policies and directives (e.g. Water Framework Directive 2000/60/EC, 2000; Marine Strategy Framework Directive 2008/56/EC, 2008; Maritime Spatial Planning Directive 2014/89/EU, 2014) has been carried out. Ecosystem Services assessment and mapping is integrated into these directives. An increasing number of scientific studies, projects, and other works were developed in this context, generating a vast body of knowledge. Despite all efforts to improve the Baltic Sea's environmental status, the targets established were not fulfilled. It is also important to analyze if current methodological approaches for assessing and mapping MES are robust enough to provide the needed results. This perspective paper analyses the status of assessment and mapping methodologies. The results showed that most of the studies were focused on qualitative assessments, with limited validation and reliability. Although the number of robust and quantitative works is increasing, more are needed. It is vital to carry out quantitative assessments to inform decision-makers better and standardize MES practices across the Baltic Sea.

1. Background

Most of the world's population is living near the coast (Luijendijk et al., 2018) and intrinsically connected and dependant on the marine environment (Agardy and Alder, 2005). The enormous diversity of marine species and habitats, and their ecological processes and functions, are responsible for generating a vast array of ecosystem goods and services (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). Ecosystem services (ES) are defined as *"the benefits nature provides to humans"* (Millennium Ecosystem Assessment, 2005). According to the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2018) ES is divided into three categories — provisioning, regulating, and cultural, covering all aspects of socio-ecologic systems (Inácio et al., 2018). The ES provided by marine ecosystems (MES) is recognized for playing an essential role in supporting human wellbeing and driving socio-economic development (Martínez et al., 2007). Marine ecosystems were mainly seen as a source of nutritional and ornamental values. However, their importance gained a more prominent role following humanity's socio-economic and

* Corresponding author.
E-mail address: pereiraub@gmail.com (P. Pereira).

https://doi.org/10.1016/j.geosus.2020.11.001

technological advances (Barbier, 2017). Nowadays, MES constitute the basis of many socio-economic systems around the world (Hattam et al., 2015).

The Baltic Sea Region is an example where MES's provision is an essential driver of socio-economic wellbeing (Ahtiainen et al., 2013, 2019). The region's history and cultural identity are intrinsically connected to the Baltic Sea. In the past, the main economic activities connected to the Baltic Sea were fisheries and maritime commerce (Håkanson et al., 2003; Lajus et al., 2013). Other activities, such as aquaculture, energy, and tourism, emerged as new important socio-economic drivers (Schultz-Zenhden and Matczak, 2012). Overall, the Baltic Sea constitutes the basis of many of the Baltic countries' socio-economic systems (Hasler et al., 2016). This importance is expected to increase in the European Green Deal and Blue and Green Growth European Agendas. Nevertheless, despite its importance, the sustainable provision of ES in the Baltic Sea, like most marine ecosystems worldwide, is at risk (Ahtiainen and Öhman, 2014; HELCOM, 2018a). An anthropogenic driven environmental degradation led to a decrease in the ecologic and environmental status of the Baltic Sea (HELCOM, 2018a). Excess of nutrients causing eutrophication events (e.g. agriculture), and hazardous substances in the sediments (e.g. urban and industrial discharges), caused by the reduced capacity of the terrestrial ecosystems to filter toxins and pollutants, are associated causes of environmental degradation in the Baltic Sea (HELCOM, 2018a; Reusch et al., 2018). The introduction of invasive species, loss of nursery grounds, and overfishing are some of the anthropogenic impacts in the Baltic Sea (Mikša et al., 2020, 2021; Swain, 2017). The cumulative effect of these impacts jeopardizes the Baltic Sea's capacity to provide ES in quantity and quality, putting at risk the livelihoods of coastal communities and the countries' socio-economic systems (Hasler et al., 2016).

Therefore, restoring the Baltic Sea's environmental and ecological status is a priority and a necessity, which can only be achieved in a coordinated effort between the countries (Elmgren et al., 2015). The decade 2021–2030 is, according to the United Nations, the decade for restoration (www.decadeonrestoration.org). The Baltic Sea is a region of the world where this strategy needs to be implemented with urgency. A great effort was carried out in the region and is considered to be on the frontline in terms of coastal and marine management (Schernewski et al., 2018). Besides enforcing multiple European Directives and policies like the Water Framework Directive (WFD) (Directive 2000/60/EC, 2000), Marine Strategy Framework Directive (Directive 2008/56/EC, 2008), Integrated Coastal Zone Management (EC, 2000), and Maritime Spatial Planning Directive (Directive 2014/89/EU, 2014), there are also regional efforts such the European Union Strategy for the Baltic Sea Region (European Commission, 2012). Several studies recognize the importance of assessing and mapping MES in supporting the achievement of the mentioned policies (e.g. Grizzetti et al., 2016; Lester et al., 2013; O'Higgins and Gilbert, 2014). However, most of the studies conclude that more robust methodological approaches are needed to improve results' reliability. This is key to extend the importance of MES assessment and mapping in supporting decision-making processes and making the results of studies more credible.

Several works were focused on identifying and summarizing information on MES (e.g. Ahtiainen and Öhman, 2014; Ahtiainen et al., 2010; Hasler et al., 2016; Söderqvist and Hasselström, 2008). However, there is a lack of information available regarding mapping and assessment efforts in the Baltic Sea from a methodological perspective. This perspective paper aims to contribute to this respect, providing (1) an overview of MES in the Baltic Sea, (2) analysing the assessment and mapping methodologies, and (3) elaborating on a perspective view of future research needs and directions.

2. The Baltic Sea region

2.1. Environmental and socio-economic setting

The Baltic Sea is one of the largest semi-enclosed water bodies in the world. It covers an area of 392,978 km^2, and it drains a basin four times larger than its dimensions. Approximately 1,633,290 km^2 (Leppäranta and Myrberg, 2009) (Fig. 1). Receives freshwater inputs from some of Europe's largest rivers (e.g. Oder, Vistula, Nemunas) and has a restricted connection with the Atlantic Ocean. The Baltic Sea is a low salinity brackish-like water body (Hordoir and Meier, 2010). The average depth is 54 m, the deepest part (Gotland Deep) reaches 459 m (Leppäranta and Myrberg, 2009). The Baltic Sea supports a reduced number of species but supplies a high number of individuals. It is estimated to host a total of 328 biotopes (HELCOM, 2013) and 2700 macroscopic species and uncountable microscopic species (HELCOM, 2018b). Some of the largest coastal lagoons in Europe are located in the Baltic Sea, which provides nursery, spawning grounds, and refugia for various saltwater and freshwater fish species (Newton et al., 2014).

The Baltic Sea Region consists of nine countries: Denmark, Sweden, Finland, Russia, Estonia, Lithuania, Latvia, Germany, and Poland. However, Baltic Sea catchments drain also areas located in Czech Republic, Slovakia, Belarus, Ukraine, and Norway. It is home to almost 85 million people (20 million living within 10 km from the coast) (Omran and Negm, 2020) and has a very rich and diverse environment in terms of historical, political, cultural, social, and economic aspects (Maciejewski, 2002) (Fig. 1). Hence, common to the nine countries in the Baltic Sea's role as the primary driver of their socio-economic activity. The Baltic Sea is one of the most used and busiest sea areas globally (Madjidian et al., 2013) and supports an enormous array of economic activities (HELCOM, 2018c). Fisheries are perhaps the oldest socio-economic activity in the Baltic Sea and still one of the most important. According to the report "The 2019 Annual Economic Report on the EU Fishing Fleet", approximately 632 538 tons of fish and shellfish were landed with an economic value of about 217 million euros (STECF, 2019). Aquaculture is a rising socio-economic activity in the Baltic. Presently there are 332 aquaculture sites in the Baltic Sea. Denmark, Finland, and Sweden invest more in this activity (STECF, 2018). The aquaculture sector is expected to increase following the European Commission Blue Growth agenda and the EU Baltic Sea Region strategic plans (European Commission, 2017). Maritime transportation is also one of the oldest socio-economic activities. Historically, the Baltic Sea was the *Hanseatic League*'s main route, a commercial and defensive confederation of merchants (Guzikova, 2020). The transportation of goods within and outside of the Baltic Sea region is essential, supporting many economic sectors. Madjidian et al. (2013) reported that up to 15% of the world's cargo is handled in the Baltic Sea. Another important sector is passenger transportation. Several internal lines comprised in 2015, 46% of all port visits (HELCOM, 2018c). Another essential socio-economic activity is coastal tourism. The diversity of landscapes across the Baltic Sea allows different types of tourism (Baltranaitė et al., 2017; Grigelis, 2013). Popular activities include beach tourism, recreational fishing, hiking, snorkelling. Tourism activities generate 3.2% GDP in the Baltic Sea Region (State of the Tourism Industry in the Baltic Sea Region, 2019). Finally, another emerging economic activity is related to the energy sector. In the Baltic Sea, both renewable (e.g. wind farms) and non-renewable (oil rigs) energy sources are exploited. With all the related infrastructure, including cables, pipes occupy a considerably large area in the Baltic Sea (HELCOM, 2018d). Through offshore wind parks, renewable energy expansion is expected to increase in the Baltic Sea following the European Green Deal (European Commission, 2019).

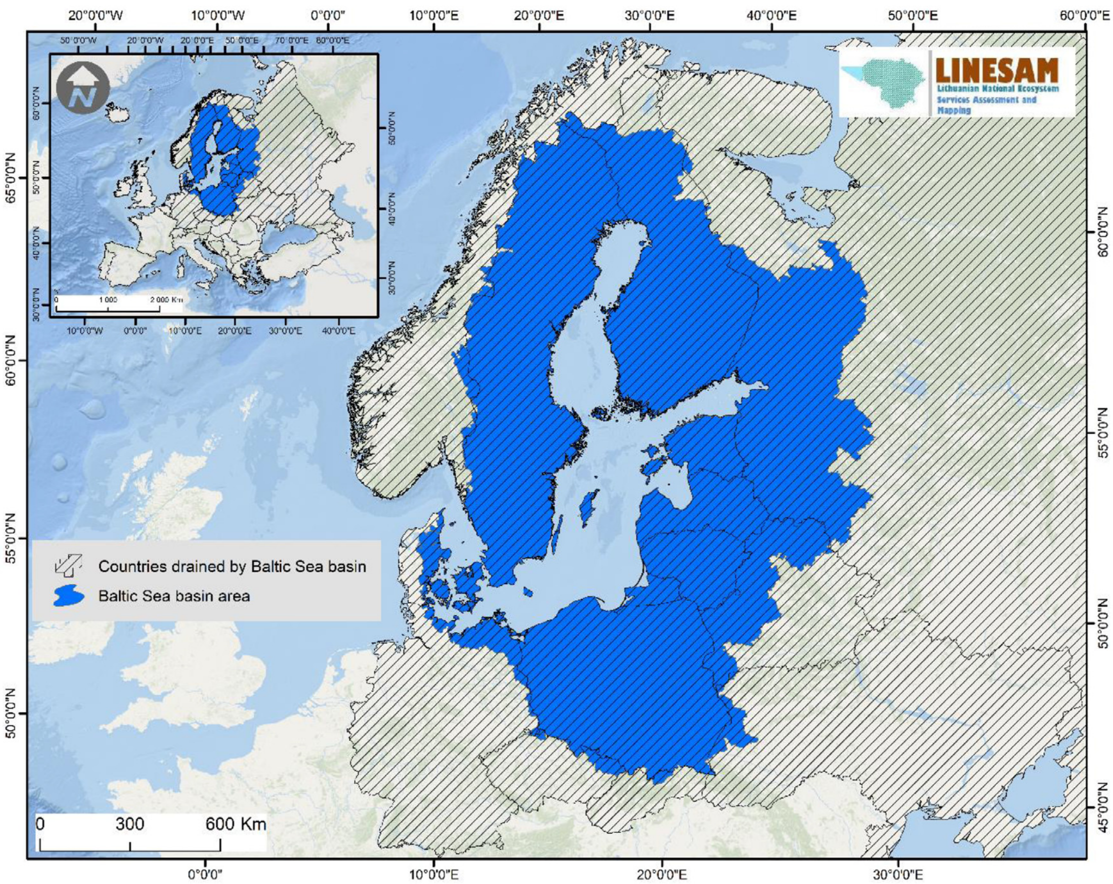


Fig. 1. Baltic Sea Region and its catchment area.

3. Ecosystem services of the Baltic Sea

3.1. Provisioning services

Provisioning services include all outputs from animals, plants, and ecosystems, which can be used for nutrition, materials, or energy (Maes et al., 2015). The Baltic Sea provides nutritional outputs from wild and farmed fish, shellfish, and plants (algae). Wild seafood (fish and shellfish) are fundamental components of the diet of Baltic countries. Many fish and shellfish species are extracted from the Baltic Sea, with the most relevant commercial fish species being cod, sprat, and herring, comprising 95% of all fisheries in the Baltic (HELCOM, 2018d). Furthermore, the provision of wild seafood is also essential for many socio-economic activities, including the fishery sector, tourism, and recreation (Garpe, 2008). Nutritional outputs from farmed fish and shellfish have gained importance in the last decades (Ahtiainen and Öhman, 2014). The most important species are salmon, trout, and blue mussels (STECF, 2018). The farming of plants (macroalgae) for nutritional purposes is not so well developed in the Baltic Sea, with only a few farms operating in Germany, Denmark, Sweden, and Estonia (Kotta et al., 2020). The Baltic Sea also provides wild plants which are used as building materials (Garpe, 2008). One example is the reed harvest. In all countries, reed is still harvested nowadays for the traditional roof building or other building applications (Köbbing et al., 2013). Wild plants, namely beach wrack accumulated at the beach, can also be potentially used to produce bioenergy (Weinberger et al., 2019). Further use of beach wrack in the Baltic Sea is currently being explored in the recent "CONTRA (Conversion of a Nuisance to a Resource and Asset) project (www.beachwrack-contra.eu). Another important provisioning service the Baltic Sea provides is the extraction of mineral resources. Sand is extracted in the Baltic Sea for construction or beach nourishment purposes (Schwarzer, 2010). Furthermore, recent research shows the existence of extensive mineral coverage in the Baltic Sea with the potentials for exploration (Kaikkonen et al., 2019).

3.2. Regulating and maintenance services

Regulating & Maintenance services include all services related to ecological functions and processes that regulate and maintain provisioning and cultural ES (Maes et al., 2015). The ecologic capacity to filtrate, remediate and remove nutrients, hazardous nuisances is one of the most critical regulating services in the Baltic Sea (Asmala et al., 2017) due to well-known problems of eutrophication and metal contaminations (Swain, 2017). Another critical service is the system's capacity for sediment retention and stabilization (Ahtiainen and Öhman, 2014). This service contributes directly and indirectly to support other ES, such as recreation. The sediments accumulated at the beach replenish or develop into new dunes and play an important role in coastal protection against flooding events. Also, the stabilization and retention of sediments play an essential role in the nutrient dynamics, removing nitrogen, phosphorous and organic material (Carstensen et al., 2020). Flood protection service is vital in the Baltic Sea. Habitats such as reef structures, hard bottoms, seagrass meadows, and reed belts attenuate wave impacts, providing flood protection to coastal communities (Liquete et al., 2013b). This service is also of high importance due to the future changes associated with climate change, including increased extreme weather events and sea-level rise (Phil Graham et al., 2008). The Baltic Sea capacity to provide wild seafood is tightly related to its capacity to maintain nursery areas and populations. Coastal lagoons, bays, fjords, and inlets as well as seagrasses, macrophytes, reefs, and other habitats, are essential to several species, such as perch, pike, flounder, and juvenile fish, by functioning as nursery and spawning grounds

(Macura et al., 2019). Maintaining these areas is crucial to ensure biodiversity and fish production (Kraufvelin et al., 2018). Another important regulating service provided by the Baltic Sea is its influence on local and regional climate regulation. As an extensive body of water, the Baltic Sea has an effect on climate regulation influencing air temperature (Bergström et al., 2001) and has the capacity to sequester carbon (Kuliński and Pempkowiak, 2011).

3.3. Cultural services

Cultural ES includes all intangible benefits from spiritual, experiential, and physical use of the environment (Maes et al., 2015). The Baltic Sea coast is a tourist destination. The diversity of landscapes and seascapes allows for a wide array of tourism-related experiential and physical land and sea activities. Surfing, scuba diving, and birdwatching are some of the popular activities. Physical activities on land include beach tourism, hiking, and cycling along the coasts. Water-related sports (e.g. surfing, kite surfing), sailing, and swimming are the preferred activities (Ahtiainen et al., 2019). The different historical, political, and socio-economic backgrounds of all Baltic countries imprint a very diverse and rich marine-related culture and heritage, such as amber goods, underwater archaeology, a history of marine aids to navigation (BRHC, 2013; Girininkas, 2010). Cultural heritage is an important feature of the Baltic Sea ecosystems' cultural services, the development of unique local cultures (Tagliapietra et al., 2020). For example, several cultural events, such as sailing, gastronomic festivals, such as International Hanseatic Days in Rostock, Germany, The Tall Ship Races in the Baltic Sea, and multiple festivals are driven by nature as an infinite source of inspiration take place annually all around the Baltic.

The Baltic Sea's complex socio-ecologic system provides a platform for scientific and educational opportunities. A high number of research institutions annually produce hundreds of scientific publications (Reusch et al., 2018). Several educational programs (e.g. Baltic Science Network and "Baltic Sea for the Curious") and research projects (e.g. BONUS BaltCoast, SECOS Project, BONUS MARES, BONUS BALTICAPP and ROSEMARIE, ECOSERV) aim to contribute to a more sustainable Baltic Sea by providing scientifically sound results to inform decision-makers better.

3.4. Ecosystem services in the governance of the Baltic Sea

National governments, governmental agencies, and the European Union manage the Baltic Sea and its ES (Ahtiainen and Öhman, 2014; Hassler et al., 2013). Also, various international directives and agreements influence Baltic Sea management. Therefore, the ES concept is being integrated into current policies at the global and European levels (Bouwma et al., 2018; Hassler et al., 2019). ES approach is useful for implementation of the requirements of the current policy targets, such as the MSFD, the WFD and the HELCOM Baltic Sea Action Plan (BSAP) (HELCOM, 2007), Biodiversity Strategy 2030 (European Commission, 2020), and for the achievement of UN Sustainable Development Goals (SDG's) (UN, 2015).

Despite the explicit dependency of a well-functioning and healthy Baltic Sea, the environmental impacts of the socio-economic activities put the sustainable provision of ES at risk. Nowadays, the Baltic Sea is considered to be one of the most heavily used and polluted marine areas (HELCOM, 2018c) and is reported to be in a poor ecological status. To reverse the environmental degradation and increase the ecological and environmental status, a joint effort coordinated by HELCOM Commission set the Baltic Sea Region as an example in coastal and marine management (Gilek et al., 2016). Still, several issues are identified concerning the use of ES valuation in the Baltic Sea context, for instance, the application of ecosystem assessment and mapping in MSP (Geneletti et al., 2020). The assessment and mapping of ES is seen as an essential tool to raise the public and stakeholders' awareness regarding the need to achieve a good environmental status brings improved socio-economic benefits (Chaudhary et al., 2015; Mikša et al., 2020). To this effect, showing the socio-economic value and the implications to the people of reaching a good environmental status might increase the national and global policy's support (Geneletti et al., 2020).

4. An ES methodological analysis in the Baltic Sea

In the last years, integrating the assessment and mapping of ES into coastal and marine management and other environmental agendas increased the number of projects and scientific works (Liquete et al., 2013a; Townsend et al., 2018). In the Baltic Sea, the BONUS Secretarial has funded several MES related projects (e.g. BONUS BaltCoast, BONUS BALTICAPP, BONUS Basmati, BONUS ROSEMARIE). Nevertheless, there is a lack of an overview status focused on the methodologies used to assess and map MES in the Baltic Sea. This results in several unanswered questions. First, are the assessment and mapping methodologies appropriate to fulfil the needs and objectives of coastal and marine management policies and frameworks? Second, will the further efforts be relevant and robust to influence or drive decision making? Answering these questions is of high importance, especially now, when new environmental targets are to be set for EU Biodiversity Strategy 2030, WFD, MSFD, and Baltic Sea Action Plan.

To provide a methodological overview, we have conducted a literature search. We used key words "Baltic" AND "ecosystem services" AND (provisioning OR regulating OR cultural) AND ("coastal OR marine"). Furthermore, we have restricted our search to studies in which the main stated objective was the ES assessment and/or mapping. The studies were searched in Google Scholar and SCOPUS databases covering the years between 2000 and 2020. In total, 100 studies were identified. A total of 34 peer-reviewed articles were selected after excluding grey literature (e.g. master and Ph.D. thesis, synthesis reports, project reports, policy briefs) and non-per reviewed articles. Information on the typology, purpose, methodology, spatial coverage and ES assessed was extracted for each study (Table 1). The majority of the studies are located in the Southern Baltic Sea (Fig. 2A and B) and assess and/or map either one or three ES categories.

- *Focus and approach:* Qualitative assessments are based on expert-based interviews (e.g. Müller et al., 2020) or public perceptions based on questionnaires (e.g. Viirret et al., 2019). Quantitative assessments apply empirical and observational data by means of modeling (e.g. Gogina et al., 2017), bio-physical indicators (e.g. Depellegrin et al., 2020) and surveys (e.g. Czajkowski et al., 2015). Semi-quantitative apply both approaches (e.g. Inácio et al., 2018). Most of the analyzed studies (14) applied a qualitative approach, followed by quantitative (13) and semi-quantitative (7). The main focus was on environmental (23 studies), followed by monetary (7) and social assessments. Social focus accounted only for four studies (Ahtiainen et al., 2013, 2019; Piwowarczyk et al., 2013; Viirret et al., 2019) (Table 1). A total of fourteen works analyzed one ES, while three studied two ES and seventeen evaluated three ES (Fig. 2A). Eighteen studies were focused on assessment, whereas sixteen mapped ES (Fig. 2B).
- *Space and time:* ES assessment and mapping cover different spatial scales: national, regional, or local studies (Table 1). Thirteen studies assessed MES at the national level (e.g. Depellegrin et al., 2016; Nieminen et al., 2019; Ruskule et al., 2018), followed by the local level (11 studies) (e.g. Piwowarczyk et al., 2013; Rashleigh et al., 2011; Schernewski et al., 2019 – Table 1), and Baltic-wide (10 studies) (e.g. Ahtiainen et al., 2019; Czajkowski et al., 2015; Sagebiel et al., 2016) (Table 1). Furthermore, they can also cover different periods, assessing past, present, or future ES provision. The majority of the studies assessed MES for the present conditions. Only while five analyzed future scenarios (e.g. Culhane et al., 2020; Schernewski et al., 2018, 2019) and four studies analyze ES provision in the past (e.g., Inácio et al., 2018, 2019) (Table 1).

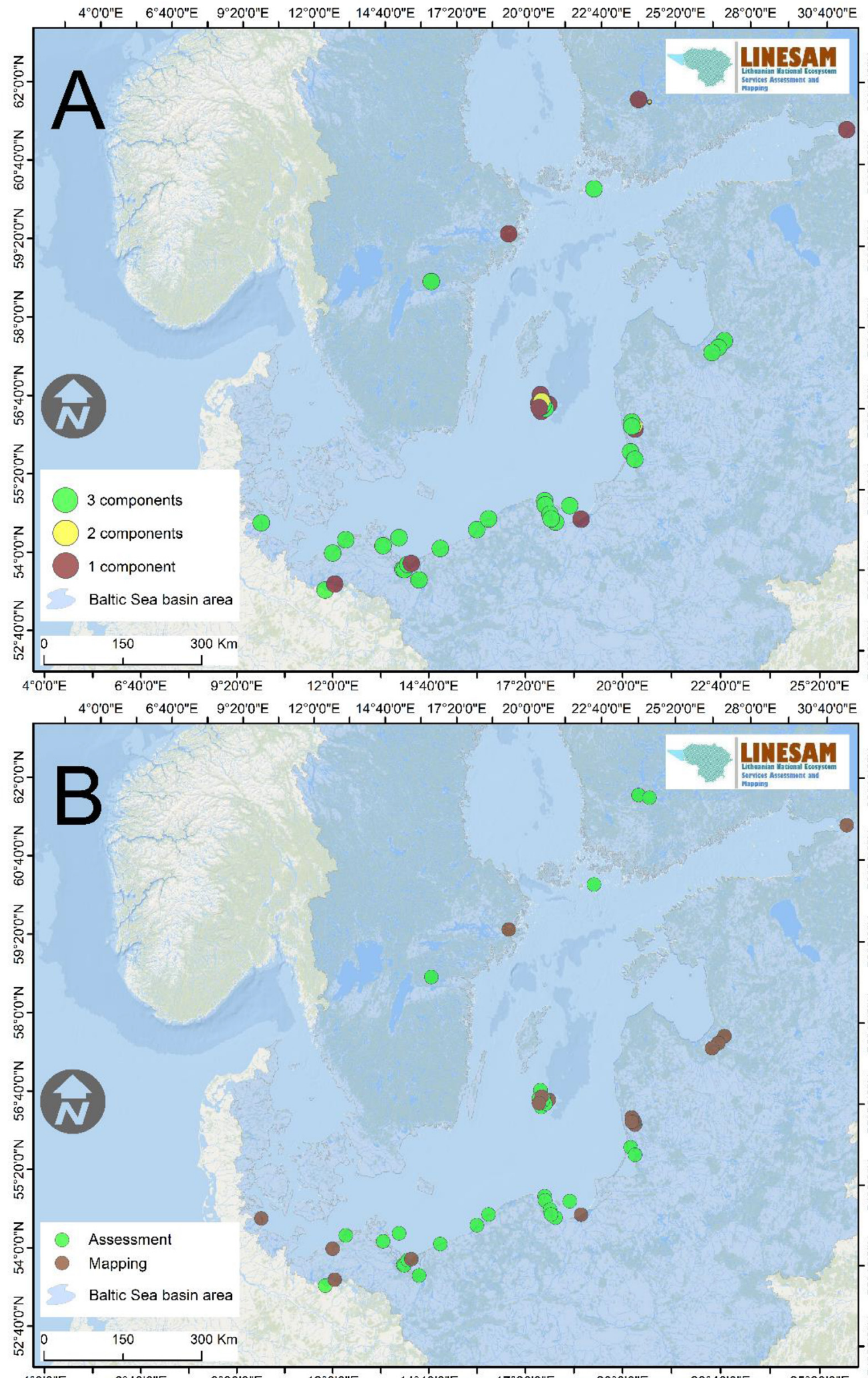


Fig. 2. A) Ecosystem services components (Regulating, Provisioning, and Cultural) studied in the Baltic Sea, and B) Assessment and Mapping works.

Table 1
analyzed studies from the literature search. Study: A – Assessment, M – Mapping. ES: P – Provisioning, R – Regulating, C – Cultural. * studies which included validation of assessment result.

Study	Spatial scale	Country	Approach	Focus	Method	ES	Temporal Scale	Reference
A	Baltic	–	Quantitative	Social	Questionnaire	C	Present	(Ahtiainen et al., 2013)
A, M	National	Latvia	Qualitative	Environmental	Expert-based	P, R, C	Present	(Armoškaitė et al., 2020)
A	Local	Poland	Qualitative	Environmental	Expert-based/ biophysical indicators	P, R, C	Present	(Beaumont et al., 2007)
A	Baltic	–	Qualitative	Environmental	Biophysical indicators	R	Present, Future	(Culhane et al., 2020)
A	Baltic	–	Quantitative	Monetary	Questionnaire, travel cost	C	Present	(Czajkowski et al., 2015)
A, M	National	Lithuania	Semi-quantitative	Monetary	Literature	P, R, C	Present	(Depellegrin and Blažauskas, 2013)
A, M	National	Lithuania	Qualitative	Environmental	Expert-based	P, R, C	Present	(Depellegrin et al., 2016)
A, M	National	Lithuania	Quantitative	Environmental	GIS-biophysical indicators	P, R, C	Present	(Depellegrin et al., 2020)
A, M	Local	Sweden	Qualitative	Environmental	Expert-based	R	Present	(Goldenberg et al., 2017)
A	Baltic	–	Quantitative	Monetary	Production function / abatement costs	R	Present	(Gren et al., 2018)
A, M	Baltic	–	Quantitative	Environmental/Social	Modeling	P, C	Present, Future	(Hyytiäinen et al., 2019)
A	Local	Germany/Poland / Lithuania	Semi-quantitative	Environmental	Expert-based/Biophysical indicators	P, R, C	Present, Past	(Inácio et al., 2018)
A	Local	Germany/Poland / Lithuania	Semi-quantitative	Environmental	Expert-based/Biophysical indicators	P, R, C	Present, Past	(Inácio et al., 2019)
A	Baltic	–	Qualitative	Environmental	Expert-based	P, R, C	Present	(Karstens et al., 2019)
A	National	Finland	Quantitative	Monetary	Statistical indicators	P	Present	(Lai et al., 2018)
A, M	Baltic	–	Quantitative	Environmental	GIS-biophysical indicators	R	Present	(Liquete et al., 2013b)
A, M	National	Germany	Qualitative	Environmental	Expert-based	P, R, C	Present	(Müller et al., 2020)
A	Local	Lithuania, Poland, Germany	Semi-quantitative	Environmental	Expert-based/ biophysical indicators	P, R, C	Present	(Newton et al., 2018)
A	National	Finland	Qualitative	Monetary	Questionnaire	C	Present	(Nieminen et al., 2019)
A	Local	Poland	Qualitative	Social	Literature	P, R, C	Present	(Piwowarczyk et al., 2013)
A	Local	Lithuania	Qualitative	Environmental	Literature search	P, R, C	Present	(Rashleigh et al., 2011)
A	National	Sweden	Quantitative	Monetary	Biophysical indicators	P, R, C	Present	(Rönnbäck et al., 2007)
A, M	National	Latvia	Semi-quantitative	Environmental	Questionnaires	C	Present	(Ruskule et al., 2018)
A	Baltic	–	Qualitative	Monetary	Literature review	P, R, C	Present	(Sagebiel et al., 2016)
A, M	Baltic	–	Quantitative	Environmental	Modeling	R	Present	*(Sandman et al., 2018)
A	Local	Germany	Qualitative	Environmental	Expert-based	P, R, C	Present, Past, Future	(Schernewski et al., 2018)
A, M	Local	Germany	Semi-quantitative	Environmental	Expert-based/Biophysical indicators	P, R, C	Present, Past, Future	(Schernewski et al., 2019)
A, M	National	Latvia	Semi-quantitative	Environmental	Expert-based/Biophysical indicators	P, R, C	Present	(Veidemane et al., 2017)
A	Local	Finland	Qualitative	Social	Questionnaires	P, R, C	Present	(Viirret et al., 2019)
A, M	National	Lithuania	Quantitative	Environmental	GIS-Biophysical indicators / modeling	P	Present	* (Inácio et al., 2020)
A	Baltic	–	Qualitative	Social	Questionnaire	C	Present	*(Ahtiainen et al., 2019)
A, M	Local	Poland - Russia	Quantitative	Environmental	GIS-Biophysical indicators / modeling	R	Present, Future	*(Allin et al., 2017)
A, M	National	Germany	Quantitative	Environmental	Biophysical indicators / modeling	R	Present	*(Gogina et al., 2017)
A, M	National	Lithuania	Quantitative	Environmental	Ecosystem mode	P. R	Present	*(Šiaulys et al., 2012)

Geography and Sustainability 1 (2020) 256–265

- *ES analyzed:* studies can assess and map one or multiple ES, belonging to one or more categories (Table 1). Two studies on provisioning (Inácio et al., 2020; Lai et al., 2018), five studies on cultural (Ahtiainen et al., 2019; Czajkowski et al., 2015; Nieminen et al., 2019; Ruskule et al., 2018) and seven studies on regulating ES (Allin et al., 2017; Culhane et al., 2020; Gogina et al., 2017; Goldenberg et al., 2017; Gren et al., 2018; Liquete et al., 2013b; Sandman et al., 2018). In terms of categories of ES, twenty-two studies assessed provisioning ES, twenty-six regulating ES, and twenty-three studies on cultural ES (Table 1).
- ***Validation:*** Validation is an essential step to produce more robust and reliable results. It is not easy to validate socio-economic or qualitative assessments since they are based on individual perceptions. From all the studies considered, only six performed validation of results (Ahtiainen et al., 2019; Allin et al., 2017; Gogina et al., 2017; Inácio et al., 2020; Sandman et al., 2018; Šiaulys et al., 2012) (Table 1). Further studies need to consider this aspect that is essential to ensure the reliability of the outputs.

5. Future perspectives

5.1. Towards a modeling-based quantitative ES assessment

The majority of the analyzed studies (16) followed a qualitative approach. This limits the reliability and credibility of those studies to be integrated into decision-making. Even though qualitative approaches are easy to apply, provide results relatively fast, and can be used to analyze "what if scenarios" (Campagne et al., 2020; Jacobs et al., 2015), several works criticized this type of methodology for their unreliable results, associated with biases or mistakes by the experts or public perception (Jacobs et al., 2015; Seppelt et al., 2011). Furthermore, qualitative ES information often lacks the explicitness to drive decision-makers processes, so it is instead regarded as an informative step to promote deeper thinking or to provide a first impression and overview (Busch et al., 2012; Schernewski et al., 2018). This criticism towards qualitative approaches and the requirement of more robust and reliable information led to a shift towards quantitative approaches (Logsdon and Chaubey, 2013). The Baltic Sea Region can follow this direction as there are conditions to do so since it is one of the most studied areas worldwide (Reusch et al., 2018). This is reflected by the increase of quantitative (13) or semi-quantitative (7) studies. However, there are conditions for the development of quantitative methodologies (Table 1). For instance, the long term monitoring data available allowed for the development and establishment of reliable hydrodynamic, physical-biogeochemical, ecologic, and food web models, such as RCO-SCOBI (Eilola et al., 2009; Meier et al., 2003), GETM (Burchard and Bolding, 2002), ERGOM-MOM (Neumann et al., 2002; Schernewski et al., 2015), ECOPATH-ECOSYM (Pauly et al., 2000). Several variables from these models can be directly linked to indicators used to quantify ES. For instance, Bauer et al. (2018) utilized the physical-biogeochemical and food web model to analyze the future distribution of fish functional groups of commercial interest, which can be linked with the supply of wild seafood. There are conditions to go towards modeling outputs to provide quantitative information on ES. Other advantages of using modeling-based approaches are providing spatial data where observations are lacking, providing quantitative information for different temporal scales, and producing outputs for several ES at once. Also, Schernewski et al. (2015) applied modeling to assess different water quality variables for the past, present, and future. Some of the modeled variables, chlorophyll *a* and nutrient concentration, can serve as indicators for regulating ES. Therefore one could cover different temporal scales and analyze changes in ES provision as in Inácio et al. (2019). Using modeling outputs can also serve as an advantage in addressing the less studied ES categories. For instance, the assessment and mapping of marine regulating ES is usually less developed and more challenging to provide an expert opinion, either due to the lack of knowledge or misunderstanding of the mechanisms responsible for its supply (Inácio et al., 2018). This is because, in an expert elicitation process, it is expected to be carried out by different groups, which may not know the ecological processes involved. Twenty-six out of the thirty-three studies carried out in the Baltic Sea assessed/mapped regulating ES. From these twenty-six, only eight used qualitative methods (Table 1). More quantitative studies are needed to assess regulating ES. The reliable models developed in the Baltic Sea allowed to understand the ecologic functions better and can be used for a more reliable assessment of regulating ES. Furthermore, models can (in some cases) provide depth specific information, more difficult to obtain via expert elicitation.

However, when going towards quantitative ES assessments, it is important to consider several aspects, such as availability, data accuracy, applicability, and models' spatial resolution. Townsend et al. (2018) argued that marine environment models perform parameterization based on limited spatial and temporal data. There is a need to communicate model uncertainty for its correct use. Modeling provides quantitative results with a spatial representation. However, it is important to understand if modeling outputs are reliable and represent with a good degree of accuracy ES dynamics. Modeling practices are less suitable to quantify socio-ecologic dynamics. In their review, Lautenbach et al. (2019) state that process and statistical models were rarely used to assess cultural ES. Since most cultural studies are based on perceptions, modeling human behavior is a very complex exercise. The most important aspect is related to models validation, which is frequently overlooked (Willcock et al., 2019). Most of the quantitative studies of Table 1 did not perform any validation of the model used. A model that is not validated cannot provide reliable results, being considered supportive information. However, it is also essential to state that not all kinds of studies (social, economic) can always provide validated results since they are based on human perceptions, hence providing useful information.

5.2. Linking existing scientific research efforts with ES and their benefits for human wellbeing

A considerable amount of data is generated and synthesized in HELCOM (https://helcom.fi/) and produced by various research projects under different funding schemes every year. However, in their analysis, Heckwolf et al. (2020) state that although the available scientific information in the Baltic could be directly linked to many existing ES, only 1.2% of the studies translate this information into benefits for humans wellbeing. Therefore, it is necessary to utilize the already existing scientific data, link it with ES's provision, and finally translate this information into socio-economic benefits. Hence, this will require establishing or improving existing multidisciplinary efforts in mapping ES. Although we did not consider grey literature in this study, we agree that it accounts for a considerable amount of information available. Information from synthesis works and policy briefs (e.g. Ahtiainen and Öhman, 2014; Ahtiainen et al., 2010; Kettunen et al., 2012; Söderqvist and Hasselström, 2008) project reports (e.g. Wanda Holzhüter et al., 2019), or MSc. or Ph.D. thesis (e.g. Ravensbeck, 2014; Salojärvi, 2014) should be synthesized and published in the future to create a comprehensive overview of MES status in the Baltic Sea. For instance, European Union countries have to provide data to the European commission to fulfil the requirements of several policies (e.g. Water Framework Directive 2000/60/EC, 2000; Marine Strategy Framework Directive 2008/56/EC, 2008). These data could be used to assess ES (Berg et al., 2015), since the countries have a monitoring program. Other type of data such as tourism or socio-demographic data is also beneficial for cultural ES assessment. ES evaluation is key to contribute to regional (e.g. European Biodiversity Strategy 2030) or global (e.g. Sustainable Development Goals, especially goal 14 – Life below water) agendas (Wood et al., 2018). HELCOM plays a central role in terms of data collection and synthesis reporting. Therefore, it is the first reference MES in the Baltic Sea.

5.3. Towards Baltic-wide collaboration

Our literature search revealed that in some Baltic areas (e.g. Denmark, Estonia and Kaliningrad Oblast of Russia), ES studies are scarce (Fig. 2). One of the main drawbacks of the assessment and mapping of marine ES is the lack of available data (Townsend et al., 2018). In the Baltic Sea, each country has a different strategy for data collection and processing. Therefore, there is no uniformization in data availability and processing. Using different classifications, indicators, metrics, spatial and temporal resolutions makes the assessment and mapping results incomparable (Bagstad et al., 2013). There is a lack of standardization across the region. For example, even though the Mapping and Assessment of Ecosystems and their Services Project (Maes et al., 2012) developed in Europe, the methods are different, often not comparable, and countries are in different stages. There is no common benefit of having ES studies in different development stages, especially for less studied MES. International collaboration groups related to MES such as the "Ecosystem Service Partnership Marine Working Group," the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the International Council for the Exploration of the Sea Working Group on Resilience and Marine Ecosystem Services (ICES-WGRMES) and the European Marine Board Working Group on Valuing Marine Ecosystems (VALMARE), where Baltic countries participate, and produce different knowledge, not always complimentary. It is time to evaluate whether these efforts have been sufficient to fulfil future environmental targets and rethink future strategies. As a single ecosystem, ensuring the sustainable future provision of ES in the world's marine areas is only possible in a collective effort. Our perspective is that a more holistic standardized classification, indicators, and methodologies should be applied to the whole Baltic Sea, putting the region in the vanguard of the assessment and mapping of marine ES.

6. Conclusion

The ES provided by the Baltic Sea are essential to ensure the well-being of the population. Assessing and mapping ES is vital to show the benefits of an environmentally improved and sustainable Baltic Sea. This requires linking the available scientific knowledge with ES and their socio-economic benefits. While extensive work has been done to assess and map ES in the Baltic, we need to rethink our current efforts and to understand if they will be enough to support future environmental and socio-economic targets. Achieving environmental and sustainability targets will only be possible through an international cooperative effort and standardization of ES practices in the Baltic Sea. Moving towards quantitative approaches and linking all available scientific knowledge with ES and their socio-economic benefits is essential, and should be one of the priorities to understand current knowledge status and identify future research directions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

"Lithuanian National Ecosystem Services Assessment and Mapping (LINESAM)" No. 09.3.3-LMT-K-712-01-0104 is funded by the European Social Fund according to the activity "Improvement of researchers' qualification by implementing world-class R&D projects" of Measure No. 09.3.3-LMT-K-712.

References

Agardy, T., Alder, J., 2005. Millennium ecosystem assessment: ecosystems and human well-being: current state and trends. In: Millennium Ecosystem, 1. Island Press, Washington, DC, p. 513 Millennium Ecosystem Assessment–459.

Ahtiainen, H., Artell, J., Czajkowski, M., Hasler, B., Hasselström, L., Hyytiäinen, K., Meyerhoff, J., Smart, J.C.R., Söderqvist, T., Zimmer, K., Khaleeva, J., Rastrigina, O., Tuhkanen, H., 2013. Public preferences regarding use and condition of the Baltic Sea – an international comparison informing marine policy. Mar. Policy 42, 20–30. doi:10.1016/j.marpol.2013.01.011.

Ahtiainen, H., Artell, J., & Helin, J. (2010). From Ecosystem Services to Benefits of the Baltic Sea – Indicators and Threats. https://doi.org/https://doi.org/https://doi.org/10.6027/TN2010-544

Ahtiainen, H., Liski, E., Pouta, E., Soini, K., Bertram, C., Rehdanz, K., Pakalniete, K., Meyerhof, J., 2019. Cultural ecosystem services provided by the Baltic Sea marine environment. Ambio 48, 1350–1361. doi:10.1007/s13280-019-01239-1.

Ahtiainen, H., & Öhman, M.C. .2014). Ecosystem Services in the Baltic Sea: valuation of Marine and Coastal Ecosystem Services in the Baltic Sea. https://doi.org/10.6027/TN2014-563

Allin, A., Schernewski, G., Friedland, R., Neumann, T., Radtke, H., 2017. Climate change effects on denitrification and associated avoidance costs in three Baltic river basin - coastal sea systems. J. Coast. Conserv. 21, 561–569. doi:10.1007/s11852-017-0530-8.

Armoškaitė, A., Puriņa, I., Aigars, J., Strāķe, S., Pakalniete, K., Frederiksen, P., Schrøder, L., Hansen, H.S., 2020. Establishing the links between marine ecosystem components, functions and services: an ecosystem service assessment tool. Ocean Coast. Manag. 193. doi:10.1016/j.ocecoaman.2020.105229.

Asmala, E., Carstensen, J., Conley, D.J., Slomp, C.P., Stadmark, J., Voss, M., 2017. Efficiency of the coastal filter: nitrogen and phosphorus removal in the Baltic Sea. Limnol. Oceanogr. 62, S222–S238. doi:10.1002/lno.10644.

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R., 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosyst. Serv. 5, 27–39. doi:10.1016/j.ecoser.2013.07.004.

Baltranaitė, E., Jurkus, E., Povilanskas, R., 2017. Impact of physical geographical factors on sustainable planning of South Baltic seaside resorts. Baltica 30, 119–131. doi:10.5200/baltica.2017.30.13.

Barbier, E.B., 2017. Marine ecosystem services. Curr. Biol. doi:10.1016/j.cub.2017.03.020.

Bauer, B., Meier, H.E.M., Casini, M., Hoff, A., Margoński, P., Orio, A., Saraiva, S., Steenbeek, J., Tomczak, M.T., 2018. Reducing eutrophication increases spatial extent of communities supporting commercial fisheries: a model case study. ICES J. Mar. Sci. 75, 1306–1317. doi:10.1093/icesjms/fsy003.

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. Mar. Pollut. Bull. 54, 253–265. doi:10.1016/j.marpolbul.2006.12.003.

Berg, T., Fürhaupter, K., Teixeira, H., Uusitalo, L., Zampoukas, N., 2015. The marine strategy framework directive and the ecosystem-based approach – pitfalls and solutions. Mar. Pollut. Bull. 96, 18–28. doi:10.1016/j.marpolbul.2015.04.050.

Bergström, S., Alexandersson, H., Carlsson, B., Josefsson, W., Karlsson, K.-G., Westring, G., 2001. Climate and Hydrology of the Baltic Basin BT – A Systems Analysis of the Baltic Sea, in: F. V., Wulff, L. A., Rahm, & P., Larsson. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 75–112. doi:10.1007/978-3-662-04453-7_3.

Bouwma, I., Schleyer, C., Primmer, E., Winkler, K.J., Berry, P., Young, J., Carmen, E., Špulerová, J., Bezák, P., Preda, E., Vadineanu, A., 2018. Adoption of the ecosystem services concept in EU policies. Ecosyst. Serv. 29, 213–222. doi:10.1016/j.ecoser.2017.02.014.

BRHC, (2013). The Changing Coastal and Maritime Culture.

Burchard, H., Bolding, K. (2002). GETM – A General Estuarine Transport Model. Scientific Documentation.

Busch, M., La Notte, A., Laporte, V., Erhard, M., 2012. Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecol. Indic. 21, 89–103. doi:10.1016/j.ecolind.2011.11.010.

Campagne, C.S., Roche, P., Müller, F., Burkhard, B., 2020. Ten years of ecosystem services matrix: review of a (r)evolution. One Ecosyst. 5, e51103.

Carstensen, J., Conley, D.J., Almroth-Rosell, E., Asmala, E., Bonsdorff, E., Fleming-Lehtinen, V., Gustafsson, B.G., Gustafsson, C., Heiskanen, A.-S., Janas, U., Norkko, A., Slomp, C., Villnäs, A., Voss, M., Zilius, M., 2020. Factors regulating the coastal nutrient filter in the Baltic Sea. Ambio 49, 1194–1210. doi:10.1007/s13280-019-01282-y.

Chaudhary, S., McGregor, A., Houston, D., Chettri, N., 2015. The evolution of ecosystem services: a time series and discourse-centered analysis. Environ. Sci. Policy 54, 25–34. doi:10.1016/j.envsci.2015.04.025.

Costanza, R., Arge, R., Groot, R., De, Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Suttonkk, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260. doi:10.1038/387253a0.

Culhane, F.E., Frid, C.L.J., Gelabert, E.R., Piet, G., White, L., Robinson, L.A., 2020. Assessing the capacity of European regional seas to supply ecosystem services using marine status assessments. Ocean Coast. Manag. 190, 105154. doi:10.1016/j.ocecoaman.2020.105154.

Czajkowski, M., Ahtiainen, H., Artell, J., Budziński, W., Hasler, B., Hasselström, L., Meyerhoff, J., Nõmmann, T., Semeniene, D., Söderqvist, T., Tuhkanen, H., Lankia, T., Vanags, A., Zandersen, M., Zylicz, T., Hanley, N., 2015. Valuing the commons: an international study on the recreational benefits of the Baltic Sea. J. Environ. Manag. 156, 209–217. doi:10.1016/j.jenvman.2015.03.038.

Depellegrin, D., Blažauskas, N., 2013. Integrating ecosystem service values into oil spill impact assessment. J. Coast. Res. 29, 836–846. doi:10.2112/JCOASTRES-D-11-00191.1.

Depellegrin, D., Menegon, S., Gusatu, L., Roy, S., Misiunė, I., 2020. Assessing marine ecosystem services richness and exposure to anthropogenic threats in small sea areas: a case study for the Lithuanian sea space. Ecol. Indic. 108, 105730. doi:10.1016/j.ecolind.2019.105730.

Depellegrin, D., Pereira, P., Misiunė, I., Egarter-Vigl, L., 2016. Mapping ecosystem services potential in Lithuania. Int. J. Sustain. Dev. World Ecol. 23, 441–455. doi:10.1080/13504509.2016.1146176.
Directive 2000/60/EC, 2000. Directive 2000/60/EC of the European Parliament: establishing a framework for community action in the field of water policy. Off. J. Eur. Parliam. L327, 1–82. doi:10.1039/ap9842100196.
Directive 2008/56/EC, 2008. Directive 2008/56/EC of the European parliament and of the council: establishing a framework for community action in the field of marine environmental policy (marine strategy framework directive). Off. J. Eur. Union 164, 19–40.
Directive 2014/89/EU, 2014. Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. Off. J. Eur. Parliam. L257, 135.
EC, 2000. Communication from the commission to the council and the European parliament on integrated coastal zone management: a strategy for Europe. Off. J. Eur. Union 27. doi:10.1017/CBO9781107415324.004, COM(2000)https://doi.org/.
Eilola, K., Meier, H.E.M., Almroth, E., 2009. On the dynamics of oxygen, phosphorus and cyanobacteria in the Baltic Sea; a model study. J. Mar. Syst. 75, 163–184. doi:10.1016/j.jmarsys.2008.08.009.
Elmgren, R., Blenckner, T., Andersson, A., 2015. Baltic Sea management: successes and failures. Ambio 44, 335–344. doi:10.1007/s13280-015-0653-9.
European Commission, (2020). EU Biodiversity Strategy for 2030. Brussels.
European Commission, (2019). The European Green Deal. COM(2019) 640 final.
European Commission, (2017). European Union Strategy for the Baltic Sea Region.
European Commission, (2012). Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions Concerning the European Union Strategy for the Baltic Sea Region.
Garpe, K. (2008). Ecosystem Services Provided by the Baltic Sea and Skagerrak. Stockholm, Sweden.
Geneletti, D., Adem Esmail, B., Cortinovis, C., Arany, I., Balzan, M., van Beukering, P., Bicking, S., Borges, P.A.V., Borisova, B., Broekx, S., Burkhard, B., Gil, A., Inghe, O., Kopperoinen, L., Kruse, M., Liekens, I., Lowicki, D., Mizgajski, A., Mulder, S., Nedkov, S., Ostergard, H., Picanço, A., Ruskule, A., Santos-Martín, F., Sieber, I.M., Svensson, J., Vačkářů, D., Veidemane, K., 2020. Ecosystem services mapping and assessment for policy- and decision-making: lessons learned from a comparative analysis of European case studies. One Ecosyst. 5, e53111.
Gilek, M., Karlsson, M., Linke, S., Smolarz, K., 2016. Environmental Governance of the Baltic Sea. Springer Cham Heidelberg, New York Dordrecht London doi:10.1007/978-3-319-27006-7_7.
Girininkas, A., 2010. Underwater archaeology in the Baltic region. Archaeol. Balt. 14, 12–17.
Gogina, M., Morys, C., Forster, S., Gräwe, U., Friedland, R., Zettler, M.L., 2017. Towards benthic ecosystem functioning maps: quantifying bioturbation potential in the German part of the Baltic Sea. Ecol. Indic. 73, 574–588. doi:10.1016/j.ecolind.2016.10.025.
Goldenberg, R., Kalantari, Z., Cvetkovic, V., Mörtberg, U., Deal, B., Destouni, G., 2017. Distinction, quantification and mapping of potential and realized supply-demand of flow-dependent ecosystem services. Sci. Total Environ. 593–594, 599–609. doi:10.1016/j.scitotenv.2017.03.130.
Gren, I.M., Nyström Sandman, A., Näslund, J., 2018. Aquatic invasive species and ecosystem services: economic effects of the worm Marenzelleria spp. in the Baltic Sea. Water Resour. Econ. 24, 13–24. doi:10.1016/j.wre.2018.02.003.
Grigelis, A., 2013. Baltica journal celebrates its 50th anniversary. Baltica 26, 1–4. doi:10.5200/baltica.2013.26.01.
Grizzetti, B., Liquete, C., Antunes, P., Carvalho, L., Geamănă, N., Giucă, R., Leone, M., McConnell, S., Preda, E., Santos, R., Turkelboom, F., Vădineanu, A., Woods, H., 2016. Ecosystem services for water policy: insights across Europe. Environ. Sci. Policy 66, 179–190. doi:10.1016/j.envsci.2016.09.006.
Guzikova, L.A., 2020. Hanseatic league as an economic and managerial phenomenon. In: Proceedings of the III International Scientific and Practical Conference, DEFIN '20. New York, NY, USA. Association for Computing Machinery doi:10.1145/3388984.3390652.
Haines-Young, R., & Potschin, M. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.
Håkanson, L., Andersson, M., Rydén, L., 2003. 4. The Baltic Sea basin : nature, history, and economy. In: Lars Rydén, P.M. (Ed.), Environmental Science: Understanding, Protecting and Managing the Environment in the Baltic Sea Region. Baltic University Press, pp. 92–119 Department of Earth Sciences, Earth Sciences, Disciplinary Domain of Science and Technology, Uppsala University.
Hasler, B., Ahtiainen, H., Hasselström, L., Heiskanen, A.-S., Soutukorva, Å., Martinsen, L., 2016. Marine Ecosystem Services : Marine Ecosystem Services in Nordic Marine Waters and the Baltic Sea – Possibilities for Valuation. Nordisk Ministerråd, Copenhagen TemaNord NV - 2016:501https://doi.org/ doi:10.6027/TN2016-501.
Hassler, B., Blažauskas, N., Gee, K., Luttmann, A., Morf, A., Piwowarczyk, J., Saunders, F., Stalmokaitė, I., Strand, H., Zaucha, J., 2019. New generation EU directives, sustainability, and the role of transnational coordination in Baltic Sea maritime spatial planning. Ocean Coast. Manag. 169, 254–263. doi:10.1016/j.ocecoaman.2018.12.025.
Hassler, B., Boström, M., Grönholm, S., 2013. Towards an ecosystem approach to management in regional marine governance? The Baltic Sea context. J. Environ. Policy Plan. 15, 225–245. doi:10.1080/1523908X.2013.766420.
Hattam, C., Atkins, J.P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., Burdon, D., De Groot, R., Hoefnagel, E., Nunes, P.A.L.D., Piwowarczyk, J., Sastre, S., Austen, M.C., 2015. Marine ecosystem services: linking indicators to their classification. Ecol. Indic. 49, 61–75. doi:10.1016/j.ecolind.2014.09.026.
Heckwolf, M.J., Peterson, A., Jänes, H., Horne, P., Künne, J., Liversage, K., Sajeva, M., Reusch, T.B.H., Kotta, J., 2020. From ecosystems to socio-economic benefits: a systematic review of coastal ecosystem services in the Baltic Sea. Sci. Total Environ, 142565 doi:10.1016/j.scitotenv.2020.142565.
HELCOM, (2018a). State of the Baltic Sea – Second HELCOM Holistic Assessment 2011-2016.
HELCOM, (2018b). HELCOM Thematic Assessment of Biodiversity 2011-2016.
HELCOM, 2018c. State of the Baltic Sea – second HELCOM holistic assessment 2011-2016. In: Baltic Sea Environment Proceedings, p. 155.
HELCOM, (2018d). HELCOM Assessment on Maritime Activities in the Baltic Sea 2018.
HELCOM, (2013). HELCOM HUB – Technical Report on the HELCOM Underwater Biotope and Habitat Classification.
HELCOM, (2007). HELCOM Baltic Sea Action Plan. Krakow, Poland.
Hordoir, R., Meier, H.E.M., 2010. Freshwater fluxes in the Baltic Sea: a model study. J. Geophys. Res. Ocean. 115. doi:10.1029/2009JC005604.
Hyytiäinen, K., Bauer, B., Bly Joyce, K., Ehrnsten, E., Eilola, K., Gustafsson, B.G., Meier, H.E.M., Norkko, A., Saraiva, S., Tomczak, M., Zandersen, M., 2019. Provision of aquatic ecosystem services as a consequence of societal changes: the case of the Baltic Sea. Popul. Ecol. 1–14. doi:10.1002/1438-390X.12033.
Inácio, M., Mikša, K., Kalinauskas, M., Pereira, P., 2020. Mapping wild seafood potential, supply, flow and demand in Lithuania. Sci. Total Environ., 137356 doi:10.1016/j.scitotenv.2020.137356.
Inácio, Miguel, Schernewski, G., Nazemtseva, Y., Baltranaite, E., Friedland, R., Benz, J., 2018. Ecosystem services provision today and in the past: a comparative study in two Baltic lagoons. Ecol. Res. 33, 1255–1274. doi:10.1007/s11284-018-1643-8.
Inácio, Miguel, Schernewski, G., Pliatsika, D.A., Benz, J., Friedland, R., 2019. Assessing changes in ecosystem services provision in coastal waters. Sustain. 11, 1–21. doi:10.3390/su11092632.
Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., Schneiders, A., 2015. 'The matrix reloaded': a review of expert knowledge use for mapping ecosystem services. Ecol. Model. 295, 21–30. doi:10.1016/j.ecolmodel.2014.08.024.
Kaikkonen, L., Virtanen, E.A., Kostamo, K., Lappalainen, J., Kotilainen, A.T., 2019. Extensive coverage of marine mineral concretions revealed in shallow shelf sea areas. Front. Mar. Sci. 6, 541. doi:10.3389/fmars.2019.00541.
Karstens, S., Inácio, M., Schernewski, G., 2019. Expert-based evaluation of ecosystem service provision in coastal reed wetlands under different management regimes. Front. Environ. Sci. 7. doi:10.3389/fmars.2019.00063.
Kettunen, M., Vihervaara, P., Kinnunen, S., D'Amato, D., Badura, T., Argimon, M., & Brink, Ten (2012).Socio-economic importance of ecosystem services in the Nordic countries. Synthesis in the Context of The Economics of Ecosystems and Biodiversity (TEEB). https://doi.org/ 10.6027/TN2012-559
Köbbing, J.F., Thevs, N., Zerbe, S., 2013. The utilisation of reed (Phragmites australis): a review. Mires Peat 13, 1–14.
Kotta, J., Jänes, H., Paalme, T., Peterson, A., Kotta, I., Aps, R., Robert, S.-K.A.K., & Fetissov, M. (2020). GoA 2.1. Assessing the PanBaltic Potential of Macroalgae Cultivation and of Harvesting Wild Stocks.
Kraufvelin, P., Pekcan-Hekim, Z., Bergström, U., Florin, A.B., Lehikoinen, A., Mattila, J., Arula, T., Briekmane, L., Brown, E.J., Celmer, Z., Dainys, J., Jokinen, H., Kääriä, P., Kallasvuo, M., Lappalainen, A., Lozys, L., Möller, P., Orio, A., Rohtla, M., Saks, L., Snickars, M., Støttrup, J., Sundblad, G., Taal, I., Ustups, D., Verliin, A., Vetemaa, M., Winkler, H., Wozniczka, A., Olsson, J., 2018. Essential coastal habitats for fish in the Baltic Sea. Estuar. Coast. Shelf Sci. 204, 14–30. doi:10.1016/j.ecss.2018.02.014.
Kuliński, K., Pempkowiak, J., 2011. The carbon budget of the Baltic Sea. Biogeosci. Discuss 8, 4841–4869. doi:10.5194/bgd-8-4841-2011.
Lai, T.Y., Salminen, J., Jäppinen, J.P., Koljonen, S., Mononen, L., Nieminen, E., Vihervaara, P., Oinonen, S., 2018. Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland. Ecol. Model. 377, 51–65. doi:10.1016/j.ecolmodel.2018.03.006.
Lajus, J., Kraikovski, A., Lajus, D., 2013. Coastal fisheries in the eastern Baltic Sea (Gulf of Finland) and its basin from the 15 to the early 20th centuries. PLoS One 8, e77059.
Lautenbach, S., Mupepele, A.-C., Dormann, C.F., Lee, H., Schmidt, S., Scholte, S.S.K., Seppelt, R., van Teeffelen, A.J.A., Verhagen, W., Volk, M., 2019. Blind spots in ecosystem services research and challenges for implementation. Reg. Environ. Chang. 19, 2151–2172. doi:10.1007/s10113-018-1457-9.
Leppäranta, M., Myrberg, K., 2009. Physical Oceanography of the Baltic Sea. Springer Science & Business Media.
Lester, S.E., Costello, C., Halpern, B.S., Gaines, S.D., White, C., Barth, J.A., 2013. Evaluating tradeoffs among ecosystem services to inform marine spatial planning. Mar. Policy 38, 80–89. doi:10.1016/j.marpol.2012.05.022.
Liquete, C., Piroddi, C., Drakou, E.G., Gurney, L., Katsanevakis, S., Charef, A., Egoh, B., 2013a. Current status and future prospects for the assessment of marine and coastal ecosystem services : a systematic review. PLoS One 8. doi:10.1371/journal.pone.0067737.
Liquete, C., Zulian, G., Delgado, I., Stips, A., Maes, J., 2013b. Assessment of coastal protection as an ecosystem service in Europe. Ecol. Indic. 30, 205–217. doi:10.1016/j.ecolind.2013.02.013.
Logsdon, R.A., Chaubey, I., 2013. A quantitative approach to evaluating ecosystem services. Ecol. Model. 257, 57–65. doi:10.1016/j.ecolmodel.2013.02.009.
Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., Aarninkhof, S., 2018. The state of the World's beaches. Sci. Rep. 8, 1–11. doi:10.1038/s41598-018-24630-6.
Maciejewski, W., 2002. The Baltic Sea Region: Cultures, Politics, Societies. A Baltic University Publication.
Macura, B., Byström, P., Airoldi, L., Eriksson, B.K., Rudstam, L., Støttrup, J.G., 2019. Impact of structural habitat modifications in coastal temperate systems on fish recruitment: a systematic review. Environ. Evid. 8, 14. doi:10.1186/s13750-019-0157-3.
Madjidian, J., Björk, S., Nilsson, A., Halén, T., 2013. CLEANSHIP – Final Project Report.
Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J.P., Grizzetti, B., Drakou, E.G., Notte, A.La, Zulian, G., Bouraoui, F., Luisa Parac-

chini, M., Braat, L., Bidoglio, G., 2012. Mapping ecosystem services for policy support and decision making in the European Union. Ecosyst. Serv. 1, 31–39. doi:10.1016/j.ecoser.2012.06.004.
Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Rivero, I.M., .Guerra, C., Castillo, C.P., .Vallecillo, S., Baranzelli, C., Barranco, R., Batista e Silva, F., Jacobs-Crisoni, C., Trombetti, M., & Lavalle, C. (2015). Mapping and Assessment of Ecosystems and their Services: Trends in Ecosystems and Ecosystem Services in the European Union Between 2000 and 2010. Brussels. https://doi.org/10.2788/341839
Martínez, M.L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., Landgrave, R., 2007. The coasts of our world: ecological, economic and social importance. Ecol. Econ. 63, 254–272. doi:10.1016/j.ecolecon.2006.10.022.
Meier, H.E.M., Döscher, R., Faxén, T., 2003. A multiprocessor coupled ice-ocean model for the Baltic Sea: application to salt inflow. J. Geophys. Res. Ocean. 108. doi:10.1029/2000JC000521.
Mikša, K., Kalinauskas, M., Inácio, M., Gomes, E., Pereira, P., 2020. Ecosystem services and legal protection of private property. Problem or solution? Geogr. Sustain. doi:10.1016/j.geosus.2020.08.003.
Mikša, K., Kalinauskas, M., Inácio, M., Pereira, P., 2021. Implementation of the European Union floods directive—requirements and national transposition and practical application: lithuanian case-study. Land Use Policy 100, 104924. doi:10.1016/j.landusepol.2020.104924.
Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: synthesis. Ecosystems. Island Press, Washington, D.C. doi:10.1196/annals.1439.003.
Müller, F., Bicking, S., Ahrendt, K., Kinh Bac, D., Blindow, I., Fürst, C., Haase, P., Kruse, M., Kruse, T., Ma, L., Perennes, M., Ruljevic, I., Schernewski, G., Schimming, C.G., Schneiders, A., Schubert, H., Schumacher, J., Tappeiner, U., Wangai, P., Windhorst, W., Zeleny, J., 2020. Assessing ecosystem service potentials to evaluate terrestrial, coastal and marine ecosystem types in Northern Germany – an expert-based matrix approach. Ecol. Indic. 112, 106116. doi:10.1016/j.ecolind.2020.106116.
Neumann, T., Fennel, W., Kremp, C., 2002. Experimental simulations with an ecosystem model of the Baltic Sea: a nutrient load reduction experiment. Glob. Biogeochem. Cycles 16, 7–19. doi:10.1029/2001GB001450.
Newton, A., Brito, A.C., Icely, J.D., Derolez, V., Clara, I., Angus, S., Schernewski, G., Inácio, M., Lillebø, A.I., Sousa, A.I., Béjaoui, B., Solidoro, C., Tosic, M., Cañedo-Argüelles, M., Yamamuro, M., Reizopoulou, S., Tseng, H.C., Canu, D., Roselli, L., Maanan, M., Cristina, S., Ruiz-Fernández, A.C., Lima, R.F.d., Kjerfve, B., Rubio-Cisneros, N., Pérez-Ruzafa, A., Marcos, C., Pastres, R., Pranovi, F., Snoussi, M., Turpie, J., Tuchkovenko, Y., Dyack, B., Brookes, J., Povilanskas, R., Khokhlov, V., 2018. Assessing, quantifying and valuing the ecosystem services of coastal lagoons. J. Nat. Conserv. 44, 50–65. doi:10.1016/j.jnc.2018.02.009.
Newton, A., Icely, J., Cristina, S., Brito, A., Cardoso, A.C., Colijn, F., Riva, S.D., Gertz, F., Hansen, J.W., Holmer, M., Ivanova, K., Leppäkoski, E., Canu, D.M., Mocenni, C., Mudge, S., Murray, N., Pejrup, M., Razinkovas, A., Reizopoulou, S., Pérez-Ruzafa, A., Schernewski, G., Schubert, H., Carr, L., Solidoro, C., PierluigiViaroli, Zaldívar, J.-.M., 2014. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. Estuar. Coast. Shelf Sci. 140, 95–122. doi:10.1016/j.ecss.2013.05.023.
Nieminen, E., Ahtiainen, H., Lagerkvist, C.J., Oinonen, S., 2019. The economic benefits of achieving good environmental status in the Finnish marine waters of the Baltic Sea. Mar. Policy 99, 181–189. doi:10.1016/j.marpol.2018.10.014.
O'Higgins, T.G., Gilbert, A.J., 2014. Embedding ecosystem services into the marine strategy framework directive: illustrated by eutrophication in the North Sea. Estuar. Coast. Shelf Sci. 140, 146–152. doi:10.1016/j.ecss.2013.10.005.
Omran, E.-S.E., Negm, A.M., 2020. In: Negm, A.M., Zelenakova, M., Kubiak-Wójcicka, K. (Eds.), Overview of the Water Bodies in the Baltic Sea Countries BT – Water Resources Quality and Management in Baltic Sea Countries. Springer International Publishing, Cham, pp. 17–42. doi:10.1007/978-3-030-39701-2_2.
Pauly, D., Christensen, V., Walters, C., 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. ICES J. Mar. Sci. 57, 697–706. doi:10.1006/jmsc.2000.0726.
Phil Graham, L., Chen, D., Bøssing Christensen, O., Kjellström, E., Krysanova, V., Markus Meier, H.E., Radziejewski, M., Räisänen, J., Rockel, B., Ruosteenoja, K., 2008. Projections of future anthropogenic climate change bt – assessment of climate change for the Baltic Sea Basin. In: Assessment of Climate Change for the Baltic Sea Basin. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 133–219. doi:10.1007/978-3-540-72786-6_3.
Piwowarczyk, J., Kronenberg, J., Dereniowska, M.A., 2013. Marine ecosystem services in urban areas: do the strategic documents of Polish coastal municipalities reflect their importance? Landsc. Urban Plan. 109, 85–93. doi:10.1016/j.landurbplan.2012.10.009.
Rashleigh, B., Razinkovas, A., Pilkaityte, R., 2011. Ecosystem services assessment of the nemunas river delta. Transitional Waters Bull. 5, 75–84. doi:10.1285/i1825229Xv5n2p75.
Ravensbeck, L., 2014. The Economics of Marine Ecosystem Services – The Fisheries Case. University of Copenhagen.
Reusch, T.B.H., Dierking, J., Andersson, H.C., Bonsdorff, E., Carstensen, J., Casini, M., Czajkowski, M., Hasler, B., Hinsby, K., Hyytiäinen, K., Johannesson, K., Jomaa, S., Jormalainen, V., Kuosa, H., Kurland, S., Laikre, L., MacKenzie, B.R., Margonski, P., Melzner, F., Oesterwind, D., Ojaveer, H., Refsgaard, J.C., Sandström, A., Schwarz, G., Tonderski, K., Winder, M., Zandersen, M., 2018. The Baltic Sea as a time machine for the future coastal ocean. Sci. Adv. 4, eaar8195. doi:10.1126/sciadv.aar8195.
Rönnbäck, P., Kautsky, N., Pihl, L., Troell, M., Söderqvist, T., Wennhage, H., 2007. Ecosystem goods and services from Swedish coastal habitats: identification, valuation, and implications of ecosystem shifts. Ambio 36, 534–544. doi:10.1579/0044-7447(2007)36[534:EGASFS]2.0.CO;2.
Ruskule, A., Klepers, A., Veidemane, K., 2018. Mapping and assessment of cultural ecosystem services of Latvian coastal areas. One Ecosyst. 3. doi:10.3897/oneeco.3.e25499.
Sagebiel, J., Schwartz, C., Rhozyel, M., Rajmis, S., Hirschfeld, J., 2016. Economic valuation of Baltic marine ecosystem services: blind spots and limited consistency. ICES J. Mar. Sci. 73, 991–1003. doi:10.1093/icesjms/fsv264.
Salojärvi, J., 2014. Economic Valuation of Ecosystem Services of the Gulf of Finland – A Pilot Study with the Choice Experiment Method. University of Helsinki.
Sandman, A.N., Näslund, J., Gren, I.M., Norling, K., 2018. Effects of an invasive polychaete on benthic phosphorus cycling at sea basin scale: an ecosystem disservice. Ambio 47, 884–892. doi:10.1007/s13280-018-1050-y.
Schernewski, G., Friedland, R., Carstens, M., Hirt, U., Leujak, W., Nausch, G., Neumann, T., Petenati, T., Sagert, S., Wasmund, N., von Weber, M., 2015. Implementation of European marine policy: new water quality targets for German Baltic waters. Mar. Policy 51, 305–321. doi:10.1016/j.marpol.2014.09.002.
Schernewski, G., Inácio, M., Nazemtseva, Y., 2018. Expert based ecosystem service assessment in coastal and marine planning and management: a baltic lagoon case study. Front. Environ. Sci. 6. doi:10.3389/fenvs.2018.00019.
Schernewski, G., Paysen, P., Robbe, E., Inácio, M., Schumacher, J., 2019. Ecosystem service assessments in water policy implementation: an analysis in urban and rural estuaries. Front. Mar. Sci. 6. doi:10.3389/fmars.2019.00183.
Schultz-Zehnden, A., Matczak, M., 2012. An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources.
Schwarzer, K., 2010. Aggregate resources and extraction in the Baltic Sea: an Introduction. J. Coast. Res. 51, 165–172.
Scientific Technical and Economic Committee for Fisheries (STECF), (2019). The 2019 Annual Economic Report on the EU Fishing Fleet (STECF 19-06), Carvalho, N., Keatinge, M. and Guillen Garcia, J. editor(s).
Scientific Technical and Economic Committee for Fisheries (STECF), (2018). Economic Report of the EU Aquaculture sector (STECF-18-19).
Seppelt, R., Dormann, C.F., Eppink, F.V., Lautenbach, S., Schmidt, S., 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J. Appl. Ecol. 48, 630–636. doi:10.1111/j.1365-2664.2010.01952.x.
Šiaulys, A., Daunys, D., Bučas, M., Bacevičius, E., 2012. Mapping an ecosystem service: a quantitative approach to derive fish feeding ground maps. Oceanologia 54, 491–505. doi:10.5697/oc.54-3.491.
Söderqvist, T., Hasselström, L., 2008. The Economic Value of Ecosystem Services Provided by the Baltic Sea and Skagerrak Ecosystem Services Provided by the Baltic Sea and Skagerrak.
State of the Tourism Industry in the Baltic Sea Region, 2019.
Swain, R.B., 2017. In: Bali Swain, R. (Ed.), Environmental Challenges in the Baltic Region: An Introduction BT – Environmental Challenges in the Baltic Region: A Perspective from Economics. Springer International Publishing, Cham, pp. 1–13. doi:10.1007/978-3-319-56007-6_1.
Tagliapietra, D., Povilanskas, R., Razinkovas-Baziukas, A., Tamin, J., 2020. Emerald growth: a new framework concept for managing ecological quality and ecosystem services of transitional waters. Water 12. doi:10.3390/w12030894.
Townsend, M., Davies, K., Hanley, N., Hewitt, J.E., Lundquist, C.J., Lohrer, A.M., 2018. The challenge of implementing the marine ecosystem service concept. Front. Mar. Sci. 5, 1–13. doi:10.3389/fmars.2018.00359.
UN, 2015. Transforming our World: The 2030 Agenda for Sustainable Development.
Veidemane, K., Ruskule, A., Strake, S., Purina, I., Sprukta, S., Ustups, D., Putnis, I., Klepers, A., 2017. Application of the marine ecosystem services approach in the development of the maritime spatial plan of Latvia. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 13, 398–411. doi:10.1080/21513732.2017.1398185.
Viirret, E., Raatikainen, K.J., Fagerholm, N., Käyhkö, N., Vihervaara, P., 2019. Ecosystem services at the archipelago sea biosphere reserve in Finland: a visitor perspective. Sustain 11, 1–18. doi:10.3390/su11020421.
Holzhüter, Wanda, K.S., Thenen, von, M., Lotta, M., Luhtala, H., Viška, M., Strāķe, S., 2019. Database Including Spatial Data on Ecosystem Services and (Anthropogenic) Pressures.
Weinberger, F., Paalme, T., Wikström, S.A., 2019. Seaweed resources of the Baltic Sea, Kattegat and German and Danish North Sea coasts. Bot. Mar. 63, 61–72. doi:10.1515/bot-2019-0019.
Willcock, S., Hooftman, D.A.P., Balbi, S., Blanchard, R., Dawson, T.P., O'Farrell, P.J., Hickler, T., Hudson, M.D., Lindeskog, M., Martinez-Lopez, J., Mulligan, M., Reyers, B., Shackleton, C., Sitas, N., Villa, F., Watts, S.M., Eigenbrod, F., Bullock, J.M., 2019. A continental-scale validation of ecosystem service models. Ecosystems 22, 1902–1917. doi:10.1007/s10021-019-00380-y.
Wood, S.L.R., Jones, S.K., Johnson, J.A., Brauman, K.A., Chaplin-Kramer, R., Fremier, A., Girvetz, E., Gordon, L.J., Kappel, C.V., Mandle, L., Mulligan, M., O'Farrell, P., Smith, W.K., Willemen, L., Zhang, W., DeClerck, F.A., 2018. Distilling the role of ecosystem services in the sustainable development goals. Ecosyst. Serv. 29, 70–82. doi:10.1016/j.ecoser.2017.10.010.