Marine Pollution Bulletin 160 (2020) 111669

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Gaps in current Baltic Sea environmental monitoring – Science versus management perspectives

Maria Kahlert[a,*], Kari Eilola[b], Leoni Mack[c], Kristian Meissner[d], Leonard Sandin[e], Helena Strömberg[f], Laura Uusitalo[d], Lena Viktorsson[b], Antonia Liess[g]

[a] Swedish University of Agricultural Sciences, Department of Aquatic Sciences and Assessment, PO Box 7050, SE-750 07 Uppsala, Sweden
[b] Swedish Meteorological and Hydrological Institute, SE-601 76, Norrköping, Sweden
[c] University of Duisburg-Essen, Faculty of Biology, 45141 Essen, Germany
[d] Programme for Environmental Information, Finnish Environment Institute, Jyväskylä and Helsinki Offices, Finland
[e] Norwegian Institute for Water Research, Gaustadalléen 21, NO-0349 Oslo, Norway
[f] Swedish University of Agricultural Sciences, Department of Aquatic Resources, The Institute of Freshwater Research, Stångholmsvägen 2, 178 93 Drottningholm, Sweden
[g] Halmstad University, Rydberg Laboratory for Applied Sciences, 301 18 Halmstad, Sweden

ARTICLE INFO

Keywords:
Biology
Marine management
Literature review
Holistic gap analysis
Stakeholder survey

ABSTRACT

Legislations and commitments regulate Baltic Sea status assessments and monitoring. These assessments suffer from monitoring gaps that need prioritization. We used three sources of information; scientific articles, project reports and a stakeholder survey to identify gaps in relation to requirements set by the HELCOM's Baltic Sea Action Plan, the Marine Strategy Framework Directive and the Water Framework Directive. The most frequently mentioned gap was that key requirements are not sufficiently monitored in space and time. Biodiversity monitoring was the category containing most gaps. However, whereas more than half of the gaps in reports related to biodiversity, scientific articles pointed out many gaps in the monitoring of pollution and water quality. An important finding was that the three sources differed notably with respect to which gaps were mentioned most often. Thus, conclusions about gap prioritization for management should be drawn after carefully considering the different viewpoints of scientists and stakeholders.

1. Introduction

Continuous environmental monitoring is the basis for understanding and implementing the most efficient actions for improving the poor ecological and environmental state of the Baltic Sea (HELCOM, 2018). Baltic Sea countries collaborate through the Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM, 2020) to assess the status of the Baltic Sea and ultimately protect and restore its ecological balance. The goals for achieving 'good status' are set by HELCOM's Baltic Sea Action Plan (BSAP) (HELCOM, 2019), which also outlines the actions needed to achieve these goals. Monitoring is regulated in HELCOM's COMBINE manual (HELCOM, 2017). The biological, chemical and physical Baltic monitoring programs also need to cover the requirements of regional, national and EU legislations. The key legislations to achieve goals related to the improvement of the ecological/environmental status of the Baltic Sea are the EU Marine Strategy Framework Directive (MSFD) (European Parliament and Council, 2008), and the EU Water Framework Directive (WFD) (European Parliament and Council, 2000). The three most important commitments and legislations under which monitoring is performed are thus the HELCOM's BSAP, the MSFD and the WFD, which are further detailed below:

(1) The BSAP is a voluntary commitment which aims at restoring good ecological status of the Baltic Sea by 2021 through the implementation of qualitative, holistic and harmonized monitoring. Its vision is to have an ecologically healthy Baltic Sea which also supports sustainable human activities. The BSAP is divided into four segments (eutrophication, hazardous substances, biodiversity, and maritime activities) for which specific objectives have been formulated (Table 1).
(2) The MSFD is a mandatory EU legislation focusing on function and sustainability of the Baltic Sea marine environment through a holistic assessment approach (Patrício et al., 2016) and aims to achieve Good Environmental Status (GES) of marine EU waters by 2020. The MSFD uses a total of 11 holistic quality descriptors (Table 1)

* Corresponding author.
E-mail address: maria.kahlert@slu.se (M. Kahlert).

https://doi.org/10.1016/j.marpolbul.2020.111669
Received 6 July 2020; Received in revised form 7 September 2020; Accepted 7 September 2020
Available online 17 September 2020

Table 1
Baltic Sea key monitoring requirements of (1) the Water Framework Directive (WFD) quality elements, (2) the Baltic Sea Action Plan (BSAP) objectives and (3) the Marine Strategy Framework Directive (MSFD) descriptors. We use "thematic categories" as a grouping term to categorize descriptors, quality elements and objectives, to highlight similarities and differences between the legislations/commitments and enable a joint gap analysis.

	Water Framework Directive (WFD)	HELCOM's Baltic Sea Action Plan (BSAP)	Marine Strategy Frame-work Directive (MSFD)
Thematic categories	Quality elements	Objectives	Descriptors
Water quality parameters	QE3: Physico-chemical	BS3: Concentrations of nutrients	D5: Eutrophication
		BS1: Clear water	
		BS5: Natural level of algal blooms	
		BS6: Natural oxygen levels	
Pollutants	QE4: Priority list pollutants	BS2: Concentrations of hazardous substances	D8: Contaminants
	QE5: Other pollutants	BS4: Healthy wildlife	D9: Contaminants in seafood
		BS8: Radioactivity	
Fisheries			D3: Commercial fish and shellfish
Biodiversity parameters	QE1: Biological	BS11: Viable populations of species	D1: Biodiversity
		BS10: Thriving and balanced communities of plants and animals	D4: Food webs
		BS7: No alien species	D2: Non-indigenous species
Sea-floor integrity			D6: Sea-floor integrity
Physical parameters	QE2: Hydromorphological		D7: Hydrographical conditions
Traffic, energy, noise		BS9: Safe maritime traffic	D11: Energy including underwater noise
Marine litter			D10: Marine litter

and several subordinate criteria and indicators for status assessment (Zampoukas et al., 2012; European Commission, 2017).

(3) The WFD is a mandatory EU legislation which aims to achieve Good Ecological Status for all EU surface and groundwaters, including coastal areas by 2027. The WFD bases the assessment of status on structural biological elements, supported by physical and chemical elements. The assessed measures are defined as quality elements (Table 1).

To promote GES of the Baltic Sea, HELCOM develops joint assessment approaches, harmonizes monitoring programs for comparability of methods, indicators, resolution in space and time, and establishes data hosts and databases to support indicator-based assessment. However, coordinated monitoring of certain key monitoring requirements of the Baltic is still insufficient (HELCOM, 2018). This is partly due to the failure to adopt to new legal requirements (Borja et al., 2010; European Commission, 2017) and to persistent gaps with respect to harmonization and old legislative requirements (Borja et al., 2010; HELCOM, 2018). For example, there is a clear need for better cooperation between countries and coordination of monitoring programs to exploit synergies between monitoring for different directives and pressures, especially others than eutrophication (Backer et al., 2010; Hering et al., 2010; HELCOM, 2018). The complex regulatory framework (e.g. Boyes and Elliott, 2014) of Baltic Sea monitoring, however, hinders a holistic view of the importance of different gaps. This complicates the implementation of new monitoring programs to fill those gaps, e.g. with the help of new monitoring techniques under development, that could potentially outperform or complement traditional methods.

The present study performs a general gap analysis of Baltic Sea monitoring to support the development of a more holistic approach. We initially defined seven major gap types (Table 2) in order to identify the most critical shortcomings of current Baltic Sea monitoring and data management in relation to the requirements set by the WFD, HELCOM's BSAP, and the MSFD. Our gap analysis is unique to incorporate the views of scientists as well as of water managers and other stakeholders, and to systematically categorize and place these gaps in thematic monitoring categories. Our study aimed to answer the following questions:

(1) Which gaps in current Baltic Sea monitoring are considered the most critical?
(2) Which thematic monitoring categories are identified as containing most gaps?

Table 2
List of the seven gap types: (G1) A certain indicator is not sufficiently monitored, due to low spatial or temporal coverage, or because of other specified or unspecified reasons. (G2) There is no indicator, or the current indicators are not adequate to assess a certain pressure. (G3) A certain pressure is not covered at all in the current monitoring. (G4) There are problems in data storage or handling. (G5) Deals with an improved or new indicator or method that should be included into current monitoring, but it is still in development, not yet operational, or decided upon. (G6) There are problems in the coordination of monitoring, often including non-harmonized methods. (G7) The costs of current (existing) methods are too high. (GNI) No specific information given about the gap type.

Gap type	Explanation		
G1	Insufficient monitoring effort	(a)	Spatially
		(b)	Temporally
		(c)	Other or no information
G2	Missing/inappropriate indicator		
G3	Missing thematic category (e.g. missing "descriptor, quality element, objective")		
G4	Problems with data storage/handling		
G5	Indicator under development		
G6	Insufficient monitoring coordination		
G7	Monitoring costs too high		
GNI	No specific information about gap type		

2. Methods

2.1. General approach

To identify the most critical monitoring gaps in Baltic Sea monitoring in relation to the requirements set forth by WFD, BSAP and MSFD, we searched for and compiled gaps from three different sources; i) peer-reviewed scientific articles selected via a systematic scientific literature review, ii) Baltic Sea related research project reports, and iii) stakeholders views gathered via an survey. These three sources were analyzed separately, and the results were compared to identify similarities, differences and knowledge gaps. To enable a common evaluation of gaps between the quality elements (WFD), objectives (BSAP) and descriptors (MSFD), these were combined under thematic categories with subcategories (see Table 1). To compare the gaps identified from the three different sources we defined seven major types of gaps before the analysis (see Table 2). The gap definitions were based on expert discussions, stakeholder interviews and a screening of gaps mentioned in the literature. After categorizing monitoring gaps and challenges into gap types, we analyzed how often these gaps were mentioned in

scientific articles, project reports and in the stakeholder survey, separately for the three sources. Each mention of a thematic category or gap was counted separately, thus it was possible for a single source to contribute more than one observation if more than one thematic category or gap was mentioned. If a source described a gap in monitoring of thematic categories neither belonging to WFD, BSAP or MSFD (as defined in Table 2), these were assigned into the category "Other". If a source described a gap in the monitoring of a certain thematic category, but did not supply enough information to specify the gap type, these were registered as the gap type "no information" (GNI). We defined a gap as being more critical if it was mentioned more often in comparison to the other gaps, as we assumed that often discussed issues were considered more important by the respective source used.

2.2. Systematic Scientific Literature review

For the article selection, we searched the Web of Science Core Collection for scientific articles published from the year 2008 onwards (when the MSFD was adopted) to March 2019 (search date: 28.2.2019) using the search terms "Baltic Sea" AND "monitor* OR assessment" which resulted in 1865 articles. A screening of the articles was made in two steps: (1) The titles were screened to dismiss articles with a title that clearly indicated that the article was not relevant for the analysis. (2) The abstracts of the remaining 1338 articles were read and a further 1010 articles were dismissed as they did not describe gaps in monitoring relevant for the study. After this initial screening 328 articles remained. Of these, 19 were not available in full text to us at the time of the analysis. After reading the full texts of the remaining 309 articles, we excluded another 100 articles because they did not mention monitoring gaps, but dealt with either management issues or status classification instead. The final systematic gap analysis is thus based on 209 relevant articles (Supplement 1).

The systematic gap analysis of the relevant 209 articles was performed using a template to search the articles for the same key information. Articles were scanned for the four keywords "monitor*", "descriptor", "indicator" and "gap" to identify article sections relevant to our analyses. The relevant sections were then read in detail to identify the thematic category/categories (Table 1) that were mentioned in the article. A template with the following questions was used to distribute the gap identification into categories: Did the authors (1) describe gaps regarding the monitoring of an existing indicator for a certain thematic category, (2) identify the need for a new indicator to reflect the thematic category adequately, (3) identify gaps regarding data storage or handling of a certain indicator, (4) propose to include a new thematic category in the monitoring programs or (5) identify further monitoring gaps? All gaps were classified following our definitions (Tables 1, 2) and compiled into a table.

2.3. Project report review

HELCOM and BONUS (the joint Baltic Sea research and development program) project reports were selected to cover existing knowledge about gaps specific to the Baltic Sea monitoring. We chose BONUS as part of our main dataset of reports as the improvement of monitoring methods is specifically included in the program. All available final and annual reports of BONUS projects from the competitive calls 2012–2017 are available through the BONUS website and were used as material for our analysis. HELCOM reports were chosen because also HELCOM is specific to the Baltic Sea, and the program had a focus on the improvement of the choice of monitoring indicators specifically in the Baltic Sea in relation to anthropogenic pressures, environmental policy and monitoring programs during 2010–2015. We searched for relevant HELCOM reports available from open data bases. For the selection of relevant BONUS and HELCOM reports for our analysis, we used the same selection criteria as for the scientific literature. In total 27 BONUS and HELCOM reports published between 2008 and 2019 were identified, dealing with the improvement of Baltic Sea monitoring. The reports were read using the same question template as for the scientific articles and analyzed for the same gap types and thematic categories in the same way as for the scientific articles. A total of 17 of the 27 reports included relevant information on monitoring gaps and were included in the final systematic gap analysis (Supplement 2).

2.4. Stakeholder survey

The same question template as for the two literature reviews was also used for the stakeholder survey, and the results were quantified in the same way to enable a direct comparison. Based on the insight from experts at our institutes, 42 key stakeholders of different national and international management institutions dealing with Baltic Sea monitoring were identified and targeted directly. We deliberately targeted national managers, agencies and ministry representatives responsible for high level monitoring planning to include their perspectives. Key stakeholders also included some research institutions where those were appointed hosts of national monitoring or data. In addition to those, the survey was also advertised via our project webpage (Finnish Environment Institute, 2019), and in meetings with relevant stakeholders to attract a wide selection of stakeholder inputs. We further encouraged dissemination to other relevant stakeholders. Following EU General Data Protection Regulation requirements, survey replies were collected anonymously. A total of 31 completed survey replies were submitted and analyzed, of which most came from Germany (11) and Sweden (11), then Finland (4), followed by Latvia (2). Estonia, Lithuania and Poland were represented by one reply each. Most stakeholders replied that their expertise was in Baltic Sea Environmental Management working with marine HELCOM and/or MSFD. See Supplement 3 for the full survey outline.

3. Results and discussion

3.1. Overview

Considering the combined view of the three different sources of information, we found that the current monitoring of the Baltic Sea does not sufficiently address the requirements set by the WFD, HELCOM's BSAP, and the MSFD. All types of sources included (articles, reports, and stakeholders) identified gaps in Baltic Sea monitoring and agreed that many assessment parameters of the Baltic Sea regulatory framework are not sufficiently monitored (Fig. 1A), and that monitoring should be intensified both temporally and spatially (Supplement 4). All types of sources most often mentioned gaps within the thematic category biodiversity parameters (Fig. 1B).

The reason why most of the gaps were encountered in the thematic category biodiversity parameters is probably because biodiversity monitoring and assessment were historically implemented much later than traditional chemical eutrophication and pollution monitoring, and are therefore less standardized (HELCOM, 2018). For decades, the focus of international concern has been eutrophication monitoring (HELCOM, 2018). Baltic Sea eutrophication monitoring therefore follows established international guidelines (Carstensen et al., 2011; HELCOM, 2017). Biodiversity monitoring was added to Baltic Sea monitoring only through the implementation of the European Union framework directives such as the WFD (2000) and MSFD (2008). In aquatic assessments, a plethora of different national methods for biodiversity monitoring exist due to the highly complex nature of biological parameters (e.g. Birk et al., 2012). This complexity is in stark contrast to easily monitored, measured and standardized chemical parameters. Due to its late implementation, biodiversity monitoring and assessment are much less standardized and harmonized (Carstensen et al., 2011). Despite the consensus of gaps in biodiversity parameters, it is difficult to identify which missing parts should be given priority in biological monitoring. Our sources point to various subcategories (i.e. WFD quality elements,

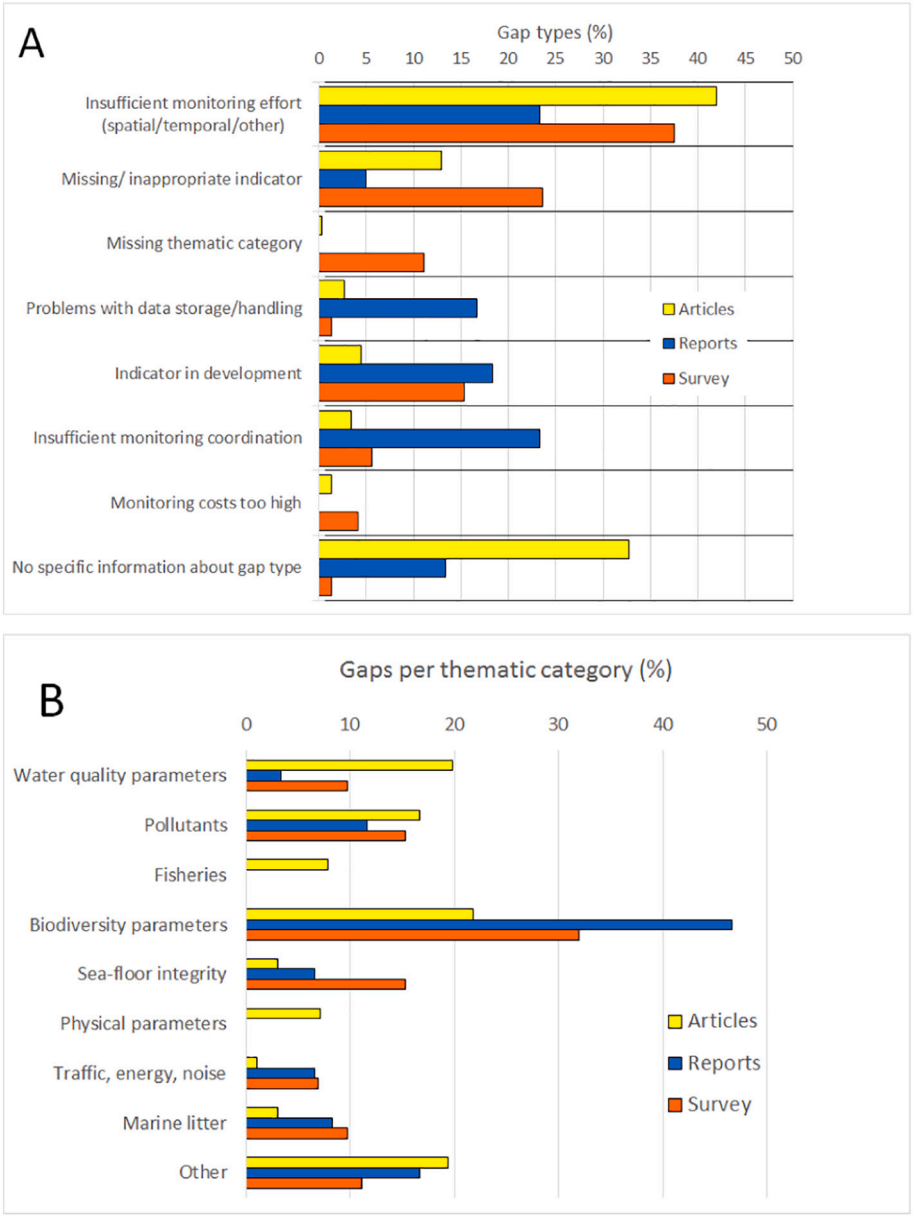

Fig. 1. Gaps in current Baltic Sea environmental monitoring in proportion to the total amount of gaps identified for each of the source types used for the review (scientific articles, project reports and stakeholder survey replies, respectively). Articles: total amount of gaps mentioned: 293 (found in 209 articles); reports: total amount of gaps mentioned: 60 (found in 17 reports); survey: total amount of gaps mentioned: 72 (found in 31 replies). (A) Gap types. (B) Gaps in different thematic categories, i.e. the Baltic Sea key monitoring requirements (of WFD, BSAP, MSFD).

BSAP objectives, MSFD descriptors) and to many different gap types. In addition to the most frequently mentioned gap, insufficient monitoring effort of existing parameters, our information sources also often mentioned missing or inappropriate indicators, insufficient monitoring coordination, problems with data storage or handling, and indicators under development, although the frequencies differed between the sources (Suppl. 4). Thus, there are many different problems with biodiversity monitoring and therefore several solutions are needed, such as implementation of cost-efficient novel methods (see methods proposed by Mack et al., submitted). Other studies suggest that improved large-scale monitoring along with an optimized statistical design of monitoring programs and better coordination will lead to increased harmonization, integration and standardization of monitoring programs (e.g. Carstensen et al., 2011; Swaney et al., 2012). Such improvements promote adequate and accessible monitoring data for fundamental and applied research. Improved data quality and accessibility, in turn, further improve analysis and evaluation (Sulkava et al., 2007), improving the efficiency of monitoring and sampling, thus benefiting all aspects of Baltic Sea environmental monitoring (HELCOM, 2018).

The three information sources (scientific articles, scientific reports, and the stakeholder survey) all mentioned non-sufficient monitoring in general and biodiversity parameter monitoring in particular most often, but they strongly differed in how often other monitoring gap types and other thematic categories were mentioned (Fig. 1, Supplement 4). The most often mentioned gap type in scientific articles was insufficient monitoring effort, whereas the other six gap types were less often mentioned in articles compared to reports or the stakeholder survey (Fig. 1A). We find three probable causes for these differences in gap type identification between articles, reports and the stakeholder survey. These causes are connected to the different focus of most scientific articles: First, most scientific articles are not written with the aim to find monitoring gaps related to requirements in legislation, but rather

focus on the study of single novel methods, or on how to use specific monitoring data for assessments or other research questions of particular importance to scientists. In these cases, the mentions of insufficient monitoring effort probably present a justification for why a certain novel method is needed for monitoring, or dissatisfaction with existing monitoring data when using them for comprehensive ecological analyses. Mentioning that indicators are missing is of course also helpful when describing a novel method in scientific articles, and indeed this gap type was the second most often mentioned one. Second, many scientists are not involved with legislative monitoring and may be unconcerned or unaware of ongoing efforts to improve routine Baltic monitoring, and of the problems in the coordination of monitoring or related administrative issues. Third, many of the scientific articles were written during a period when the regulations scrutinized here (WFD, MSFD), or their updated revisions (BSAP), were new and generally not yet that well known among scientists. The bias of most researchers towards their research fields is reflected by the fact that the key word in the MSFD legislation, i.e. descriptor, is rarely used in scientific articles. It is also reflected in the relatively large number of gap type GNI in the articles: In a third of all cases where articles described a gap in monitoring in a certain thematic category, the article did not supply enough information to specify gap type, thus forcing us to categorize the gap type as “no information” (GNI) (Fig. 1A). In summary, we assume that articles were not focused on the actual monitoring programs and gaps therein, but rather on the development of monitoring methods, indicators or collection of data needed for solving scientific questions within a certain thematic category. Very few articles focused on a holistic analysis of Baltic Sea monitoring or on monitoring gaps in relation to legislative requirements. Our findings fit well to the study of Choi (2005), stating that “[researchers] are less interested in broad issues, for example, the ‘big picture’ social or policy aspects of their work” whereas “…[policymakers] are more interested in broad issues, for example, solutions that can be generally applied to a wide variety of problems”.

In contrast to scientific articles, the analyzed reports came from projects that explicitly focused on improving Baltic Sea monitoring by analyzing monitoring gaps or suggesting how to deal with these gaps. Reports were thus focused on gaps in data storage or handling, coordination of monitoring, or highlighted that there are plans to implement new indicators that are not operational yet, which is likely why these three gaps were mentioned as often as insufficient monitoring effort, and more frequently than in scientific articles or by the stakeholders. In most cases, reports gave sufficient information to categorize a gap into a type, i.e. gap type GNI was relatively rare compared to scientific articles. Mentioning specific gap types does require detailed knowledge of administrative and managerial aspects of Baltic Sea monitoring. This shows that report authors are more aware of the practical challenges of data handling and routine monitoring coordination. We assume that the gap type “missing thematic category” was not taken up at all by the reports because most of them are based on projects with predefined thematic categories as a basis. Finally, the stakeholder survey represents a mixture of viewpoints. Insufficient monitoring effort was mentioned most often, but stakeholders highlighted that an indicator or a thematic category was missing more often than articles or reports did. Both stakeholders and reports mention that new indicators were under development but not yet operational more often than articles do, probably because articles mostly deal with completed research projects, and not with the implementation of new indicators or methods. We hypothesize that responding stakeholders were especially motivated to respond to gain visibility for an indicator they were working on or trying to include in future monitoring programs, and that both report authors and stakeholders had a deeper insight into ongoing indicator development and implementation issues compared to scientific article authors. The very low amount of gap types without further information (GNI) reflects the fact that the survey questions were formulated such that they were able to successfully categorize gap type information, with only free text answers introducing some ambiguity.

The three sources differed not only in the frequency of mentioned gap types, but also in which thematic categories they identified gaps in. As stated before, biodiversity parameters were mentioned most often by all sources as the thematic category with gaps in relation to the Baltic Sea regulatory frameworks (Fig. 1B). However, the share of the different thematic categories varied among the three sources (Fig. 1B). In reports, biodiversity parameters dominated clearly, while in scientific articles, pollution and water quality parameters were mentioned nearly as often as biodiversity. Stakeholders mentioned sea-floor integrity with a higher frequency than did the other two sources. The reasons for these patterns are unclear. One possible explanation is the historical focus on eutrophication and pollution monitoring, resulting in a recent effort to compensate shortcomings in the monitoring of biodiversity. Therefore, projects addressing indicators to monitor biodiversity and methods to enable their implementation are currently promoted, reflected in project reports and in the views of stakeholders with a deep insight into ongoing issues (Suppl. 2). One could also hypothesize that the need for more research on biodiversity parameters is not yet reflected in scientific articles, because of the time lag from the current identification of knowledge gaps to the setting up of calls for research projects to cover those gaps, and finally the publication of scientific articles.

In summary, while it was possible to answer which thematic categories contained the most gaps (biodiversity parameters), we cannot easily summarize which gap types in the current Baltic Sea monitoring are, or are considered, the most critical. It is clear, however, that consulting only one of these sources would have given a less comprehensive picture of the situation, and potentially have led to a false notion of understanding the bigger picture. Scientific articles give a picture that monitoring data are missing to carry out an adequate ecosystem analyses of the Baltic Sea, but also have an intrinsic bias towards the researchers' interests and expertise (e.g. in terms of specific organisms or methods), and were mostly not as connected to environmental policy and monitoring programs as the reports and the stakeholder replies we reviewed. On the other hand, most reports were directed towards the goals of the underlying project, and were therefore biased towards already identified gaps. Such reports often dealt with only one or a few categories, or a single indicator, and were seldom aimed at giving a holistic overview, except for HELCOM (2018). Further, reports are in general often centered around well-established national reporting to the EU and HELCOM, with the aim of demonstrating that national monitoring efforts and indicators exist, and that the specific legislative requirements are met. Therefore, reports may omit issues related to monitoring gaps that have not been highlighted in legislation or earlier analyses, and are also less likely to report that a thematic category is entirely missing. Indeed, scientific articles did not only highlight gaps in the thematic category biodiversity parameters, but almost equally often in water quality parameters and pollutants, indicating that even if the monitoring of those parameters is more standardized, scientists still are not satisfied with it. We are aware that the limited number of reviewed reports and stakeholder replies in comparison to the scientific articles might increase the chance for a bias. Due to the open and anonymous nature of the stakeholder survey, no selection of replies was performed, which also increases the chance of a bias. On the other hand, the stakeholder survey provided us with the possibility to directly approach the people in charge of Baltic Sea monitoring and collecting their views on current developments, whereas both reports and especially articles might be less up to date. Despite the associated limitations of individual sources, we still think that only a quantitative analysis of all sources allows proper comparison of the different viewpoints. The results of both reports and the stakeholder replies reflected a different view from that of the scientific articles, and it therefore is important to examine all sources when deciding upon the prioritization of monitoring gaps.

Our analysis clearly demonstrates that managerial conclusions about which gaps to prioritize should be drawn carefully, bearing in mind that the different sources of information have different emphasis.

Researchers, water managers and other stakeholders from different fields of expertise can have quite different viewpoints on where to focus measures to improve Baltic Sea monitoring and assessments. Thus, it is very important that measures to improve Baltic Sea monitoring do not fall prey to partial lobbying interests (Freire-Gibb et al., 2014), but are adapted to the problem at hand (Swaney et al., 2012) in a cooperative manner, on a regional level and with the involvement of all concerned parties. The Baltic Sea has been pointed out as the marine water body with the highest level of regional monitoring cooperation (Freire-Gibb et al., 2014), and HELCOM as a model of success for international monitoring coordination (Backer et al., 2010; Freire-Gibb et al., 2014). It is essential that this high level of cooperation persists in future, even in times of waning environmental interest or economic growth (Backer et al., 2010; Freire-Gibb et al., 2014), in order to monitor, preserve and manage the Baltic Sea ecosystem in a sustainable manner for the benefit of all neighboring countries as well as for the benefit of future generations.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2020.111669.

CRediT authorship contribution statement

Maria Kahlert: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Project administration; Kari Eilola: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing; Leoni Mack: Conceptualization, Methodology, Writing - Review & Editing; Kristian Meissner: Conceptualization, Writing - Review & Editing, Project administration; Leonard Sandin: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing; Helena Strömberg: Formal analysis, Writing - Review & Editing; Laura Uusitalo: Conceptualization, Methodology, Writing - Review & Editing; Lena Viktorsson: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing; Antonia Liess: Conceptualization, Writing - Original Draft, Writing - Review & Editing.

Declaration of competing interest

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

Acknowledgements

This work resulted from the BONUS FUMARI project (Finnish Environment Institute, 2019) which has received funding from BONUS (Art. 185), which is jointly funded by the EU, the Academy of Finland and the Swedish Research Council Formas. We would like to thank especially Harri Kuosa, SYKE, for the help with report selection. We also thank the reviewers for their valuable comments.

References

Backer, H., Leppanen, J.M., Brusendorff, A.C., Forsius, K., Stankiewicz, M., Mehtonen, J., Pyhala, M., et al., 2010. HELCOM Baltic Sea action plan - a regional programme of measures for the marine environment based on the ecosystem approach. Mar. Pollut. Bull. 60, 642–649.

Birk, S., Bonne, W., Borja, A., Brucet, S., Courrat, A., Poikane, S., Solimini, A., et al., 2012. Three hundred ways to assess Europe's surface waters: an almost complete overview of biological methods to implement the Water Framework Directive. Ecol. Indic. 18, 31–41.

Borja, A., Elliott, M., Carstensen, J., Heiskanen, A.S., van de Bund, W., 2010. Marine management - towards an integrated implementation of the European Marine Strategy Framework and the Water Framework Directives. Mar. Pollut. Bull. 60, 2175–2186.

Boyes, S.J., Elliott, M., 2014. Marine legislation – the ultimate 'horrendogram': international law, European directives & national implementation. Mar. Pollut. Bull. 86, 39–47.

Carstensen, J., Dahl, K., Henriksen, P., Hjorth, M., Josefson, A., Krause-Jensen, D., 2011. Coastal monitoring programs. In: Treatise on Estuarine and Coastal Science, Vol 7: Functioning of Ecosystems at the Land-Ocean Interface. vol. 7. pp. 175–206.

Choi, B.C.K., 2005. Can scientists and policy makers work together? J. Epidemiol. Community Health. https://doi.org/10.1136/jech.2004.031765.

European Commission, 2017. Commission Directive (EU) 2017/845 of 17 May 2017 Amending Directive 2008/56/EC of the European Parliament and of the Council as Regards the Indicative Lists of Elements to Be Taken Into Account for the Preparation of Marine Strategies (Text With EEA Relevance).

European Parliament, and Council, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Off. J. Eur. Union L327, 1–73.

European Parliament, and Council, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (text with EEA relevance). Off. J. Eur. Union L164/19.

Finnish Environment Institute, 2019. Future marine assessment and monitoring of the Baltic – BONUS FUMARI. Retrieved 14 February, 2020, from. https://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/BONUS_FUMARI/Future_Marine_Assessment_and_Monitoring_(48355).

Freire-Gibb, L.C., Koss, R., Margonski, P., Papadopoulou, N., 2014. Governance strengths and weaknesses to implement the marine strategy framework directive in European waters. Mar. Policy 44, 172–178.

HELCOM, 2017. Manual for marine monitoring in the COMBINE Programme of HELCOM. Retrieved 5 June, 2020, from. https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-guidelines/combine-manual/.

HELCOM, 2018. State of the Baltic Sea – second HELCOM holistic assessment 2011–2016. Baltic Sea Environment Proceedings 155. ISSN 0357-2994. Available at. www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/.

HELCOM 2019. Baltic Sea Action Plan. Retrieved 31 July, 2019, from http://www.helcom.fi/baltic-sea-action-plan.

HELCOM, 2020. Baltic marine environment protection commission - about us. Retrieved 14 July, 2019, from. https://helcom.fi/about-us/.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C.K., Heiskanen, A.-S., et al., 2010. The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. Sci. Total Environ. 408, 4007–4019.

Mack, L., Attila, J., Aylagas, E., Beermann, A., Borja, A., Hering, D., ... Liess, A., 2020. A synthesis of marine monitoring methods with the potential to enhance the status assessment of the Baltic Sea. Front. Mar. Sci. 7, 552047. https://doi.org/10.3389/fmars.2020.552047.

Patrício, J., Little, S., Mazik, K., Papadopoulou, K.-N., Smith, C.J., Teixeira, H., Hoffmann, H., et al., 2016. European marine biodiversity monitoring networks: strengths, weaknesses, opportunities and threats. Front. Mar. Sci. 3, 161 (doi: 110.3389/fmars.2016.00161).

Sulkava, M., Luyssaert, S., Rautio, P., Janssens, I.A., Hollmén, J., 2007. Modeling the effects of varying data quality on trend detection in environmental monitoring. Ecological Informatics 2 (2), 167–176. https://doi.org/10.1016/j.ecoinf.2007.03.008.

Swaney, D.P., Humborg, C., Emeis, K., Kannen, A., Silvert, W., Tett, P., Pastres, R., et al., 2012. Five critical questions of scale for the coastal zone. Estuar. Coast. Shelf Sci. 96, 9–21.

Zampoukas, N., Piha, H., Bigagli, E., Hoepffner, N., Hanke, G., Cardoso, A., 2012. Monitoring for the Marine Strategy Framework Directive: Requirements and Options. JRC Scientific and Technical Reports. http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/23169/1/lbna25187enn.pdf.