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The Baltic Health Index (BHI): Assessing the social–ecological status of the Baltic Sea

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Abstract

1. Improving the health of coastal and open sea marine ecosystems represents a substantial challenge for sustainable marine resource management, since it requires balancing human benefits and impacts on the ocean. This challenge is often exacerbated by incomplete knowledge and lack of tools that measure ocean and coastal ecosystem health in a way that allows consistent monitoring of progress towards predefined management targets. The lack of such tools often limits capabilities to enact and enforce effective governance.
2. We introduce the Baltic Health Index (BHI) as a transparent, collaborative and repeatable assessment tool. The Index complements existing, more ecological-oriented, approaches by including a human dimension on the status of the Baltic Sea, an ecosystem impacted by multiple anthropogenic pressures and governed by a multitude of comprehensive national and international policies. Using a large amount of social–ecological data available, we assessed the health of the Baltic Sea for nine *goals* that represent the status towards set targets, for example, clean waters, biodiversity, food provision, natural products extraction and tourism.
3. Our results indicate that the overall health of the Baltic Sea is suboptimal (a score of 76 out of 100), and a substantial effort is required to reach the management

objectives and associated targets. Subregionally, the lowest BHI scores were measured for carbon storage, contaminants and lasting special places (i.e. marine protected areas), albeit with large spatial variation.

4. Overall, the likely future status of all goals in the BHI averaged for the entire Baltic Sea is better than the present status, indicating a positive trend towards a healthier Baltic Sea. However, in some Baltic Sea basins, the trend for specific goals was decreasing, highlighting locations and issues that should be the focus of management priorities.
5. The BHI outcomes can be used to identify both pan-Baltic and subregional scale management priorities and to illustrate the interconnectedness between goals linked by cumulative pressures. Hence, the information provided by the BHI tool and its further development will contribute towards the fulfilment of the UN Agenda 2030 and its Sustainability Development Goals.

KEYWORDS

ecosystem-based management, health, management targets, social–ecological system, sustainability

1 | INTRODUCTION

The health of the oceans and especially of their coastal areas is inextricably linked to human well-being and societal development, as marine ecosystems generate a large share of services needed and used by humans (Franke et al., 2020; Neumann et al., 2017). Unfortunately, human activities often have negative impacts on marine resources (Halpern, Frazier, et al., 2015) and utilization of ecosystem services (or benefits, Díaz et al., 2015) has caused rapid changes in coastal seas world-wide (Cloern et al., 2016; Duarte et al., 2020; Jouffray et al., 2020). Improving the health of coastal and open sea marine ecosystems, that is, sustainably delivering a range of benefits to people now and in the future (Halpern et al., 2012), hence represents a substantial challenge for marine resource management since it requires balancing human benefits and impacts on the ocean. This challenge is exacerbated by often limited capabilities to enact and enforce effective governance due to limited knowledge about the cumulative effects caused by the multiple pressures marine ecosystems presently face. Reaching sustainability goals through ecosystem-based management (EBM) of the oceans thus requires an understanding of interactions between nature, society and the economy (Crowder & Norse, 2008; Long et al., 2015; Merkel, 1998). This is especially relevant following commitment of the global community to the 2030 Agenda for Sustainable Development, where in particular the Sustainable Development Goal (SDG) 14 (Life below water) seeks a balance between environmental, economic and social sustainability in relation to oceans and coastal development (UN, 2015). Besides that, many other SDGs, such as SDG 3 (Good health and well-being), 8 (Decent work and economic growth), 9 (Industry, innovation and infrastructure), 11 (Sustainable cities and communities), 12 (Responsible consumption and production), 13 (Climate Action) and 17 (Partnerships for the goals) are relevant for developing the sustainable use and management of the Baltic Sea. Consequently, there is an urgent need for adequate metrics and tools that quantitatively and comprehensively measure ocean and coastal ecosystem health for better monitoring of progress towards predefined management targets.

The Ocean Health Index (OHI) is a well-tested and widely applied approach to capture the human benefits and the interdependence between humans and nature (Halpern et al., 2012). It defines a healthy ocean as sustainably delivering a range of benefits to people now and in the future (Halpern et al., 2012). The OHI scores quantitatively a suite of socio-ecological benefits and ecosystem services (called *goals* in OHI) the ocean provides to humans (e.g. food provision, natural products extraction, and tourism and recreation) including conservation objectives (e.g. clean waters and biodiversity). These scores are calculated by measuring the status relative to their defined targets as well as the pressures and resilience measures that most influence that aspect of ocean health (Halpern et al., 2012). Globally, the OHI framework has been used to annually assess 220 coastal nations and territories from 2012 to 2020 (Halpern et al., 2012, 2017; Halpern, Longo, et al., 2015). OHI assessments use open data science tools and best practices to ensure that methods are transparent, collaborative and repeatable. As each assessment can build directly on previous work rather than starting from scratch (Lowndes et al., 2017), it makes a valuable integrated evaluation tool that can inform EBM (Longo et al., 2017) and tracks the progress to reach the SDG targets (Halpern et al., 2017). Furthermore, the OHI is a scalable approach which can be modified to match regionally or locally relevant questions and management targets that are framed by area-specific conservation objectives and data availability. Consequently, OHI assessments have been tailored to smaller areas at finer spatial scales in almost 20 places, from countries to smaller regions within countries (Lowndes et al., 2015).

We here present a first assessment of Baltic Sea health using the OHI approach. The semi-enclosed Baltic Sea is a classic example of a brackish ecosystem impacted by multiple anthropogenic pressures comprising eutrophication, elevated levels of hazardous substances, introduction of non-native species and habitat degradation as well as unsustainable fishing pressure (Elmgren et al., 2015; Reusch et al., 2018; Rickels et al., 2019). The Baltic Sea is also one of the fastest warming large marine ecosystems on the globe (Rutgersson et al., 2014). Cumulative effects of these multiple pressures have impaired the resilience of the Baltic Sea ecosystem (Korpinen et al., 2012) and substantially changed ecosystem structure and function (Casini et al., 2008; Lindegren et al., 2012; Möllmann, 2019; Möllmann et al., 2009).

Nine countries border the Baltic Sea and its catchment area has a total population of ~90 million people (Elmgren et al., 2015). The countries surrounding the Baltic Sea have varying policy priorities, financial resources, industrial structures and socio-economic development levels (Purju & Branten, 2013) making joint environmental management challenging (Varjopuro et al., 2014). However, several efforts have been made to evaluate parts (e.g. biodiversity, fish) as well as the holistic state of the Baltic Sea environment (e.g. Andersen et al., 2017; Heiskanen et al., 2019; HELCOM, 2010, 2018b; ICES, 2013; Ojaveer & Eero, 2011; Söderqvist et al., 2005). The most prominent examples are the two holistic environment assessments by HELCOM (Helsinki Convention, HELCOM, 2010, 2018b). However, while these assessments are strong in evaluating the impacts of human activities on the ecosystem, they have not been designed to include the benefits provided to humans. This lack of a human dimension may demotivate decision-makers to allocate sufficient resources for remediation or restoration of the Baltic Sea, despite the increasingly strong scientific evidence of the anthropogenic degradation of its status. Public policy needs to serve multiple goals and interests (e.g. species conservation, food production, aesthetic values, recreation, economic growth) and to objectively consider costs and benefits for restoration. Hence, additional to ecological state, an assessment of ecosystem health through the human lens of meeting societal goals and delivering desired benefits and ecosystem services is needed (Halpern et al., 2014).

We introduce the Baltic Health Index (BHI) that tailors the OHI approach to the unique needs of environmental management of the Baltic Sea. Our BHI assessment presents the first transboundary application of the OHI framework in a region governed by a multitude of comprehensive national and international policies, and which can thus serve as an example for areas with similar policy landscapes in Europe and beyond. The BHI complements existing, more ecological-oriented assessments (e.g. HELCOM, 2018b) by providing a human dimension on the status of the Baltic Sea. Using the best available local data, we assessed the health of the Baltic Sea and its spatial variation. Here, we discuss our process and the implications of the results for local (e.g. bays and basins) and regional (e.g. Baltic Sea) management as well as future research.

2 | MATERIALS AND METHODS

We developed the BHI following the standard methodology of the OHI (Halpern et al., 2012, 2017; Halpern, Frazier, et al., 2015; Halpern, Longo, et al., 2015), and tailored this assessment approach to best represent the social–ecological system of the Baltic Sea. In the process of developing the BHI, we followed four best practices (Lowndes et al., 2015):

1. incorporation of key characteristics and priorities of the study area into the OHI framework design before gathering necessary information;
2. a priori definition of spatial boundaries to achieve a balance between availability of data and operational management areas;
3. development of the goal models to provide a fuller picture concerning key characteristics and priorities outlined in (1); and
4. documenting and sharing data, methods and tools openly throughout the assessment process (GitHub, 2016; RStudio Team, 2016).

Overall, we developed the BHI based on openly accessible data, and conducted data preparation, combination and modelling in a transparent and repeatable way (Lowndes et al., 2017). Full details on the BHI calculation can be found at https://github.com/OHI-Science/bhi, while data and code are available at https://github.com/OHI-Science/bhi-prep.

2.1 | Expert and stakeholder process

We designed an expert elicitation process involving a diversity of scientists and environmental managers to allow for an objective, transparent and well-informed BHI development and assessment. In this process, we engaged scientists and representatives from non-governmental organizations as well as from management authorities from the entire Baltic region in four BHI workshops. However, small-scale fisheries and tourist sectors were not included here as no representative was found. The goal of the process was better alignment of the global OHI-assessment framework to existing management targets for the Baltic Sea. At the first workshop (in 2014), potential BHI goals and data availability for these as well as pressure and resilience were discussed. In the second workshop (in 2015), the final BHI structure and data sources to be used were agreed upon. Subsequently, the BHI core team gathered the data in a continuous dialogue with 'goalkeepers' (see below for more information) to assure the quality and proper interpretation. Preliminary BHI calculations were discussed in the third workshop (in 2016) and critically evaluated. Some goals were subsequently recalculated, and the revised results were presented for collective agreement and support from experts.

At the beginning of the process we assigned a 'goalkeeper' to each BHI goal (see below), that is, an expert in a particular field/subject, to ensure the scientific quality of each goal in the assessment. Goalkeepers supervised the whole BHI process, especially decisions on data use and treatment for goal calculations, as well as decisions on management targets. We repeated the expert elicitation process several times, both using remote communication tools and expert meetings, assuring consistent implementation of newly available information and data. During the three expert workshops, every goalkeeper was also part of all other goal discussions, which opened up some general discussions, such as '*do we use a similar approach for setting management targets across goals*'. The entire expert and stakeholder process strongly facilitated a close cooperation between goalkeepers and the BHI team and helped in integrating diverse knowledge and data in one comprehensive assessment product.

2.2 | Assessment regions

We divided the Baltic Sea into spatial units that account for the large heterogeneity in climate, hydrography and biodiversity as well as geographical and social gradients. We initially used the 17 Baltic Sea sub-basins (in line with the second holistic assessment of HELCOM, 2018b) and subsequently intersected these with the boundaries of the nine nations bordering the Baltic Sea (territorial waters and exclusive economic zones, EEZ) using the geographic information system ArcGIS (ESRI, 2016). For the resulting 42 BHI regions (see Figure S1 in Supporting Information), goal scores were computed and then aggregated into (a) region-specific scores and (b) scores for the entire Baltic Sea as a whole (using area-weighted averaging). For some of the goals, only one value existed for the whole Baltic Sea, for example, for the sprat biomass (NP), and in these cases, all smaller BHI units were assigned the same score value.

2.3 | Baltic Health Index goals

The BHI assesses nine of the 10 goals initially outlined in the OHI (Halpern et al., 2012, ohi-science.org/ohi-global). We excluded the *coastal protection goal*, since coastal erosion is a minor issue in large parts of the Baltic Sea due to the shallowness of the coasts and sheltering archipelagos. However, due to future climate change and potential sea level rise, this goal will likely need to be included in future assessments. The definition of the goals and their reference points are tailored to best address critical management and policy objectives for the Baltic Sea (see Table 1, and for all goal-specific models and more detailed information see Supporting Information).

Each goal score is calculated along four dimensions (Figure 1):

1. **Present status *x*** is a goal's current value compared to its reference point, that is, the management target.
2. **Trend *T*** is the average percentage change in a goal's status over the most recent 5 years.
3. **Pressures *P*** are presented by the weighted sum (based on relative effects of different pressures on the given goal) of the ecological and social pressures that negatively affect the status of the goal.
4. **Resilience *r*** includes three types of measures (Halpern et al., 2012): *ecological integrity* (i.e. the status of the biodiversity goal), *goal-specific regulations* aimed at addressing ecological pressures and *social integrity* (such as political instability and corruption, obtained from the World Governance Indicator) that increase status by reducing or eliminating pressures.

Each of these dimensions incorporates both ecological and social data as the focus of the assessment is on the human benefits derived from the ecosystem.

The overall goal scores are calculated as the average of present (*x*) and likely future status. Likely future status is calculated as current status modified by the recent trend (*T*), cumulative pressures and resilience (*r*) associated with the goal. Each goal status and trend are calculated individually by goal and region (see Figure 1 and Halpern et al., 2012; Halpern, Frazier, et al., 2015; Halpern, Longo, et al., 2015 for more details). Below we describe in detail the development and assessment of the various goals within the BHI (see also Table 1). The maximum score for each goal and the entire BHI is 100, where 100 does not represent pristine conditions, but instead represents if the reference points (shown in Table 1) are achieved. The flowerplots in Figure 2 were produced using the circlize tool (Gu et al., 2014).

2.3.1 | Artisanal fishing opportunity (AO)

The AO goal assesses the opportunities to engage with coastal non-recreational fishing. For the BHI, we focused on coastal fish stocks as a proxy for fishing opportunities and used abundance data for coastal piscivores, cyprinids and other mesopredator (i.e. mid-trophic level fish) species (see HELCOM, 2018b). The AO model assesses the health of these fish stocks, represented by the mean of two HELCOM Core Indicators for stock abundance (HELCOM, 2018b) and we used the good environmental status (HELCOM, 2018b) as the reference point for the AO goal.

2.3.2 | Biodiversity (BD)

Contrary to the global OHI, we did not separate the BD goal into species and habitats but instead combined both together. We used the already available assessment results from HELCOM (2018b), which consist of five components: benthic and pelagic habitats, fish, mammals and seabirds and has been evaluated using the biological quality ratios and seabird abundance, derived in the integrated biodiversity assessments from HELCOM (the HELCOM assessment tool: https://github.com/NIVA-Denmark/BalticBOOST).

These are based on core indicators for key species and species groups, including abundance, distribution, productivity, physiological and demographic characteristics. Statuses of these five biodiversity components are aggregated first within each component, combining coastal area values with area-weighted averages, then combining the values for coastal and offshore areas of each BHI

TABLE 1 Goal description, its definition and reference points used

Goal	Goal/Subgoal	Definition	Reference point
	Artisanal fishing opportunity (AO)	Opportunity to engage in coastal non-recreational fishing	Good environmental status (GES) for coastal fish indicators
	Biodiversity (BD)	Existence value of biodiversity measured through the conservation status of marine species	Good environmental status (GES) for biodiversity components
	Carbon storage (CS)	Conservation status of natural habitats providing long-lasting carbon storage	Presence of *seagrass*. Exceptions for certain regions where no seagrass growth is possible (see Supporting Information)
	Clean water (CW)/contaminants	Captures the degree to which marine areas are unpolluted by contaminants	Polychlorinated biphenyls (PCB), dioxins and PFOS below thresholds; and all persistent, bioaccumulative and toxic SVHC monitored
	CW/eutrophication	Captures the degree to which marine areas are unpolluted by nutrients	Winter nutrients, summer chlorophyll *a* and Secchi and oxygen debt reach GES targets
	CW/trash	Captures the degree to which marine areas are unpolluted by trash	Maximum amount of trash in 2010
	Food provision (FP)/fisheries	Harvest of sustainably caught wild seafood	Species biomass at max. sustainable yield (MSY) and species fishing mortality at (FMSY)
	FP/mariculture	Production of sustainable cultured seafood	Maximum nutrient discharge for phosphorus (P) and nitrogen (N) below recommended level
	Livelihoods and economies/economies	Revenues from marine-related sectors.	A 1.5% annual growth between 2010 and 2020
	LE/livelihoods	Livelihood for people living on the coast, encompassing all the marine sectors that supply jobs	Maximum region-to-country employment ratio of the past 5 years, and highest country employment rate in the last 15 years
	Natural products (NP)	Sustainable harvest of natural products used for reasons other than food provision	Sprat biomass at MSY yield (BMSY) and sprat FMSY
	Sense of place (SP)/iconic species	Cultural, spiritual or aesthetic connection to the sea afforded by iconic species	All assessed species conservation status classified as of least concern
	SP/lasting special places	Geographic locations that hold particular value for aesthetic, spiritual, cultural, recreational or existence reasons, and how well they are protected	10% of sea area protected with a fully implemented management plan
	Tourism (TR)	Opportunity to enjoy coastal areas for recreation and tourism	An annual growth of 2.2% for 10 years from 2010 onwards for all three tourism categories

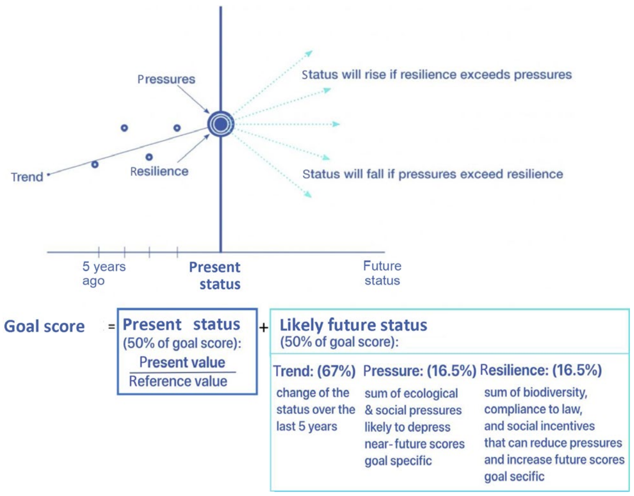


FIGURE 1 Illustration of how the BHI score is calculated based on the Ocean Health Index framework. Note that the status will rise relative to current trend trajectory if resilience exceeds pressures, though this could still mean a decline in status (if the trend is strongly negative); and similar (but opposite) for when pressures exceed resilience, that is, status will fall relative to trend trajectory

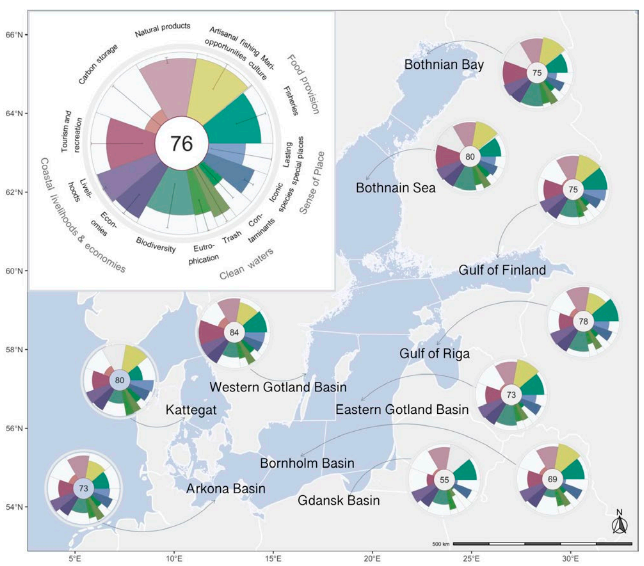


FIGURE 2 Spatial patterns in BHI scores. The large flowerplot indicates overall BHI score (index, centre number), with petal lengths indicating relative values (0–100) for each goal and subgoal. The lengths of the bars transecting each goal and subgoal petal represent the spatial variability of the score values of the particular goal or subgoal. Small flowerplots indicate basin-specific score (centre number) and goal values (petal lengths) of the major basins. Colours correspond to goals and subgoals, and the goal petals on small plots correspond with goals indicated on the large flowerplot. The width of each petal represents the contribution to the Index score. The results for the smaller basins can be found at Table S2 in Supporting Information and at: https://baltic-ohi.shinyapps.io/dashboard

region with equal weight. A single biodiversity status score per region is calculated as geometric mean of the five components (see Supporting Information). As reference point, we used a core indicator threshold of 0.75 abundance (good environmental status decided by HELCOM) for the seabirds. For the other four components (benthic habitats, pelagic habitats, fish and mammals), a biological quality ratio (BQR) of 0.6 was developed by HELCOM with the aim to represent good status and was used as here as the target.

2.3.3 | Carbon storage (CS)

The CS goal assesses the potential of coastal vegetation to capture and store carbon and uses data on spatial coverage of eelgrass *Zostera marina* from the HELCOM HOLAS assessment (HELCOM, 2010). Carbon stocks in coastal sediments and ecosystems are substantial compared to the open ocean (Regnier et al., 2013), but often data are very limited (Testa et al., 2017). As reference point we used the spatial extent of the presence of eelgrass before and after 1995, with the exception of low-saline areas such as the Gulf of Bothnia where eelgrass does not naturally occur (Kindeberg et al., 2019; Röhr et al., 2016). We are aware that the confidence of this goal might be low as many other coastal vegetation could not be included, but we wanted to include the goal as the potential to capture carbon is an important ecosystem service.

2.3.4 | Clean water (CW)

In contrast to the global OHI (Halpern, Longo, et al., 2015), we assessed the CW goal based on three subgoals—Eutrophication, Contaminants and Trash—each having a unique set of pressures and resilience. The CW goal scores highest when the pollution level is low, that is, targets of the Baltic Sea Action Plan or Marine Strategy Framework Directive (MSFD) are met. The *eutrophication* subgoal combines five eutrophication indicators: concentrations of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) during winter, chlorophyll *a* concentration and Secchi depth during summer, and oxygen debt. The first four indicators and their reference points are taken from HELCOM (2013; Baltic Sea Environmental Proceedings No 143; HELCOM, 2013). The oxygen debt and its reference has been obtained from https://github.com/ices-tools-prod/HEAT (HELCOM, 2018a).

The *contaminant* subgoal captures the degree to which waters are unpolluted by contaminants. As contaminant indicators, we used concentrations of dioxin and dioxin-like compounds, polychlorinated biphenyls (sum of the six indicator PCBs #28, #52, #101, #138, #153 and #180), and perfluorooctanesulfonic acid (PFOS) in fish. These indicators were selected because the substances are hazardous (i.e. they are persistent, bioaccumulative and toxic) and pose a risk to organisms living in the Baltic Sea and to humans, and there is monitoring data available. As reference levels, we used targets agreed on internationally (see Supporting Information). In addition to the three contaminant indicators, we calculated the monitored proportion of persistent, bioaccumulative and toxic substances of very high concern (SVHC) on the

Candidate List (Annex XV) of the EU chemical regulation REACH (also part of the BHI Resilience assessment, see below).

The reference point is having all contamination levels of the three pollutants/pollutant groups fall below their respective thresholds, and all persistent, bioaccumulative and toxic SVHC monitored.

The *trash* subgoal assesses the ability to prevent litter from entering the sea and harming the coastal and marine environment. Marine litter is a global concern, impacting all marine environments. For the Baltic Sea, no comparable long-term trash datasets exist. We, therefore, used model data on the countries' amount of mismanaged plastic litter that has the potential to enter the ocean (Jambeck et al., 2015, see Supporting Information). The modelled data have been downweighted for Russia, Germany, Denmark and Sweden (by the proportion of the coastal population in relation to national population) to better account for the litter that actually reaches the Baltic Sea. Currently, there is no official quantitative reference point set. Therefore, we set a spatial reference point to make them comparable across BHI regions, where the upper reference point is the maximum amount in 2010 of litter among all Baltic Sea countries, and the lower reference point is zero litter in the Baltic Sea. This subgoal does not capture microplastic, as no coherent datasets are yet available, although microplastic is known to cause harm to the environment (Galloway et al., 2017; Graca et al., 2017; Koelmans et al., 2017).

2.3.5 | Food provision (FP)

The FP goal typically assesses two subgoals addressing wild-caught fisheries and mariculture. In the Baltic Sea, *mariculture* is dominated by the production of rainbow trout *Oncorhynchus mykiss* in Finland, Denmark, Sweden and Germany (Flores Carmenate, 2016). Overall, the yield and economic value of mariculture are small, representing approximately 0.5% of the total fisheries economic value (EC, 2013). For the BHI, we were not able to find enough current data particularly regarding sustainability and nutrient use for defining the reference point of the mariculture and have, therefore, not assessed this subgoal.

For the subgoal *wild-caught fisheries*, we included spawning stock biomass and fishing mortality data for both the western and eastern Baltic cod *Gadus morhua* and the Baltic herring *Clupea harengus membras* stocks (ICES, 2020) as these are the most important commercial open sea fisheries for human consumption in the Baltic Sea. In assessment of the goal, we used reference points for biomass and fishing mortality corresponding to the maximum sustainable yield approach (MSY, see Table 1, Halpern et al., 2014) and applied in the stock assessments of the International Council for the Exploration of the Sea (ICES), which inform fisheries management within the reformed Common Fisheries Policy (CFP) of the European Union (https://ec.europa.eu/fisheries/cfp_en). MSY represents the highest theoretical equilibrium yield that can be continuously taken from a stock under existing average environmental conditions without significantly affecting the reproduction process. However, this approach did not account for the drastic reduction in growth and body condition for the Eastern Baltic cod stock over the past two decades (Casini et al., 2016). To account for this reduced body size, we penalized the Eastern Baltic cod score using Fulton's *K* condition index, a proxy for the cod condition (Casini et al., 2016, see also Supporting Information).

2.3.6 | Livelihoods and economies (LE)

The LE goal contains the two subgoals: *livelihoods* and *economies*. While the subgoal *livelihoods* aims to assess employment in maritime sectors, data on employment in specific marine-related sectors in the Baltic Sea coastal areas were not available at a regional level. Hence, we used the finest-available regional data (Eurostat NUTS2 regions) on employment rates for the age group 15–64 (Eurostat, see Supporting Information), assuming these to reflect a similar employment situation in the marine sectors. As a reference level we used maximum region-to-country employment ratios of the past 5 years, and highest country employment rate in the last 15 years. The region-to-country ratio puts the value into local context, then adjusting with respect to highest country employment rate in the last 15 years from around the Baltic Sea situates the ratio in broader geographic context.

We computed the *economies* subgoal using sector-specific values (gross value added) associated with maritime-related industries and a 1.5% annual growth rate as the reference level (EC, 2013).

2.3.7 | Natural products (NP)

The assessment of the NP goal was restricted to the small pelagic fish sprat (*Sprattus sprattus)* which is mainly used for fish meal production or animal food (see Supporting Information). The goal was assessed using spawning stock biomass and fishing mortality data as well as related MSY reference points from ICES (2020). No data for other natural products were readily available at the time of the assessment.

2.3.8 | Sense of place (SP)

The SP goal contains two subgoals, namely *iconic species* and *lasting special places*. We derived a list of 15 *iconic species*: cod, flounder, herring, sprat, perch, pike, salmon, trout, white-tailed sea eagle, common eider, grey seal, harbour seal, ringed seal, harbour porpoise and European otter, from a survey sent to 89 experts (36 responses) from Baltic Sea countries. These species were then assigned a threat category (ranging from 'extinct' to 'least concern') based on International Union for Conservation of Nature assessments (IUCN, 2015), and assigned a numeric weight based on that category. We calculated the goal score as the average weight of all species assessed (see biodiversity goal for more information) with a reference level at which all species are in the 'least concern' category.

For the subgoal *lasting special places*, the designation and management of marine protected areas (MPAs) captures the commitment of a country to preserving areas of biological, aesthetic or ecosystem service value. We computed the score based on HELCOM MPA data (http://mpas.helcom.fi/apex/f?p=103:17), which include all MPAs the countries have reported to HELCOM. This gave a conservative estimate of the area under protection, since some national MPAs are not reported to HELCOM, but facilitated a consequent description of the level of protection across all countries in the region. The area of MPAs was related to the total sea area in the BHI region. We used the internationally agreed goal of protecting 10% of sea area as a reference point. To account for that MPAs only provide adequate protection if they are properly managed, we multiplied the area of each MPA by a factor depending on implementation status (0.1 = MPAs without an adopted plan, 0.4 = partly managed MPAs, 1.0 = MPAs with full management) before calculating the percent area protected. Thus, the score can only reach 100 if management plans have been fully implemented.

2.3.9 | Tourism (TR)

In the BHI, we used data on coastal accommodations (nights stayed in tourist accommodation establishments, in coastal regions) and coastal tourism revenue (gross value added) from the EU Study on Blue Growth (see Supporting Information). Economic activities categorized under either Accommodation or Transport in the Coastal Tourism sector were included. No sustainability measure of coastal tourism on the Baltic Sea scale was found, and thus this dimension was not included. The tourism model also incorporates the nights of stay in accommodations in coastal regions, which used Eurostat dataset on nights spent at tourist accommodation establishments by coastal and non-coastal area (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tour_occ_nin2c&lang=en).

The status is the ratio of coastal tourism revenue relative to the coastal accommodations per area, scaled by the reference point. As the reference point, we used the highest ratio across all countries in a 10-year time frame (see Supporting Information). Sustainability of the TR goal could not be assessed because reference points for sustainable tourism do not presently exist. Furthermore, no Baltic-wide recreational data were available. Hence, we refer to this goal as *tourism* only, as compared to *tourism and recreation* in the global OHI (Halpern et al., 2012).

2.4 | Likely future state

Our strong focus on sustainability in the index calculation requires that both the *current status* and the *likely direction of change* in this status influence the score of each goal. We explicitly focus on the near-term future (future trends are calculated over 5 years) rather than longer term sustainability because the near-term future is most relevant to policymakers and long-term future states of many of the subgoals are very difficult to project. To improve our understanding of the likely near-term future condition, *resilience* and *pressure* dimensions are included to provide additional information beyond the recent trend. The OHI approach identifies those factors that negatively affect a goal as *pressures* and those that positively affect a goal as *resilience* (see Section 2). The expectation of a likely future condition suggested by the trend will become more or less optimistic depending on the effects of *pressures* and *resilience* (Figure 1). Note that the likely future status does not predict the future, but only estimates what the status score is likely to be in approximately 5 years hence, given what is known today about recent trends and the counterbalance of pressure versus resilience metrics.

2.4.1 | Pressures

We used readily available data at consistent spatial scales for the following *pressure* categories: (a) proxies for nutrient loading and pollution (total nitrogen and phosphorus load from land, atmospheric load of polychlorinated biphenyls (PCB 153), inverse Secchi depth as a proxy for algal blooms and trash), (b) proxies for habitat destruction (anoxic area, oil spills, bottom trawling), (c) climate (surface water salinity and sea surface temperature), (d) non-indigenous species (number of non-indigenous and cryptogenic species) and (e) social pressures (indicators from the World Governance Index). For each goal and subgoal, we relied on expert knowledge to determine the relevant pressures and rank them as 'high' (score = 3), 'medium' (score = 2) or 'low' (score = 1; see Supporting Information, Table S3 for pressure rankings for all goals). Subsequently, we summed the weighted intensities of each stressor within a pressure category and divided the value by the maximum weighted intensity that could be achieved by the worst stressor across all categories (Halpern et al., 2012).

2.4.2 | Resilience

In both the OHI and BHI, *resilience* contains three components: ecological integrity, goal-specific regulations and social integrity. The *ecological integrity* is measured as biodiversity (same as in the BD goal). *Social integrity* is measured by using the World Governance Index, same as in the global OHI assessment (Halpern et al., 2012). In comparison to the global OHI, we greatly advanced the *goal-specific regulation* component in the BHI, by performing a country-specific compliance analysis. We assessed the degree of implementation of 13 European Union (EU) and two international laws (see Supporting Information, Table S4) having implications for environmental management and protection in the Baltic Sea area.

An institutional resilience assessment that accounts for the degree of implementation of important legislation, such as the EU

Marine Strategy Framework Directive (MSFD; EC, 2008), is essential as it evaluates the extent to which (cumulative) pressures to the Baltic Sea can be reduced. Our analysis of each of the 15 sources of legislation included several succeeding steps (see more details in the Supporting Information). First, we mapped the legal frameworks and all the direct and clear compliance obligations established by the legislator. For instance, when the law says the *Member States shall report*… the legislator choice of word (*shall*) clearly gives an order (an obligation). Another clear common obligation is the time frame established in the law, which Member States and Commission have to obey, for example, specific dates, or use of the terms *yearly*/annually etc. Once this mapping phase was concluded, the next step was to search and find reports of compliance to each law for each country analysed. The information contained in the reports was used for the compliance assessment and scoring. We developed a scoring system with four categories: *full*, *partial*, *fail* and *not applicable* (for a detailed approach see the Supporting Information). A *full* score was only awarded when a given country fully implemented and thus complied with the law. *Partial* scores can range from 1% to 99% compliance with the legal text. A *fail* score was given when the country had an obligation to report, but it did not obey, when it did not follow the legal instructions respecting thresholds or minimum legal standards, or when it failed to take action when it was required to. The *not applicable* score represents either a lack of information in the report regarding a specific obligation or indicates that compliance was not assessed at all, such as in the case of Russia where EU legislation does not apply. We decided to weight the different directives according to their specific assessment quality and ability to assess compliance (see Table S5 in Supporting Information).

3 | RESULTS AND DISCUSSION

3.1 | BHI goal scores and its regional variability

Overall, the regional BHI scored 76 out of a possible maximum of 100 (Figure 2) indicating that the health of the Baltic Sea is suboptimal, and that substantial efforts are required to reach the management objectives and associated targets. Subregionally, the lowest BHI scores were observed for the Gdansk Bay (55), Kiel Bay (65), The Sound (66) and Bornholm Basin (69). The four basins scored low mainly due to low scores of *contaminants* (7, 6, 15 and 29 respectively), and mostly low scores for *carbon storage* (9, 45, 96 and 15 respectively) and *lasting special places* (10, 93, 39 and 10 respectively).

Highest subregional BHI scores, indicating better ocean health, were obtained for the Western Gotland Basin (84), Northern Baltic Proper (82), Bothnian Bay (80) and Kattegat (80). These regions score highest compared to other regions due to their higher scores in *contaminants* (61 and 67 for Western Gotland Basin and Kattegat respectively), *lasting special places* (78, 65, 36 and 92 respectively) and *artisanal fishing opportunities* (78, 99, 100 and 100 respectively).

3.1.1 | Carbon storage

A major result of our BHI assessment is a very low score for *carbon storage* (average 20, lowest 6, highest 44). With a few exceptions (e.g. The Sound, score = 96), in most subregions of the Baltic Sea, the *carbon storage* potential is assessed to be very or extremely low. These results are mainly due to the use of eelgrass, a marine seagrass with high carbon sequestration capacity (Boström et al., 2014; Kindeberg et al., 2019; Röhr et al., 2016, 2018), as the indicator species in this goal. Thus, for the low saline (<5) basins (Bothnian Sea, Gulf of Bothnia, eastern Gulf of Finland) beyond the main geographical distribution limits of eelgrass, our assessment indicates no *carbon storage* potential. However, other primary producers for which we lack carbon sequestration data, such as reed *Phragmites australis*, pondweeds (*Stuckenia pectinata* and *Potamogeton* spp.) and other submerged brackish water habitats dominating in bays and lagoons and covering vast areas may be important for carbon burial in low saline, sheltered areas. A high potential for carbon sequestering has been shown also for the canopy-forming seaweed *Fucus vesiculosus*, but we lack data on transport rates and burial areas (Attard et al., 2019; Krause-Jensen et al., 2018). Our assessment of the *carbon storage* goal is hence likely an underestimation of the actual *carbon storage* potential which may have artificially decreased the overall BHI score in many subareas. Better data on distribution (depth limits and areal extent) and function (sequestration rates, transport and burial processes) of submerged macrophytes are required to accurately assess this goal in the future.

3.1.2 | Socio-economic goals

The coastal *livelihoods* and *economies* (average 96, lowest 85, highest 96) generally scored high with little subregional variability indicating the general economic prosperity of the countries bordering the Baltic Sea. Unfortunately, no data could be obtained from Russia for these important goals. The high score for the *livelihoods* subgoal (average 98, lowest 97, highest 99) reflects high employment rates in marine sectors in many countries. Similarly, the high score for the *economies* subgoal (average 93, lowest 91, highest 93) is indicating the thriving of coastal/marine economies and by that indirectly benefit people at the coast. It is important to note that the subgoal *economies* describes one part of the human dimension of the BHI and therefore combines data from several marine sectors, where some are independent on the state of the environment (e.g. shipping) and some are dependent on the environment (e.g. tourism, fisheries). The *economies* are clearly of high value to many people, even those who do not directly participate in the industries but value community identity, tax revenue and indirect economic and social impacts of a stable coastal economy.

The *tourism* goal, based on coastal accommodation, scored not so high as the *livelihoods and economies* goal (average 76, lowest 19, highest 99), and showed a large spatial variability. High scores are found for Sweden (99) and Finland (90), while low scores are calculated for Lithuania (19) and Poland (28), though Poland is catching up in the tourism sector, its economic growth rate in the Coastal Tourism sector is highest of any country around the Baltic Sea.

However, the scores for these socio-economic goals may be overestimated since we lack indicators on the sustainability (such as energy and water use efficiency, recycling, ecotourism) of economic activities in the region.

3.1.3 | Biodiversity and sense of place

The assessment of biodiversity resulted in moderate goal scores (average 70, lowest 29, highest 91) for all Baltic Sea subregions, with higher scores in the north (e.g. Bothnian Bay, 90) and low scores in the south (e.g. Bornholm Basin, 31). In the *sense of place* goal only the *iconic species* subgoal scored high (average 79, lowest 72, highest 85). In contrast, several relatively low individual scores were derived for the *lasting special places* subgoal (average 58, lowest 10, highest 99). This large subregional variability reflects differences in protected area cover, but also the differential progress in implementing MPAs' management plans. For most BHI regions, the target of declaring 10% of the marine area as MPAs is already met, but many MPAs are categorized as only 'designated' or 'partly managed'.

3.1.4 | Clean water and fisheries—The major concerns

Traditionally, the major ecological concerns in the Baltic Sea include the availability of clean water and the sustainability of fisheries (Elmgren et al., 2015). The BHI goal of *clean water* comprises the levels of contamination with various chemical substances, nutrient inputs from multiple sources (mainly agriculture but also waste water treatment plants, industries, managed forestry, storm overflows and natural background sources; Heiskanen et al., 2019), and the recently developing concern of *trash* polluting the marine environment. Our BHI calculations indicate generally low water quality in the Baltic Sea with very high subregional variability (average 60, lowest 21, highest 87) with the contaminants subgoal scoring low for the entire Baltic Sea and many of the subregions (average 42, lowest 6, highest 67). The BHI treated the *contaminants* subgoal originally through three contaminant indicators for human health (dioxins, PCBs and PFOS). However, many not monitored but harmful, persistent and bioaccumulating contaminants are emitted into the environment (Sobek et al., 2016). Hence, we added to the original *contaminants* score, the proportion of monitored persistent, bioaccumulative and toxic SVHC (see Section 2) to account for lack of data and knowledge on currently used and emerging hazardous substances. This modification of the goal resulted in the overall low score because only a small number (spatial average is 40%, ranging from 0 to maximum of 63%) of these new hazardous substances are currently monitored in the entire Baltic Sea. The low score can thus be seen as a result of lacking data and knowledge (see Section 2), rather than an assessment of the known impact of contaminants. We hope that future management and monitoring will broaden the scope with less focus on legacy contaminants and more emphasis on the challenges and potential risk caused by new and emerging SVHC contaminants as well as combined effects caused by mixtures of chemicals.

Negative impacts of *eutrophication* include summer algal blooms, mostly consisting of cyanobacteria, and large hypoxic bottom areas. Because of the poor status, eutrophication is a major focus on the Baltic Sea environmental agenda. The BHI assesses this subgoal through five indicators (winter nitrate and phosphorus, summer chlorophyll *a*, Secchi depth and oxygen debt; see Section 2) yielding comparatively low scores (average 72, lowest 50, highest 99) which show that the present status is relatively far away from accepted target levels (HELCOM, 2013). Exceptionally poor scores for *eutrophication* are seen in the Gulf of Riga (50), Central Baltic Sea basins (i.e. Western (64) and Eastern (66) Gotland Basins, Northern Baltic Proper (64)) as well as Bornholm Basin (67). However, the most northern basin, Bothnian Bay (83) and a few areas in the south-western Baltic Sea, for example, Great Belt (99) and Kiel Bay (99) are characterized by relatively high scores.

The impact of fishing has also been one of the major concerns in the Baltic Sea, particularly concerning the major commercial targets cod and herring. Stock assessments for both species were the basis for our *fisheries* subgoal (see Section 2), which scored relatively high for the entire Baltic Sea (average 82, lowest 49, highest 96). However, there is a large discrepancy in the status of the herring and cod stocks, the latter (Western and Eastern Baltic cod) being below sustainable MSY reference points due to overfishing and environmental change (Casini et al., 2016; ICES, 2020; Möllmann, 2019; Orio et al., 2019). Excluding herring stocks from the score, which are in a better state (see Supporting Information) decreased the overall regional score to 73.

Artisanal fishing opportunities (AO) scored high but varied across the Baltic Sea region (average 93, lowest 66, highest 100). The lowest score was calculated for the coastal areas in The Sound (66) and the highest for the coastal areas in Eastern Gotland Basin (99), Bornholm Basin (100), Kattegat (100), Bothnian Bay (100) and Northern Baltic Proper (99). Note that the level of confidence in the AO assessment differs throughout the Baltic Sea, but is higher in those areas having the longest data series. Coastal fish communities are local in their appearance (Olsson et al., 2011; Östman et al., 2017) and the current monitoring programs do not cover all coastal areas. As such, the reference points are locally derived and varies between areas and coastal fish communities (HELCOM, 2018b; Olsson, 2019). In several areas, the data available represent shorter time series (<10 years of data) which also limits the confidence of the status assessment. Furthermore, we currently lack a comprehensive compilation of data on access to the fishery, which limits the applicability of the AO goal in assessing the provisioning of ecosystem services by coastal fisheries. However, it is essential to include this goal as it represents the coastal fishing opportunity, which is an important use of the Baltic Sea environmental resources distinct from the commercial fishing represented in the *food provision: fisheries* subgoal, and not captured elsewhere in the BHI.

3.2 | Likely future status

An important asset of the BHI compared to other assessments of the Baltic Sea such as HOLAS II (HELCOM, 2018b) is the consideration of the likely future change of the socio-ecological system, and that this new approach accounts for the relative effects of human pressures on and resilience of the ecosystem centrally in the assessment (Halpern et al., 2012). However, the BHI approach embeds the challenge of anticipating likely future direction of change in status. We hence deliberately focused on the near-term future, that is, 5 years only, rather than long-term sustainability, since long-term future states are difficult to project and are associated with high uncertainty. Furthermore, the short-term future is also most relevant to policymakers, which makes the results useful for deciding upon urgent measures needed to remediate the state of the sea.

To further illustrate the interactions between the different BHI components that are involved in the likely future calculation (i.e. resilience, pressures and trend, Figure 1), we demonstrate the various effects of these components in computing the *eutrophication* subgoal across three Baltic Sea basins (Figure 3). In the Bornholm Basin, the likely future status was higher (71) than the current status (64), due to a positive trend (+0.1) of the eutrophication indicators during the last 5 years combined with a high resilience (66) in relation to pressures (44, Figure 3). In the Bothnian Sea, the likely future status (79) was higher than the current status (67) even so the trend was negative (−0.14), but note that here the resilience score (84) is very high in relation to the non-existing pressure (0, Figure 3), as the maximum allowable input of the nutrient loads of both nitrogen and phosphorus (both are the pressure component) is below the thresholds (set by the HELCOM BSAP process). In contrast, in the Gulf of Riga, the likely future status was lower (48) than the current status (52) due to a strongly negative trend (worsening of the status, −0.4), even though, the resilience (73) was higher than the pressure (21, Figure 3). The negative trend indicates that urgent management actions are needed for improving the eutrophication status in the Gulf of Riga, in particular as also long-term projections indicate a slow recovery from eutrophication (Murray et al., 2019).

Overall, the likely future status of all goals averaged for the whole Baltic Sea is higher than the present status (Figure 4), which is a positive sign for Baltic Sea management. The subregional variability varies across goals and in a few cases the likely future status was worse than the present status (24 of 269, 8.9% of all goals and subgoals status across all subregions). This lower future status was present in particular in four goals/subgoals (we list only the difference which are larger than one): (a) *artisanal fishing opportunities*

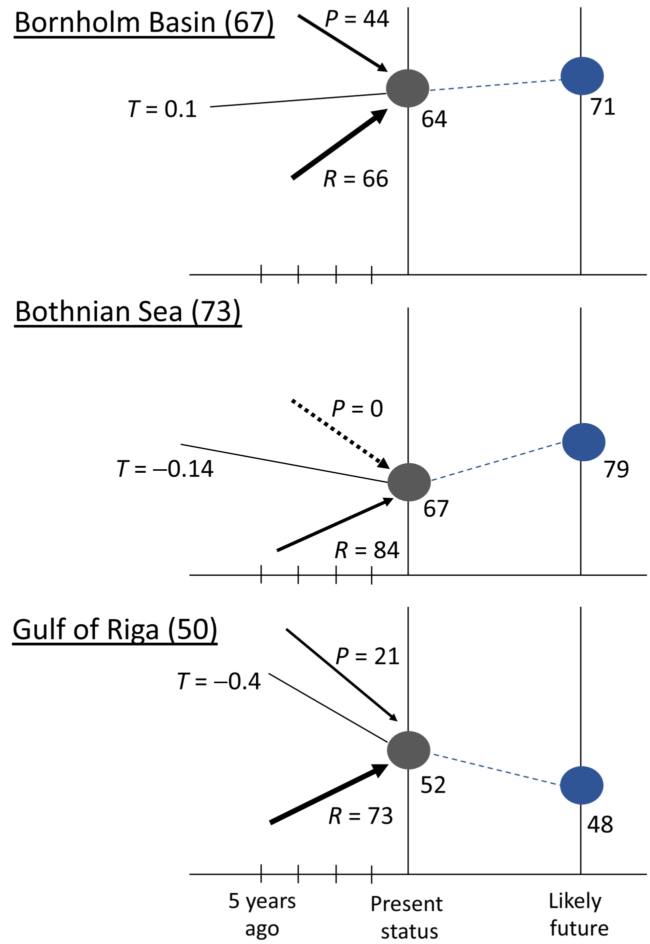


FIGURE 3 Eutrophication values of Bornholm Basin, Gdansk Basin and Gulf of Riga. The trend (*T*), pressure (*P*), resilience (*R*), present status (on the vertical present status point), likely future (on the vertical likely future status point, and the total basin-specific eutrophication scores (in parenthesis after the basin name) are given to illustrate the interplay between these different components of the BHI. The thickness of the pressure and resilience arrows indicate the values of these components. Slope direction indicates the trend values

in the Northern Baltic Proper Sea (−2) and Eastern Gotland Basin (−3); (b) *biodiversity* in the Bay of Gdansk (−1); (c) *eutrophication* in the Quark (−10), Gulf of Riga (−5) and Eastern Gotland Basin (−1), contaminants in the Sound (−9), Bornholm Basin (−6), Great Belt (−5), Kiel Bay (−4), fisheries in Bay of Gdansk (−6), Arkona Basin (−2), see also Supporting Information in Table S6).

The assessment of the likely future status rewards the presence of regulatory and management measures which we estimated using the proxy of countries' compliance to laws and regulations. Cumulative environmental pressures are a growing topic of research, but resilience measures and the ways they work or fail to counterbalance pressures are an important piece of information in order to gain a comprehensive picture of the situation. While the BHI future estimates may be overly optimistic, the different ways the BHI components interact to produce likely future status highlight the importance of having the quantitative information and records of both ecological and governance data

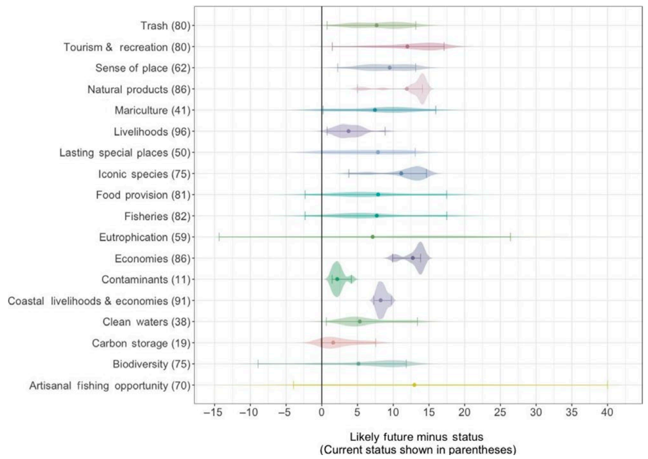


FIGURE 4 Difference between likely future and current status for each goal and subgoal for the whole Baltic (point) and the subregional variability (horizontal lines, with shaded density curves). The horizontal lines show min–max ranges and the shaded areas show the distribution of subregions' associated values across the ranges, that is, the thicker the shaded area, the more subregions with values in that vicinity. Values greater than zero on the *x*-axis (likely future minus status) indicate the likely future status is greater than the current status, while values less than zero indicate expected decline in status going into the future

to understand and estimate likely future changes, which can serve as indicators for management priorities.

3.3 | Reference levels

Baltic Health Index scores clearly depend on the reference levels and the philosophy behind setting these. For example, intuitively trash is a much smaller problem in the Gulf of Finland than eutrophication. However, a drastic reference level of 'no trash pollution' is set because no other quantitative reference exists yet, while the international agreed BSAP reference level 'allows' a certain level of eutrophication. Consequently, trash scored lower (55) in the Gulf of Finland than eutrophication (71). Such differences in reference level 'philosophy' have been heavily discussed during BHI expert workshops and are an important outcome of the BHI project. Currently, we are far from a consistent reference level setting approach in the BHI, but also in other comprehensive assessments (such as HELCOM HOLAS II). This shortcoming is exacerbated by the common practice of setting reference levels based on single sectors and single impacts. However, clearly impacts such as eutrophication and fisheries are linked, and additive and/or synergistic effects of cumulative drivers affect their status which should be reflected in the reference level (Giakoumi et al., 2015; Halpern, Frazier, et al., 2015; Hunsicker et al., 2015). In general, reference points should be science informed, but optimally would be to develop these reference points in a co-design process with diverse stakeholders and scientists in order to define goals of restorative and active intervention and implement appropriate management measures (Franke et al., 2020). Learning exercises are needed to successfully operationalize and implement ocean management strategies that integrate environmental, social, cultural, health at local and regional scales. These different 'management experiments', that is, adjusting different solutions in different regions, can help to potentially overcome conflicting societal interests and to identify common values (Franke et al., 2020). Therewith, different regions could learn from different management practices.

The purpose of this Perspective is to highlight the need to (a) provide a conceptual and simultaneously operational ocean health framework that integrates the links between ocean and human health and (b) address potential solutions and obstacles to sustain and restore a healthy and productive ocean for future generations through advancing approaches for a broad transdisciplinary integration of marine sciences.

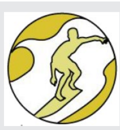
3.4 | BHI in comparison to other assessments

Several assessment approaches have been developed and applied to large marine areas in open and coastal waters (Borja et al., 2016). Within the Baltic Sea, foundational holistic assessments (HOLAS I & II) have been conducted by HELCOM (2010, 2018b) and assessed the state of the Baltic Sea ecosystem, environmental pressures and human well-being. HOLAS II assessed the status for the period 2011–2016, that is, a slightly earlier period than used for the BHI (except for biodiversity, which is from the same period), and concluded that 'the environmental health of the Baltic Sea does not meet the objectives of the Baltic Sea Action Plan' (HELCOM, 2018b). BHI and HOLAS II cannot be directly compared due to their different approaches and partially different sets of targets. For instance, in contrast to HOLAS II, the BHI assessed carbon storage, natural products, tourism, livelihood and economy as well as the sense of place. Also, the underlying assumptions of the two assessments are different. The BHI approach (and the OHI framework in general) focus on the assessment of how oceans provide benefits for humans, whereby HOLAS II focused more directly on ecosystem status classification. It is, however, obvious that both assessments carry the same important and urgent message that the Baltic Sea health status is not sufficient because many management targets have not been reached. From the BHI perspective, it becomes clear that the status of the Baltic Sea is with 76 not sufficient, that is, the target (100) has not been reached. For example, the *fisheries*, *biodiversity* and *eutrophication* goals/subgoals are below 100, indicating that GES target (based on the EU MSFD) has not been achieved.

4 | CONCLUSIONS

We conducted the first assessment of Baltic Sea health following the internationally applied OHI framework. Such a quantitative and comprehensive assessment requires robust and continuous monitoring data and needs to be flexible to include new studies, indicators and knowledge, especially for target setting (Borja et al., 2016). One objective of this initial BHI assessment was to identify lacking or deficient data (Table 2). For example, the assessment of carbon storage was limited, and thus likely underestimated, due to a lack of distribution and carbon sequestration data for other submerged

TABLE 2 Data limitations for each goal (bold) and subgoal are listed

Goal	Goal/subgoal	Data limitations
	Artisanal fishing opportunity	Data are not extensive enough to support a full analytical assessment, lack of data on the need and access of the fishery
	Biodiversity	Currently the condition of habitats and biotopes are not assessed, no real functional biodiversity included
	Carbon storage	Seagrass extent data are limited and no information on other carbon storage habitats (such as wetlands), missing reference levels
	Clean water/ contaminants	The assessment is based on few contaminant indicators and the combined effect of contaminants is not accounted for, due to lack of relevant data
	Eutrophication	Almost the same data and reference levels as for the HELCOM HOLAS II assessment have been used but without any weighting of any indicator
	Trash	No Baltic Sea wide macro and micro trash long-term data available yet
	Food provisioning/ fisheries	Eastern Baltic cod status difficult to assess with the MSY approach, other fish species (e.g. flounder *Platichthys solemdali*, salmon *Salmo salar*) are also used for human consumption in the Baltic Sea, but not included here, as data are limited
	Mariculture	Very little sustainability data exit (e.g. nutrient, antibiotic release, fish escape), no reference point, spatial farm data are not transparent and difficult to collect
	Economies	No sustainable economic data exit, sustainable reference levels taken from EU report
	Livelihoods	No sustainable livelihood and reference data exit
	Natural products	Only one Baltic Sea wide assessment unit for sprat, other natural products information is missing or difficult to assess
	Sense of place/ iconic species	Limited expert survey to determine iconic species in the Baltic Sea region
	Last special place	There are no comprehensive data on areas providing cultural services, therefore marine protected areas and their management plan implementation are used as proxy. This assumes that the existing MPAs are chosen to represent important cultural values
	Tourism	No Baltic Sea-wide ecotourism data and sustainable reference levels exist

macrophytes than eelgrass. The livelihoods and economies goal was also difficult to calculate because no indicators exist on the level of sustainability of economic activities. Further, in some cases, reference points are either unclear or missing. Future BHI assessments will hopefully benefit from recent sampling and monitoring activities.

Our first BHI assessment is not the final word on the health state of the Baltic Sea. It however provides a robust platform for a constructive dialogue on strengths and weaknesses as well as the required next steps to improve the assessment. In this first assessment, the BHI added new dimensions beyond previous Baltic Sea assessments by integrating new goals such as livelihoods and economies, natural products, carbon storage and tourism, along with advancements of resilience metrics based on countries compliance assessment to regulations, future trend assessments and transparent, reproducible methods with openly available code (https://github.com/OHI-Science/bhi-prep). Furthermore, BHI takes the likely near-term future of the goals into account when assessing their state, which helps focus on mitigation actions on the most severe pressures.

The BHI outcomes can be used to identify both pan-Baltic and subregional scale management priorities (focusing on goals with low scores and likely future status) and to illustrate the interconnectedness between goals linked by cumulative pressures. Hence, the information provided by the BHI and its further development will contribute to the fulfilment of the UN Agenda 2030 across the SDGs goals (Lubchenco & Gaines, 2019). Here, in particular the SDG 17 'Strengthen the means of implementation and revitalize the global partnership for sustainable development', will help to provide a new narrative for the 'Baltic Sea contribution to people'. Also, our findings and our transdisciplinary approach (through workshops and target setting) can provide important insights to the current Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) framework (Díaz et al., 2019; IPBES, 2019) for assessing the state of biodiversity and ecosystem services at both regional (see also Culhane et al., 2020) and global scales. The UN has proclaimed the 'Decade of Ocean Science for Sustainable Development' and the 'Decade on Ecosystem Restoration' (both 2021–2030) to support 'efforts to reverse the cycle of decline in ocean health and gather ocean stakeholders world-wide'. Our Baltic Sea case study could be an important example for other marine regions of how the most severe threats to ocean health (e.g. hazardous substances, nutrient load) can be identified and mitigated.

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CONFLICT OF INTERESTS

Andrea Belgrano is an Associate Editor for People and Nature, but was not involved in the peer review and decision-making process. There are no other conflicts of interest.

AUTHORS' CONTRIBUTIONS

T.B. coordinated the BHI project and led the project meetings; T.B., A.D.C., E.C., J.S.L., J.R.G. and B.S.H. planned the study and calculated the scores; A.D.C., E.C., J.S.L. and J.R.G. led the data analysis. All the authors contributed to the design of the study, the development of the goals and the writing of the manuscript. All the authors approved the manuscript for submission.

DATA AVAILABILITY STATEMENT

Data and the code can be found at https://baltic-ohi.shinyapps.io/dashboard.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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