**SP35 - Sea Level Rise in Europe: Adaptation measures and decision-making principles**

*Explanation for changes in the conclusion:*

Some of the specific reasons for changing the conclusion are:

- We wanted to better summarise all parts of the text: as for the previous version, the two parts of the text (adaptation measures and decision-making principles) were not well balanced and did not reflect all the main conclusions of the first and second parts of the manuscript;

- Moreover, as regards the first paragraphs of the conclusion summarising the first part of the manuscript (adaptation measures), some phrases were very specific to the basins, and we already have another section for this (key developments per basin), so we felt it would be better to have more general concluding remarks, leaving the specific findings for the other section. In this sense, please note that all sentences with specific examples have been deleted to avoid repetition.

- We have also tried to highlight the points where further research is needed, which is a result that can help to improve further elaboration of the issues, which were not properly highlighted in the previous version of the conclusion.

- We have included some statements that are general and applicable to all sea basins, and are previously placed in the section ‘key developments per basin’ in the conclusion, thus making it more comprehensive.

- As one of the main outputs of the manuscript was Table 1 with the adaptation measures, we have also highlighted this at the beginning of the conclusion in order to make the conclusion more coherent and with clear references to the specific parts of the text that are more important.

**CONCLUSION**

This paper has conducted a review of the literature on coastal adaptation. The main outcome of this process, which is summarised in Table 1, was the collection and categorisation of 17 adaptation measures to SLR, focusing on European sea basins and targeting four climate impacts, namely coastal flooding, saltwater intrusion, coastal erosion and impacts on ecosystems and estuaries. The table combines two categorisations regarding the responses to SLR: first, a top-level categorisation of adaptation measures according to the four main types of response identified by the IPCC, and a further elaboration taking into account the sub-KTM to SLR developed by the EEA. By reviewing the relevant literature on European sea basins, the paper has shown that adaptation strategies on Europe’s coasts include a mix of hard and soft measures, planning measures, policy developments and stakeholder and community engagement. A common theme across all the basins is the shift towards a combination of traditional engineering solutions with soft measures, such as nature-based solutions.

The measures discussed in this paper are generally subject to trade-offs that should be considered when planning for coastal adaptation. In order to accurately analyse existing trade-offs, it is important to understand the effectiveness and feasibility of these measures. The paper identified a critical gap in the literature in this regard. In particular, there is a scientific need to assess the effectiveness and feasibility of individual measures and in context-specific cases. Such a research gap, if addressed, could advance knowledge and contribute to the field of coastal adaptation. Hence, these findings suggest that future research can expand the literature review to include more studies, and that more research is also needed to learn about the trade-offs of implementing each of these measures as well.

In terms of decision making approaches, the paper has shown that coastal adaptation is a complex undertaking mainly because of five key common characteristics, namely the diversity of fundamentally different measures, the multiple objects and trade-offs, the multiple interests and social conflicts, the long time horizon, and the large and deep uncertainties involved in such decisions. To support decision-making processes, analytical tools are available, ranging from relatively low-burden tools such as adaptation pathway analysis and multi-criteria analysis to technically sophisticated methods such as robust decision- making and real-option analysis.

Integrating local communities into decision-making processes and emphasising the importance of continuous monitoring and flexible management strategies are notable trends. Ensuring that these trends lead to appropriate mixes of coastal adaptation measures being found depends on the continued support and involvement of public and private sector stakeholders in effective multi-level governance. To this end, it should be noted that there is a large discrepancy between the normative and descriptive literature in the participatory approaches for supporting decisions, and more empirical work is therefore needed to understand the conditions under which participatory adaptation processes are delivered.

**KEY DEVELOPMENTS PER BASIN**

Adaptation to SLR in Europe has been approached through various types of measures to accommodate, protect, advance and retreat. Below, we summarise the main developments organised by the different sea basins.

In the Baltic Sea basin, for accommodate measures, progress has been made, with several Baltic nations incor- porating SLR projections into their spatial planning and land use regulations. Notably, Estonia has implemented a Maritime Spatial Plan for 2022 that integrates SLR informa- tion. In terms of protect measures, upgrading coastal defences, e.g. with sea walls, embankments and dikes, has been implemented, while nature-based solution initiatives to re- store and create wetlands and coastal marshes that can act as buffer zones and reduce wave energy are also underway. For instance, the Danish Baltic coast provides the first large- scale example of successful managed realignment with the restored Gyldensteen Coastal Lagoon, which has to date en- hanced ecological status and species richness in the project area (Thorsen et al., 2021). The Baltic Sea basin has also seen progress in marine environment conservation, which can po- tentially enhance living marine resources and related fishing activities. Key to furthering coastal adaptation in the basin is ensuring that solutions are also linked to financing mecha- nisms that can mobilise co-finance, e.g. from the private sec- tor, to supplement national public funding.

In the North Sea basin, SLR information has been inte- grated into coastal planning at the national and sub-national levels in most countries, while North Sea basin countries are implementing different mixes of hard and soft pro- tect measures. In the Netherlands, the Delta Programme includes a comprehensive mix of measures to maintain a healthy groundwater system, using spatial planning and other context-specific strategies while providing more space for water and enhancing urban and ecological values. Sand nour- ishment is also growing in importance as a coastal protect measure in the Netherlands, alongside dike upgrading and re- inforcement. In Germany, there is an emphasis on integrated coastal zone management and dike upgrading and widening that incorporates flexibility for future SLR. In the UK, a mix of protection, beach nourishment and managed retreat is be- ing considered for different portions of the coastline. These countries each reflect different approaches to addressing un- certainty that should be iterated and revisited as more infor- mation on SLR becomes available in the future.

In the Mediterranean Sea basin, key developments include the mainstreaming of SLR information into planning through the development of national adaptation plans, e.g. in Spain and Italy. Furthermore, insurance is emerging as an accommodate measure to address SLR-related risks, e.g. in Spain and France. Soft protect measures, such as sand nourishment and nature-based solutions more broadly, are important in the Mediterranean Sea basin, with coastal reforestation and the restoration of dunes and marshes implemented in various regions to act as natural barriers. Other examples are cliff strengthening and stabilisation measures that include green and grey options focusing on reducing erosion and enhanc- ing natural protection along coastal cliffs, e.g. in Croatia and Italy. Several major urban areas in the basin have initiated large-scale adaptation measures. For example, the Venice MOSE project is a system of mobile barriers constructed to protect Venice from high tides and flooding, while the city of Barcelona has introduced green infrastructure projects that focus on permeability and water retention to combat both SLR and increased rainfall. Such differentiated measures ap- propriate to the specific biophysical and socio-economic con- text at issue should be further supported through participatory co-development approaches for coastal decision-making (Bisaro et al., 2024).

In the Black Sea basin, there is an increased emphasis on developing monitoring and early-warning systems to help manage SLR and the associated flood risks. Furthermore, ef- forts have focused on upgrading and modernising existing coastal infrastructure to enhance resilience to rising sea lev- els. For example, in Romania, a major initiative combining sand nourishment and cliff stabilisation with marine mea- sures including artificial reef building is being implemented to reduce coastal erosion risks exacerbated by SLR and to enhance resilience in the tourism sector. Furthermore, imple- mentation of such nature-based solutions that also benefit lo- cal economies is promising and should be explored for scal- ing up coastal adaptation in the basin.

In the Atlantic Ocean basin, countries are implement- ing a range of adaptation measures, with an emerging fo- cus on nature-based solutions and improved spatial plan- ning to reduce risks to coastal development across the en- tire basin. Soft protect measures, such as cliff strengthening and sand nourishment, are being implemented in Portugal, while restoration measures, protecting against wave energy and therefore limiting erosion and sediment accumulation, are being implemented in Spain, Portugal and France. Ad- vance strategies are also being implemented through nature- based solution approaches, as in Spain, where the national adaptation plan envisions the regeneration of beaches and ar- tificial dune systems to reduce erosion and revitalise coastal ecosystems, e.g. in the restoration one of the largest dune sys- tems of the Cantabrian Sea. Furthermore, in France, coastal land in the south-west of the country has been advanced with the creation of a vegetated area with the specific intention of supporting natural accretion of land and surrounding low areas. Finally, retreat measures are also being implemented, as in Portugal, where the progressive removal of construc- tions located in flood-critical territories along the coastline is being implemented through spatial planning instruments to manage the risk of SLR.

Common themes and general trends are further highlighted in the conclusion.