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Bridging the Science-Policy Gap – Toward Better Integration of Decision Support Tools in Coastal and Marine Policy Implementation

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Decision support tools (DSTs), like models, GIS-based planning tools and assessment tools, play an important role in incorporating scientific information into decision-making and facilitating policy implementation. In an interdisciplinary Baltic research group, we compiled 43 DSTs developed to support ecosystem-based management of the Baltic Sea and conducted a thorough review. Analyzed DSTs cover a wide variety of policy issues (e.g., eutrophication, biodiversity, human uses) and address environmental as well as socio-economic aspects. In this study, we aim to identify gaps between existing DSTs and end-user needs for DSTs for supporting coastal and marine policy implementation, and to provide recommendations for future DST development. In two online surveys, we assess the awareness and use of DSTs in general, as well as policy implementation challenges and DST needs of representatives of public authorities from all Baltic countries, in particular. Through a policy review we identify major policy issues, policies, and general implementation steps and requirements and develop the synthesis-matrix, which is used to compare DST demand and supply. Our results show that DSTs are predominantly used by researchers. End-users from public authorities use DSTs mostly as background information. Major obstacles for DST use are lacking awareness and experiences. DST demand is strongest for the policy issue eutrophication. Furthermore, DSTs that support the development of plans or programs of measures and assess their impacts and effectiveness are needed. DST supply is low for recently emerging topics, such as non-indigenous species, marine litter, and underwater noise. To overcome existing obstacles, a common database for DSTs available in the BSR is needed. Furthermore, end-users need guidance and training, and cooperation between DST developers and end-users needs to be enhanced to ensure the practical relevance of DSTs for supporting coastal and marine policy implementation. To fill existing gaps, DSTs that address impacts on human welfare and link environmental and socio-economic

aspects should be developed. The Baltic Sea Region serves as a best practice case for studying DSTs and their practical use. Hence, our results can provide insights for DST development in other marine regions. Furthermore, our methodological approach is transferable to other areas.

Keywords: decision-making, Baltic, end-user needs, environmental science and policy, tools and approaches, science and policy interface

INTRODUCTION

Intensified human use of coasts and seas leads to increased spatial conflicts and challenges to protect and preserve coastal and marine habitats under changing environmental conditions. To tackle these challenges, and protect our coasts and marine waters, the European Union (EU) has adopted a wide spectrum of sectoral and ecosystem-based coastal and marine policies. The Marine Strategy Framework Directive (2008/56/EG) (MSFD) is the first legislation, specifically aimed at the protection of the marine environment and its natural resources. The Recommendations on Integrated Coastal Zone Management (ICZM) adopted in 2002, and the Maritime Spatial Planning Directive (2014/89/EU) (MSPD) define principles and requirements of sound planning and management of human activities at sea. Jointly, the MSFD and MSPD (including principles of ICZM) offer a comprehensive and integrated approach to the protection of all European coasts and seas (EC, 2019a).

Recent EU directives, such as the MSFD, MSPD, and Water Framework Directive (WFD), are often comprehensive, integrative and ambitious, but provide a higher degree of flexibility in comparison to traditional, sectoral policies (Liefferink et al., 2011; Hassler et al., 2019). For instance, they require a complex and stepwise implementation process and strong integration of different environmental objectives, different sectors and disciplines, existing legislation, various decision-making levels, and technical, socio-economic and legislative instruments (Borja, 2005; Apitz et al., 2006). At the same time, their requirements often remain vague and pose challenges for their implementation in national systems and practice, as illustrated for the WFD (Borja, 2005), ICZM Recommendations (Støttrup et al., 2017), MSFD (van Leeuwen et al., 2014), and MSPD (Westholm, 2018; Hassler et al., 2019). Hence, causing delays in policy implementation and leaving policy objectives unmet (Karlsson and Gilek, 2020).

Decision support tools (DSTs) play an important role in incorporating scientific information into decision-making and supporting policy implementation (Borja et al., 2016). Furthermore, they can help to overcome several implementation challenges: Firstly, policy implementation across Europe requires comparability between member states and joint approaches, especially within regional seas. Widely accepted tools allow comparability of the implementation process and the results. Secondly, with growing complexity of legislation and their requirements, the information need for successful implementation is increasingly growing. DSTs can serve as a knowledge base and allow authorities and less trained experts to utilize this knowledge and experience and enable them to facilitate the implementation. Thirdly, implementation requires decisions, public acceptance of these decisions and subsequent measures. DSTs can make processes/approaches transparent, foster the inter-subjectivity of decisions and can be beneficial for public acceptance. At the same time, complex policies with multiple objectives require complex DSTs. For stepwise implementation processes specific tailor-made tools for each or several steps are needed.

In the past decade, numerous DSTs have been developed within research projects and published within scientific literature (Smith et al., 2007; Grêt-Regamey et al., 2017; Pınarbaşı et al., 2017). Yet, their transfer into practice often remains impeded and their application by end-users (e.g., public authorities) for supporting policy implementation seems to be limited. This has been shown, for instance, for MSP (Janßen et al., 2019; Pınarbaşı et al., 2017) or the use of ecosystem services-based tools (Grêt-Regamey et al., 2017). Furthermore, the need for tools and approaches, which incorporate data and information of marine ecosystems and human-induced pressures, for supporting policy implementation is emphasized in policy-driven research agendas, such as the joint Baltic Sea research and development program, BONUS (Snoeijs-Leijonmalm et al., 2017). Consequently, an overview of DSTs available to support coastal and marine policy implementation is needed, DST demands need to be assessed and future needs for DST development must be outlined. To ensure the practical relevance and acceptance of DSTs, end-users have to be involved in defining DST demand and design.

The Baltic Sea Region (BSR) provides an excellent example for studying DSTs and their practical use by public authorities involved in policy implementation. The semi-enclosed Baltic Sea is affected by multiple environmental pressures and among the most intensively studied seas with long-term data series available (Reusch et al., 2018). With the Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention), adopted in 1974 by the surrounding countries, the BSR has a long history of international cooperation (Backer and Leppänen, 2012) and is regarded as a blueprint for a successful policy development and implementation in Europe. This has been demonstrated by the implementation of the Baltic Sea Action Plan (BSAP) and the implementation of MSP. Furthermore, with a joint Baltic Sea research and development program, the BSR can be regarded to be at the forefront in DST development. An overview of existing tools for supporting coastal and marine policies can motivate an international audience to adapt Baltic DSTs.

Concrete objectives of this study are: (a) to assess the current use of DSTs based on a comprehensive stocktaking; (b) to identify major policies, policy issues, policy implementation steps and

requirements for which DSTs are needed, (c) to recognize policy implementation challenges faced by public authorities in order to identify their demand for DSTs, (d) to analyze the degree to which policy and end-user needs are already met by DST supply and identify current gaps, and (e) to provide recommendations for most needed DSTs and enhanced integration for supporting policy implementation.

MATERIALS AND METHODS

The four main methods are partly interlinked in order to meet the objectives of this study (cf. **Figure 1**). The stocktaking questionnaire assesses the current uses of DSTs in the BSR. In the policy review, we identify policy issues, policies, policy implementation steps and requirements that are relevant for the management of the Baltic Sea and could be supported by DSTs. The policy review is used as background for developing the end-user survey and the synthesis-matrix that is used to summarize and analyze our results. The end-user survey is used to identify policy implementation challenges and end-user needs for DSTs. The DST review, is closely connected to and builds upon the DST inventory of Nygård et al. (2020) and assesses the availability of DSTs for supporting policies and their implementation. Results of the end-user survey and DST review are summarized according to the synthesis matrix and form the DST supply and demand for the gap-analysis. Based on the results and end-user suggestions for DST improvement, we distil recommendations for future DST development. They are closely connected and build upon related studies by Nygård et al. (2020) and van Beest et al. (2020).

Stocktaking Questionnaire

We assessed the general use of DSTs in the BSR using an online questionnaire (hereafter referred to as stocktaking questionnaire). Concrete questions asked for (1) respondents' level of knowledge and use of DSTs, (2) the purpose for which they use DSTs, (3) obstacles that restrict them from using DSTs, (4) their familiarity and satisfaction with existing DSTs, and (5) whether they see a lack of DSTs for a specific purpose or field. The stocktaking questionnaire was distributed using the online survey tool JotForm[1] and was accessible in March 2019. Since the aim was to assess the general use of DSTs in the BSR, the target group included representatives of public administration, and international organizations and institutions [e.g., Helsinki Commission (HELCOM), VASAB Secretariat, International Council for the Exploration of the Sea (ICES) and EU], but also researchers, and others (e.g., NGOs and private companies). Around 800 persons were directly addressed via email. In addition, invitations to participate in the stocktaking questionnaire were published on the webpage and social media pages of the Stockholm University Baltic Sea Center.

In total, 108 responses were received and analyzed. Yet, the number of responses among countries in the BSR varied strongly, including 48 from Sweden (45%), 21 from Finland (20%), 9 from Germany (8%), 6 for Estonia and Lithuania (each 6%), four from Denmark and Latvia (4%), and two from Poland and Russia (each 2%). Three participants mentioned multiple Baltic Sea countries (3%) and one indicated to be working on the EU level. 39% of the participants are from research institutes, 54% from public administration, 8% from NGOs and 5% others (e.g., private companies or consultancies).

To analyze DST uses in the BSR we divided respondents of the stocktaking questionnaire into two groups: (1) respondents working in administration (Admin group or Group A) and (2) respondents from research institutes and universities, NGOs, private companies and consultancies (Research & Others or Group R&O).

Policy Review

Global, European, and Baltic Sea regional policies relevant for the Baltic Sea were reviewed in order to identify major policy issues and common policy implementation steps and requirements. The EUR-Lex database[2] was used to search for EU policy documents. For EU policies, we focused mainly on directives and regulations as they are legally binding for all member states. The search terms 'coastal' and 'marine' were used and only policies that included the subject matter 'Environment' were included. This resulted in 38 directives and 71 regulations that are currently in force. Of these, 14 directives and 52 regulations were amendments or specifications of previous policies and were not regarded separately. Additionally, 18 were excluded because they regulate common standards, design requirements, work safety aspects, funding, data accessibility, public participation, or impact assessments in general, but did not directly address coastal or marine issues, or because they were not relevant for the Baltic Sea. The remaining 26 policies were complemented by EU fisheries policies and EU strategies. For this, we used the EUR-Lex summaries of EU legislation section and considered the topics 'Environment and climate change' and 'Maritime Affairs and Fisheries' and identified 12 additional policies. Finally, 8 global and regional policies were added, resulting in a total of 46 policies (incl. MSFD and MSPD). Global policies included international conventions and Baltic Sea regional policies covered the Helsinki Convention and BSAP.

We analyzed to what extent the policy issues of the remaining 44 policies overlap thematically with the MSFD and its eleven descriptors and the MSPD, which addresses human uses and conflicts. The overview of reviewed policies and the degree to which they are covered by the MSFD and MSPD is provided in the **Supplementary Material** and **Table 1**.

Furthermore, we reviewed the specific implementation steps and requirements included in all 46 policies in order to define generalized steps and requirements that can be found in global, European and Baltic Sea regional policies. Identified policy issues, steps and requirements were used to develop the synthesis-matrix structure for summarizing results for end-users' policy implementation challenges and DST demand, and DST supply.

[1]https://eu.jotform.com

[2]https://eur-lex.europa.eu/

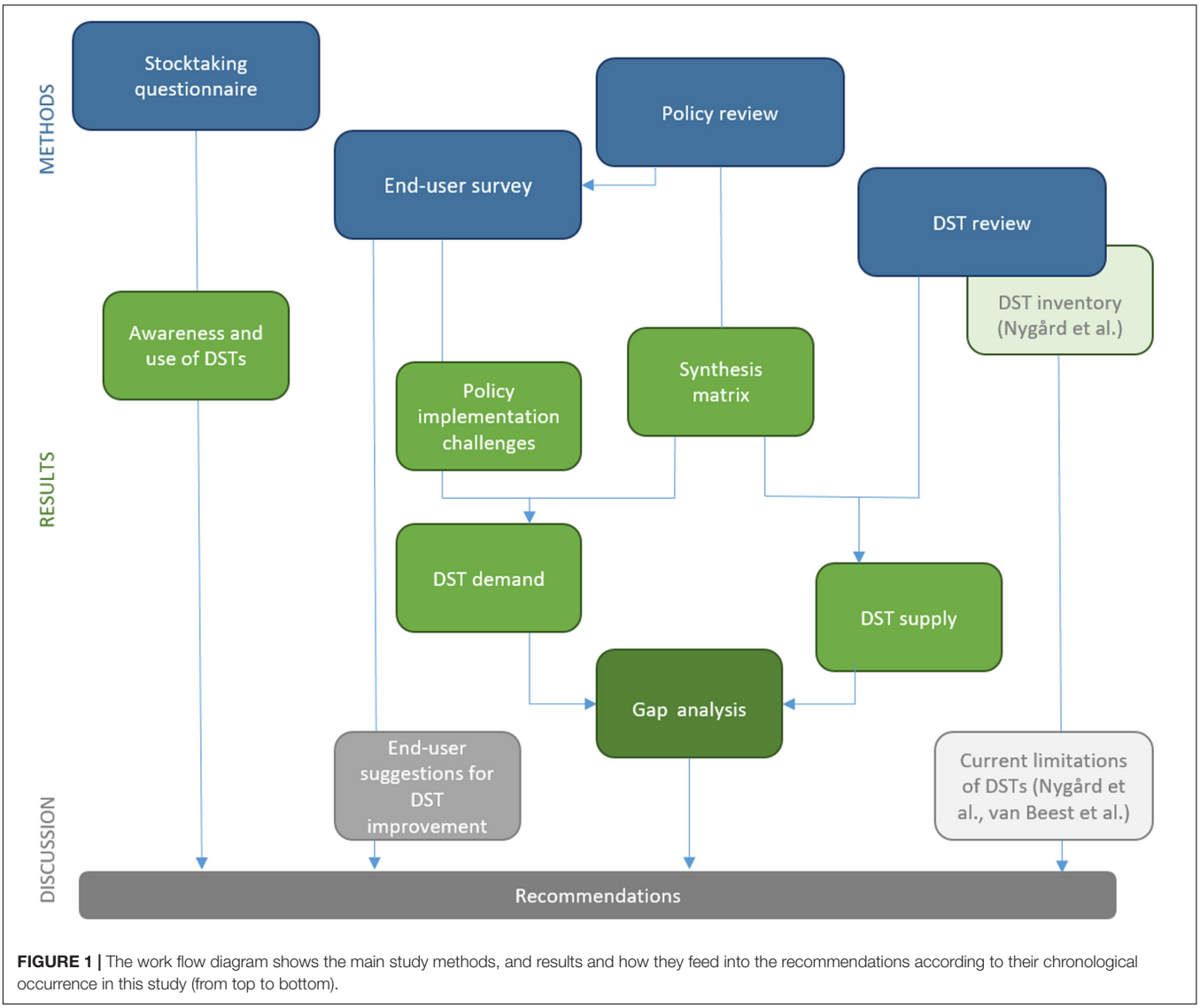

FIGURE 1 | The work flow diagram shows the main study methods, and results and how they feed into the recommendations according to their chronological occurrence in this study (from top to bottom).

End-User Survey

The specific DST demand of representatives of public authorities and agencies responsible for policy implementation was assessed in a second online survey (hereafter referred to as end-user survey). Authority representatives from all HELCOM working groups were identified and contacted to ensure the participation of people representing a broad spectrum of authorities and sectoral backgrounds relevant for the Baltic Sea.

Personal invitations to participate in the online survey were sent to approximately 150 selected end-users. They were asked about (1) current and future challenges in coastal and marine policy implementation, (2) their level of DST use to address these challenges, and (3) their suggestions for future DST developments to ensure practical relevance for end-users. In addition, they were asked about DST demand for concrete policies and their implementation steps. For this, selected policies and their implementation steps were listed and respondents were asked to select those, for which they see a demand or add additional ones. In addition, they specified the demand in an open-ended question. The selection of policies was based on the previous policy review. The full survey is included in the **Supplementary Data Sheet 1**. It consisted mostly of open-ended questions, and respondents were also given the opportunity to elaborate their opinion and suggestions in a personal interview. It was also distributed using JotForm and launched online from mid-December 2019 to January 31, 2020.

In total, 32 responses were received, including 9 from Sweden, 6 from Germany, 3 from Estonia, Latvia and Poland, 2 from Finland and 1 from Denmark, Lithuania and Russia. Two respondents were EU representatives and one anonymous response was received. Respondents' work background included pollution and hazards, eutrophication, conservation, invasive species, coastal protection, MSP, fisheries, tourism and hydrography. Several respondents did not indicate specific topics, but mentioned that their work is related to

various activities related to the protection of the Baltic Sea or the implementation of the BSAP or MSFD in general.

All survey responses were analyzed and coded using MAXQDA, an analysis software for qualitative and mixed methods data[3]. We used an inductive approach for coding end-user survey results for current DST use, obstacles and recommendations. Results for current and future challenges and specific DST demand were coded deductively according to the policy issues and policy implementation steps and requirements, identified in the policy review. Codes for challenges and demand were allocated into respective matrix cells (cf. **Supplementary Data Sheet 2**). Afterward, the allocated codes, were counted and represented as absolute values. Multiple codes in a single matrix cell resulting from one person were counted only once. On the overall level, each end-user that indicated a challenge or demand respectively, is also only counted once.

[3]https://www.maxqda.de/

TABLE 1 | Overview of available decision support tool (DST) types and specific DSTs resulting from the stocktaking.

DST type	DSTs included in inventory	
Assessment Tools	BEAT 3.0	Mytilus
Provide evaluations of an area, aspect, or impact based on fixed or flexible criteria	BWMC tool CHASE EUTRO-OPER EUTRO-OPER HEAT 3.0 InSAT Marmoni tool MESAT	NEAT VEMU 3 WATERS IA tool BSII BSPI LPI
Models Simulate a certain scenario or provide quantitative values	ACC-Human BALTCOST BALTSEM-POP ERGOM-MOM GETM-GITM GROWA-DENUZ-WEKU-MEPHOS NEST	POPCYCLING-Baltic RAUMIS Recreation Site Values TargetEconN VEMALA MONERIS
GIS-based Models and Planning Tools	BIAS	
Communicate an issue in form of maps can be interactive	Baltic Explorer EcoImpactMapper FIT InVest Marxan SOCOPSE Symphony Tool4MSP Zonation	
Stakeholder Tools	MIRADI	
Focus on stakeholder involvement and aim to improve communication	MIRACLE StakePrefTool	
Frameworks Provide an overall concept or guidance and are applicable to projects at different scales	MareFrame SAF	

DST Review

The DST review builds upon the DST inventory by Nygård et al. (2020). Information on the 43 DSTs included in the inventory is provided in the BONUS DESTONY DST database "Decision support tools for the Baltic Sea"[4]. We reviewed these DSTs and assessed the availability of DSTs for supporting global, EU and Baltic Sea regional level coastal and marine policies. We analyzed each DST according to the policy issues, policies, and their implementation steps and requirements that it addresses. For this, available information in the database was reviewed and complemented by additional internet search. In the study by Nygård et al. (2020) and the resulting DST database, each DST is assigned to the major problem that it addresses (e.g., eutrophication). In this study, we included multiple problems (here referred to as policy issue) in case the DST was not restricted to a single problem. Hence, the number of DSTs available for a policy issue differs between the studies. Furthermore, we re-classified the DSTs according to their objectives and output. All DSTs that were reviewed in this study are listed in **Table 1** according to their DST type. A brief description of each DST is included in the **Supplementary Data Sheet 3**). It provides additional information about their scope of applicability, level of expertise, and time effort required, and shows their allocation according to policies, policy issues, implementation steps and requirements. More detailed information for each DST is provided in the BONUS DESTONY DST database (see footnote 4).

RESULTS

Awareness and Use of Decision Support Tools

Results of the stocktaking questionnaire showed that most respondents know what DSTs are, but differences between respondent groups can be observed (**Table 2A**). The majority has used DSTs, but the level of use differs between the two groups. Around 44% of all respondents do not apply DSTs themselves, but make use of DST outcomes. This is similar between both groups (43 and 46%). However, while only 9% of Group A use DSTs as primary users, 15% of Group R&O indicated they were primary users (20%, if only researchers are included). Significant differences exist with respect to DST development. While 35% of the respondents in the Group R&O were involved in DST development (44%, for researchers), this was only the case for 24% of Group A.

The purpose for which DSTs are used differs slightly between respondent groups (cf. **Table 2B**). Respondents from Group A use DSTs mostly as input for own/other assessments/analyses (44%), to assess a specific problem (41%), and to get a first idea of things (37%). In contrast, Group R&O mostly used DSTs to assess different scenarios (50%), as input for own/other assessments/analyses (46%), and for communication with stakeholders and public (39%, or 46% if only researchers are considered).

[4]http://nest.su.se/bonus_dst/

TABLE 2 | Results of the stocktaking questionnaire shown separately for the respondents working in administration (Admin group, Group A) and all other respondents (Researchers and Others, Group R&O).

	All (%) (*N* = 108)	Admin group (%) (*N* = 54)	Researchers & Other (%) (*N* = 54)	Researchers only (%) (*N* = 41)
(A) How do you grade your experiences with DSTs?				
I do not know what it is	15	19	11	12
I have an idea of what they are for	36	39	33	**24**
I have used the outcome of the tools	44	43	46	46
I am a primary user	12	9	15	**20**
I have taken part in the development	30	24	35	**44**
(B) For what Purposes do you use DSTs?				
To get a first idea of things	35	37	33	37
To narrow down uncertainties	17	17	17	17
For communication with stakeholders and public	36	33	39	**46**
To overcome data gaps	23	22	24	27
To assess different scenarios	42	33	50	**56**
To assess a specific problem	38	41	35	**41**
As input for own/other assessments/analyses	45	44	46	44
Other	16	19	13	**7**
(C) Which of the following aspects has stopped you from using DSTs?				
Time constraints	24	35	13	12
Financial constraints	10	11	9	7
Lack of experiences	41	52	30	27
Lack of data	24	30	19	17
Lack of knowledge about availability of tools	49	65	33	29
Lack of DSTs for my area of work	22	20	24	22
Lack of DSTs for my regional spatial scale	17	15	19	20
Lack of acceptance by stakeholders/public	6	6	7	7
Other	8	6	11	12
(D) Do you see a lack of DSTs for a specific purpose or field?				
Yes	30	26	33	34
No	70	74	67	66

Results for all respondents and researchers only are shown in comparison. Differences of 5% and more between the Group R&O and Researchers only are indicated in bold.

Factors that constrain DST use differ significantly between the groups (cf. **Table 2C**). In general, Group A selected more obstacles (126 vs. 83 indications). The order of constraints is largely the same, but the frequency of being selected differs strongly for both groups. The main obstacles are a lack of knowledge about the availability of DSTs (Group A: 65%; Group R&O: 33%) and a lack of experiences (52 and 30%). In Group A, time constraints (35% vs. 13% in Group R&O) and lack of data (30% vs. 19% in Group R&O) were also frequently selected. 24% of Group R&O also mentioned a lack of tools for their specific area/field of work and 19% mentioned a lack of tools for their regional spatial scale as constraints. These factors were mentioned in Group A by 20 and 15% respectively. Among other limiting factors, single respondents mentioned low reliability, insufficient uncertainty analysis, lacking accuracy for the level required for their work, and difficulties in understanding and interpreting results.

In total, 30% of all respondents (Group A: 33%, Group R&O: 26%) see a lack of DSTs for a specific purpose or area (cf. **Table 2D**). Respondents' specifications for lacking DSTs were coded and included in the synthesis-matrix. They will be presented as part of the DST demand and gap-analysis sections.

Out of the 43 DSTs listed in the inventory, 35 were included in the stocktaking questionnaire and evaluated against respondents' level of knowledge about and satisfaction with each tool (**Figure 2**). About half of the listed DSTs (18 DSTs, 51%) were known by less than 20% of all respondents. Among end-users working in administration this was the case for 22 DSTs (62%), and among researchers for 15 DSTs (37%). Only 9 DSTs have been applied (directly or indirectly) by at least 10% of the respondents. The most commonly applied tools are BSII, BSPI, HEAT 3.0, and Symphony. BSII, BSPI and HEAT 3.0 have been used to support the HELCOM Holistic Assessment of the Ecosystem Health of the Baltic Sea. Five DSTs (MIRADI, Symphony, VEMALA, VEMU 3, and WATERS IA Tool) are more often known and used by respondents in Group A. MIRADI was developed by the conservation measures partnership, an international network of conservation practitioners such as NGOs and public authorities. Symphony was developed specifically to support MSP in Sweden. The remaining four are country-specific. VEMALA and VEMU 3 have been developed to support the implementation of the WFD in Finland and WATERS IA Tool in Sweden respectively. Beside these four, all of the other tools are predominantly used by researchers and others.

Shortcomings associated with known DSTs were given by 53 respondents (50%) and include a lack of, or poor data and missing updates (12 respondents) and lack of transparency (9 respondents). Furthermore, DSTs were perceived to be too general or not suitable for spatial scales needed for management (8 respondents), but also too narrow (2 respondents) and thus, not transferable. Being too complicated or requiring special expertise (7 respondents), lacking communication of data quality and uncertainties (6 respondents) and oversimplification (4 respondents) were additional shortcomings. Single respondents also mentioned lacking trust in DSTs, difficulties in explaining outcomes to stakeholders, lacking acceptance, limited number of

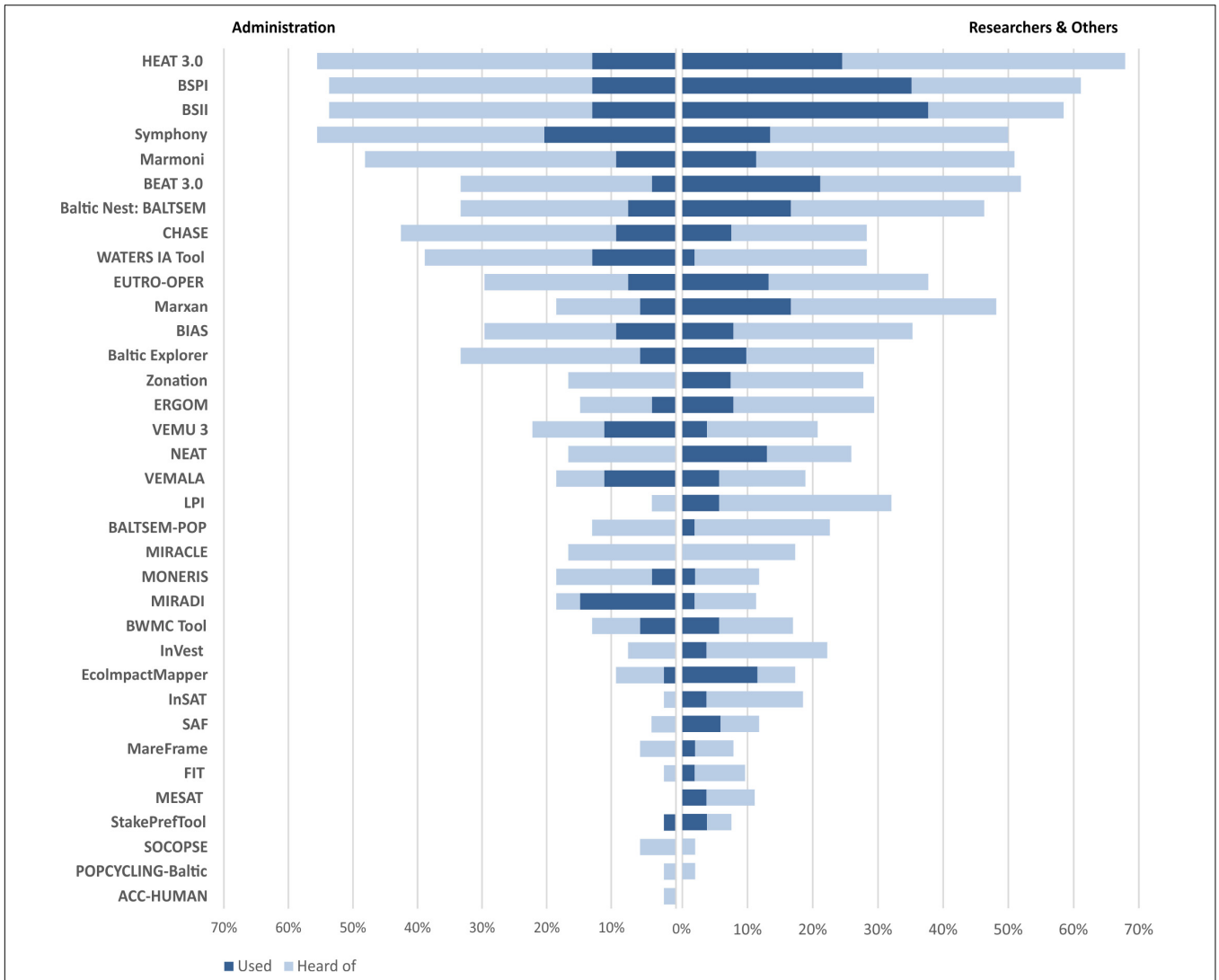

FIGURE 2 | Level of awareness and use of decision support tools (DSTs) among respondents of the stocktaking questionnaire. Results are shown separately for end-users working in public administration (Administration) and end-user working in research institutes, universities, NGOs, private companies, and others (Researchers and Others).

scenarios that can be analyzed, poor documentation, and lack of additional benefits.

Synthesis-Matrix

The policy review was conducted as background for the development of the end-user survey and the synthesis-matrix. As such, it is not presented separately in the results section. Here we present how the policy review resulted in the synthesis-matrix structure. It compares policy issues and policy implementation steps and requirements (cf. **Figure 3**) that were identified in the policy review. The synthesis-matrix is subsequently used to analyze the results of the DST review and end-user survey.

Out of 44 reviewed policies five are considered to be not thematically covered by the policy issues included in the MSFD or MSPD (cf. **Supplementary Material** and **Table 1**). Policies that are thematically not covered by the MSFD and MSPD are the Floods Directive (FloodsD), Bathing Water Directive (BWD), Geneva Convention, United Nations Framework on Climate Change, and EU Strategy on Climate Change Adaptation. Eleven policies were only partially covered. Missing aspects were air pollution from shipping and land-based sources, human pathogens, coastal flooding and adaptation, and climate change. In order to cover human pathogens and coastal flooding and adaptation, we included the BWD and FloodsD in the synthesis-matrix structure (cf. **Figure 3**) to complement the policy issues covered by the MSFD and MSPD.

Air pollution is not directly addressed by the MSFD or MSPD, but can be considered as a pressure causing eutrophication or contamination. Despite acknowledging the importance to consider climate change effects on the marine environment and human uses, we did not include it as a separate policy issue, but rather as an external pressure affecting all other topics. Hence,

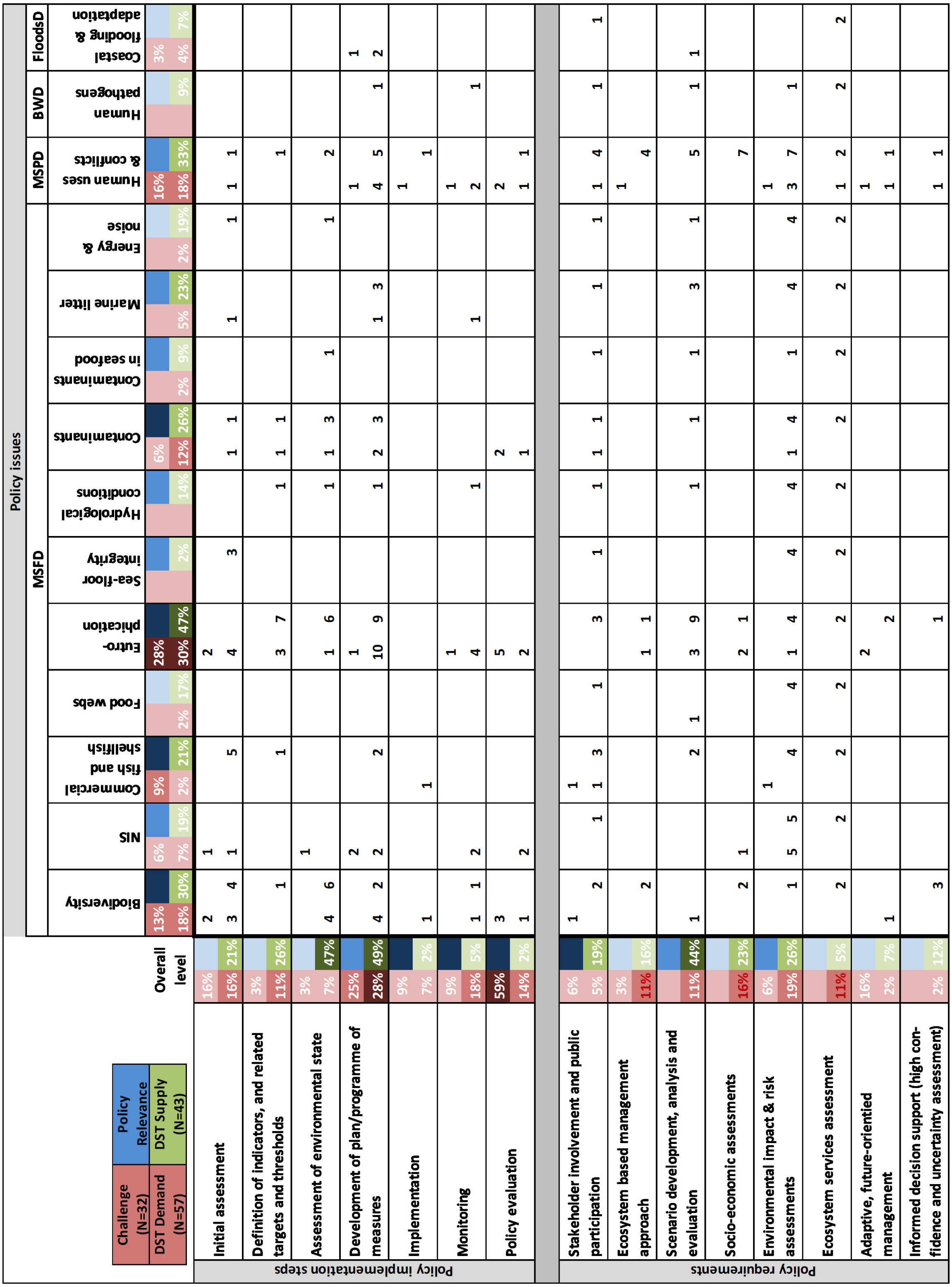

FIGURE 3 | The synthesis-matrix structure and policy relevance (indicated in blue) resulted from the policy review. Numerical values presented in the synthesis-matrix summarize the results of the end-user survey and DST review. End-user challenges are shown in the upper left corner of each square (red), DST demand in the lower left corner (red), and DST supply in the lower right corner (green). Different shades for each color on the overall level categorize each section on a categorical scale from low (light colors) to high (dark colors).

it was indirectly included as part of the policy requirements (*y*-axis) under the aspect 'adaptive, future-oriented management.' Aspects such as marine data, knowledge and research, maritime surveillance, security, safety, cooperation and innovation are among the objectives of the Integrated Maritime Policy and Blue Growth Strategy. Yet, we did not include them among the policy issues, because they can hardly be regarded in isolation from the identified policy issues. Hence, we also included them indirectly in the policy steps and requirements. In total, 14 policy issues are included in the synthesis-matrix and represented by four EU directives (cf. **Figure 3**, *x*-axis).

On the *y*-axis, we included seven generalized policy implementation steps and requirements that can be found in EU and Baltic Sea regional policies. They are shown in **Table 3** with a brief explanation for their inclusion in the synthesis matrix.

For each policy issue and implementation step and requirement the level to which it is addressed by the reviewed policies was assessed. In the synthesis-matrix this is referred to as 'Policy relevance' and indicated on a categorical scale (low, medium, high) (cf. **Figure 3**). The scale reflects their relative occurrence in the reviewed policy documents. As such, long-established policy issues such as biodiversity and eutrophication, which are addressed in various policies are categorized as high (indicated in dark blue). In contrast, emerging issues such as noise and energy, or those reflected in a low number of policies (e.g., human pathogens and coastal flooding and adaptation) are categorized as low (indicated in light blue).

Policy Implementation Challenges

The end-user survey assessed end-users' policy implementation challenges and needs for DSTs for specific policies. Results for policy implementation challenges were coded according to the synthesis-matrix and included in **Figure 3**.

Most of the 32 respondents of the end-user survey mentioned challenges related to general governance issues (19 end-users, 59%), which can hardly be addressed by DSTs. In the synthesis-matrix (**Figure 3**), they are reflected in the step Policy evaluation, and include challenges such as conflicting policy objectives (e.g., between climate change adaptation or blue growth and biodiversity), lacking coherence of policies (e.g., upstream and downstream or joining monitoring efforts), lack of financing, and legal or governmental changes. Lacking political will has been mentioned particularly with regard to the implementation of measures especially in relation to biodiversity and eutrophication. Moreover, the need for international regulations, lack of joint standards, and limited data accessibility pose challenges for end-users.

Development of plans or programs of measures, needed to improve the status of the Baltic Sea, is seen as a major challenge by 25% of the respondents. Particular challenges referred to the identification of measures that limit the spread of non-indigenous species (NIS), reduce diffuse nutrient sources, and balance biodiversity conservation with use of coastal areas for recreation, settlements, and coastal protection.

Among the policy requirements, adaptive, future-oriented management was the most often mentioned challenge (5 end-users, 16%). Specific challenges are for instance, understanding effects of climate change (e.g., on eutrophication) and taking them into account in long-term planning and management.

Furthermore, reaching policy objectives, such as reducing eutrophication and fishing pressure and managing hazards (e.g., contaminated wrecks and munition), were mentioned as challenges. In the synthesis-matrix they are included on the overall level for the respective policy issue. In general, Eutrophication (9 end-users, 28%), Human uses and conflicts (5 end-users, 16%), and Biodiversity (4 end-users, 13%) were most commonly mentioned among the challenges. Concrete examples for eutrophication are lacking knowledge about impacts of diffuse sources, such as agriculture and gray water from ships, on eutrophication. Concrete examples related to biodiversity and NIS are lacking knowledge and background information on species distribution and needed ecological coherences for different species and habitats, as well as lacking information concerning impacts of NIS.

About half of the respondents of the end-user survey (15 end-users, 48%) do not use DSTs to address the identified challenges. The other half (16 end-users, 52%) uses them directly or indirectly, for instance within projects or using outcomes of DSTs applied by experts. Policy issues for which end-users mostly used DSTs were Eutrophication and Human uses conflicts (MSP).

While some end-users work specifically on the implementation of single policies (e.g., MSFD, MSPD), others work on specific policy issues (e.g., Eutrophication, Biodiversity). DST needs for supporting the implementation of specific policies and their concrete implementations steps were assessed in the end-user survey. Results are shown in **Table 4** in comparison to the number of available DSTs for each policy (based on DST review).

End-user demand for DSTs is strongest for the BSAP (30 end-users, 94%) and the MSFD (18 end-users, 56%). For the MSFD, supporting tools are especially needed for defining or reviewing targets and indicators (mentioned by 12 of 18 end-users). Demand for DSTs was also high for the WFD and MSPD (38% each). For the WFD, supporting tools for the characterization of catchment, key pressures and impacts are mostly needed (8 of 12 end-users), but also for determining the good environmental status (GES) and developing and implementing programs of measures (6 of 12). Strongest demand for the MSPD exists for supporting tools for preparing spatial management plans (9 of 12 end-users) and for defining future conditions (7 of 12 end-users). For the Birds and Habitats Directive (HD) a DST demand was indicated by 8 end-users (25%). Here, supporting tools for establishing Natura 2000 network (6 of 8 end-users), assessing natural habitat types and species, establishing conservation measures and management plans, and monitoring (5 of 8 end-users each) are most needed. The Common Agriculture Policy and Common Fisheries Policy were mentioned by 9 (28%) and 8 (25%) end-users.

Additional policies for which a general DST demand was indicated were the EU Regulation on Invasive Alien Species, the EU Strategy for the Baltic Sea Region (each 6 end-users, 19%), EU Integrated Maritime Policy, EU Strategy on Adaptation

TABLE 3 | General policy implementation steps and requirements that resulted from the policy review and rationales for the inclusion in the synthesis-matrix.

		Rationale for inclusion in the synthesis-matrix
Policy implementation steps (and specifications)	**Initial assessment** (e.g., characterization and analysis of pressures and impacts, uses of marine environment and costs of its degradation) **Definition of indicators, and related targets and thresholds** **Assessment of environmental state** (e.g., based on indicator applications and outcomes for a status assessment) **Development of plan/program of measures** (e.g., identification of potential measures and assessment of their environmental effectiveness; assessment of social and economic impacts, incl. cost-effectiveness) **Implementation (of plan/measures)** **Monitoring** (e.g., assessment of progress towards targets and effectiveness of implemented measures)	The steps initial assessment to monitoring are strongly focused on the policy cycle of the MSFD and WFD, which are considered to be among the most holistic EU policies. Especially the initial assessment and assessment of environmental state are quite particular for the two directives. Other steps, such as implementation of plans or measures or monitoring can be found in most EU policies. The terminology of the steps is closely related to the MSFD, but includes also more general steps. For instance, the identification and choice of measures required by various policies are included in the step development of plan/program of measures.
	Policy evaluation (e.g., of overall governance issues such as implementation structure and process, coherence with other policies, coherence between land and sea, standardization)	In addition to the six steps of the policy cycle we added the step policy evaluation. It does not directly refer to a specific implementation step in the policy cycle, but covers overall governance issues.
Policy requirements (and specifications)	**Stakeholder involvement and public participation**	The right for access to information and public participation in environmental decision-making is regulated in the Aarhus Convention and the subsequent EU Public Participation Directive. Consequently, the requirement for public participation is included in all EU environmental policies.
	Ecosystem-based management	The ecosystem approach is the primary framework for action under the Convention on Biological Diversity (CBD). It balances the conservation and sustainable use of ecosystems. As such, it has been included as a strategy for an integrated management of land, sea and living resources. The requirement to make use of ecosystem-based management has been included in many EU and Baltic Sea Regional policies (e.g., MSFD, WFD, and BSAP). The allocation of DSTs to this requirement is based on the study by Nygård et al. (2020) and refers to all DSTs that include all components of the DAPSIWRM Framework, or all components except for Drivers
	Scenario development, analysis and evaluation	DSTs for scenario development, analysis and evaluation play an important role for assessing the effectiveness of different management options. They can for instance be used for the identification of targets or thresholds, and for assessing impacts of measures.
	Socio-economic assessment (e.g., economic valuations, impacts on social well-being, aspects such as conflicts, acceptance, etc.)	The requirement to consider socio-economic aspects and assess socio-economic impacts can be found in various EU and Baltic Sea regional policies.
	Environmental impact and risk assessment (incl. risks and impacts on human health)	Environmental assessments are conducted in order to protect the environment and human health from negative impacts of planned projects and to take them into account during decision-making processes. They are required for certain projects, plans, and programs under the EU Environmental Impact Assessment (EIA) Directive and the EU Strategic Environmental Assessment (SEA) Directive and for transboundary projects under the Espoo Convention. Hence, the need to conduct environmental impact or risk assessments is included in many EU and Baltic Sea regional policies.
	Ecosystem services assessment (assessment of benefits that people derive from ecosystems/direct or indirect contributions to human well-being)	The ecosystem service concept is has gained political interest and has been embedded in most recent EU and Baltic Sea Regional policies. For instance, the requirements to map and assess ecosystem services or to assess impacts on ecosystem services are included in the EU Biodiversity Strategy 2020 and the EU Regulation on Invasive Alien Species.
	Adaptive, future-oriented management (e.g., consideration of future long-term drivers/pressures such as climate change, population growth, etc.)	Adaptive management is among the principles of the ecosystem approach. Furthermore, we included climate change effects on the marine environment and human uses under this requirement.
	Informed decision support based on information with high confidence and uncertainty assessment	Many EU and Baltic Sea Regional policies require the use of best available scientific information. The allocation of DSTs to this requirement is based on the study by van Beest et al. (2020) and includes all DSTs that include a high level of confidence and uncertainty assessment

TABLE 4 | End-user needs for decision support tools (DSTs) addressing coastal and marine policies (bold) and their specific implementation steps (based on end-user survey) are shown in comparison to DSTs available to support each policy (based on DST review). Included policies are listed according to major policy fields.

Policy/Implementation step	End-user demand		DST supply	
	#	%	#	%
Water Protection and Management				
Helsinki Convention/Baltic Sea Action Plan (BSAP)	**30**	**94%**	**15**	**36%**
EU Marine Strategy Framework Directive (MSFD)	**18**	**56%**	**24**	**57%**
(Initial) assessment	7	39%		
Determination/review of good environmental status (GES)	9	50%		
Establishment/review of environmental targets and indicators	12	67%		
Implementation/continuation of monitoring programs	9	50%		
Development/review of programs of measures	9	50%		
Implementation	6	33%		
Review	4	22%		
EU Water Framework Directive (WFD)	**12**	**38%**	**16**	**38%**
Characterization of catchment, key pressures and impacts	8	67%		
Definition of environmental objectives	4	33%		
Definition of program of measures	7	58%		
River Basin Management Plans	5	42%		
Implementation of program of measures	7	58%		
Monitoring	7	58%		
Revision	1	8%		
Groundwater Directive	**1**	**3%**	**1**	**2%**
REACH Regulation	**1**	**3%**	**1**	**2%**
Protection of Nature and Biodiversity				
Convention on Biological Diversity (CBD)	**1**	**3%**	**3**	**7%**
EU Birds and Habitats Directives (HD)	**8**	**25%**	**4**	**10%**
(Initial) assessment of natural habitat types and species	5	63%		
Establishment of special areas of conservation (Natura 2000 network)	6	75%		
Establishment of conservation measures and management plans	5	63%		
Monitoring	5	63%		
Implementation	4	50%		
Revision	2	25%		
EU Regulation on Invasive Alien Species (IAS)	**6**	**19%**	**0**	**0%**
EU Biodiversity Strategy 2020	**5**	**16%**	**2**	**5%**
Waste Management				
EU Single-Use Plastics Directive	**2**	**6%**	**0**	**0%**
EU Waste Framework Directive	**1**	**3%**	**0**	**0%**
Maritime Affaires				
EU Integrated Maritime Policy (IMP)	**5**	**16%**	**0**	**0%**
EU Maritime Spatial Planning Directive (MSP)	**12**	**38%**	**12**	**29%**
Organizing stakeholder participation	2	17%		
Organizing the process through pre-planning	1	8%		
Defining and analyzing existing conditions	4	33%		
Defining and analyzing future conditions	7	58%		
Preparing and approving the spatial management plan	9	75%		
Implementing and enforcing the spatial management plan	5	42%		
Monitoring and evaluating performance	6	50%		
Adapting the spatial management process	3	25%		
Fisheries				
EU Common Fisheries Policy (CFP)	**8**	**25%**	**1**	**2%**
Climate Change				
EU Strategy on Adaptation to Climate Change	**5**	**16%**	**0**	**0%**
Other				
EU Common Agriculture Policy (CAP)	**9**	**28%**	**0**	**0%**
EU Strategy for the Baltic Sea Region (EUSBSR)	**6**	**19%**	**0**	**0%**

Percentages indicated for each policy are based on the total number or respondents of the DST survey (N = 32) and DSTs (N = 43) respectively. Percentages indicated for specific implementation steps are based on the total number of respondents that indicated a need for the specific policy.

to Climate Change, EU Biodiversity Strategy 2020 (each 5 end-users, 16%) and EU Single-Use Plastics Directive (2 end-users, 6%). Single persons also mentioned a DST demand for the Groundwater Directive, REACH Regulation, Convention on Biological Diversity, and the EU Waste Framework Directive.

DST Demand

End-users' DST demand is based on the open-ended questions for DST needs (end-user survey) and lacking DSTs for a specific purpose or field (stocktaking questionnaire), which were coded according to the policy issues as well as policy implementation steps and requirements included in the synthesis-matrix. Presented results are based on the responses of 57 end-users (32 respondents of the end-user survey and 25 respondents of the stocktaking questionnaire). As shown in **Figure 3**, the DST demand was highest for the policy issue Eutrophication (17 end-users, 30%). A moderate DST demand was mentioned for Biodiversity, Human uses and conflicts (10 end-users, 18% each), and Contaminants (7 end-users, 12%). Four respondents (7%) indicated a DST demand for NIS, three (5%) for Marine litter and two (4%) for Coastal flooding and adaptation. For the remaining issues, a demand was mentioned by one or no respondent.

Developing plans/programs of measures is not only seen among the main challenges, but also the implementation step for which DSTs are required most (16 end-users, 28%). In contrast, the DST demand for implementing these plans or measures is low (4 end-users, 7%). Furthermore, end-users indicated a moderate demand for the initial assessment (9 end-users, 16%), definition of indicators, targets and thresholds (6

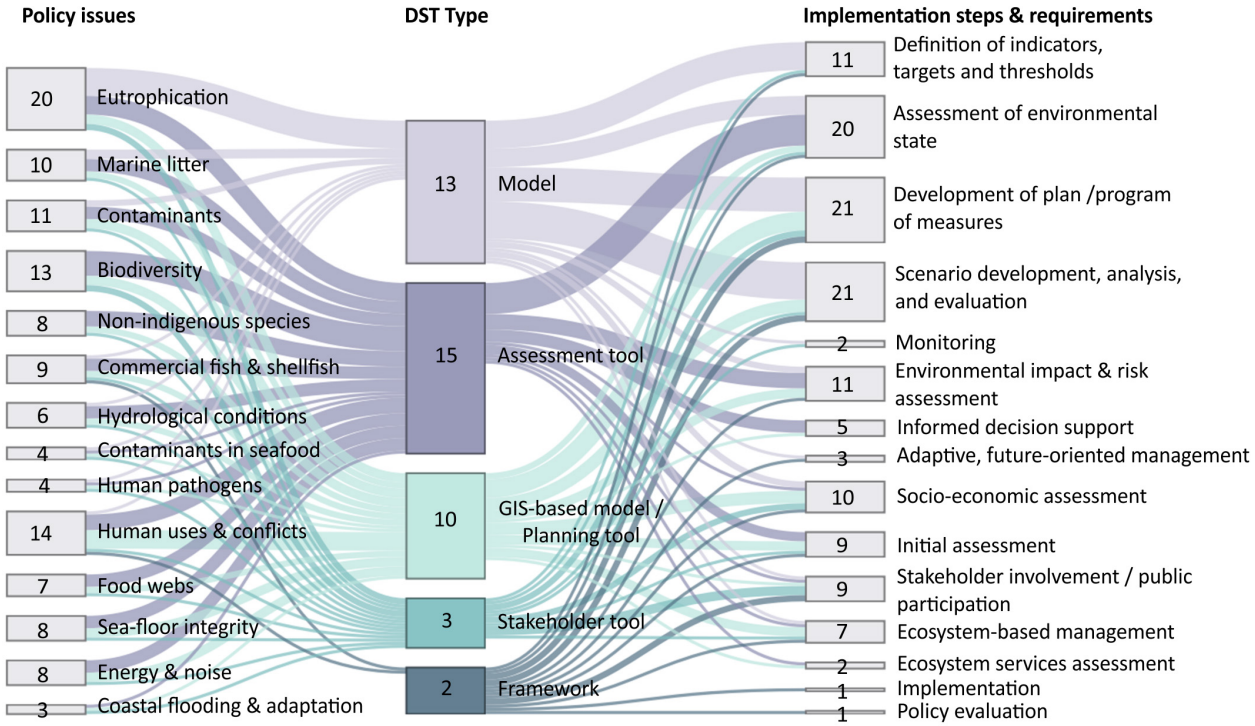

FIGURE 4 | Availability of decision support tools (DST) and DST types for policy issues and implementation steps and requirements based on the DST review.

end-users, 11%), and monitoring (10 end-users, 18%). The DST demand for monitoring includes both, a demand for DSTs to assess the effectiveness of implemented measures, but also a demand for DSTs that support the establishment of effective monitoring networks.

Environmental impact and risk assessment (11 end-users, 19%) and socio-economic assessment (9 end-users, 16%) are the policy requirements with the highest demand (both moderate). Respondents also mentioned a moderate demand for DSTs addressing the development and analysis of scenarios, ecosystem-based management approach, and ecosystem-service assessments (6 end-users, 11% each). The latter two were predominantly mentioned by researchers.

DST Supply

The DST supply resulted from the review of the 43 DSTs included in the DST inventory of Nygård et al. (2020) and shows the number of DSTs available to support each policy issue and implementation step and requirement. The policy issues that are best covered by DSTs are Eutrophication (20 DSTs, 47%), Human uses and conflicts (14 DSTs, 33%), and Biodiversity (13 DSTs, 30%) (**Figure 4**). DSTs available for Eutrophication are predominantly models, for Human uses and conflicts GIS-based models and planning tools, and for Biodiversity assessment tools. Coastal flooding and adaptation (3 DSTs, 7%), Contaminants in seafood, and Human pathogens (each 4 DSTs, 9%) are least addressed by DSTs. For these issues, only general DSTs, such as MESAT, InVEST, and StakePrefTool were found.

Policy implementation steps most covered by DSTs are Assessment of environmental state (20 DSTs, 47%) and Development of plan/programs of measures (21 DSTs, 49%). Both steps are covered mostly by models. Least covered steps are Monitoring (2 DSTs, 5%), Implementation, and Policy evaluation (1 DST, 2% each). The latter two, are only covered by one Framework (SAF). The policy requirement with the largest number of DSTs is Scenario development, analysis and evaluation (21 DSTs, 47%), which is overlapping with the step Development of plan/program of measures. Environmental impact and risk assessment and Socio-economic assessment are addressed by 11 (19%) and 10 (16%) DSTs. Least addressed requirements are Adaptive, future-oriented management (3 DSTs, 16%) and Ecosystem services assessment (2 DSTs, 5%).

Gap Analysis

In order to assess potential gaps, we compared DST demand and supply for each matrix cell using a categorical scale (low, moderate, and high) as shown in **Figure 5**. Gaps are shown in red or orange and indicate a demand that exceeds the DST supply. The overall level shows gaps for DSTs supporting Monitoring. According to the gap-analysis, DSTs are lacking especially for monitoring eutrophication, but also for biodiversity, NIS, marine litter, and human uses and conflicts. Further gaps are shown for the step policy evaluation. This step refers to overall governance issues such as policy implementation structures and processes, coherence between different policies, but also

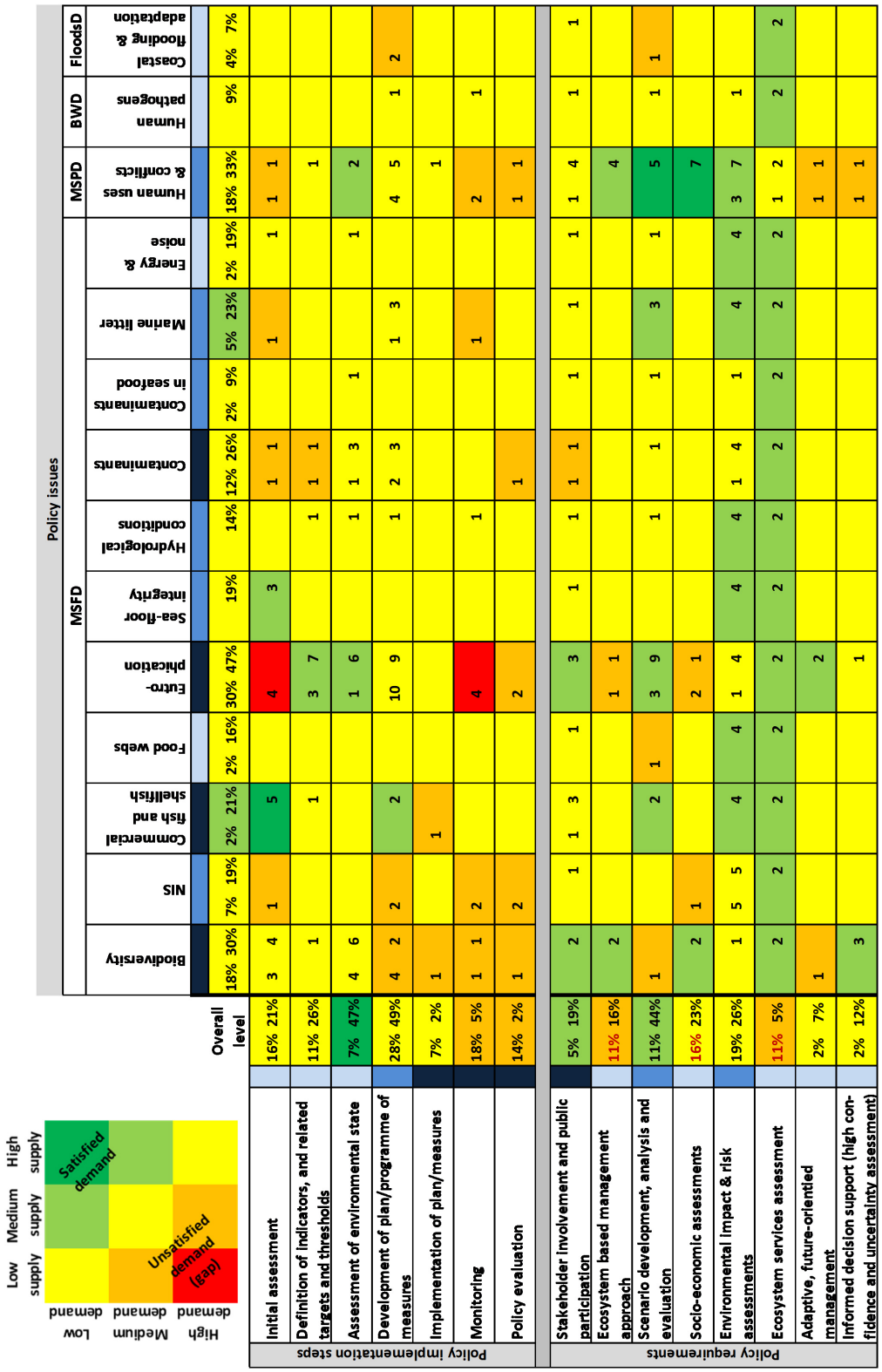

FIGURE 5 | In the gap analysis DST supply and DST demand are compared on a categorical scale. On the overall level, the scale indicated in the synthesis-matrix is used. In the inner matrix, the categorical scales for DST supply is low (0–1 DST), moderate (2–4 DSTs), high (5 or more DST) and for DST demand low (0 end-users), medium (1–3 end-users), high (4 or more end-users).

between land and sea as well as the need for using common standards within the BSR.

Gaps for policy requirements exist on an overall level for DSTs supporting the ecosystem-based management approach and for ecosystem services assessments. Both requirements have only recently been included in EU policies, as indicated by the low policy demand. The need for DSTs to address them was mentioned predominantly by researchers. In contrast, a satisfied demand is shown for ecosystem services for all policy issues, except human uses and conflicts. This is a weakness of the gap-analysis and will be addressed in the discussion.

For policy issues, the supply and demand on the overall level is mostly balanced. However, gaps are shown for single policy implementation steps and requirements for several issues. Gaps exist for DSTs that support the initial assessment for eutrophication in particular, but also for NIS, contaminants, marine litter and human uses and conflicts. Gaps for DSTs that address the development of plans and measures exist for biodiversity, NIS, and coastal flooding and adaptation. The need for DSTs supporting socio-economic assessments exists mostly on a general level. Gaps are shown for DSTs for socio-economic assessments in relation to NIS and eutrophication. Gaps for DSTs addressing adaptive, future-oriented management, for instance, by assessing future or long-term drivers or pressures such as climate change or population growth, are shown for biodiversity and human uses and conflicts.

On the overall level, the gap-analysis shows a satisfied demand for the policy issues commercial fish and shellfish and marine litter. For steps and requirements this is the case for assessment of environmental state, stakeholder involvement and public participation, and scenario development, analysis and evaluation. For environmental impact and risk assessment and ecosystem services assessments a satisfied demand is shown for the majority of policy issues.

DISCUSSION

Use and perception of DSTs in the BSR has been widely studied in the context of MSP (e.g., Stelzenmüller et al., 2013; Gee et al., 2019; Janßen et al., 2019; Pınarbaşı et al., 2019). In this study, we focused on end-users' current uses and demands for DSTs for supporting the management of the Baltic Sea. We included a wide range of DSTs and end-users from various backgrounds in order to distil key recommendations for future DST development and for enhancing their integration into coastal and marine policy implementation. Yet, being based on a limited number of DSTs and end-user perceptions, this study has some methodological limitations that one has to bear in mind. Hence, in the discussion we first point out some weaknesses, before we discuss the results and provide recommendations.

Methodological Limitations

First, the 43 DSTs reviewed in this study were taken from the DST inventory by Nygård et al. (2020), who conducted a comprehensive stocktaking and review of available DSTs in the BSR. Yet, the term DST can be broadly understood as any computer-based tool that condenses complex information in order to support decision-making. There is a diverse understanding of the concept, and some tools included in the DST inventory might not be perceived as DSTs in a strict sense. On the contrary, the DST inventory focuses on tools primarily developed for use in the BSR. Even though, DSTs that were originally developed for other sea areas, but adapted primarily to the Baltic Sea, were also included (e.g., InVEST). However, the initial focus on DSTs developed for the BSR excluded some DSTs that were included in other studies (e.g., Aries, SeaSketch).

Second, results of the end-user survey for policy implementation challenges, DST demand, and end-user suggestions included in this study, reflect personal opinions of a limited number of end-users. Thus, the results might partly differ in another sample of end-users. Most of our respondents were positive or not aware of DSTs. Hence, critical opinions are less reflected in our results. Since we focus on providing recommendations to overcome gaps and satisfy existing end-user needs, we can build upon these mainly positive opinions. Nevertheless, one has to bear in mind that decision-making and policy implementation are not straight forward processes and can be affected by factors that can hardly be addressed by DST (e.g., legal or governmental changes, lacking finances or lobbyism).

Third, in the gap analysis we compared DST demand and supply on an overall level for all policy issues, implementation steps and requirements, but also more specifically for steps and requirements for a particular policy issue (inner matrix). The numbers for DST demand are based on open-ended answers given by end-users, and are therefore low especially in the inner matrix. As a result, for many cells of the inner matrix no demand is indicated. If the DST supply is moderate (2 DSTs or more) for the same cell, the gap-analysis shows a satisfied demand, even if only generally applicable DSTs are available (e.g., in case of ecosystem services). Consequently, results for the inner matrix should be regarded with caution.

Bearing these limitations in mind, we will discuss our main findings and provide recommendations for future DST development, based on the identified demand, gaps and end-user suggestions.

Gaps and Development Areas for Which DSTs Are Most Needed

According to the gap analysis, none of the policy issues faces a concrete gap. Despite this, we see several potential development areas.

Eutrophication is seen as a major challenge among representatives of public authorities in the BSR and there is a strong demand for DSTs in this field. At the same time, this is the issue for which DST supply is largest. The majority of respondents in both surveys stated that their work is related to eutrophication. Consequently, the high demand could on one hand be generated by the imbalance of end-users in this work field in comparison to other topics. On the other hand, it could be generated by the existing supply, as people are likely to demand what they already know and are used to. However, there are several other factors that could cause this

mismatch between available DSTs and their use in practice. The majority of DSTs that address eutrophication are models, which usually require special expertise and are therefore not directly applicable by non-experts. Despite this, models help to assess consequences of alternative management options and are considered to be important for environmental decision-making (Schmolke et al., 2010). Several respondents of the end-user survey stated, that they use outcomes of nutrient load models (such as VEMALA, MONERIS) to support decision making. Yet, these models are often country- or catchment-specific and not easily transferable to other regions (cf. Nygård et al., 2020; DESTONY DST database). This limits the availability of DSTs for end-users and could also explain the high demand. Furthermore, despite successful efforts to reduce nutrient loads in response to European and Baltic Sea regional policies (e.g., BSAP, MSFD, WFD), the environmental status of the Baltic Sea for eutrophication has not improved and additional measures are required in order to reach a good status (Schernewski et al., 2015; Heiskanen et al., 2019). Developing plans or programs of measures are seen as a major challenge among end-users in general, but for eutrophication in particular. Consequently, DSTs supporting the identification of suitable measures and demonstrating their effectiveness are needed. A strong cooperation between developers and end-users might make it possible to adjust existing tools to meet this demand.

Managing biodiversity and human uses and conflicts are also seen as challenges among end-users in the Baltic, and there is a moderate demand for DSTs in both fields. Especially DSTs that link both issues are demanded by end-users, for instance to assess anthropogenic impacts (e.g., agriculture, fisheries or changes in hydro-morphological conditions) on biodiversity or to plan measures (incl. MPAs) to protect biodiversity. This demand can be tackled in the context of MSP, and various DSTs (such as Marxan) have been developed to assist marine spatial planners (Pınarbaşı et al., 2017), yet their application in MSP practice remains limited (Janßen et al., 2019; Pınarbaşı et al., 2019).

A low DST demand is indicated for policy issues that are addressed by only a few policies according to our policy review (e.g., food webs, energy and noise, human pathogens, and coastal flooding and adaptation). Especially for recently emerging issues, such as energy and noise, the demand is likely to be low, because of the relatively low number of experts that are currently working in this field. Yet, underwater noise is still increasing and the knowledge and understanding of its impacts on marine species is limited (Farcas et al., 2016; Markus and Sánchez, 2018). Currently, only one tool (BIAS) models noise levels and assesses impacts of noise on marine species in the Baltic Sea. Hence, we see a high development potential for DSTs addressing underwater noise.

NIS and marine litter are also among the more recently emerging issues that have a low DST demand. Yet, both topics are dominantly included in more general DSTs that combine effects of NIS and/or marine litter with other anthropogenic pressures to assess cumulative impacts (e.g., BSII). However, specific DSTs to address NIS and marine litter are rare or lacking. One example is the BWMC tool that assesses risk introduction of NIS in ballast water. In order to satisfy end-user demand and for supporting the implementation of the EU Regulation on Invasive Alien Species, DSTs that assess risks of NIS are especially needed.

The importance of integrating natural and socio-economic aspects in coastal and marine management is widely recognized (Turner, 2000; Støttrup et al., 2017). Nevertheless, DSTs that support coastal and marine policy implementation mostly address environmental aspects (Pınarbaşı et al., 2017; Nygård et al., 2020). Our results also indicate a demand for DSTs supporting socio-economic assessments, ecosystem-based management (EBM), and ecosystem services. Yet, DSTs for these requirements were mainly demanded by researchers, but rarely mentioned by end-users from public authorities. The concepts of ecosystem services and EBM were only recently included in EU environmental policies and lacking in older, sectoral-based policies (Bouwma et al., 2018). Furthermore, the need for socio-economic assessments is highlighted especially in the MSFD and WFD (Ahtiainen et al., 2014). These requirements have been adopted only in more recent and holistic legislation and the level to which they are operational differs among member states, as illustrated by Hassler et al. (2019) for the implementation of MSPD requirements in the BSR. As such, the requirements might not yet be perceived as urging topics among representatives of public authorities. Yet, the European Commission recently published a working document on integrating ecosystem services into decision-making (EC, 2019b) and it is likely that they will gain increasing importance in future policy documents. Furthermore, Nygård et al. (2020) found a lack of DSTs that address the impacts on human welfare. DSTs that assess impacts on ecosystem services could fill this gap. Consequently, we recommend that DSTs, which address impacts on welfare and link environmental and socio-economic aspects should be developed.

Need for Raising Awareness About Available DSTs

Lacking awareness about the availability of DSTs has been identified as the main obstacle for DST use in this study as well as previous work (e.g., Pınarbaşı et al., 2017; Janßen et al., 2019). To raise awareness about DSTs, end-users need regularly updated information about available DSTs. Hence, a central DST database and information platform, which provides information about benefits, but also shortcomings of each DST, is urgently needed. Its long-term maintenance needs to be ensured and end-user needs have to be taken into account in the database development. Furthermore, end-user suggestions addressed the need to widely distribute information about available DSTs, e.g., by providing links on social media or web pages and ensure that they are permanently accessible.

Another limiting factor was lacking experience in applying DSTs. To overcome this, end-users need guidance or training. The majority of reviewed DSTs was found to be well documented and often published in reports or scientific articles (Nygård et al., 2020). Yet, lacking time to learn and apply them was identified as a constraint, especially among end-users from public authorities. Hence, in addition to the documentation in reports

or publications, user-friendly and easily accessible guidelines, free online tutorials or webinars for potential end-users are needed.

Need for Improving DST Quality

Shortcomings that end-users associated with known DSTs included oversimplification and poor communication of data quality and uncertainties. A review of ecological models used for supporting environmental decision making, conducted by Schmolke et al. (2010) revealed that good modeling practice is often lacking and that uncertainties are insufficiently communicated. This has also been observed for the DSTs included in this study (cf. van Beest et al., 2020). However, many environmental policies call for informed decision making based on scientific evidence. In order to increase the use of DSTs in policy implementation, end-users' confidence in DSTs and their outputs is crucial. Consequently, uncertainties should be better documented and communicated (van Beest et al., 2020).

Some end-users also suggested that increased flexibility of DSTs could improve their practical relevance. For instance, DSTs should be flexible, so that outputs can be adjusted according specific end-users needs. This includes for instance adjusting the level of detail provided by DST outputs, so that it can be used for detailed assessments but also for communicating results to stakeholders or the public. It was further suggested that DSTs should be spatially flexible, allowing applications for the Baltic Sea, national, or water body-specific level. User-friendliness has been frequently mentioned as an important factor for end-users. Characteristics associated with it include transparency and ease of use especially by non-scientists. Allowing different types of input data and data sharing were mentioned as additional factors that enhance user-friendliness. At the same time, there seems to be a need for standardized inputs and outputs in order to ensure comparability and ability to link specific tools rather than developing general DSTs. Hence, we recommend that tools should be flexible, so that the output can be adjusted according to the needs of specific end-users.

Integration of DSTs Into Coastal and Marine Policies

Recognition of DSTs in policy documents was suggested in order to increase the practical relevance of DSTs. According to our results, the most frequently known and used DSTs in the BSR are HEAT 3.0, BSPI, BSII and Symphony. The first three were developed by or in close cooperation with HELCOM and have been applied to support the Holistic Assessment of the Ecosystem Health of the Baltic Sea (HOLAS). Hence, they are directly used to support the implementation of the BSAP. Symphony, assess cumulative impacts of human pressures and has been developed and used by the Swedish Agency for Marine and Water Management (SwAM) to support the implementation of MSP in Sweden. These examples emphasize that a close cooperation with public authorities and recognition of DSTs in policy documents can enhance their level of use for supporting coastal and marine policy implementation. Hence, the use of data and spatial scales relevant for policy implementation can facilitate the integration of DSTs into coastal and marine policies.

CONCLUSION

Our research approach was suitable for identifying gaps between existing DSTs and policy and end-user needs in the BSR. Based on the results of this study and related studies by Nygård et al. (2020) and van Beest et al. (2020) we provide the following recommendations for future DST development:

Recommendations to overcome gaps and satisfy end-user needs

- New DSTs should support the development of plans and programs of measures, especially for the policy issues biodiversity, non-indigenous species, eutrophication and human uses and conflicts.
- DSTs covering policy issues not previously considered need to be developed: especially for non-indigenous species, but also for marine litter and underwater noise.
- Tools that address impacts on welfare and link environmental and socio-economic aspects should be developed.

Recommendations for increasing awareness

- End-users need information about existing DSTs: a user-friendly database that is maintained over the long-run is needed
- End-users need training and guidance: user-friendly guidelines, online tutorials – even cooperation with tool hosts.
- End-users should play an essential role in the development of DSTs, even take part in the development.

Recommendations for improving DST quality

- Outcome uncertainties should be documented and communicated – this important feature is not available in most existing DSTs.
- To fulfill the ecosystem approach, standard formats for DST inputs and outputs should be developed to enable interoperability - one tool covering all segments is not needed.
- DSTs need a host with continuous funding for maintenance and further development to be operational and useful for end-users.
- Tools should be flexible, so that the output can be adjusted according to the needs of specific end-users.

Even though, the recommendations are based on studying existing DSTs and end-user needs in the BSR, this study has relevance for DST developers and end-users in other regions as well.

Since eight of the nine countries surrounding the Baltic Sea are EU member states, the common EU policies are important for the BSR and are dominating in our policy review. Hence, the identified policy issues, steps and requirements that are used in the synthesis-matrix, are relevant for all EU member states, and are directly applicable to compare DST demand and supply in other regional seas. Furthermore, our methodology can be used as a framework and transferred to non-EU regions.

Furthermore, the Baltic Sea Region is considered to be at forefront of policy implementation in Europe. Hence, it is likely that policy implementation challenges, mentioned by end-user involved in our study, are also faced by end-users in other regional seas, and that their DST needs are similar. In particular, the DST demand for policy steps and requirements, could give an indication for potential DST demand and gaps for other regions as well. Yet, DST demands for policy issues are not easily transferable, because the main anthropogenic pressures differ among regional seas. Also obstacles for DST use (e.g., lacking awareness and experience) and shortcomings associated with existing DSTs (e.g., oversimplification and lacking communication of uncertainties) are not specific for Baltic DSTs. Thus, our recommendations for increasing awareness and improving DST quality are generally applicable.

Finally, the DST inventory by Nygård et al. (2020) and subsequent DST review conducted in this study, provide an overview of DSTs available in the BSR. They can be used as a foundation for developing new or adjusting the existing DSTs for applications in other regions.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

JS developed the manuscript concept, developed and conducted the end-user survey and policy review, took care of the data analysis, and wrote the manuscript. LB and JS developed and conducted the stocktaking questionnaires. GS supported the manuscript concept development. KP supported the stocktaking questionnaire and gap-analysis. JS, LB, JC, BG, BH, VF, HN, GS, AS, FB, and MZ contributed to the DST review and derivation of recommendations. All the authors contributed ideas for and provided comments on the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.587500/full#supplementary-material

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.