Rebuttal

The paper "*Sea level Rise in Europe: impacts and consequences*" aims at providing an overview of the main type of impacts of SLR on the coast at the European scale. Three main processes are considered, i.e. flooding, erosion and saltwater intrusion, all having widespread impacts at the coast, also depending on the local setting. So it is not easy to have an overview at the continental scale. Moreover, the three processes are frequently overlapping, and this is addressed in the paper (such as in section 5.6). However, some repetition among chapters is present (see comments below) and might be avoided.

I indicate below, for each section, some comments. Additional minor suggestions are listed at the end of this document. Overall, I suggest minor revision.

Specific comments

The paper frequently refers to IPCC report and previous literature; in some cases, I found reported data not suitable to the case. This is the case of **section 2**, lines 129-130: "(…) *it is suggested that by 2100 coastal retreat could reach approximately 100 m for a 4°C temperature increase*". This overall estimate is not appropriate, since coastal retreat largely depends on coastal slope and beach morphology (without considering sediment supply but "pure" SLR) so it should not be indicated as a constant value for any degree of global warming.

We removed the too detailed estimate.

Again in section 2, at line 131 the possible threat to UNESCO World Heritage Sites is mentioned but no references are provided. A couple of papers dealing with WHS at risk for coastal flooding and SLR are, in case:

Reimann et al., 2018. *Mediterranean UNESCO World Heritage at risk from coastal flooding and erosion due to sea-level rise*. Nat Commun 9, 4161. https://doi.org/10.1038/s41467-018-06645-9

Romagnoli et al. 2022. *Coastal Erosion and Flooding Threaten Low-Lying Coastal Tracts at Lipari (Aeolian Islands, Italy).* Remote Sens.14(13), 2960; https://doi.org/10.3390/rs14132960

References are added. We have also included this additional reference, with directly address the impact of sea level rise and coastal erosion on UNESCO sites:

Haigh, I.D., Dornbusch, U., Brown, J., Lyddon, C., Nicholls, R.J., Penning-Roswell, E. and Sayers, P. Climate change impacts on coastal flooding relevant to the UK and Ireland. MCCIP Science Review 2022, 18pp. doi: 10.14465/2022.reu02.cfl, 2022.

In **section 3** the common approach applied for the analysis, namely the SPRC framework, is introduced. I expected a longer section than the present one (that is just 7 rows), citing other examples of coastal studies where this approach has been successfully applied, such as (for instance):

Villatoro et al. 2014. An approach to assess flooding and erosion risk for open beaches in a changing climate, Coastal Engineering, 87, 50-76, https://doi.org/10.1016/j.coastaleng.2013.11.009.

We deliberately keep this section short, because it is simply introducing the concept, which is then explored in depth in the sections below. Thanks for your suggestion regarding adding additional references. We have added the reference you recommend, and three other studies that use this framework:

Haigh, I. D., Nicholls, R. J., Penning-Rowsell, E. C., and Sayers, P.: Climate change impacts on coastal flooding relevant to the UK and Ireland, MCCIP Rolling Evidence Updates, 18 pages, https://doi.org/10.14465/2022.REU02.CFL, 2022.

Thorne, C.R., Evans, E.P. & Penning-Rowsell, E.C., 2007. Future flooding and coastal erosion risks, Thomas Telford Services Ltd. London, UK

Donovan, B., Horsburgh, K., Ball, T. and Westbrook, G. Impacts of climate change on coastal flooding. MCCIP Science Review 2013, 211-218, doi:10.14465/2013.arc22.211-218, 2013.

Also, the citation of "traditional exposure vulnerability approach" might be supported by some references.

We have referenced the following paper:

Nicholls, R., et al. (2008), "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates", OECD Environment Working Papers, No. 1, OECD Publishing, Paris, https://doi.org/10.1787/011766488208.

In Figure 2, the sketch of should also report the term “Consequences” to be complete, otherwise delete it from the caption (as it is in figures 3, 7, 10).

Thanks for your comment, this is a good point. Receptors and consequences are essentially the same thing and different studies use SPR and SPRC interchangeable. As consequences are not reffered to in the figures, we have as you suggested removed it. Hence, we just refer to Source-Pathway-Receptor throughout.

Section 4 on coastal flooding is probably the more complete. I give below just some comments/suggestion.

In “4.1 Source”, among interannual SL variability (lines 185-187) it might be also cited the role of oceanographic processes at the basin/sub-basin scale. For the Mediterranean, these are recent references:

Menna et al., 2022. *Climatic, Decadal and Interannual variability in the Upper Layer of the Mediterranean Sea Using Remotely Sensed and In-Situ Data*. Remote Sens. 2022, 14(6), 1322; https://doi.org/10.3390/rs14061322.

Meli, M. et al. 2023. *Sea-level trend variability in the Mediterranean during the 1993–2019 period*. Frontiers in Marine Science, 10:1150488. https://doi.org/10.3389/fmars.2023.1150488

Added accordingly

Some estimates referred to the text are not easily checked from figures. For instance:

-at lines 288-290 it is mentioned “*the probability of compound flooding (….) is projected to robustly increase by the end of the 21th century*”. Based on figure 4b I understand that this larger probability increase is represented by D T of 40-80 % (orange to red colors), is it correct? It might be useful to quantify also in the text to help readers.

Added the 40-80% in the text

In Subsection 4.4, at lines 383-385 some estimates are given in the text for the increase in flooded area due to events with different recurrence times. I found not easy to compare these values with figure 3.6.

We agree it is a bit confusing that we refer to the area in percentage, yet Figure 3.6 shows thea rea in $Km^{2.}$ Because the results are presented in Paprotny et al. (2019) by Country it is not easy to summaries the results here in a single sentence in km^2. However, to help clarify we have added the following sentence referring readers to Table 4 in that paper:

'for size of area flooding in km^2 see Table 4 in Paprotny et al. (2019) for more details.'

Subsection 4.5 on "initiative to develop flood-related climate services in Europe" is useful. Dealing with Adaptation, possible overlaps with related chapter of the Assessment Report might be checked and, in case, cross-reference is suggested.

Cross reference added

Section 5 on coastal erosion from my point of view needs some clarification and possible reorganization due to some repetition.

The section mostly deals with processes affecting low-lying costs, i.e. the most threatened by SLR. A cliffed coast is instead represented in figure 7 (although erosion processes and impacts of SLR on this type of coast are not really accounted in the paper). I noted this discrepancy also in the Abstract (lines 28-29) where cliff failure is mentioned for coastal erosion - I suggest to simplify that sentence in "*Coastal erosion leads also to damage and....(...*)" and avoid mentioning cliffs.

Adjusted in abstract

Also, the concept of "negative coastal balance=erosion" given in "5.2 - Pathway for erosion" (line 500) is, in principle, correct for beaches. In cliffed costs, erosion and shoreline retreat are directly related to the balance between assailing force of waves and resisting force of the

cliff material, when the former exceeds the latter. That is another reason to clarify with type of coasts the chapter is focusing on.

We agree with the reviewer mainly in the sense that at hard cliffed coasts negative sediment budget will result also in wave cut notches, and eventual cliff collapse and erosion, but in much larger time scales. We have added a phrase 'especially at sandy beaches' and we thank the reviewer for the suggestion

On the other side, at line 511, where it is mentioned "(….) *factors that affect the erodibility of the beach*" it might be added "*and the cliff*".

We have replaced the word beach with coast.

A definition of coastal erosion is provided at line 459, in subsection 5.1. Other definitions might be confusing or not univocal, such as the above cited (at line 500) that "*coastal erosion takes place when the sediment budget of a given area becomes negative*", for the reasons explained above. I suggest deleting this sentence since it only reflects part of the process, whose complexity is better explained in the text just below (lines 500-511).

We have changed the sentence to 'Sandy beach erosion takes place when the sediment budget of a given area becomes negative'.

Another definition is given at line 514, in "Receptor and consequences of erosion" ("*Coastal erosion is the process by which the land is worn away and is submerged in water")*; this might be misleading. Submergence is also due to episodic flooding, not necessarily to coastal erosion. A further definition at lines 578-579 ("*Erosion is a physical phenomenon where sand is removed from the shoreface and deposited elsewhere, usually offshore"*) is also misleading because sediment transport and deposition are parts of cyclic processes modelling the emerged and submerged beach and should not be confused with (permanent) sediment loss that leads to erosion.

We have added the word permanent in the sentence: 'Coastal erosion is the process by which the land is worn away and is permanently submerged in water'.

Among factors indicated as drivers of coastal erosion in subsections 5.1 and 5.2, some concepts and terms might be more precise and inclusive, trying at the same time to avoid repetitions.

For instance, instead than "*terrestrial sediment supply*" (line 471) the indication of "*sedimentary balance of the coastal stretch*" would be better used, because it includes also marine sediment supply, not only terrestrial one.

We are a bit confused with this comment as the list of factors is meant not to be exhaustive. All the factors we mention affect the sediment budget and terrestrial supply is one of them; while the other factors affect onshore transport, among others. So we don't think there is a false statement here.

Factors influencing the sedimentary balance at the coast, both natural (climatic) and anthropogenic, should encompass a view to river catchment basins. This link should be better evidenced in a source-to-sink approach. An example of this is provided by references below:

Meli and Romagnoli, 2022. *Evidence and implications of hydrological and climatic change in the Reno and Lamone river basins over the last century and in related coastal area, Emilia-Romagna, Northern Italy.* Water, 14, 20650, doi: 10.3390/w14172650

Other natural factors with possible negative effects on the coastal budget are the occurrence of canyons' heads in the nearshore, that can subtract sediment from longshore drift. This potential effect could be mentioned, since this process is more frequent than commonly considered.

We would like to thank the reviewer for the reference which we cite in the paper. We also mention the effect of canyons as a sediment sink and a source of erosion which is a very good point as well.

Among "human" factors (cited at line 507) it might be also mentioned the reduction of natural defence capability of the beach (its own resilience) due to alteration of natural coastal dynamics, and the stiffening of the coast caused by the construction of "hard" protection structures.

We are confident that this point is already touched in this section; e.g.:

'In principle, coastal erosion can be the result of any process that alters the sediment transport patterns. This can be either hydrodynamic (e.g., changes in wave intensity or direction, sea level, etc) (Sierra and Casas-Prat, 2014), related to the presence of obstacles like hard

structures (Loureiro et al., 2012; Noble, 1978), or factors that affect the erodibility of the coast (Feagin et al., 2019). ‘

To conclude, subsections 5.1 and 5.2 are partially overlapping. The Authors might consider if there a way to avoid this.

We understand the point and we have checked carefully in the manuscript. For homogeneity reasons we present all impacts using the Source, Pathway, Receptor framework. Before there is a general introduction with definitions and drivers so some overlapping is inevitable, but we don’t think the same points are repeated. We have already made several changes and if the reviewer has further specific suggestions, we are happy to consider them.

Among the coastal monitoring programs mentioned in subsection 5.3 it might be included the long-term, regular monitoring carried out since the 1983 on the Emilia-Romagna coast (regional scale) on the emerged and submerged beach and on the shoreline (see public reports, https://www.arpae.it/it/temi-ambientali/mare, and adopted indicators on coastal erosion, https://webbook.arpae.it/erosione-costiera/index.html).

We thank the reviewer for the constructive comment and we have added the information in the revision.

In Table 1 -Summary of the methods for monitoring, for what regards Drones, it might be added something like: “*Marine drones such autonomous surface vehicles (ASVs) are usefully applied for monitoring the nearshore in shallow water and for testing the effects of mitigation strategies against erosion"*Ref: Stanghellini et al., 2022; https://doi.org/10.3390/rs14225901

We have added the reference in the Drones section where we now mention also terrestrial and floating cases of autonomous surveying.

In subsection 5.4 “Historical shoreline change” it should be mentioned that many coastal areas are artificially stabilized, otherwise estimate given for erosion in Europe should be much worser.

It is a fair point and we have added a relevant statement: “It is important to highlight that several of the accreting or stabilizing trends found in Europe are due to human interventions, either through beach hardening or nourishment projects.”

In subsection 5.5 “Future shoreline change due to SLR” (I suggest adding this specific to the title), in the sentence regarding Mediterranean beaches (lines 557-558), I do not understand how the beach narrowness should depend on slope. Coarse-grained beach with higher slope may be narrow (but they are less vulnerable to SLR), while low-gradient, sandy beaches may be narrow or large for different reasons... and will be more exposed to SLR to due to their reduced height.

The reviewer is right and the statement was left there by mistake after edits by different co-authors. Beach narrowness may correlate with slope, but this is irrelevant to the context of the paragraph. We have rephrased the sentence to: “Mediterranean beaches are more susceptible to the negative effects of SLR because they are narrower as a consequence of the lower tidal range and milder wave climate”

Furthermore, I question the projections reporting shoreline retreat (at lines 561-562): it should be specified (also in the caption of figure 9) that these estimates only represent effects due to SRL (according to a “bathtub approach” with respect to terrain model, I suppose), but they do not take into account the coastal morpho-dynamic evolution neither sedimentary budget, as it would be requested for estimating shoreline retreat due to erosion. These further aspects are well addressed in subsection 5.6, but not clarified here.

De Santiago is not applying a bathtub approach but morphodynamic models which simulate shoreline change by including cross-shore and alongshore sediment transport formulations, short- and long-term processes and considering hard structures. Other cited works apply the Bruun rule considering beach slope data and to some extent sediment budgets. Of course, any empirical or process-based model has its limitations, but we think that it’s beyond the scope of the current manuscript to go into such discussions.

Section 6 on saltwater intrusion follows the same organization of previous sections (SPRC framework) and provides also some indications on possible adaptation measures. Very minor corrections to text and figures are indicated below.

Done

Section 7: it is not clear to me the reason for this section dealing with impacts of SLR on specific environments (estuaries) and ecosystems. The impacts include all the three previously considered (flooding, erosion, saltwater intrusion) so it cannot be easily moved into one of the previous sections as it is. However, I found it disconnected to the rest of the paper.

The last paragraph (lines 793-796) is instead more general and partly overlaps with other sections of the chapter, also repeating some previous concepts; consider moving it or deleting it.

We removed it.

Minor comments and technical corrections:

-lines 56, 97: check parenthesis (too many open)

Corrected

-lines 113-114 there is a repetition of what already reported at lines 107-108.

Sentence 107-108 removed

-line 298 in the sentence "(…) *can also erode riverbanks and cause landslides, leading to further flooding*" the Author would probably mean the "breaking of the embankments/levees". This would be more correct than a general term "landslides".

Adjusted

-line 323: you could rewrite as "(….) *and stabilization of beaches and dunes*"

Adjusted

-line 330-331: "(….) *a continued decline in the extent of natural systems* (…)", this reduction in the extent can be very well expressed with the concept of "coastal squeeze".

Added

-line 467: I would delete citation "Romagnoli et al., 2022" from here (it is also mentioned just below as local-scale study).

Done

-line 647: in the caption of Fig. 11 it might be specified "(b) *current situation, with effects due to climate change and human activities*". Note that in the sketch c) the word "subsidence" should be corrected.

Added

-line 693: "(…) *such as due to subsidence*" would sound better.

Added

-Figure 13: this figure might be more extensively explained, it is very cryptic. SAR seems not mentioned in the text but only in the figure caption.

Thank you, we have improved the caption and text around the figure.

-line 755: a parenthesis is lacking at the end of the sentence "(*Figure 14*)".

Done

-**Figure 14**: correct in the caption "*upconing*", it is the scientific term for the process indicated in figure.

Done

-**line 774**: delete "other" from "*On the one hand*".

Done