Sea Level Rise in Europe: knowledge gaps identified through a participatory approach

Coordinating lead author: José A Jiménez[1]
Authors: Gundula Winter[2], Antonio Bonaduce[3], Michael Depuydt[4], Giulia Galluccio[5], Bart van den Hurk[2], H.E. Markus Meier[6], Nadia Pinardi[7], Lavinia G. Pomarico[8], Natalia Vazquez Riveiros[9]

[1]Laboratori d'Enginyeria Marítima, Universitat Politécnica de Catalunya·BarcelonaTech, Barcelona 08034, Spain.
[2] Deltares, Boussinesqweg 1, Delft, The Netherlands.
[3] Nansen Environmental and Remote Sensing Center (NERSC), Bergen, Norway.
[4] Joint Programming Initiative – Climate, Brussels, Belgium.
[5] Euro-Mediterranean Center on Climate Change, 20123 Milano, Italy.
[6] Leibniz Institute for Baltic Sea Research Warnemünde, 18119 Rostock, Germany.
[7] Decade Collaborative Center for Coastal Resilience, Department of Physics and Astronomy, University of Bologna, Italy.
[8] Joint Programming Initiative Healthy and Productive Seas and Oceans, Brussels, Belgium.
[9] UMR 6538 Geo-Ocean, CNRS, IFREMER, UBO, Plouzané, France.

Correspondence to: José A Jiménez (jose.jimenez@upc.edu)

Abstract

The Intergovernmental Panel on Climate Change (IPCC) plays a pivotal role in delivering information and knowledge on sea level rise (SLR), a global threat impacting coastlines worldwide. However, considerable disparities still persist in Europe in understanding and applying sea level science, evaluating its repercussions, and devising effective adaptation strategies. These are influenced by local factors such as diverse environments, socioeconomic conditions, policy contexts, and diversity in stakeholder involvement, producing in turn varying knowledge gaps and information needs across European sea basins. In this context, this chapter presents the findings of a comprehensive scoping process carried out by the European Knowledge Hub on Sea Level Rise (KH SLR) to define the outline of the first KH SLR Assessment Report. It consists of the analysis of stakeholder responses to an online survey and insights shared during four regional workshops, aiming to pinpoint critical gaps in available information on SLR and its potential consequences in European sea basins. It considers viewpoints from both scientific and policy perspectives, engaging stakeholders from academia and research, and government sectors. The analysis is divided into three categories: i) SLR science and information, ii) SLR impacts, and iii) SLR adaptation policies and decision-making. Regarding SLR science and information, many respondents found that relevant gaps exist in regional SLR projections and uncertainties, particularly related to long-term (from multi-decadal to end of century) SLR induced by potential melting of large icesheets. Interestingly, the perspective on information gaps is different for scientists (emphasizing the need to increase regional projection capabilities) and government users (stressing the availability of accurate projections for their regions). Regarding impacts and hazards, shoreline erosion stands out as a dominant concern in all sea basins except the Arctic, while emerging issues like saltwater intrusion and the role of SLR in compound risks associated with extreme water levels and river flow were also given significant regional relevance. With regards to policy and decision making, existing adaptation plans are perceived as ineffective and lacking adaptability, with gaps related to underestimated impacts and urban planning. Participants, especially end-users of sea-level knowledge, emphasised the relevance of improved information dissemination and communication to support informed decision-making.

1. Introduction

Despite the global threat posed by sea level rise (SLR) to coastlines worldwide and the crucial role played by the IPCC in providing assessments based on existing literature (IPCC, 2021; IPCC, 2022), there remains an uneven distribution in both the knowledge and application of sea level science, the assessment of its impacts, and the formulation of adaptation plans (Magnan et al., 2023; McEvoy et al., 2021). This may be associated with local factors such as the diversity of environments, socioeconomic conditions, policy contexts, and stakeholders, which cause local needs and knowledge gaps to vary from one site to another. As decisions regarding the response to SLR need to be made at a national, regional or local scale, it is necessary to assess knowledge gaps and needs at the same scale. This is the ambition of the European Knowledge Hub on Sea Level Rise (KH SLR) which was initiated with the objective of providing easily accessible and practical knowledge on regional and local sea level changes and their consequences. For each of the ocean and sea basins surrounding Europe (Fig. 1, Table 1), characteristics on drivers of sea level variability, coastal occupation, SLR impacts and approaches to SLR adaptation are recognised.

To achieve its long-term goals (see Sea Level Rise in Europe: a Knowledge Hub at the ocean-climate nexus), the initial implementation phase of the KH SLR centred on a scoping process. This process consisted of four key components that collectively contributed to identifying the primary issues pertinent in European Seas. The approach followed a bottom-up methodology, which integrated the viewpoints and contributions of representative stakeholders from European Seas. As suggested by (Fraussen et al., 2020), an effective stakeholder consultation approach involves a hybrid array of tools, encompassing open surveys, workshops, conferences and closed consultations with specific interest groups. This comprehensive approach enhances engagement with a diverse range of stakeholders and ensures a rich inflow of information.

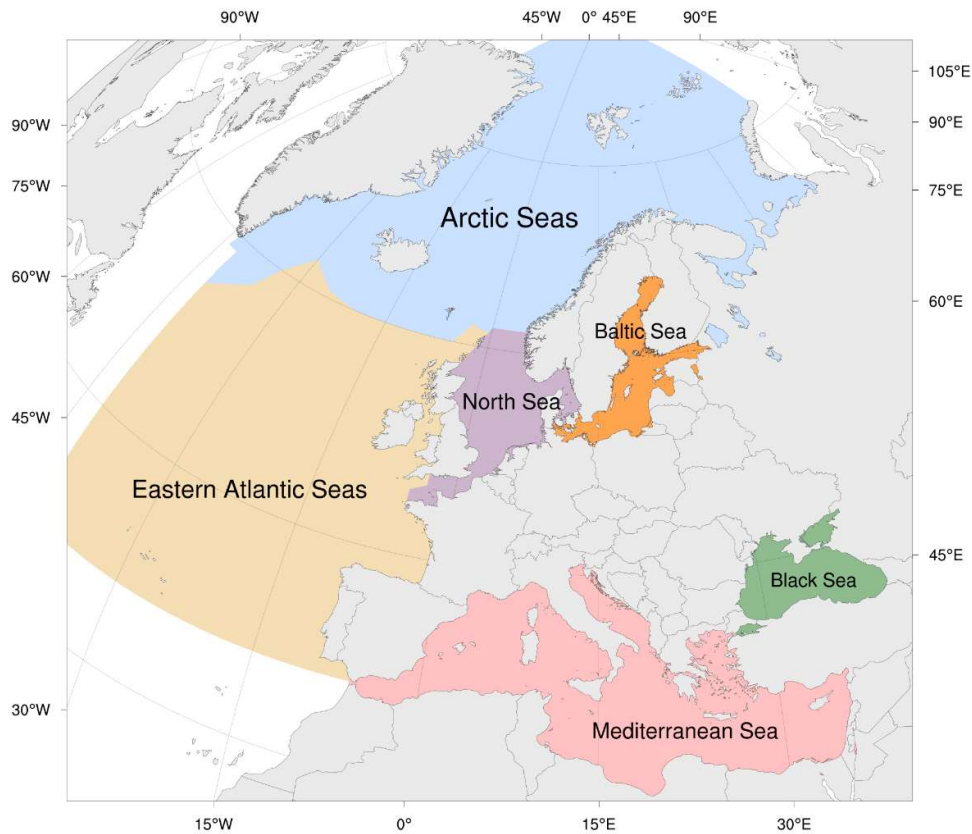



Figure 1. KH categorization of sea and ocean basins across Europe into regional seas, which serves to organise the consultation process.

The KH SLR scoping process adopted this hybrid approach through four key components: (i) an online survey, designed to collect insights and perceptions on SLR in European sea basins from a diverse range of stakeholders; (ii) four dedicated workshops on SLR, tailored to each basin, which provided focused discussions and knowledge exchange, enabling a deeper understanding of regional challenges; (iii) a pan-European conference on SLR, serving as a platform for experts and stakeholders from across Europe to share their expertise, experiences, and perspectives on SLR; (IV) a closed consultation with member country representatives involved in the Joint Programming Initiatives (JPI), JPI Climate and JPI Oceans.

The Sea Level Conference 2022, promoted by the KH SLR, focused on evaluating and exchanging scientific knowledge and policy development regarding SLR in European coastal regions. Rooted in findings from the survey and scoping workshops, it featured insights from experts from the Knowledge Hub as well as invited experts and policymakers from each basin, through a combination of keynotes, panels, and posters. The outcomes aimed to provide accessible and updated knowledge tailored to users across European basins, addressing the needs of policymakers, coastal planners, and stakeholders.

This work provides a comprehensive summary of the scoping process undertaken in the survey and sea basin-specific workshops, and presents the key findings from each. The primary objective of this process is to identify critical gaps in available information on regional SLR and its potential impacts in European sea basins and to discern the knowledge requirements and areas necessitating further research for both experts and stakeholders. These findings form the basis for this assessment report and are expected to inform future research endeavours and policy decisions.

Table 1. Basic indicators per European sea basins (data sources and methodology are shown in Supplementary material) (LECZ: low elevation coastal zone, between 0 and +10 m above MSL; GIA: glacial isostatic adjustment). Rates of SLR per European regional seas for 1950-2014 based on (Dangendorf et al., 2019). Coastal archetypes as defined in Haasnoot et al (2019). Methods to derive extension of archetypes and population are shown in the Supplementary material. (*) The extension of the coastal zone along the European sea basins used to measure archetypes and population in LECZ is shown in figure S2 (supplementary material).

Basin name and countries (*)	Mean SLR 1950-2014 (mm/year)	Coastal archetypes (%)	Population in LECZ (2020)
North Sea (*Denmark, UK, Germany, Norway, Netherlands, Belgium*)	1.5 ± 0.1	Urban: 6.44 % Rural: 62.62 % Urban delta: 0.49 % Rural delta: 2.73 % Urban estuary: 0.72 % Rural estuary: 23.91 % Urban delta/estuary: 0.41% Rural delta/estuary: 1.82% Cliff: 0.87 %	24.88 M people
Arctic Seas (*Norway, Iceland*)	1.5 ± 0.1 1.4 ± 0.1 (GIA corrected)	Urban: 4.29 % Rural: 84.39 % Urban estuary: 0.44 % Rural estuary: 5.90 % Cliff: 4.97 %	9.02 M people
Atlantic coast (*France, Spain, Ireland, UK, Portugal*)	1.2 ± 0.1		
Baltic Sea (*Sweden, Denmark, Finland, Latvia, Estonia, Lithuania, Poland, Germany*)	-1.1 ± 0.4 1.8 ± 0.4 (GIA corrected)	Urban: 6.26 % Rural: 77.09 % Urban delta: 0.11 % Rural delta: 0.66 % Urban estuary: 1.03 % Rural estuary: 14.19 % Urban delta/estuary: 0.01% Rural delta/estuary: 0.46 % Cliff: 0.18 %	6.90 M people
Mediterranean Sea (*Spain, France, Italy, Croatia, Montenegro, Albania, Greece, Malta, Turkey*)	1.2 ± 0.1	Urban: 6.55 % Rural: 73.95 % Urban delta: 0.07 % Rural delta: 1.00 % Urban estuary: 0.38 % Rural estuary: 17.31 % Urban delta/estuary: 0.05% Rural delta/estuary: 0.60 % Cliff: 0.54 %	12.38 M people

Black Sea (*Romania, Bulgaria, Turkey*)	1.2 ± 0.1	Urban: 7.45 % Rural: 78.57 % Urban delta: 0.03 % Rural delta: 2.11 % Urban estuary: 0.90 % Rural estuary: 1.55 % Urban delta/estuary: 0.02% Rural delta/estuary: 9.34 % Cliff: 0.05 %	1.31 M people

2. Methods

2.1 Survey design and data collection

The KH SLR conducted an online survey targeting stakeholders involved in coastal planning and research, especially those whose work is related to or influenced by SLR. The online questionnaire was hosted on the EU Survey platform (https://ec.europa.eu/eusurvey/runner/KH-SLRsurvey2022). Invitations to participate were distributed through various channels, including the JPI Climate and JPI Oceans websites and social media channels, direct outreach to individuals within government offices, and distribution via mailing lists. Invited participants were also encouraged to share the survey with others who identified within the target audience. The first round of invitations was dispatched in January 2022, followed by multiple reminders in the first half of 2022. The data presented here reflect responses received until July 2022, in anticipation of the Sea Level Rise Conference 2022 held by the KH SLR in October 2022 in Venice, Italy.

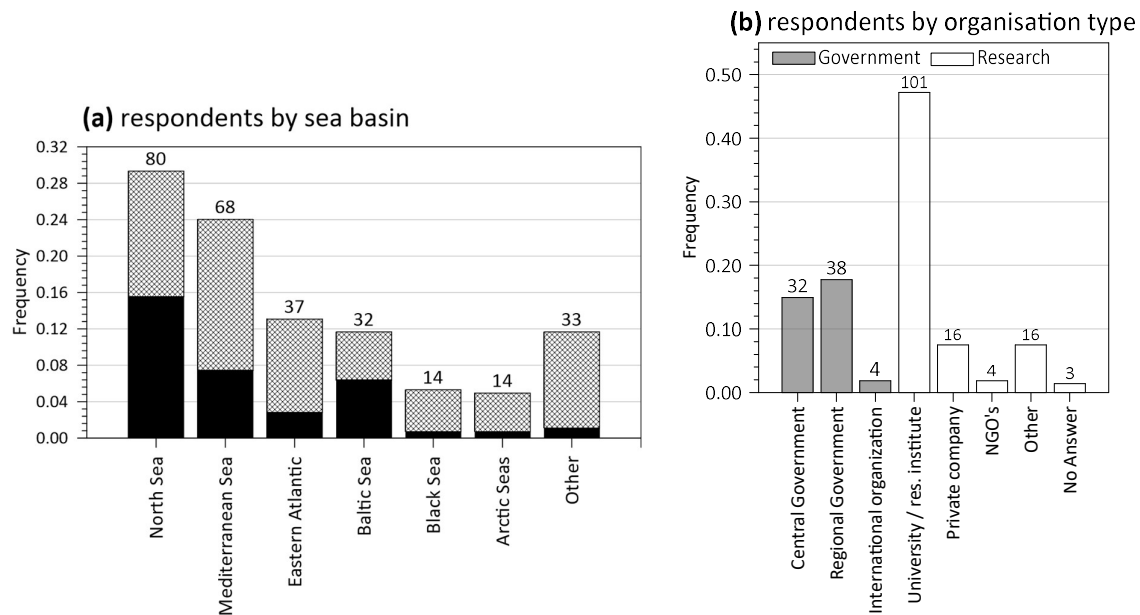
In total, we received responses from 200 participants across 23 European countries (94 % of the participants) and 8 non-European countries (6% of participants), who provided information and perceptions about the covered sea basins according to the distribution shown in Figure 2. The participants were broadly categorised in two professional groups (Figure 2): (i) government, encompassing individuals working within regional or central government agencies and international organizations (about 35% of the total); and (ii) research, including those affiliated with universities, research institutes, private companies and NGOs (about 65 % of the total).

The survey questionnaire commenced with a concise introduction, outlining its purpose. It was structured in four sections. The first section sought information about the respondents, including the type of institution/organization they were affiliated with and the specific sea basin that best aligned with their work. For both questions, participants had the option to select multiple responses when applicable. The second section consisted of five closed-ended questions and one open-ended question, with the aim of assessing the need for, availability of, requirements for, and usage of SLR information. The third section featured three closed-ended questions, serving the purpose of identifying the most relevant impacts associated with SLR. It also assessed the availability and importance of impact assessments. The final section included three closed-ended questions and two open-ended questions, focused on policy decisions and adaptation strategies related to SLR. The survey concluded with a general question about the perceived usefulness of SLR information in IPCC Assessment reports. A comprehensive list of all survey questions can be found in the supplementary material.

To assess closed-ended questions related to specific topical statements, a Likert-type scale with five response categories was employed, spanning from "strongly disagree (1)" to "strongly agree (5)." Likewise, a similar scale was utilised to gauge the perceived significance of the impact assessment, offering choices from "not important (1)" to "very important (5)." Similarly, when evaluating the effectiveness of adaptation strategies, the scale ranged from "non-existent (1)" to "very effective (5)."

To determine the overall relevance of multiple answers, a *total score* was calculated, that considered responses from all surveyed sea basins. This score was computed by summing the percentages of respondents who selected each answer across all basins. The resulting score ranges from 0, which signifies that no respondents selected the answer across any sea basin, to

600, indicating unanimous selection of the answer across all six sea basins, with each basin contributing a maximum of 100 to the total score.

120 Regarding open-ended questions, we categorised responses by keywords that encapsulated their content. These keywords were then visualised using a word cloud chart to highlight the most pertinent topics, while estimating the percentage of times they were identified by participants.

125 **Figure 2. (a) Breakdown of respondents by sea basin (solid black bars: % government respondents; cross-hatched bar: % research respondents). "Other" refers to areas of interest other than the European sea basins, such as global ocean or Pacific (only 10 of respondents declared an area of interest outside the European sea basins). (b) Distribution of respondents by organization type. The numbers above each bar indicate the total number of respondents for each category (sea basin and organization type). Note that respondents can be representative of more than one basin and may belong to two different institutions.**

130 **2.2 Scoping workshops**

The scoping workshops conducted in 2022 played a pivotal role in the process of identifying the requirements of policy makers, coastal planners, and stakeholders at large. The insights gathered from these workshops were instrumental in shaping and collaboratively designing the key themes related to SLR drivers, impacts, and policy options for each of Europe's major sea basins to be addressed in the Assessment Report.

135 Four scoping workshops were run online between March and May 2022. Each workshop had a specific focus on one or two European sea basins and was organised by one or more partner institutes within the respective region, with support from the Secretariat to the KH SLR (table 2).

140

Table 2. List of scoping workshops.

Region	Organisers	Dates	Attendees
North Sea & Arctic Ocean	Deltares, NL and Nansen Environmental and Remote Sensing Center, NO	21-22 March 2022	65
Eastern Atlantic	French Research Institute for Exploitation of the Sea, FR	28-29 April 2022	42
Mediterranean & Black Seas	Universitat Politècnica de Catalunya·BarcelonaTech, ES; University of Bologna, IT, and Euro-Mediterranean Centre on Climate Change, IT.	5-6 May 2022	70
Baltic Sea	Leibniz Institute for Baltic Sea Research Warnemünde, DE; Federal Maritime and Hydrographic Agency of Germany, DE, and Tallinn University of Technology, EE.	9-10 May 2022	70

145

The agenda of the workshops mirrored the structure of the survey, although each specific workshop adapted it slightly. This approach ensured that results would be comparable and allowed for a cohesive discussion of the three main sections: i) SLR physical science and data; ii) SLR hazards and impacts; iii) SLR adaptation policies and decision-making. The agenda was further divided into distinct segments, including keynote speeches, stakeholder contributions, and expert presentations from 150 the scientific community. In addition to these, interactive breakout sessions were incorporated, moderated by the workshop conveners. These interactive sessions were facilitated using the remote collaboration tool Mural. The detailed agendas of scoping workshops can be seen in the Supplementary material.

Each online workshop spanned two days, totalling eight hours of engagement, and attracted a diverse range of participants, with attendance ranging from 42 to 70 registered individuals (table 2). Participants ranged from stakeholders from each 155 European sea basin who participated in the survey, to others who responded to either personalised or public invitations. Upon approval of their registration, participants received comprehensive materials, including the agenda, meeting link, detailed instructions, and expectations from their active involvement in the workshop.

3. Results

3.1 Survey

160 Sea level rise information

When asked about the availability of essential information and data on SLR required for their work, approximately 32% of the respondents expressed that a substantial portion of this information is missing. This observation holds true across different respondent profiles (government: 33%; research: 32%) (see Table S1 in supplementary material). The highest percentage reporting a lack of information was identified in the Arctic (43%) and Mediterranean (40%) sea basins. Notably, there was a 165 significant difference between science (34%) and government (57%) respondents in these regions, emphasizing the disparity in access to information. In contrast, the lowest percentages of respondents indicating information deficits were associated with the Baltic Sea (25%) and North Sea (26%) basins (Fig. 3).

Among the various types of available information, global sea level projections received the highest accessibility and utilization scores (total score of 455/600). Regional sea level projections followed closely (total score of 367/600) as depicted in Figure 170 3. Importantly, there were no significant disparities observed across different sea basins with differences remaining under 15%. However, it is worth noting that the Black Sea and Arctic basins exhibited the largest deviations from the prevailing trend regarding information accessibility (global and regional projections as information types). Nevertheless, these findings show

the disparity in the use of SLR information among stakeholders across different sea basins. Hirschfeld et al. (2023) previously pointed to this inconsistency in the use of SLR information by coastal planners in their adaptation efforts.

175

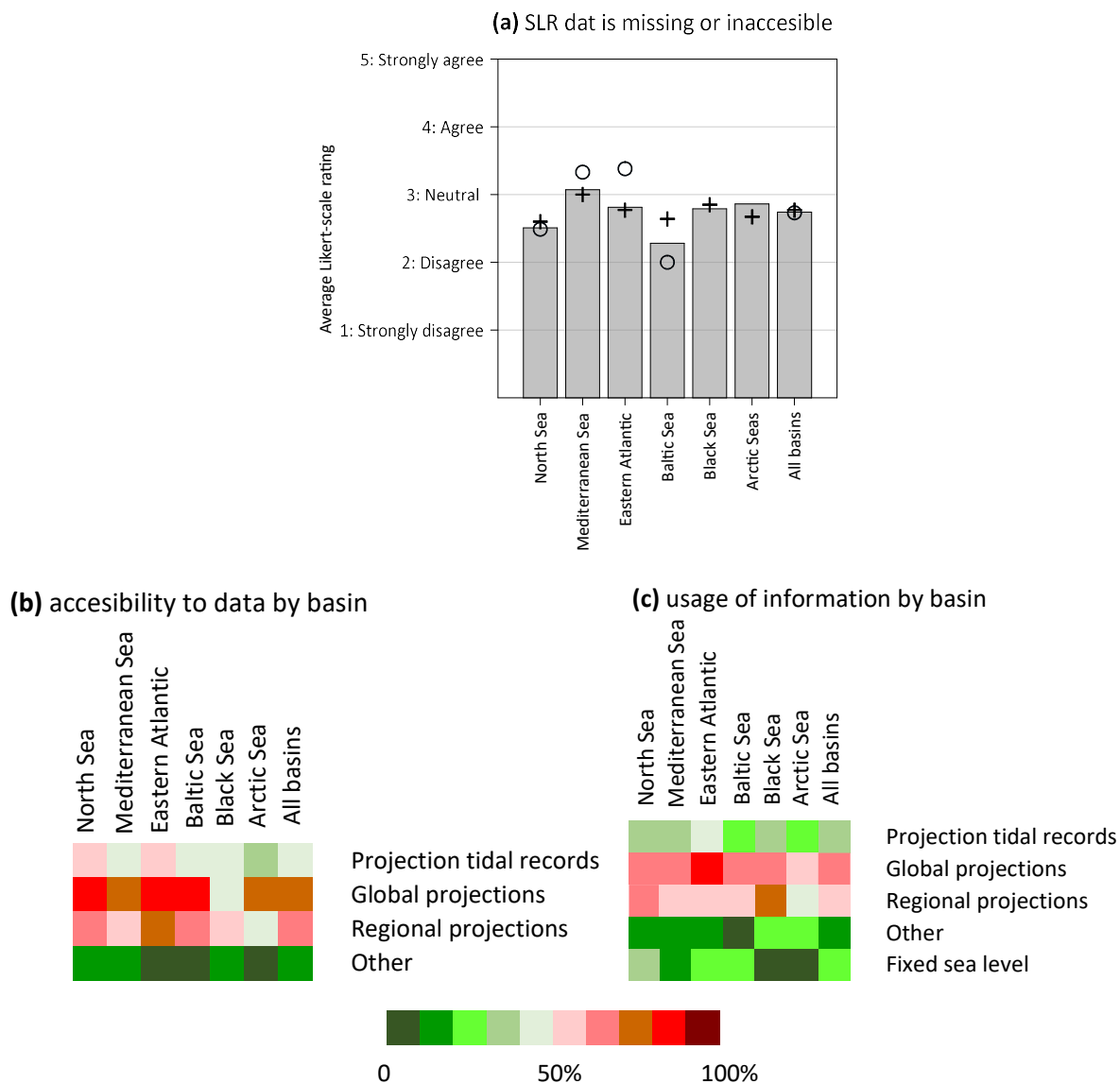



Figure 3. (a) Average rating on the Likert-scale to the statement "For my work crucial information and data on SLR is missing and/or not accessible" (o: government; +: scientists; grey bar: total). (b) Percentage of respondents who reported having access to specific types of SLR data/information (original question was "What type of SLR data and/or information do you have access to?") (c) Percentage of respondents who reported the use of the mentioned type of SLR data/information (original question was "What type of SLR data and/or information do you use?")

All respondents unanimously concurred on the necessity for periodic updates to SLR projections and the importance of comprehending the associated uncertainties in these projections (see Table S1 in supplementary material). Over the years, SLR projections and their uncertainty have undergone notable evolution, as evidenced by (Garner et al., 2018) and (Bamber et al., 2022) among others, emphasizing the need for regular updates.

Figure 4 shows the word clouds generated from responses to an open-ended question seeking to identify the most relevant knowledge gaps in SLR among respondents from both science and government. The percentage of responses identifying each keyword-related issue per respondents' category is shown in Table 3. The identified gaps are notable in three topics: regional and local SLR projections, the overall level of uncertainty associated with these projections, and, most significantly, the uncertainty related to contributions from ice sheet melting. Both government and scientist respondents identified the same gaps, albeit with slight variations in their perspectives and relative importance (Table 3). For instance, government respondents emphasised the need for precise regional projections, viewing them as the ultimate product. In their perspective, these projections play a crucial role in fulfilling their responsibilities and, in relation to this, uncertainty emerges as the second most identified issue and, in this case, these stakeholders are concerned about how to address it. On the other hand, scientists prioritise a more comprehensive understanding of the various factors influencing regional projections, considering these insights as the final goal to be achieved. Uncertainty is highly mentioned, especially with regard to the factors contributing to it. In addition to these commonly recognised gaps, scientists expressed heightened concern regarding other common issues. These include improving local SLR projections, which requires a more accurate understanding of ground level movements. Surprisingly, government respondents appear to be less concerned about this matter. Furthermore, both types of respondents acknowledge the necessity of comprehending the impact of SLR on extreme water levels, as well as its influence on compound/cascading events, and multi-hazard risks, although the latter is given lower priority.

Figure 4. Word cloud representation of responses to the open-ended question "From the perspective of your work, what are the largest knowledge gaps in SLR?" from scientists (left) and government (right) respondents (Generated using the WordArt Generator by WordArt.com) (see table 3 for their quantitative representativity).

Table 3. List of keywords and percentage of responses within the type of respondents who identify a keyword-related issue to the open-ended question "From the perspective of your work, what are the largest knowledge gaps in SLR?" (only issues with a response rate larger than 5% are shown). Examples of different responses associated to the same keyword indicating a different view/interest in the issue.

Respondents' profile	Scientists		Government	
Keywords and % of responses identifying a keyword-related issue over the total of responses	Regional projections	19 %	Regional projections	29 %
	Local projections	13 %	Uncertainty	18 %
	Ice sheet contribution	11 %	SLR acceleration	11 %
	Extreme sea levels	10 %	Extreme sea levels	9 %
	Uncertainty	10 %	Ice sheet contribution	9 %
	Impacts	7 %	Impacts	9 %
	Ground motion	6 %	Longer-term projections	5 %
Example of different views on the same topic: *regional projections*	Determining relative importance of different regional contributions (land subsidence, isostatic adjustment, glacier melting, sediment compaction).		Regional mean sea level projections for the inner German Bight for different IPCC scenarios.	
Example of different views on the same topic: *uncertainty*	Refining uncertainty in future sea level projections associated with deep ocean contribution, Arctic contribution, ice sheet mass change.		The largest gap is not the question of understanding how uncertain any given SLR scenario is, but rather dealing with the fact that all SLR scenarios are uncertain.	

Impacts

The experts assessed the most relevant impacts of SLR for each of the sea basins by selecting from a list of the most common impacts along the European coast (Fig. 5). Among these impacts, *coastal/beach erosion* emerged as the most critical concern, with a total score of 537/600, prevailing in all basins except the Arctic Sea. The prominence of this issue can be attributed to the essential role played by beaches, not only in supporting coastal tourism and the regional economy but also in providing a natural defence for inland areas. Furthermore, this is a widely recognised SLR-induced impact (e.g. (Nicholls and Cazenave, 2010), the importance of which has been documented along the European coastline (e.g. Vousdoukas et al., 2020a). The reduced significance of this impact in the Arctic Seas can be attributed to the fact that this region has the lowest percentage of sandy shoreline (e.g. Luijendijk et al., 2018), and the largest representation of cliffs among the analysed sea basins (Table 1).

The second most pertinent impact identified was the influence of SLR in *increasing storm impacts*, a concern uniformly acknowledged across all sea basins (total score of 480/600). This impact is well-documented and widely acknowledged, involving the projected rise in extreme water levels due to SLR, thereby increasing the likelihood of present-day storm surges and inundation events (e.g. Vousdoukas et al., 2018). Conversely, *permanent inundation* due to SLR is generally perceived as a less significant impact (361/600). It will primarily affect very low-lying and unprotected areas, with relatively limited extent, mainly concentrated in natural areas (e.g. Antonioli et al., 2020).

Damage or loss to public infrastructure (471/600) and, in a slightly smaller proportion, *private properties* (417/600), were identified as relevant impacts. This is highly related to the large exposure of these assets along the European coasts and with expected increase in damage under SLR (e.g. Vousdoukas et al., 2020b)

Groundwater salinisation (338/600) is a lesser concern in the Eastern Atlantic, Black Sea and Arctic basins. In contrast, it holds substantial importance in the remaining sea basins. This significance is grounded in the presence of pre-existing soil salinisation issues (Daliakopoulos et al., 2016), and the anticipation of potential salinity challenges exacerbated by climate-related factors (e.g. Falloon and Betts, 2010; Oude Essink et al., 2010). The relatively limited attention given to this impact can be linked to the predominant role played by other natural and anthropogenic variables that affect groundwater salinity (e.g. Taylor et al., 2013).

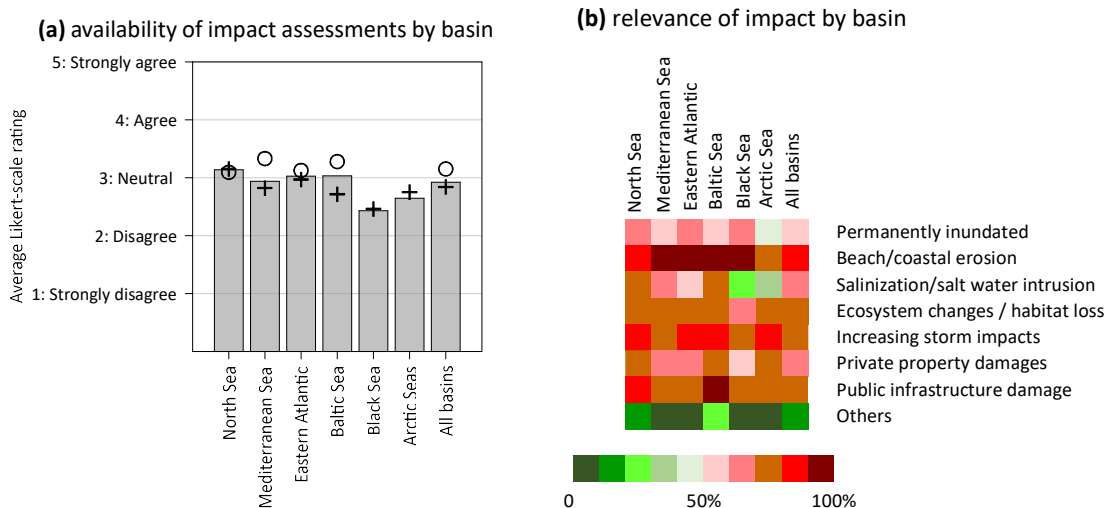



Figure 5. (a) Average rating on the Likert-scale to the statement "High quality and up-to-date assessments of SLR-induced impacts are available for making decisions on planning"), (o: government; +: scientists; grey bar: total; the values for government representatives from the Black and Arctic seas are excluded due to their low representation, with only two respondents each). (b) Relevance of specific SLR-induced impacts in each sea basin indicated by the percentage of respondents who identified these impacts.

The relevance of these impacts for the European sea basins is underscored by the nearly unanimous consensus among respondents (mean value of 4.55 in the Likert scale) on the need to employ impact assessments in shaping planning decisions amidst SLR (see Table S2 in supplementary material). Despite this consensus, approximately 39% of all respondents faced challenges due to the absence of current and high-quality and up-to-date assessments of SLR-induced impacts. This perception was consistent across all sea basins, with the Black Sea and Arctic Sea facing the most pronounced gaps in available assessments (Fig. 5). Government respondents conveyed a more positive outlook compared to those from the research sector (see Table S2 in supplementary material). Specifically, 44% of research respondents disagreed or strongly disagreed with the statement "high-quality and up-to-date assessments of SLR-induced impacts are available for making decisions on planning," whereas only 32% of government respondents held this view.

Adaptation

Lastly, respondents were queried on the performance of adaptation plans and strategies aimed at addressing the impacts of SLR in their respective regions (see Table S3 in supplementary material). Regarding the *effectiveness* of current adaptation plans, a noteworthy 51% of respondents assessed them as either insufficient or inexistent (Fig 6). Significantly, scientists exhibited a more critical perception in this regard, with an additional 18% deeming the plans as insufficient compared to government respondents. Nevertheless, a relatively low proportion of respondents (7.5%) indicated the complete absence of adaptation plans, aligning with the findings of a recent survey of McEvoy et al. (2021) on the planning approaches of European countries in response to SLR. Notably, the Black Sea basin emerged as the region where the absence of plans was most conspicuous.

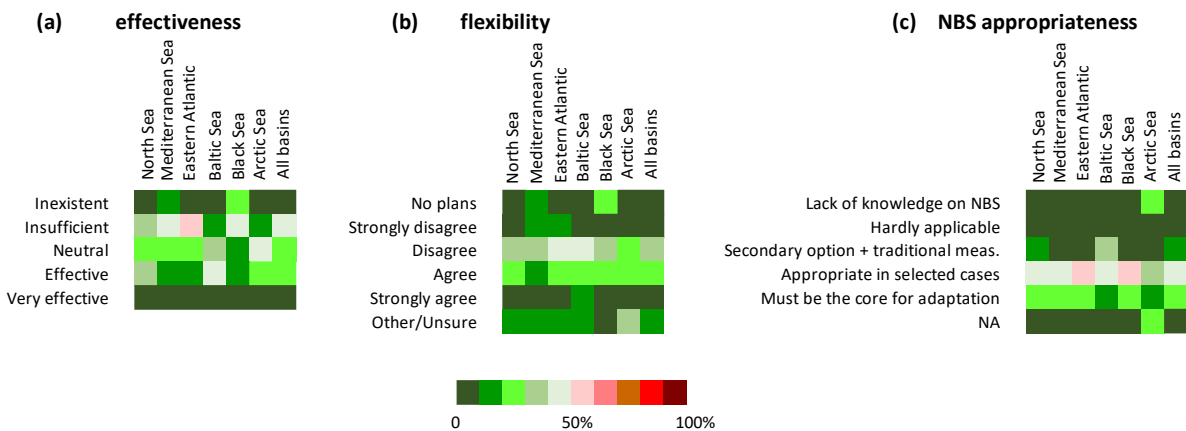



Figure 6. Percentage of responses by sea basin for the following questions/statements: (a) "How effective do you consider the present adaptation strategy to SLR in your country/region?". (b) "Existing adaptation strategies/plans are flexible enough to adapt to future updates in SLR-induced impacts, or to cope with the inherent uncertainty in their assessment". (c) "Nature-based solutions (NBS) are appropriate as adaptation measures to SLR in your country/region".

Regarding the perceived flexibility of existing adaptation strategies and plans in the face of future SLR-induced impacts (or vice versa, the ability to cope with the inherent uncertainty in their assessment), 40% of respondents expressed the view that existing plans lack sufficient flexibility (see Table S3 in supplementary material). This perception remained relatively consistent across different sea basins, with the Arctic and Black Sea exhibiting the lowest perceived lack of flexibility. In general, there were no significant differences in perception based on respondent type, except in the North Sea where government respondents were notably less positive about flexibility, with a 15% difference compared to scientists. It is

important to note that flexible adaptation allows for plan adjustments in response to future changes. Unless plans are designed

275 with an adaptation pathways-like approach (Haasnoot et al., 2013), achieving this flexibility can be challenging. In this context, Kim et al. (2022) introduced a framework for assessing flexibility in adaptation plans.

Participants were asked to identify areas where considerations related to SLR are often neglected but should be incorporated into decisions and policy objectives. Fig 7 shows word clouds generated from responses to this open-ended question, while Table 4 provides the distribution of most frequent responses according to the type of respondents. A significant proportion of

280 respondents (68 % and 65 % for scientist and government respectively) either did not respond to this question or indicated that there were no relevant decision requiring the inclusion of SLR considerations that did not include it. Notably, scientists identified a greater number of issues in comparison to government respondents (Fig 7). Those who identified such omissions emphasised key gaps primarily related to management issues in the coastal zone or, directly, SLR-induced impacts such as salt-water intrusion or damage to infrastructure (previously prioritised in Fig 5). A prominent emerging issue is the interaction

285 of SLR with coastal ecosystems, which is mentioned in different ways, including its impact on existing ecosystems, disruptions of ecosystem services, and ecosystem management. This aligns with the growing concerns about the anticipated impact of SLR on coastal habitats, particularly in areas such as coastal wetlands (e.g. Schuerch et al., 2018), and the projected decline in services provided by coastal ecosystems (e.g. Paprotny et al., 2021). Furthermore, urban planning is a notable concern, in line with the expected impacts of SLR on coastal cities (e.g. Abadie et al., 2019). This indicates that the legal competence of cities

290 in managing coastal issues is often insufficient and underlines the necessity of integrating SLR considerations in urban planning frameworks. Other identified concerns include the influence of SLR on river flow and flood management, a topic gaining increased attention in the context of compound risks (e.g. Bermúdez et al., 2021); and the effects of SLR on seawater intrusion and, consequently, in freshwater management (e.g. Ketabchi et al., 2016) and agriculture (e.g. Gopalakrishnan et al., 2019).

295

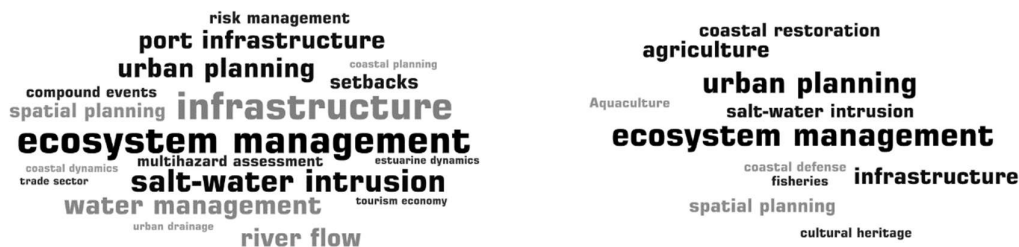



Figure 7. Word cloud representation of responses to the open-ended question "Are there other decisions/purposes for which you currently don't consider SLR, but for which you think it would be important to do so?" from scientists (left) and government (right) respondents (Generated using the WordArt Generator by WordArt.com) (see table 4 for their quantitative representativity).

300 **Table 4. List of keywords and percentage of responses within the type of respondents who identify a keyword-related issue to the open-ended question "Are there other decisions/purposes for which you currently don't consider SLR, but for which you think it would be important to do so?" (only issues with a response rate larger than 5% are shown).**

Respondents' profile	Scientists		Government	
Keywords and % of responses identifying a keyword-related issue over the total of responses	Infrastructures	13 %	Ecosystem management	23 %
	Ecosystem management	13 %	Urban planning	19 %
	Salt-water intrusion	9 %	Infrastructures	12 %
	Water management	7 %	Agriculture	12 %
	Urban planning	7 %	Spatial planning	8 %
	River flow	7 %	Salt-water intrusion	8 %
	Port infrastructure	7 %		

Lastly, in response to the increasing recognition of nature-based solutions (NBS) (e.g. European Environment Agency, 2021), we included a specific question about their suitability as adaptation measure to address SLR-induced impacts. While all respondents recognised the value of incorporating NBS in coastal adaptation plans, the majority viewed their effectiveness as conditional, dependent on site-specific circumstances (Fig. 6c) (see Table S3 in supplementary material). This perspective emphasises the importance of providing a more comprehensive account of the co-benefits and lessons learned from prior implementations of NBS measures (e.g. Moraes et al., 2022). Furthermore, it calls for a rigorous evaluation of their effectiveness when compared to artificial protection structures (e.g. Morris et al., 2018) and substantiated evidence of their long-term cost-effectiveness and self-sustainability (e.g. Toimil et al., 2020).

Finally, it is worth noting that all respondents quasi-unanimously acknowledged the high level of usefulness of IPCC reports for their work, as evidenced by an average rating of 4.4 on the Likert scale (see Table S3 in supplementary material). This consensus is consistent across different sea basins and respondent types.

3.2 Workshops

In this section, key points derived from the workshop discussions are presented. While the discussions were extensive and covered a wide range of issues, we focus on points that complement the survey results presented in the previous section or are considered relevant for further specification. Results are presented following the three main themes: SLR information, hazards & impacts; and adaptation.

North Sea and Arctic basins

Sea level rise information

Recurrent themes in the sessions focusing on the physical science of SLR included the need for locally specific reconstructions and projections of *extreme sea levels*. It was recommended to incorporate local observations when studying historical extreme events, as this forms the foundation for precise impact assessments and statistical analysis. Additionally, research-oriented attendees expressed their desire for *comprehensive guidance* regarding existing models, recent developments, their limitations, and how to interpret model outputs. This is particularly crucial when dealing with low probability, high-impact scenarios and associated sea-level projections.

Hazards & impacts

With respect to hazards and impacts, regional assessments should encompass a comprehensive understanding of the *interplay of various processes that contribute to the magnitude of sea-level extremes*. This includes accounting for vertical land movements, shifts in wind patterns, and the spatial extent of compound flooding events in coastal areas. While it is true that the consequences of SLR, such as erosion, salt intrusion, and flooding, may differ among regions, there is potential for *mutual learning and information exchange*. This includes sharing data, tools, and the development of a *European catalogue of relevant historical events*.

Adaptation and decision making

During the sessions focused on policy and adaptation, a clear consensus emerged regarding the need for a *comprehensive overview of adaptation options*. Such an overview should encompass details on the suitability of individual options in specific environments, the scalability of pilot initiatives, an evaluation of the co-benefits and drawbacks associated with each measure, and real-world examples of successful applications. Policy-makers demonstrated a particular interest in *exploring NBS* and

sought guidance on *structuring the adaptation planning process*, for example, through Dynamic Adaptive Policy Pathways (Haasnoot et al., 2020). The participants also expressed a desire for a comparative assessment of policies across different countries to facilitate shared learning and to evaluate and compare the progress in adaptation across countries. To encourage community and stakeholder engagement, attendees stressed the importance of *transparent communication and the use of clear*

345 *visualizations*. Policy-makers specifically emphasised the need for *geo-visualization tools that support decision-making and communication*. They also requested scientists to provide clear explanations of *how global SLR data is downscaled* and how this data is interpreted within a local context.

Eastern Atlantic basin

Sea level rise information

350 The discussions highlighted several knowledge gaps that have relevant implications for future SLR management. These gaps encompass the need for *comprehensive SLR scenarios tailored to estuaries*, as well as the necessity of conducting *local-scale assessments* to bridge geographic information disparities. Furthermore, the discussions underscored the importance of enhancing the *spatial resolution of climate models and projections*, as well as incorporating *low likelihood scenarios*. The monitoring of ice sheets and other key processes was actively discussed in the context of the set-up of *early warning systems*.

355 Key areas for advancement were identified, including the imperative to *improve ice sheet modelling*, to gain a deeper understanding of *climate system tipping points*, especially in the context of ice sheets, and to *update sea level budgets* (e.g. WCRP Global Sea Level Budget Group, 2018) along coastlines.

Hazards and impacts

A strong consensus emerged regarding the pivotal need to better *assess the combined impact of waves, surges, tides and mean*

360 *SLR*. Ideally, future planning should consider the potential for internal variability in *compound flood hazards*, such as the combination of storm surges with river discharges and SLR, including changing trends in storminess. *Cascading impacts* involving SLR and human activities, such as salt intrusion affecting agriculture, was widely acknowledged but often overlooked in planning. The *protection of cultural heritage* requires specific actions, yet the implementation of informed preservation strategies seems to face obstacles due to the absence of systematic and localised assessments.

365 Adaptation and decision making

Throughout this session, it became evident that the *adequate identification and improved engagement of stakeholders* are fundamental prerequisites for the adaptation process, requiring additional efforts. Participants stressed the importance of enhancing the language used in *communication,* particularly when reaching out to the general public and policymakers. National debates on SLR adaptation were also deemed crucial. A key focus was on clearly presenting the *co-benefits of*

370 *adaptation* and delineating the costs of taking action and, just as crucially, the cost of inaction. The need to *increase confidence in SLR projections* was also highlighted. Related to this, there was a unanimous consensus on the necessity of *developing multiple SLR scenarios tailored to different stakeholder groups*. Governmental agencies, already actively involved in political measures against sea level impacts, require a different level of information than local communities, who may not fully grasp the urgency of SLR due to perceiving it as similar to present-day floods.

375 **Mediterranean and Black Sea basins**

Sea level rise information

The gaps and needs raised by stakeholders during the sessions related to SLR information can be grouped in four main categories. An integrative *data management* approach was recommended to facilitate the integration of different data types, to

establish standards for defining metadata and quality control, and endorsing a data policy promoting the free and open exchange

380 of sea level data at the European level. Regarding *sea level data gaps*, key objectives should focus on sustaining the current tidal stations network (see Pérez Gómez et al., 2022), improving data distribution, and expanding spatial coverage, especially along the northern African coast. This includes the establishment of "open sea" tidal stations to enhance large-scale sea level monitoring. Standardised quality control procedures and data processing methods are essential (e.g. IOC, 2020).

There is a need for robust local *sea level projections* with quantified uncertainties, as well as examining low-probability, high-
385 impact scenarios, and comprehensive numerical modelling of extreme water levels that considers various contributing factors like meteo-tsunamis, and river discharge – sea level interaction. Digital Twins could be considered for testing coastal adaptation options (e.g. Pillai et al., 2022). To comprehensively address SLR impacts and risks, there is a need for *multidisciplinary data* and model simulations. While the European Marine Observation and Data Network (EMODnet) provides human activity data, their potential for SLR risk assessment remains untapped. Coastal vulnerability data is scarce
390 and lacks standardization. Considering factors like sediment balance is crucial for long-term coastal erosion estimates, yet accurate data on sediment balance is often lacking. It is strongly recommended to establish requirements for high-resolution bathymetry and digital terrain models tailored for SLR and inundation analysis.

Hazards & impacts

In relation to SLR impacts, attendees confirmed impacts identified in the survey, specifically erosion and flooding. Erosion
395 was recognised as a critical factor that diminishes the coastal resilience to SLR and heightens its vulnerability. Additionally, discussions highlighted the significance of compound flooding, especially taking into account its occurrence along the sea basin. Participants also underscored the importance of addressing the impact of salt-water intrusion on freshwater resources due to SLR, especially in light of the expected increase in desertification in these sea basins (e.g. Gao and Giorgi, 2008). In the context of assessing risks and impacts, it was deemed essential to consider *'what if'* scenarios for SLR, including extreme
400 SLR scenarios. Given the prevalence of low-lying sedimentary features like deltas and coastal plains in the region, controlling and measuring local *vertical land movements* was considered crucial. Also, an accurate estimation of the *vulnerability of the densely populated* coastal zones, and their *exposure* and values were considered as a top priority.

The second part of the session was dedicated to eliciting crucial information required for assessing hazards, risks, and impacts. Notably, inputs often mirrored the participants' local experiences, emphasizing the significance of accessing specific data that
405 might already be available and accessible in other locations. This highlights a key characteristic of the region: stakeholders from various countries and institutions exhibit a diverse spectrum of profiles in terms of data accessibility, assessment methodologies, and their commitment to conducting assessments at different scales. Significant knowledge gaps related to hazards and vulnerability were particularly evident in the southern Mediterranean Sea and non-European coastal areas.

Adaptation and decision making

410 Several key themes emerged as relevant areas requiring attention in the forthcoming assessment report with regard to SLR adaptation strategies and policies. Foremost among these was the imperative of incorporating the *needs and challenges of future generations* into the frameworks. The second priority highlighted the necessity to bridge the knowledge gap by *standardizing the information derived from observations and models*, with the aim of informing and prioritizing action. Integrated Coastal Zone Management was underlined as a foundational paradigm for the development of new policy
415 instruments aimed at bolstering coastal resilience, as an integral component of Marine Spatial Planning strategies. Additionally, any adaptation policy should take into account social factors and community engagement, ensuring a *participatory decision-making process* where diverse stakeholders have a voice. This approach also requires the implementation of *effective outreach and communication strategies*.

Baltic Sea basin

420 Sea level rise information

Participants highlighted that there is a need to *constrain the uncertainty in SLR* along the Baltic coast, primarily arising from various sources, including the relative contributions of melting from the Greenland and Antarctic ice sheets and regional differences in the response of sea levels to atmospheric forcing, among others (e.g. Weisse et al., 2021). It was considered necessary to have *high resolution projections of future total water level extremes* including wind contribution to properly
425 reflect the spatial variability of sea level variations across the basin. The need to separate the effects of natural variability and anthropogenic global warming on long-term sea level changes was also emphasised. In addition, participants highlighted the need for progress in the *characterization of drivers involving sea level variations triggering natural hazards*, which might be amplified under SLR, including meteo-tsunamis and storm surges.

Hazards & impacts

430 In addition to well-documented erosion and flooding risks along the Baltic coast, other often overlooked impacts of SLR, such as *salt-water intrusion and freshwater salinization*, will be equally important for some areas. *Compound events*, such as the combined effects of extreme sea levels and high river discharges, pose a threat to coastal communities like Stockholm, Pärnu and Klaipeda, among others, especially in scenarios of rising sea levels and increased precipitation.

In the Baltic Sea, key locations such as St Petersburg, Stockholm and the Kiel Canal have already experienced or are projected
435 to face substantial impacts from extreme sea levels and SLR. A recurring theme across these locations is the utilization of locks and water control infrastructure as a means to mitigate and adjust to elevated water levels. These *critical infrastructures* play a vital role in safeguarding coastal cities, preventing saltwater intrusion, and regulating levels for shipping across the region. Consequently, the challenge lies in effectively adapting to SLR while preserving the functionality of these vital systems.

Adaptation and decision making

440 Several topics related to adaptation were raised, often applicable to any sea basin. Enhancing the response to SLR involves *integrating SLR-related policy and marine spatial planning*, traditionally more focused on marine ecosystems. Identifying and addressing conflicts of interest, such as conservation versus economic development, is essential. Identifying the obstacles hindering implementation and devising workable solutions can help ensure the success of these initiatives.

Striking a balance between *communicating scientific uncertainty* and providing specific policy-compliant data is challenging
445 but crucial. Overemphasis on uncertainty can potentially hinder adaptation efforts. It is recommended combining short-term and long-term planning, with a *focus on adaptive planning approaches*. Assessing the outcomes of SLR-related adaptation measures and policies, particularly for innovative measures like *nature-based approaches*, is critical. This includes an examination of their scalability and applicability across different contexts.

Recognizing the *role of insurance and banking sectors in SLR policy and planning* is pivotal for future coastal development.
450 Effective communication with these influential stakeholders is vital due to their potential on future coastal development.

4. Discussion

The presented results encapsulate the perceptions and interpretations of survey and workshop participants regarding questions and discussions on SLR within three pivotal themes across European sea basins: SLR information, hazards, impacts, and adaptation. The varying percentage of participation among different participant profiles in each basin may contribute to the
455 spatial differences observed in responses. However, considering the number of completed surveys, workshops attendance, and

the interactive dynamics established during these events, the results are considered to provide a representative insight into the topics investigated across European sea basins. It is however essential to note that, from a quantitative perspective, the participation of stakeholders and, in particular, government representatives from the Arctic Seas and Black Sea basins were notably lower than other regions, reducing the significance of the findings for these areas.

460 While the distinctive characteristics of each sea basin affect specific elements there, some shared issues highlight their importance in understanding sea level requirements for the key themes under discussion.

During almost all scoping workshops, there was a common consensus regarding the importance of *local sea level data* to accurately assess spatial sea level variations within basins, especially concerning extreme water levels. In addition to expanding existing tidal networks, it was suggested to encourage sea level monitoring through citizen science sensors such as low-cost

465 Global Navigation Satellite System (GNSS) receivers and pressure sensors (Ahmed et al. 2023). This approach not only has the potential to raise awareness among coastal communities about (extreme) sea level conditions but also leads to a more extensive and high-resolution network of coastal sea level data, addressing spatial variability effectively (e.g. Spicer et al., 2021). In addition to incorporating new data, it was acknowledged that there is an urgent need for harmonization among existing data portals providing tide gauge information, such as the Global Sea Level Observing System (GLOSS) and European

470 data portals (e.g. Pérez Gómez et al., 2022). This also includes updating metadata related to tidal gauges, which is indispensable for accurately reconstructing and interpretating observed sea level, for instance related to vertical land movement (e.g. Latapy et al., 2023).

Uncertainty emerged as a recurring theme in both survey and workshops, independent of the respondent's sea basin of origin. Striking the right balance between effectively conveying uncertainty while providing specific data crucial for policy

475 compliance remains a relevant challenge. In this regard, Kopp et al. (2023) identify the communication of uncertainty and ambiguity as a key challenge in translating sea-level science to inform long-term coastal planning. During the workshops, some stakeholders acknowledged that an excessive emphasis on uncertainty could lead to delays or hinder progress in planning or implementation of adaptation measures. However, it is essential to recognise that the tolerance for uncertainty varies based on its intended use (e.g. long/short term applications) and the risk perceptions of individuals and groups. There tends to be a

480 higher tolerance for uncertainty when the potential value at risk is relatively low (e.g. Hinkel et al., 2019).

In connection with this prevailing uncertainty, respondents also emphasised the importance of investigating *low-probability, high-impact SLR scenarios*. While these scenarios may be unlikely to materialise, they hold significance from a risk-management standpoint (e.g. Hinkel et al., 2015). Research-sector stakeholders underscored the need for advancing our understanding of the contributions of *ice sheets* to future SLR (e.g. Bamber et al., 2022; Van De Wal et al., 2022). Management

485 professionals emphasise the need for regional projections that facilitate impact analysis (e.g. Dayan et al., 2021). One highlighted concern pertains to the necessity for enhanced information and data to improve current and future *regional and local sea-level change* estimations. Specifically, they emphasised the importance of assessing the local impact of *vertical land movements* on relative SLR. This assessment should encompass both natural and human-induced factors to accurately gauge relative SLR and, in turn, enhance assessments of SLR-induced hazards (e.g. Nicholls et al., 2021).

490 Participants recognised the importance of integrating comprehensive *multidisciplinary data* for assessing risks, including both exposure and vulnerability characteristics in susceptible areas, particularly in the Low Elevation Coastal Zone (LECZ). In many instances, these factors significantly influence the estimated risk (e.g. Neumann et al., 2015).

In terms of hazards and their impacts, scoping workshops consistently highlighted the need for multi-hazard risk assessments. Specifically, the workshops brought attention to *compound coastal floods*, in which elevated sea levels coincide with high

495 river flow or heavy rainfall events. This was also identified as an impact to be considered in the open-ended questions of the

survey (Fig 7). From a risk management perspective, the significance of such occurrences lies in their potential to amplify the impact of the individual hazards and/or accumulate them within a specific region (Zscheischler et al., 2020). Within the context of this scoping process, it is crucial to recognise that SLR may influence the likelihood of occurrence and intensity of these events through anticipated changes in local extreme sea levels (e.g. Moftakhari et al., 2017), which may also affect the spatial distribution of high-risk locations (see e.g. Bevacqua et al., 2019).

To enhance the assessment of the primary SLR-induced hazard identified by stakeholders in the global survey (Fig. 5), long-term coastal erosion, there was an emphasis on considering additional factors influencing the *sediment budget* such as sediment supplies from rivers, where the impact of river damming plays a relevant role in modulating the expected erosion, especially in deltas (e.g. Ericson et al., 2006).

It is interesting to note that, while *saltwater intrusion* received one of the lowest overall relevance scores in the survey (Fig 5), it was consistently brought up by participants in all scoping workshops. This emphasis is justifiable when we consider that coastal aquifers serve as critical freshwater sources for many coastal areas, and these resources face threats from both groundwater extraction and rising sea levels (e.g. Ferguson and Gleeson, 2012). The growing concern regarding SLR and its impact on seawater intrusion is evident in the recent metanalysis of seawater intrusion research by Cao et al. (2021), which identified the impact of SLR as the most widely discussed topic. In this regard, Ketabchi et al. (2016) identified key knowledge gaps on the impacts of SLR on seawater intrusion, and recommended main aspects for future research. The relevance of this impact also aligns with the findings from open-ended survey questions, where participants highlighted water management and agriculture issues (Fig. 7).

On adaptation topics the survey responses showed slight differences in responses across sea basins, albeit within a relatively narrow range (Fig 6). This variability aligns with findings from McEvoy et al. (2021), who observed regional differences in adaption planning in their analysis of European countries' approaches to SLR planning. One key aspect was the necessity of *tailoring SLR information* to different application domains, involving different stakeholders, institutions and their specific information needs (see also e.g. Hinkel et al., 2019; Durand et al., 2022). The relevance of taking *social factors* into account when formulating adaptation strategies was also noted, since barriers and limits to adaptation often stem from social aspects rather than purely technical factors (e.g. Adger et al. 2009; Hinkel et al. 2018; Galluccio et al. 2024). Additionally, there was a consensus on the importance of the effective communication of this information to stakeholders and the enhancement of *visualization techniques* to engage local communities (e.g. Calil et al., 2021).

When *comparing responses from government and research participants* in the survey, both groups generally exhibited similar behaviour in responding to various questions. However, a significant divergence emerged regarding their views on two practice-oriented issues: the availability of impact assessments and the effectiveness of adaptation plans. Government respondents tended to be more positive than their research counterparts, expressing greater confidence in the availability of high-quality and up-to-date impact assessments as well as in the effectiveness of adaptation plans. An exception to this was found in the North Sea basin, where government respondents were less confident on the flexibility of adaptation strategies than researchers. Finally, it has to be considered that while the availability of impact assessments is a quantifiable matter, the effectiveness of the adaptation plans is arguably a matter of perception for most part. In practice, the true effectiveness of these plans remains unverified until they are implemented and operational under the projected scenarios.

Lastly, it is important to acknowledge that the results presented herein represent the prevailing perceptions of stakeholders across European sea basins regarding various aspects to SLR. These findings should be interpreted with the other chapters of this report, where detailed analyses are provided on the current state of data/information availability on SLR (Melet et al.

535 2024), the resulting impacts (van de Wal et al. 2024), adaptation policies (Galluccio et al. 2024) and the governance landscape (Bisaro et al. 2024) throughout European sea basins.

Conclusions

The combination of survey and regional workshops has effectively revealed shared knowledge gaps and needs concerning
540 SLR across European sea basins. This assessment spans both scientific and governmental perspectives, classified into three main SLR-related themes: information on SLR, its impacts, and adaptation policies and decision making.

In terms of SLR information, notable gaps involve regional SLR projections and uncertainties, particularly related to long-term SLR induced by large-scale ice-sheet melting. Scientists view these gaps as objectives, seeking to refine regional projections and reduce uncertainty. In contrast, government users see these gaps as barriers to achieve their specific goals, for
545 which they need accurate SLR projections for their regions and advise on how to deal with uncertainty.

Concerning hazards and impacts, shoreline erosion emerged as a prominent issue across sea basins (except in the Arctic), with emerging issues like saltwater intrusion being recognised as undervalued and necessitating additional attention due to potential impacts on agriculture, freshwater resources and coastal ecosystems. Among these emerging issues, the role of SLR in compounding risks events, such as those related to extreme water levels and river flow, was underscored. Participants also
550 emphasised the necessity for high-quality and updated impact assessments to inform adaptation planning to SLR.

Concerns were raised about existing adaptation plans, revealing a common perception of inefficient and inflexible strategies to address SLR impacts. Some gaps were identified, particularly related to undervalued impacts, with urban planning being a prominent aspect needing attention. Furthermore, participants, particularly end-users, expressed the need for enhanced information dissemination and more effective communication of relevant data and information to support decision-making.

555 Stakeholders emphasised the crucial role of trans-national collaboration in sharing experiences and expertise regarding various aspects of sea level rise. They noted the disparities in responses among different regions, along with shared concerns and interests, highlighting the importance of knowledge exchange to foster harmonization across European sea basins. Initiatives like the Knowledge Hub on Sea Level Rise and the development of a European Assessment Report serve as prime examples of such exchanges. These efforts aim to harmonise knowledge pertinent to SLR, facilitating more accurate impact assessments
560 and more informed decision-making processes regarding coastal adaptation to SLR.

Data availability

The collected data are not publicly available as the participants of this study did not give written consent for their data to be shared publicly. Anonymised data can be provided by the corresponding author upon request.

565

Author contributions

JAJ wrote the paper with text contributions from GG, GW, LGP, MM and NVR. The survey was designed, conducted and analysed by JAJ. The scoping workshops were conducted by AB, GW and BvH (North Sea and Arctic Seas); JAJ, GG and NP (Mediterranean Sea and Black Sea), MM (Baltic Sea), NVR (Eastern Atlantic). LGP and MD provided support to all
570 workshops. All authors participated in the iterations and revisions of the paper.

Competing interests

The contact author has declared that none of the authors has any other competing interests.

Acknowledgements

We sincerely thank all the participants in the survey and scoping workshops for contributing their knowledge, experience and
575   information to this work. We thank Bernd Brügge who actively collaborated in the scoping work and comanaged the Baltic
Sea workshop and Kevin Parnell who helped with the realisation of that workshop. We thank Robyn Gwee, Nathalie Dees,
Geerit Hendriksen and Marta Marcos for their contribution to data included in Table 1. The work of the first author was
supported by the *C3RiskMed* (PID2020-113638RB-C21) research project, funded by the Spanish Ministry of Science and
Innovation (AEI/10.13039/501100011033) and by the Spanish Research Agency (AEI).

580   **References**

Abadie, L. M., Galarraga, I., Markandya, A., and Sainz De Murieta, E.: Risk measures and the distribution of damage curves
for 600 European coastal cities, Environmental Research Letters, 14(6), 064021, https://doi.org/10.1088/1748-
9326/ab185c, 2019.Ahmed, T., Creedon, L., and Gharbia, S.S.: Low-Cost Sensors for Monitoring Coastal Climate
Hazards: A Systematic Review and Meta-Analysis, Sensors, 23(3), 1717, https://doi.org/10.3390/s23031717, 2023.

585   Adger, W.N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D.R., ... and Wreford, A: Are there social limits to
adaptation to climate change?, Climatic change, 93, 335-354, https://doi.org/ 10.1007/s10584-008-9520-z, 2009.

Antonioli, F., De Falco, G., Lo Presti, V., Moretti, L., Scardino, G., … and Mastronuzzi, G.: Relative Sea-Level Rise and
Potential Submersion Risk for 2100 on 16 Coastal Plains of the Mediterranean Sea, Water, 12(8), 2173,
https://doi.org/10.3390/w12082173, 2020.

590   Bamber, J.L., Oppenheimer, M., Kopp, R.E., Aspinall, W.P., and Cooke, R.M.: Ice Sheet and Climate Processes Driving the
Uncertainty in Projections of Future Sea Level Rise: Findings From a Structured Expert Judgement Approach, Earth's
Future, 10(10), e2022EF002772, https://doi.org/10.1029/2022EF002772, 2022.

Bermúdez, M., Farfán, J. F., Willems, P., and Cea, L.: Assessing the Effects of Climate Change on Compound Flooding in
Coastal River Areas, Water Resources Research, 57(10), e2020WR029321, https://doi.org/10.1029/2020WR029321,
595   2021.

Bevacqua, E., Maraun, D., Vousdoukas, M.I., Voukouvalas, E., Vrac, M., Mentaschi, L., and Widmann, M.: Higher probability
of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change, Science
Advances, 5(9), eaaw5531, https://doi.org/10.1126/sciadv.aaw5531, 2019.

Bisaro, A., Galluccio, G., Fiorini Beckhauser, E., Romagnoli, C., McEvoy, S., … and Slinger, J.: Sea Level Rise in Europe:
600   Governance Context and Challenges, State Planet Discuss, [preprint], https://doi.org/10.5194/sp-2023-37, in press,
2024.

Calil, J., Fauville, G., Queiroz, A., Leo, K., Mann, A., Wise-West, T., Salvatore, P., and Bailenson, J.: Using Virtual Reality
in Sea Level Rise Planning and Community Engagement—An Overview, Water, 13(9), 1142,
https://doi.org/10.3390/w13091142, 2021.

605   Cao, T., Han, D., and Song, X.: Past, present, and future of global seawater intrusion research: A bibliometric analysis, Journal
of Hydrology, 603, 126844, https://doi.org/10.1016/j.jhydrol.2021.126844, 2021.

Daliakopoulos, I.N., Tsanis, I.K., Koutroulis, A., Kourgialas, N.N., Varouchakis, A.E., Karatzas, G.P., and Ritsema, C.J.: The threat of soil salinity: A European scale review, Science of the Total Environment, 573, 727–739, https://doi.org/10.1016/j.scitotenv.2016.08.177, 2016.

610 Dangendorf, S., Hay, C., Calafat, F.M., Marcos, M., Piecuch, C.G., Berk, K., and Jensen, J.: Persistent acceleration in global sea-level rise since the 1960s, Nature Climate Change, 9(9), 705–710, https://doi.org/10.1038/s41558-019-0531-8, 2019.

Dayan, H., Le Cozannet, G., Speich, S., and Thiéblemont, R.: High-End Scenarios of Sea-Level Rise for Coastal Risk-Averse Stakeholders, Frontiers in Marine Science, 8, 569992, https://doi.org/10.3389/fmars.2021.569992, 2021.

615 Durand, G., Van Den Broeke, M.R., Le Cozannet, G., Edwards, T.L., Holland, P.R., … and Chapuis, A.: Sea-Level Rise: From Global Perspectives to Local Services, Frontiers in Marine Science, 8, 709595, https://doi.org/10.3389/fmars.2021.709595, 2022.

Ericson, J., Vorosmarty, C., Dingman, S., Ward, L., and Meybeck, M.: Effective sea-level rise and deltas: Causes of change and human dimension implications, Global and Planetary Change, 50(1–2), 63–82,
620 https://doi.org/10.1016/j.gloplacha.2005.07.004, 2006.

European Environment Agency: Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction, Publications Office, https://data.europa.eu/doi/10.2800/919315, 2021.

Falloon, P., and Betts, R.: Climate impacts on European agriculture and water management in the context of adaptation and mitigation—The importance of an integrated approach, Science of the Total Environment, 408(23), 5667–5687,
625 https://doi.org/10.1016/j.scitotenv.2009.05.002, 2010.

Ferguson, G., and Gleeson, T.: Vulnerability of coastal aquifers to groundwater use and climate change, Nature Climate Change, *2*(5), 342–345, https://doi.org/10.1038/nclimate1413, 2012.

Fraussen, B., Albareda, A., and Braun, C.: Conceptualizing consultation approaches: Identifying combinations of consultation tools and analyzing their implications for stakeholder diversity, Policy Sciences, 53(3), 473–493,
630 https://doi.org/10.1007/s11077-020-09382-3, 2020.

Galluccio, G., Bisaro, A., Becjauser, E.F., Aleu, R.B., Hinkel, J., Casas. M.F., Espin, O., Vafeidis, A.T. and Campostrini, P.: Sea level rise in Europe: Adaptation measures and decision-making principles, State Planet Discuss, [preprint], https://doi.org/10.5194/sp-2023-35, in review, 2024.

Gao, X., and Giorgi, F.: Increased aridity in the Mediterranean region under greenhouse gas forcing estimated from high
635 resolution simulations with a regional climate model, Global and Planetary Change, 62(3–4), 195–209, https://doi.org/10.1016/j.gloplacha.2008.02.002, 2008.

Garner, A.J., Weiss, J.L., Parris, A., Kopp, R.E., Horton, R.M., Overpeck, J.T., and Horton, B.P.: Evolution of 21st Century Sea Level Rise Projections, Earth's Future, 6(11), 1603–1615, https://doi.org/10.1029/2018EF000991, 2018.

Gopalakrishnan, T., Hasan, M., Haque, A., Jayasinghe, S., and Kumar, L.: Sustainability of Coastal Agriculture under Climate
640 Change, Sustainability, 11(24), 7200, https://doi.org/10.3390/su11247200, 2019.

Haasnoot, M., Kwadijk, J., van Alphen, J., Le Bars, D., van den Hurk, B., … and Mens, M.: Adaptation to uncertain sea-level rise; how uncertainty in Antarctic mass-loss impacts the coastal adaptation strategy of the Netherlands, Environmental Research Letters, 15(3), 034007, https://doi.org/10.1088/1748-9326/ab666c, 2020.

Haasnoot, M., Brown S., Scussolini, P., Jiménez J.A., Vafeidis, A., and Nicholls, R.J.: Generic adaptation pathways for coastal
645 archetypes under uncertain sea-level rise, Environm. Res. Comm., 1, 7, 071006, doi: 10.1088/2515-7620/ab1871, 2019.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., and Ter Maat, J.: Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change, 23(2), 485–498, https://doi.org/10.1016/j.gloenvcha.2012.12.006, 2013.

650   Hinkel, J., Aerts, J.C., Brown, S., Jiménez, J.A., Lincke, D., ... and Addo, K.A.: The ability of societies to adapt to twenty-first-century sea-level rise, Nature Climate Change, 8(7), 570-578, https://doi.org/10.1038/s41558-018-0176-z, 2018.

Hinkel, J., Church, J.A., Gregory, J.M., Lambert, E., Le Cozannet, G., … and Van De Wal, R.: Meeting User Needs for Sea Level Rise Information: A Decision Analysis Perspective, Earth's Future, 7(3), 320–337, https://doi.org/10.1029/2018EF001071, 2019.

655   Hinkel, J., Jaeger, C., Nicholls, R.J., Lowe, J., Renn, O., and Peijun, S.: Sea-level rise scenarios and coastal risk management, Nature Climate Change, 5(3), 188–190, https://doi.org/10.1038/nclimate2505, 2015.

Hirschfeld, D., Behar, D., Nicholls, R.J., Cahill, N., James, T., … and Yokoki, H.: Global survey shows planners use widely varying sea-level rise projections for coastal adaptation, Communications Earth & Environment, 4(1), 102, https://doi.org/10.1038/s43247-023-00703-x, 2023.

660   IOC/UNESCO: Quality Control of in situ Sea Level Observations: A Review and Progress towards Automated Quality Control, Vol. 1. Paris, UNESCO, IOC Manuals and Guides No.83, (IOC/2020/MG/83Vol.1), 2020.

IPCC: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., … and Zhou, B., Eds.), Cambridge University Press, 2021.

665   IPCC: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.-O. Pörtner, D.C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, Eds.), Cambridge University Press, 2022.

Ketabchi, H., Mahmoodzadeh, D., Ataie-Ashtiani, B., and Simmons, C.T.: Sea-level rise impacts on seawater intrusion in
670   coastal aquifers: Review and integration, Journal of Hydrology, 535, 235–255, https://doi.org/10.1016/j.jhydrol.2016.01.083, 2016.

Kim, M.-J., Nicholls, R.J., Preston, J.M., and De Almeida, G.A.: Evaluation of flexibility in adaptation projects for climate change, Climatic Change, 171(1–2), 15, https://doi.org/10.1007/s10584-022-03331-0, 2022.

Kopp, R.E., Oppenheimer, M., O'Reilly, J.L., Drijfhout, S.S., Edwards, T.L., … and Xiao, C.: Communicating future sea-
675   level rise uncertainty and ambiguity to assessment users, Nature Climate Change, 13(7), 648–660, https://doi.org/10.1038/s41558-023-01691-8, 2023.

Latapy, A., Ferret, Y., Testut, L., Talke, S., Aarup, T., Pons, F., Jan, G., Bradshaw, E., and Pouvreau, N.: Data rescue process in the context of sea level reconstructions: An overview of the methodology, lessons learned, up-to-date best practices and recommendations, Geoscience Data Journal, 10(3), 396–425, https://doi.org/10.1002/gdj3.179, 2023.

680   Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., and Aarninkhof, S.: The State of the World's Beaches, Scientific Reports, 8(1), 6641, https://doi.org/10.1038/s41598-018-24630-6, 2018.

Magnan, A.K., Bell, R., Duvat, V.K.E., Ford, J.D., Garschagen, M., … and Winter, G.: Status of global coastal adaptation, Nature Climate Change, 13(11), 1213–1221, https://doi.org/10.1038/s41558-023-01834-x, 2023.

McEvoy, S., Haasnoot, M., and Biesbroek, R.: How are European countries planning for sea level rise? Ocean & Coastal
685   Management, 203, 105512, https://doi.org/10.1016/j.ocecoaman.2020.105512, 2021.

Melet, A., van de Wal, R., Amores, A., Arns, A., Chaigneau, A.A., … and Slangen, A.: Sea Level Rise in Europe: Observations and projections, State Planet Discuss. [preprint], https://doi.org/10.5194/sp-2023-36, in review, 2024.

Moftakhari, H.R., Salvadori, G., AghaKouchak, A., Sanders, B.F., and Matthew, R.A.: Compounding effects of sea level rise and fluvial flooding, Proceedings of the National Academy of Sciences, 114(37), 9785–9790, https://doi.org/10.1073/pnas.1620325114, 2017.

Moraes, R.P.L., Reguero, B.G., Mazarrasa, I., Ricker, M., and Juanes, J.A.: Nature-Based Solutions in Coastal and Estuarine Areas of Europe, Frontiers in Environmental Science, 10, 829526, https://doi.org/10.3389/fenvs.2022.829526, 2022.

Morris, R.L., Konlechner, T.M., Ghisalberti, M., and Swearer, S.E.: From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence, Global Change Biology, 24(5), 1827–1842, https://doi.org/10.1111/gcb.14063, 2018.

Neumann, B., Vafeidis, A.T., Zimmermann, J., and Nicholls, R.J.: Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding—A Global Assessment, PLOS ONE, 10(3), e0118571, https://doi.org/10.1371/journal.pone.0118571, 2015.

Nicholls, R.J., and Cazenave, A.: Sea-Level Rise and Its Impact on Coastal Zones, Science, 328(5985), 1517–1520, https://doi.org/10.1126/science.1185782, 2010.

Nicholls, R.J., Lincke, D., Hinkel, J., Brown, S., Vafeidis, A.T., Meyssignac, B., Hanson, S.E., Merkens, J.-L., and Fang, J.: A global analysis of subsidence, relative sea-level change and coastal flood exposure, Nature Climate Change, 11(4), 338–342, https://doi.org/10.1038/s41558-021-00993-z, 2021.

Oude Essink, G.H.P., Van Baaren, E.S., and De Louw, P.G.B.: Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands, Water Resources Research, 46(10), 2009WR008719, https://doi.org/10.1029/2009WR008719, 2010.

Paprotny, D., Terefenko, P., Giza, A., Czapliński, P., and Vousdoukas, M.I.: Future losses of ecosystem services due to coastal erosion in Europe, Science of the Total Environment, 760, 144310, https://doi.org/10.1016/j.scitotenv.2020.144310, 2021.

Pérez Gómez, B., Vilibić, I., Šepić, J., Međugorac, I., Ličer, M., … and Zodiatis, G.: Coastal sea level monitoring in the Mediterranean and Black seas, Ocean Science, 18(4), 997–1053, https://doi.org/10.5194/os-18-997-2022, 2022.

Pillai, U.P.A., Pinardi, N., Alessandri, J., Federico, I., Causio, S., Unguendoli, S., Valentini, A., and Staneva, J.: A Digital Twin modelling framework for the assessment of seagrass Nature Based Solutions against storm surges, Science of the Total Environment, 847, 157603, https://doi.org/10.1016/j.scitotenv.2022.157603, 2022.

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M.L., Wolff, C., … and Brown, S.: Future response of global coastal wetlands to sea-level rise, Nature, 561(7722), Article 7722, https://doi.org/10.1038/s41586-018-0476-5, 2018.

Spicer, P., Schlichting, D., Huguenard, K., Roche, A.J., and Rickard, L.N.: Sensing storm surge: A framework for establishing a citizen scientist monitored water level network, Ocean & Coastal Management, 211, 105802, https://doi.org/10.1016/j.ocecoaman.2021.105802, 2021.

Taylor, R.G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., … and Treidel, H.: Ground water and climate change, Nature Climate Change, 3(4), 322–329, https://doi.org/10.1038/nclimate1744, 2013.

Toimil, A., Losada, I.J., Nicholls, R.J., Dalrymple, R.A., and Stive, M.J.F.: Addressing the challenges of climate change risks and adaptation in coastal areas: A review, Coastal Engineering, 156, 103611, https://doi.org/10.1016/j.coastaleng.2019.103611, 2020.

van De Wal, R.S.W., Nicholls, R.J., Behar, D., McInnes, K., Stammer, D., … and White, K.: A High-End Estimate of Sea Level Rise for Practitioners, Earth's Future, 10(11), e2022EF002751, https://doi.org/10.1029/2022EF002751, 2022.

van de Wal, R.S.W., Melet, A., Bellafiore, D., Vousdoukas, M., Camus, P., … and Staneva, J.: Sea Level Rise in Europe: Impacts and consequences, State Planet Discuss, [preprint], https://doi.org/10.5194/sp-2023-38, in press, 2024.

Vousdoukas, M.I., Mentaschi, L., Hinkel, J., Ward, P.J., Mongelli, I., Ciscar, J.C., and Feyen, L.: Economic motivation for
730   raising coastal flood defenses in Europe, Nature Communications, 11(1), 2119, https://doi.org/10.1038/s41467-020-15665-3, 2020b.

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Jevrejeva, S., Jackson, L.P., and Feyen, L.: Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard, Nature Communications, 9(1), 2360,://doi.org/10.1038/s41467-018-04692-w, 2018.

735   Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L., Plomaritis, T.A., Athanasiou, P., Luijendijk, A., and Feyen, L.: Sandy coastlines under threat of erosion, Nature Climate Change, 10(3), 260–263, https://doi.org/10.1038/s41558-020-0697-0, 2020a.

WCRP Global Sea Level Budget Group.: Global sea-level budget 1993–present, Earth System Science Data, 10(3), 1551–1590, https://doi.org/10.5194/essd-10-1551-2018, 2018.

740   Weisse, R., Dailidienė, I., Hünicke, B., Kahma, K., Madsen, K., Omstedt, A., Parnell, K., Schöne, T., Soomere, T., Zhang, W., and Zorita, E.: Sea level dynamics and coastal erosion in the Baltic Sea region, Earth System Dynamics, 12(3), 871–898, https://doi.org/10.5194/esd-12-871-2021, 2021.

Zscheischler, J., Martius, O., Westra, S., Bevacqua, E., Raymond, C., … and Vignotto, E.: A typology of compound weather and climate events, Nature Reviews Earth & Environment, 1(7), 333–347, https://doi.org/10.1038/s43017-020-0060-
745   z, 2020.