IRTA RECERCA I TECNOLOGIA AGROALIMENTÀRIES

SEVENTH FRAMEWORK PROGRAMME

RISES-AM- EU Research Project

Management options to adapt to high-end scenarios of sea-level rise: implications for deltaic coastal wetlands

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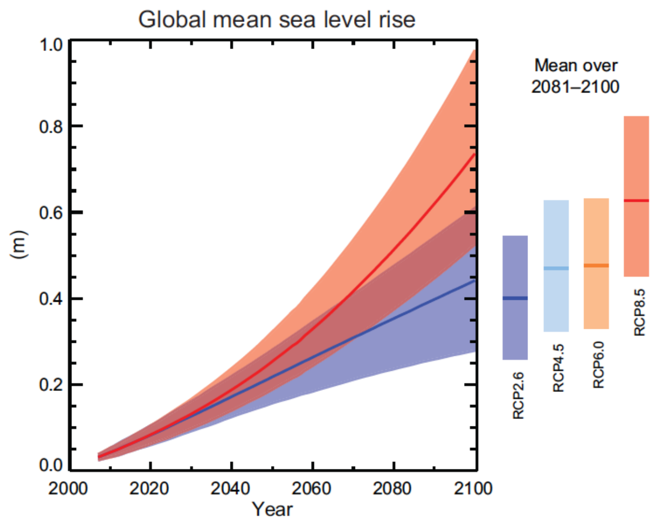
Summary

1) High-end scenarios of sea level rise
2) The projecte RISES-AM-
3) Mechanisms of adaptation of deltas to relative sea level rise
4) Management options, some examples

Projections of sea level rise (IPCC, 2013)



High-end scenarios

1. Up to date most of the efforts have focused on mitigation measures to avoid a mean global temperature rise above 2ºC.
2. However, emissions keep rising and there is a high chance to go beyond this limit by the end of the century
3. Thus, it is important to put more efforts in mitigation but also increase efforts in adaptation to high-end scenarios.
4. High-end scenarios are those assuming a global warming higher than 2ºC and a sea level rise around 1 m by the end of this century (RCP 8.5).
5. The European Union has given priority to research projects looking at the impacts and adaptation to high-end scenarios.

Deltas in Time of Climate Change

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The Projecte RISES-AM-

1. **R**esponses to coastal climate change: **I**nnovative **S**trategies for high **E**nd **S**cenarios -**A**daptation and **M**itigation-

2. Objectives:

   – To increase the knowledge on the response of coastal systems to climate variability, through the development of models and risk analysis.

   – To develop and analyze adaptation pathways of the most vulnerable coastal systems at global, regional and local scales, including solutions based on ecological engineering and green infrastrcutures.

   – To identify synergies between adaptation and mitigation options at all scales.

   – In the Ebro Delta de project will model the impacts of relative sea level rise on rice fields and wetlands, with and without additional adaptation measures.

Deltas in Time of Climate Change

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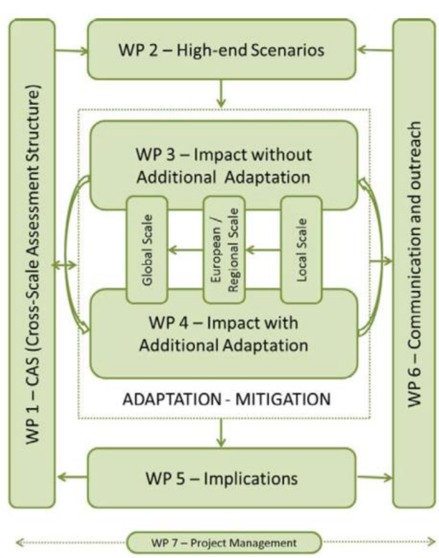
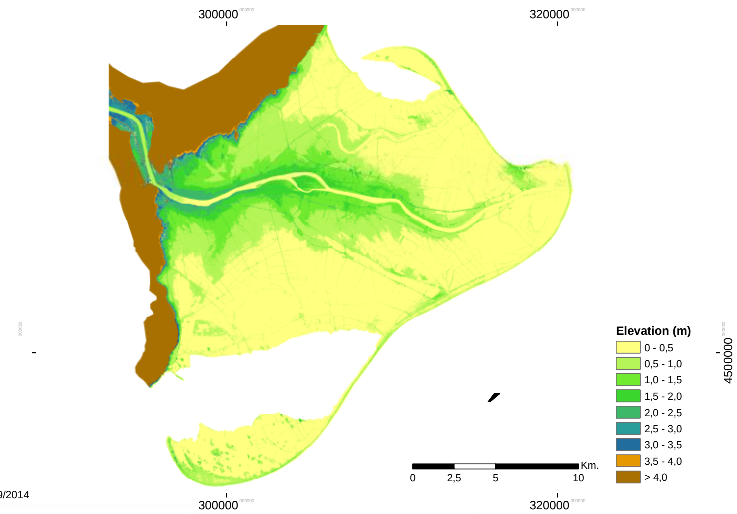
The Project RISES-AM-



The case of deltas: vulnerability versus resilience

Deltas represent 1% of the Earth surface but more than 500 million live in !!!

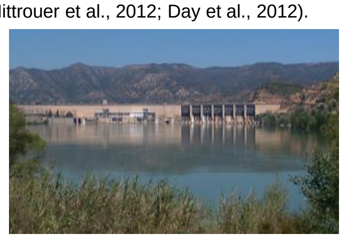


The response of deltas to SLR: natural mechanisms

• The existing literature focuses on the **feed-back mechanisms between water level, sedimentation and vertical accretion** at the scale of the marsh platform under tidal forcing (Kirwan and Temmerman, 2009; Fagherazzi et al., 2012), but these mechanisms are also at work at the scale of the whole delta.

• **Pulsing events supplying large amounts of suspended sediment** (i.e, large river floods, hurricanes, etc.) also enhance marsh formation and accretion (Day et al., 1995; Reyes et al., 2004; Day et al., 2007; Falcini et al., 2012). Marshes and coastal wetland forests with high mineral sediment inputs adjust more quickly to SLR than sediment deficient ones (D'Alpaos et al., 2011; Day et al., 2012). Mudd (2011) reported that marshes established through pulses of sediment result in estuaries that are far more efficient in trapping sediment. Thus if sediment supply returns to the pre-pulsed level the marsh may continue to be viable under a higher SLR.

The **mechanisms of sediment capture can be enhanced either by natural feedbacks or by manipulating sediment delivery** using pulses from a managed dam release or a controlled river diversion (Rovira and Ibáñez, 2007; Day et al., 2009; Mudd, 2011; Nittrouer et al., 2012; Day et al., 2012).



The response of deltas to SLR: natural mechanisms

When the feedbacks among sea level, river flow and sediment dynamics are considered at the proper scale, that is the whole delta, a clearer picture of the dynamic response of deltas to SLR appears. The enhanced sedimentation and vertical accretion of a deltaic wetland due to an increase in sea level and flooding frequency is part of a wider response of the deltaic system to RSLR.

We propose the existence of **three main mechanisms for deltas to cope with RSLR** that are self-enforcing as the rates increase (Figure 1), tending to enhance the efficiency of the deltaic sedimentary trap:

a) an **increase in the frequency of delta lobe switching** with accelerated SLR leading to the formation of new lobes in shallow areas and the consequent increase in the efficiency of sediment deposition,
b) an **increase in the frequency and magnitude of flood events** in the delta plain as a consequence of an increased overflowing through the river natural levees, leading to enhanced sediment inputs and the trapping efficiency of the delta,
c) an **increase in the frequency and magnitude of overwash events** in the delta fringe allowing sandy beaches to quickly adapt to SLR.

Deltas are highly vulnerable... if they are strongly impacted by human activities... but **resilient and resistant if the natural processes are at work** (naturally or by restoring them).

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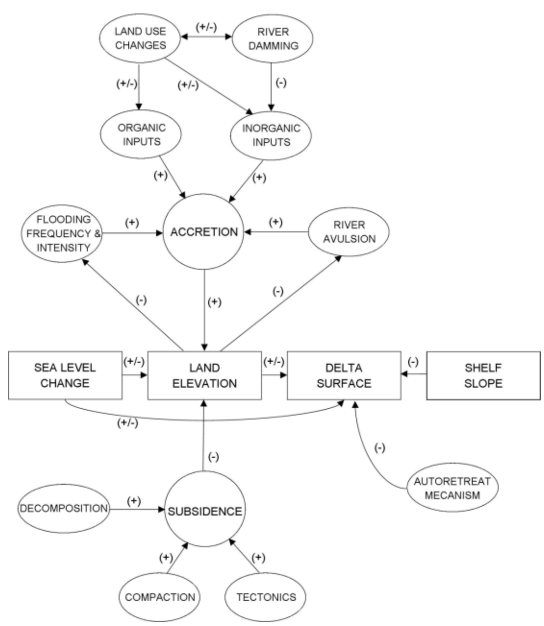
The response of deltas to sea level rise: natural mechanisms



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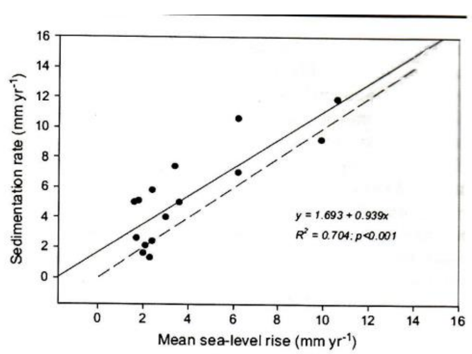
The response of marshes to SLR and sediment inputs

-**Feed-back between flooding and vertical accretion**

- **Effects of increasing or restoring sediment pulses**



Alongi (2008). Mangrove forests: resilience, protection from tsunamis and responses to global climate change. Est Coast Shelf Sci 76: 1-13.

Mudd (2011). The life and death of salt marshes in response to anthropogenic disturbance of sediment supply. Geology 39(5): 511-512.

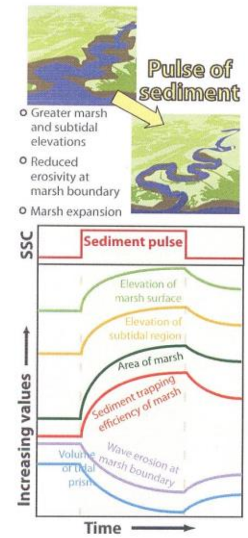


Figure 1. Diagram showing the effects of a pulse in sediment supply on the properties of an estuary and its marshes.

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Non-linear and non-equilibrium response of marshes to RSLR

Feedback between inundation depth and suspended sediment concentrations allows marshes to quickly adjust their elevation to a change in sea-level rise rate.

Analytical theory suggests that the influence of vegetation on the feedback between inundation and accretion leads to a relationship where marshes adjust to step changes in sea-level rise rates more quickly than predicted by an exponential function. **This leads to the counterintuitive condition where marshes adjust to large changes in sea-level rise rates faster than they adjust to small changes in sea-level rise rates** (Fig. 5)

(Kirwan and Temmerman 2009, *Quaternary Science Reviews* 28: 1801-1808).

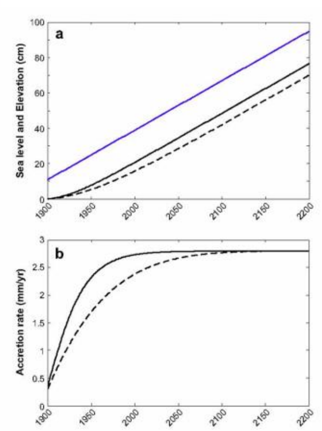

Fig. 1. Modeled response of marsh elevation (a) and accretion rate (b) to an abrupt increase in sea-level rise rate from 0.3 mm/yr to 2.8 mm/yr (Gehrels et al., 2008). Model experiments begin with a surface in equilibrium with a 0.3 mm/yr rate of sea-level rise, and demonstrate adjustment to a step change in the rate of sea-level rise beginning in 1900 AD. Blue line denotes sea level, solid black line denotes Morris model, dashed black line denotes Temmerman model. Since absolute elevations are different in each model (due to different tidal ranges and local model parameters), we plot elevation changes relative to their initial value which we set to zero in all model experiments. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

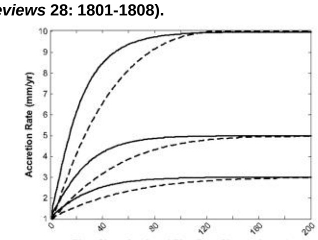

Fig. 5. Response of modeled accretion rates to step changes in the rate of sea-level rise. Experiments begin with a marsh surface in equilibrium with a 1 mm/yr rate of sea-level rise. Sea-level rise rates increase abruptly to 3, 5, or 10 mm/yr at time zero. Black line: Morris model; Dashed line: Temmerman model.

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Managing humanized deltas to cope with rising sea-level

- Although some deltas may have survived high rates of SLR in the past, the question in scientific terms and the challenge in management terms are: **can human-disturbed deltas survive future accelerated rates of SLR ?**

-There is a **need to expand the time horizon (beyond 2100)** for the analysis of the impacts of climate change on deltas (and low-lying coasts in general), since **sea-level will keep rising** even if Tº stabilizes.

- Long-term projections and/or **high-end scenarios** are starting to be considered in the new assessments, in part **because short-term management options may compromise long-term strategies**.

- There is a **need to define the long-term options** according to the new projections of sea-level rise (2200 to 2500), considering both the rate and the total amount of sea-level rise.

- Up to now, **adaptation options considered for expected SLR have been largely based on protection measures**, with little attention to accommodation, restoration, and retreat approaches (Nicholls et al., 2011). However, under high-end scenarios of RSLR a protection strategy may not be feasible or sufficient, and new adaptation options and pathways must be considered.

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The future of deltas beyond the present century: expected sea-level rise

Source: Jevrejeva et al. (2012): Sea level projections to AD2500 with a new generation of climate change scenarios. *Global & Planetary Change* 80-81: 14-20.

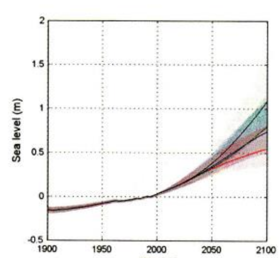

Fig. 3. Sea level projections by 2100 with RCP scenarios; red– RCP3PD, blue– RCP4.5, green– RCP6 and black – RCP8.5. Shadows with similar colour around sea level projections are upper (95%) and low (5%) confidence levels.

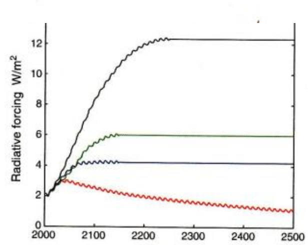

Fig. 1. Radiative forcings for the RCP scenarios; red– RCP3PD, blue– RCP4.5, green– RCP6 and black – RCP8.5.

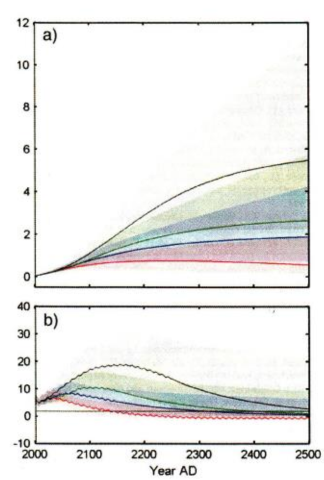

Fig. 4. (a) Sea level projections by 2500 with RCP scenarios; red– RCP3PD, blue– RCP4.5, green– RCP6 and black – RCP8.5. Shadows with similar colour around projections are upper (95%) and low (5%) confidence level. (b) Rates of sea level rise (colour scheme the same as panel a). The black horizontal line corresponds to the rate of sea level rise during the 20th century (1.8 mm/yr).

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Adaptation options for high-end scenarios of SLR

- The current approach (structural): **rising dikes** (The Netherlands).

- The alternative approach (functional): **rising grounds** (Ebro Delta).

- The combined approach (structural & functional): **rising dikes & rising grounds** (Mississippi Delta).

• The **current view** is that protection is the best (or the only) strategy for future SLR up to 2 to 5 meters. Beyond 5 meters the retreat would be the best (or the only) strategy (Tol et al. 2006).

• The **alternative view** suggest that “rising dikes” will be only feasible if “rising grounds” is also implemented; if not, retreat will be the only solution in the long-run. Rising grounds could be the main strategy in most deltas.

• **We propose that “rising grounds” is the best adaptation strategy in most deltas** for high-end scenarios of SLR, though in some cases the option of retreating may be necessary in combination with structural and functional measures.

• The **different options should be applied as a function of the natural and human features of deltas** (population and urbanisation level, availability of sediment sources, local rates of relative sea-level rise, etc.).

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The structural protection strategy: the case of The Netherlands

Katsman et al. 2011. Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta. The Netherlands as an example. *Climatic Change*, DOI 10.1007/s10584-011-0037-5

-The Dutch State Commission requested to the experts (Vellinga et al. 2008) an assessment exploring the **high-end climate change scenarios for flood protection**.

- The study considered a **local mean sea level rise in 2200 of 1.5 to 3.5 meters**. The increase in peak river discharge was also considered, yielding a 10% increase for the year 2100.

-In order to assess the flood risks, the **combined effects of sea level rise, changes in storm surge height and increased river discharge** were assessed.

- Among the most critical issues is the protection of the **Rotterdam harbor**, which is protected by a storm surge barrier and it is programmed to close automatically when the local water level reaches 3 m above normal conditions. Nowadays, the criterion corresponds to an economically acceptable closing frequency of about once every 10 years. In future scenarios **water level is expected to reach the closure criterion 5 to 50 times more often than at present**.

- Despite the increasing flooding risks, **the national policy still relies on protection measures**, but other measures such us restoring the floodplains, re-connecting tidal wetlands to the open sea and promoting sediment inputs to the delta are increasingly considered.

- The review of the existing assessments leads to the conclusion that the Dutch protection strategy based on “rising dikes” is thought to be feasible, since the maximum expected SLR under the worst case scenario is about 5-6 m. However, this assumption may be valid only if the required level of economic investment is maintained.

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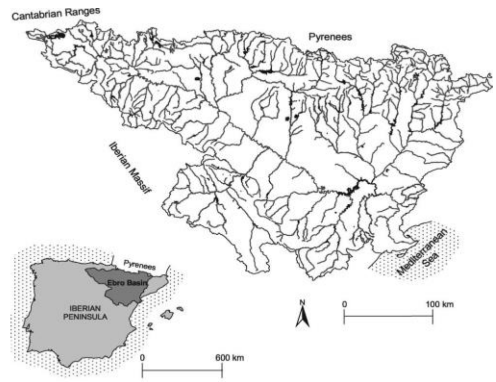
The functional protection strategy: the case of the Ebro Delta

•The **Ebro Delta** has a watershed with a Mediterranean climate in which large river floods with a **high suspended sediment load** were usual before and after human intervention. Values **from 0.1 to 10 g/l** were usual in the Ebro River before dam construction (Ibañez et al. 1996).

• Only recently, after 1960's the Ebro River has undergone a **dramatic reduction of sediment fluxes (up to 99%) due to dam construction**. Suspended sediment load is presently <0.01 g/l (Rovira et al. 2012).



• Nowadays the delta has **very little protection infrastructures** against coastal and river flooding due to the fact that most of the delta is still above sea level, and the storm surge and river floods are not a serious threat. Only very large floods (50- 100 yr return period) have the chance to flood the delta plain.

Ibáñez, C., Prat, N. and Canicio, A. (1996). Changes in the hidrology and sediment transport produced by large dams on the lower Ebro river and its estuary. *Regulated Rivers* 12(1):51-62.

Rovira, A., Alcaraz, C. & Ibañez, C. (2012). Spatial and temporal dynamics of suspended load at-a-cross-section: The lowermost Ebro River (Catalonia, Spain). *Water Research* 46: 3671-3681.

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The functional protection strategy: the case of the Ebro Delta

• During the last century most of the delta was devoted to rice farming and the **farmers were promoting the sediment inputs to the rice paddies** in order to improve rice production. The rice system was very efficient at distributing riverine sediments, and it may be used in the future provided we recover at least part of the sediment flux.

• In fact, **most of the rice fields were created in the XIX century through engineering projects designed to bring riverine sediments to the salt marshes**. This is a nice example of "classical" ecological engineering and ecosystem service !

• Mister Polet and the old culture of sediment (and water) management in the Ebro Delta. He still remembers the **practice of "silting", in which farmers were paying a tax to the irrigation company to be able to get sediments** after the rice harvest. After the deposition, there was a hard work with man power and horse power to distribute the sediments.

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The functional protection strategy: the case of the Ebro Delta

•Historical **accretion rates in the rice fields >0.5 cm/yr before dam construction** in the lower Ebro river, and recent (after dam) accretion rates of 0.5 cm/yr in brackish wetlands connected to the river (Ibáñez et al. 1997, Ibáñez et al. 2010).

• **The historical accretion rates (0.5 cm/yr) in the rice fields (period 1860-1960) were achieved by using 5% of the Ebro river flow**. This means a sediment supply of about 0.5 Million Tn/yr, for a surface of 20000 Ha (70% of the emerged delta plain).

• The sediment load before dam construction is estimated to be about 28 Million Tn/yr (Ibáñez et al. 1997). **To get an accretion of 1 cm/yr for the whole emerged delta plain (27000 Ha) we need about 1.3 Million Tn/yr, which is 10 times more the present sediment load but 20 times less the pre-dam sediment load.**

• Thus, **recovering about 20% of the original load** (5-6 Million Tn/yr) and supplying about 20% of this load to the delta plain **we could obtain a vertical accretion of 1 cm/yr in average**. This is **only considering the inorganic accretion** component, and when the organic contribution is considered the accretion rates can be significantly higher. Should all the pre-dam sediment load be recovered and used, accretion rates would be up to 10 cm/yr.

• This sediment management scheme **is feasible provided that a sediment by-pass system is implemented in the lower Ebro dams** (Rovira & Ibáñez, 2007).

Ibáñez et al. 2010. Vertical accretion and relative sea level rise in the Ebro Delta wetlands. *Wetlands*, DOI 10.1007/s13157-010-0092-0.

Rovira and Ibáñez. 2007. Sediment management options for the lower Ebro river and its delta. *Journal of Soils and Sediments* 11: 1-11.

Ibáñez et al. 1997. Morphologic evolution, relative sea-level rise and sustainable management of water and sediment in the Ebre Delta. *Journal of Coastal Conservation*. 3: 191-202.

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The combined protection strategy: the case of the Mississippi Delta

Blum and Roberts (2009). Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nature Geoscience* 2: 488-491.

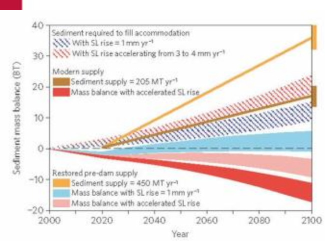

Figure 4 | Sediment mass balance for the delta region with modern sediment loads, and with hypothetical restored sediment loads. Supplies are held to 0 until the year 2020, then projected to the year 2100: the blocks at the right illustrate the standard deviation for modern loads, and ±10 for restored loads. The sediment required to fill accommodation is estimated for steady sea-level rise of 1 mm yr^{-1}, and sea-level rise that accelerates linearly from 3 to 4 mm yr^{-1} between the years 2000 and 2100. Each mass balance estimate uses subsidence models from Fig. 3c to define the upper and lower boundaries, and a 40% trapping efficiency.

• Mass balance considerations ensure that the future deltaic landscape cannot resemble the recent past, and **even the most prudent selection of diversion sites can only slow the overall rate of submergence**.

• **A recent state-of-the-art model provides quantitative estimates for two diversions located to the south of New Orleans**, which would have access to 45% of the lower Mississippi sediment load, or about 25% of the total Mississippi and Atchafalaya loads.

• **With a trapping efficiency of 40%,** and values for subsidence and sea-level rise similar to those above, **700-900 km^2 of new land can be built by the year 2110**.

• These modelling efforts highlight the mass balance problem, because the **new land to be built is <10% of the extra submerged area that we predict for the year 2100**.

• **Diversions that disperse sediment into partially submerged or still emergent areas farther upstream will build or sustain more land-surface area with the available sediment supply**: upstream diversions can leverage organic contributions to marsh accretion, as well as maximize the trapping efficiency because most sediment would be deposited on marsh and swamp surfaces, in tidal channels or in shallow lakes or bays where storm-generated sediment resuspension and landward transport is common.

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The combined protection strategy: the case of the Mississippi Delta

The case of the Mississippi Delta is one in which the combination of the structural and functional strategies may be required to adapt to high-end scenarios of SLR. The strategy of **"rising grounds"** is already being implemented in many wetland areas through controlled diversions to mitigate land loss (Day et al., 2009; Nittrouer et al., 2012; Day et al., 2012). The recently released 2012 Coastal Master Plan proposes river diversions to divert sediment and fresh water from the Mississippi and Atchafalaya rivers into adjacent basins, to reconnect the river to delta wetlands (Falcini et al., 2012).

However, the strategy of **"rising dikes"** is also being implemented, and the most characteristic case is the reinforcement of the protection dikes in New Orleans after hurricane Katrina (Day et al., 2007). With high-end scenarios of SLR and the occurrence of hurricanes, the protection of New Orleans exclusively with dikes will not be feasible.

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Natural mechanisms	Management options
- High fluvial sediment load through flood pulses (i.e., Asian and Mediterranean Deltas). - Deltaic river avulsions depositing sediment in shallow areas (i.e., Mississippi Delta) - Excess of sand for the delta fringe allowing beaches to quickly adapt to SLR through overwash (i.e., Ebro Delta). - Positive feedbacks between RSLR, river switching and frequency of levee overflowing and marsh flooding, leading to increased sedimentation. - Positive feedbacks between RSLR and marsh flooding through tidal flow and storm surge, leading to increased sedimentation.	- Use of the irrigation network for fluvial sediment delivery to the rice fields and wetlands (i.e., Mediterranean and Asian Deltas). - High organic accretion and low mineral input requirements for fresh and brackish wetlands and rice fields (i.e., Mediterranean and Asian Deltas). - Possibility of using controlled diversions during river floods to feed wetlands with suspended sediments (i.e., Mississippi Delta). - Support of local farmers and stakeholders to active sediment management options (i.e., Ebro Delta and Mississippi Delta). - Possibility of restoring the river sediment flux through by-pass techniques in the reservoirs (i.e., Ebro Delta). - High rates of vertical accretion and elevation gain in non-impounded coastal wetlands due to efficient capture of re-suspended sediment (i.e., Ebro Delta).

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