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Discussions

Invited perspectives: Nature-based solutions to mitigate coastal flood risks – Optimizing success through knowledge co-production

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Abstract. Nature-based solutions are increasingly suggested for mitigating coastal flood risks in the face of climate change. Managed realignment (MR), a coastal adaptation strategy that entails the landward realignment of coastal defences to restore coastal habitats (often saltmarshes), plays a pivotal role in implementing nature-based solutions in the coastal zone. Across Europe, more than 130 sites have been implemented so far, often to harness their potential to mitigate coastal flood risks while restoring coastal habitats (www.omreg.net). However, local communities often oppose MR projects, not only because they are seen as returning hard-won land to the sea but also because their coastal protection function is less trusted than traditional hard engineering techniques. This scepticism has foundation. The proclaimed coastal protection function of MRs is based on a broad body of literature on the protective function of natural saltmarshes. However, contrary to natural saltmarshes, MRs are often semi-enclosed tidal basins with narrow breaches to the open sea/estuary. Recent studies indicate that MR-internal hydrodynamics may significantly reduce their coastal protection, depending on their engineering design. To successfully implement MR, a much-improved scientific knowledge base is needed, as well as a process for addressing community concerns and genuinely engaging stakeholders in decision-making beyond the usual obligatory consultancy approach. Here, we propose the co-production of scientific knowledge with local communities and stakeholders to optimize the success of coastal nature-based solutions and promote community acceptance.

1 Introduction

Global sea-level rise (SLR) is one of the most certain and long-lasting consequences of climate change; by 2300 it is expected that global sea levels will rise by 0.3 m, in a best-case scenario, and 16 m in a worst-case scenario (Fox-Kemper et al., 2021). Globally, coastal communities are suffering from the impacts of SLR, both from increased coastal erosion (Vousdoukas et al., 2020) and coastal flooding (Hinkel et al., 2014). Nature-based solutions (NBS) to climate-change challenges are gaining in popularity amongst coastal managers due to their proclaimed cost-effectiveness compared to traditional engineering solutions, and their multiple co-benefits (Macdonald et al., 2020; Van Zelst et al., 2021). Managed realignment (MR), for example, is a widespread type of NBS, where existing sea defences are realigned inland to create intertidal habitat, mostly saltmarshes, in the intervening space (Esteves, 2014). They are widely praised for their role in compensating coastal wetlands for anthropogenically induced losses elsewhere (Morris, 2013), and for their ability to reduce coastal wave and storm surge heights, hence enhance coastal protection levels and/or reduce coastal protection costs (Möller, 2019; Roca and Villares, 2012; Van Zelst et al., 2021; Wamsley et al., 2010). So far, at least 22,000 ha of MR has been implemented globally, with an average scheme size of 161 ha, but there is a large variability between different regions (ABPMer, 2021, Fig. 1). In the UK, the country with the largest number of MRs, by November 2021 a total of 77 schemes have been implemented with an average scheme size of 39 ha, whereas in China a total of three reported schemes have been implemented with an average of 3,079 ha (ABPmer, 2021).

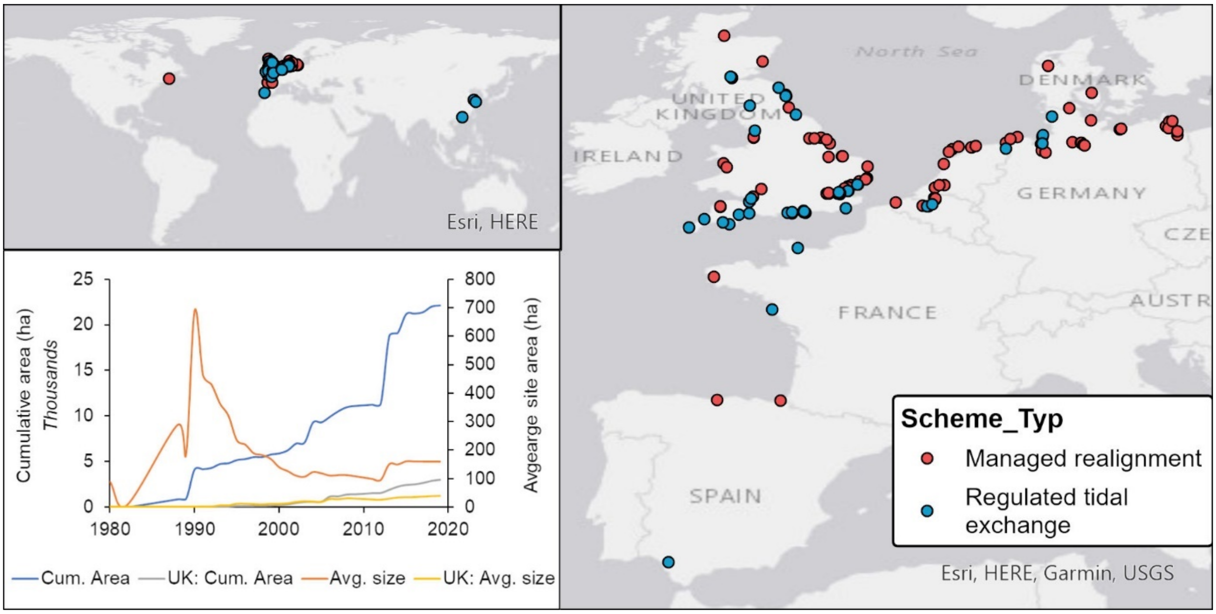

Figure 1: Spatial distribution of Managed Realignments (red dots) and Regulated Tidal Exchange schemes globally (upper left panel) and in Europe (right panel). Lower left panel: Cumulative areas (ha) of coastal Managed Realignments and Regulated Tidal Exchange globally (blue) and in the UK (grey) and average scheme sizes (ha) for sites globally (orange) and in the UK (yellow). Data Source: Omreg database (http://www.omreg.net, accessed on 17 Nov 2021).

However, the implementation of MR is often perceived negatively by coastal communities and faces societal opposition, primarily because MR means giving previously used/cultivated land back to the sea. This opposition has cultural and socio-economic causes (Goeldner-Gianella, 2007; Rupp-Armstrong and Nicholls, 2007) but is also an indicator for a profound mistrust in the effectiveness of NBS to mitigate coastal flood risks (Möller, 2019; Roca and Villares, 2012). And this scepticism is not unfounded. While natural saltmarshes on open NW European coasts have been shown to reduce wave heights of extreme storms (Möller et al., 2014), and natural saltmarshes covering extensive areas (e.g. Mississippi Delta) have been shown to reduce storm surge inundations (Wamsley et al., 2010), the energy dissipating potential of saltmarshes within MR sites is much less understood. This potential may differ from natural marshes due to their artificially semi-enclosed nature related to their specific scheme design (Kiesel et al., 2020). Addressing community opposition and scepticism to MR implementation is crucial as the few targeted studies on the effectiveness of MR to mitigate coastal flood

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risks suggest that only larger schemes may be effective (Kiesel et al., 2020; Stark et al., 2016). Such large schemes particularly require the endorsement and trust from coastal communities.

Like other forms of natural resource management, the implementation of MR necessarily involves community engagement (Tubridy et al., 2022). The effective design of any project requires a sound scientific understanding of the bio-physical processes involved, while successful implementation usually depends in part on how well projects represent the needs of multiple stakeholders, including local communities. Stakeholder engagement and participatory approaches in natural resource management, including flood management, have long been critiqued for offering only tokenistic opportunities for communities to contribute (Blunkell, 2017). Community involvement is often limited to data collection (e.g. citizen science), and the engagement process usually begins too late in the cycle of project design to allow for more than very basic consultation (Few et al., 2007). As a result, designing projects based on robust science and community engagement usually occur in isolation, with project design taking place much earlier than community consultation.

Further research is needed to investigate the use of MR as NBS to address rising sea levels in the context of climate change. These NBS projects, and others that will undoubtedly emerge from efforts to adapt to climate change, are ideal opportunities for genuine knowledge co-production, embracing the best-practice principles of scientific practice and participation. In this perspectives piece, we discuss four current challenges around the implementation of MR to mitigate flood risks and suggest that developing a robust scientific basis for flood mitigation and effective participation can occur in parallel rather than separately. Specifically, we propose that involving stakeholders in the design of projects, as well as later phases of implementation, may facilitate more meaningful participation than traditional approaches to community engagement and produce more effective MR schemes.

2 Challenge 1: Understanding how saltmarshes mitigate coastal flood risks

The argument that MR schemes are efficient in mitigating coastal flood risks originates from a broad body of literature on natural coastal wetlands. These have been shown to be effective in reducing relative SLR (RSLR), particularly where RSLR rates have historically been compounded by anthropogenic subsidence and the disconnection of coastal lowlands from riverine and marine sediment sources, such as river deltas or estuaries (Temmerman and Kirwan, 2015; Temmerman et al., 2013). Kirwan et al. (2016) and Coleman et al. (2022), for example, show that tidal marshes globally are usually accreting sediment at the same, or a higher, pace than current local SLR. They further show that low elevation marshes, are more efficient in accreting sediment vertically than high-elevated marshes because low-elevation sites are inundated more frequently allowing for more sediment to be deposited. This negative feedback mechanism between marsh elevation and sediment accretion makes tidal marshes ideal landscapes to reduce RSLR rates and mitigate permanent inundation of coastal lowlands (Temmerman and Kirwan, 2015; Temmerman et al., 2013). The conservation and restoration of coastal wetlands is therefore thought to be essential for the protection against large-scale land losses under the projected climate change scenarios, e.g. as suggested for the Mississippi Delta (Fischbach et al., 2019).

The RSLR-reducing effect of coastal wetlands, however, does not merely reduce land losses but also increases the dissipation of storm surge and wave energies (Shepard et al., 2011; Van Zelst et al., 2021), primarily caused by reduced water depths and increased vegetation-induced surface roughness (Möller, 2006; Wamsley et al., 2010). Particularly well established is the effect of saltmarshes to attenuate coastal wave heights. Möller et al. (2014) measured a 12-20% reduction of wave heights over a 40 m stretch of saltmarsh and attributed 40-60% of this attenuation to the presence of saltmarsh vegetation. On most coastlines with saltmarshes present, the overall wave attenuation may lead to a full attenuation of waves when they reach the coastline (Yang et al., 2012), hence reducing the risk of coastal flooding from wave overtopping and the pressures on coastal defences (Van Zelst et al., 2021). Moreover, saltmarshes are effective in reducing coastal erosion, a potential indirect cause of coastal flooding (Pollard et al., 2019), through increasing the sediment's shear strength and the potential protective function of flexible vegetation (Möller et al., 2014). Where saltmarshes are eroded, coastal wave heights are expected to increase due to reduced surface roughness and a reduction in foreshore elevations associated with increased water depths and wave heights (Fagherazzi and Wiberg, 2009).

Besides their wave-height reducing effect, saltmarshes are also reported to significantly reduce still water levels during storm surges. However, the range of reported attenuation rates varies greatly between 1.7 cm/km and 70 cm/km (Vafeidis et al., 2019), with most of the field and modelling evidence available for the Mississippi Delta, where vast areas of saltmarsh exist. Meanwhile, the attenuation values reported for storm-surge heights over smaller saltmarshes are less conclusive. In the Scheldt estuary (Belgium), measured water-level attenuation rates suggest the existence of a critical marsh width, below which saltmarshes may lose their capacity to attenuate storm surge heights (Stark et al., 2016). Moreover, the ratio of subtidal to intertidal areas within a saltmarsh and the storm duration appear to control the capacity of saltmarshes to attenuate storm water levels (Stark et al., 2016). For the highest water levels, even amplification of storm water levels has been reported (Stark et al., 2015). Water level amplification is thereby attributed to the reflection of the tidal wave against the sea defence, located at the landward edge of the saltmarsh and truncating the natural marsh extent (Stark et al., 2016). This highlights the importance for current and future saltmarsh management to ensure the maintenance of saltmarsh elevations and lateral extents, particularly under projected rates of future SLR (Reed et al., 2018).

A key process driving the SLR-induced loss and truncation of saltmarshes globally is coastal squeeze (Schuerch et al., 2018), i.e. "intertidal habitat loss which arises due to the high water mark being fixed by a defence and the low water mark migrating landwards in response to sea level rise" (Pontee, 2013, p. 206). Managed realignment is widely considered as a key management strategy to counteract coastal squeeze and restore the saltmarshes' coastal protection function where this has been reduced as a consequence of SLR-induced habitat size reduction (Doody, 2013). However, we argue that the above outlined uncertainties around the effectiveness of saltmarshes in reducing coastal flood risks are even larger, and less studied, for such MR schemes than for natural saltmarshes.

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3 Challenge 2: Designing Managed Realignment to mitigate coastal flood risks

Managed realignments are considered an important management option to mitigate the loss of coastal saltmarshes to coastal squeeze (Doody, 2013; Morris, 2013). The provisioning of additional accommodation space for saltmarshes to establish is especially efficient in areas where historic land reclamation has led not only to the direct loss of saltmarshes due to land conversion, but also to low-lying coastal areas (often below mean sea level) that are at risk from coastal flooding. The implementation of MRs thereby provides space for truncated saltmarshes to extend further inland and occupy a wider elevation range, and providing sufficient sediment supply, these low-lying, newly inundated wetlands will quickly gain elevation (Liu et al., 2021; Spencer et al., 2012). Most notably, these areas include substantial areas around some of the world's largest estuaries (De Vriend et al., 2011) and deltas (Tessler et al., 2016), where historic coastal wetland losses and current coastal flood risks are highest.

In estuaries and deltas, MR may not only provide flood risk mitigation through the deceleration of tidal surges or wind waves over the vegetated saltmarsh surface, but also by storing flood water from either the river or the sea (Huguet et al., 2018). For example, in the Scheldt estuary (Belgium/Netherlands) it has been modelled that a potential loss of its largest saltmarsh area (ca. 3000 ha) may increase the maximum water level within the broader estuary by up to 19 cm during storm surges (Smolders et al., 2015). However, the location and size of MRs within estuaries is crucial for their capacity to reduce flood risks; in fact, schemes implemented in the wrong part of the estuary may lead to increases of estuarine water levels during storm surges and a potential loss of other wetland areas due to increased sediment demands (French, 2008; Leuven et al., 2019). Pre-implementation routines therefore usually involve the modelling on the hydrodynamic impacts of MRs on the wider estuarine environment, considering different possible scheme locations, sizes and designs (Townend and Pethick, 2002; Pontee, 2015).

However, modelling is not routinely conducted for the hydro- and morphodynamic processes within the MR, hence little is known about the so-called "within-marsh" attenuation, i.e. the direct reduction of current velocities and water levels during storm surges through the increased surface roughness of shallow vegetated saltmarsh surfaces. In contrast to natural saltmarshes MRs are often characterized by one or multiple narrow inlets forming a semi-enclosed tidal basin where hydro- and morphodynamics may differ to those on natural marshes (Kiesel et al., 2020). Increasingly, MRs are also implemented on open coastlines, where estuarine water level variations are negligible, and increased coastal protection is solely achieved by within-marsh attenuation (Kiesel et al., 2019). Presumably, the lack of meaningful pre-implementation, within-marsh modelling is because modelling the geomorphic evolution of newly inundated saltmarshes, e.g. the development and evolution of tidal creek networks, is challenging and associated with significant uncertainties (Kiesel et al., 2022). Meanwhile, field and modelling data from natural marshes indicate that the MR size, as well as the nature of the tidal creek networks, may play a deciding role in whether a saltmarsh attenuates or amplifies storm surge water levels (Kiesel et al., 2020; Stark et al., 2016). Moreover, this efficiency of MR saltmarsh to attenuate storm surge water levels has been suggested to be reduced for more extreme events, associated with higher inundation depths (Fig. 2) (Hofstede, 2019; Kiesel et al., 2022; Kiesel et al., 2020).

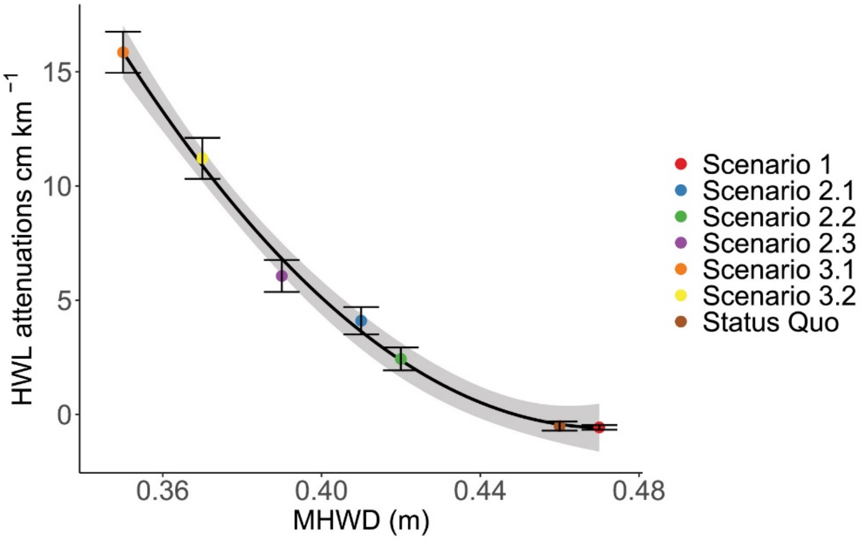

Figure 2: Modelled attenuation rates (cm km-1) for the MR Freiston Shore (for equinox spring tides) as a function the mean high water depth (MHWD) for a series of design scenarios (Kiesel et al., 2020). Status quo – three breaches (ca. 50 m each); scenario 1 – complete removal of sea defence; scenario 2 - one breach of 45 m (scenario 2.1), 99 m (scenario 2.2), and 30 m (scenario 2.3); scenario 3 – extended site area of 1,416,350 m2 instead of 650,067 m2 (scenario 3.1), and 1,124,400 m2 instead of 650,067 m2 (scenario 3.2). Source: Kiesel et al. 2020, with permission from Elsevier.

Both the size of the MR and its developing tidal creek network are controlled by differing designs of MRs (Chirol et al., 2018; Kiesel et al., 2020). Available types of MR include the complete removal of the original sea defence, the punctual breaching of the original defence (one or several breaches), Regulated Tidal Exchange (where the tidal regime within the MR is controlled through sluices) and Unmanaged Realignment (where accidental breach or abandoned coastal land convert to coastal wetlands). Kiesel et al. (2020) suggest that MR designs that reduce the Mean High Water Depth (MHWD) within the site are most efficient in providing tide and storm surge attenuation (Fig. 2). This can either be achieved by increasing the size of the scheme or reducing the number and/or size of breaches of the original sea defence. However, the complete removal of the original defence, likely to create the most natural habitat, is least effective in reducing coastal flood risks (Fig. 2; Kiesel et al., 2020), suggesting that optimizing the MR's flood mitigation benefits may have trade-offs. Meanwhile, reducing tidal exchange through narrowing tidal breaches and increasing MR size may have undesired impacts on the social acceptability of MR schemes. For example, reduced tidal exchange and uniformly shallow inundation depths are likely to reduce the ecological value of the newly created saltmarsh (Pétillon et al., 2010), with implications for the aesthetic appearance and the touristic value of the site. To avoid such negative impacts from MR implementation, more recently, tidal exchange within MRs has been reduced by infilling MRs with externally sourced sediment (Dale et al., 2021), while introducing an increased habitat diversity. Meanwhile, larger sites, despite being suggested to be more effective in reducing coastal flood risk, equate to more land being 'abandoned'.

Here, we argue that while more research is needed to optimize the coastal protection function of MRs, implementation of effective MR is also inherently linked to the cultural values and practical interests of local communities; large MRs can only be implemented with community support, which in turn relies on the proposed scheme to be of cultural and practical value, as well as effective in delivering coastal protection (or any other pre-defined ecosystem service).

4 Challenge 3: Implementing Managed Realignments for coastal communities

Perceptions of coastal communities towards the implementation of MRs widely vary within and between schemes and communities (Yamashita 2021a; Goeldner-Gianella 2007; Myatt-Bell et al., 2002). However, available peer-reviewed literature on community perception is very sparse. A review by Yamashita (2021) found just nine references relating to public attitudes to MR schemes. Meanwhile, public opposition is considered a key obstacle to MR implementation among practitioners (Esteves & Thomas 2014), resulting in the delay or abandonment of schemes (Adnitt et al., 2021). For example, at Devereux Farm (Part 2), Essex, UK, the suggested diversion of the coastal footpath associated with the proposed MR implementation raised strong local opposition, which ultimately led the abandonment of the project (Shiers, 2014). In Donna Nook, North Lincolnshire, UK, a public enquiry delayed the MR implementation by nearly 10 years (Burston, 2018). Whilst public acceptance is known to practitioners as a major barrier to implementing schemes, there is no comprehensive data in the public domain on where abandoned schemes are and the reasons for public opposition.

From the limited literature on this topic and our experience of working with practitioners, key reasons for public opposition to MR schemes include changes to public access and fear of landscape change (Yamashita 2021b), combined with a limited understanding of the benefits of the new intertidal habitats, e.g. for coastal protection (Myatt et al. 2003a; Myatt et al. 2003b; Goeldner-Gianella 2007; McInnes et al., 2021). This is illustrated by our observation that despite coastal managers and scientists arguing for reduced design levels and coastal defence costs behind vegetated wetlands (Burgess-Gamble et al., 2017; Macdonald et al., 2020; Van Zelst et al., 2021) most newly established defences on the landward side of MR schemes are at least as high and strong as the original defences to reassure local communities. Nevertheless, MRs are often promoted to coastal communities as coastal protection projects, with co-benefits in habitat creation and carbon sequestration (Burgess-Gamble et al., 2017).

In reality, the primary driver for MR implementation is often to increase natural habitat and biodiversity in relation to upholding environmental policy such as the EU Habitat Directive, attracting significant amounts of private investment (Morris, 2013). Once implemented, MRs are often managed and run by wildlife charities, whose primary interest is the restoration of the marsh's ecological value, hence the post-implementation monitoring is usually focussed on elevation changes and the ecological site development (Mossman et al., 2012; Spencer et al., 2012). Very little research has been conducted on the effectiveness of MR scheme to mitigate coastal flood risks for communities. This knowledge gap has created a sense of uncertainty around the value of MR sites for communities; it is hence not surprising that the trust in MR

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schemes to mitigate coastal flood risks is low. Here, we suggest that limited scientific understanding of the flood risk benefits of MRs (Challenge 2) contributes to the lack of community trust in these projects.

The knowledge gap and uncertainty around the effectiveness of MR for flood protection offers two opportunities; firstly, to advance scientific understanding of how these projects function, and secondly to develop methods of engaging community to genuinely participate in decision-making for NBS and their design, and develop trusting relationships between scientist practitioners and communities.

5 Challenge 4: Developing participatory approaches to stakeholder involvement

The notion of involving stakeholders in decision making to design and implement NBS stems from wider shifts in the rhetoric, thinking and practice of natural resource management over the past three decades. The participatory paradigm embodies the ideas, values, methods and behaviours that have emerged to challenge the power dynamics deeply embedded in development throughout the 50s, 60s and 70s; traditionally, the role of experts and professionals has been to design solutions while local communities have been framed as ‘the problem’ (Chambers, 1998). Participatory thinking recognises the power imbalance inherent in these dynamics and reframes ‘the problem’ as one of how professionals engage with communities. In the early 1990s, participatory approaches were envisaged as alternative ways of thinking and acting that shifted the goal of development from designing solutions *for* communities to designing solutions *with* communities, to achieve empowerment as well as the more pragmatic outcomes of development projects (Park, 1992). In the years that followed, participation has become orthodoxy beyond the sphere of development, including more widely in academic research (Pain and Francis, 2003) and the practice of natural resource management in developed regions, such as engaging local communities for flood risk mitigation (Kelly and Kelly, 2017; Liski et al., 2019).

Early efforts to embrace participation have been heavily critiqued for a multitude of reasons. In brief, “Shifts in language have not been accompanied by quite as significant changes in development thinking and practices as they imply” (Cornwall, 2006, p. 78). Two criticisms that are echoed strongly in natural resource management and research relate to the nature and degree of participation. Firstly, Pimbert (2004) distinguishes between engagement in rhetoric only compared to engagement that involves transformation, where transformation refers to multidirectional learning with a genuine capacity for change. Research projects that engage stakeholders in some form of participation often fail to move beyond rhetoric. Secondly, Bergold and Thomas (2012) highlight challenges associated with the degree of participation, including the point along the research continuum that stakeholders are engaged. Participation is usually relegated to a ‘later’ stage of research once the serious decisions about defining problems and setting model parameters have been made by professionals and experts; often stakeholders are invited to select from pre-defined solutions rather than contributing to scenario building. Thus, mismanaged participation can risk reinforcing or recreating existing inequalities within new institutional frameworks that only partially fulfil the participatory orthodoxy.

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An alternative to traditional 'top down' methods of community engagement is to begin the participatory process early in project design, allowing community values and beliefs to inform scenario building. This approach, known as 'knowledge co-production', has been adopted for climate change adaptation (Singh et al., 2021), developing 'sustainable future' scenarios (Iwaniec et al., 2020), and flood hazard mapping (Luke et al., 2018) among other applications. In the context of flood risk management, co-production is usually limited to agenda-setting and evaluation (Mees et al., 2018). In part, the capacity for genuine knowledge co-production, such as developing scenarios for MR, depends on the accuracy of scientific knowledge as well as appropriately timed engagement. Ideally, a 'bottom up' approach would engage communities in every phase of designing and implementing a flood mitigation project.

In the case of MR, investigating the potential use of projects for coastal protection and flood mitigation will necessarily involve both improving scientific understanding of biophysical processes and developing *effective and meaningful* community engagement. Best practice knowledge co-production offers a way forward.

6 Towards co-producing MR schemes with coastal communities

For MR schemes, knowledge co-production involves engaging communities and other stakeholders early enough in the project development to contribute meaningfully to the negotiation of goals and objectives, modelling parameters, and scenario building, as well as in later project stages, including selecting the optimal scenario for implementation and assessing project effectiveness over the longer term.

Scenario building through community engagement has previously been adopted for coastal management in the context of governance and selecting decision-making approaches for climate change mitigation. Tompkins et al. (2008) highlight the need to incorporate stakeholder preferences into climate change planning, as well as to ensure stakeholders understand the necessary trade-offs involved in any coastal management decision. We propose using a scenario-building stakeholder model to engage communities in each phase of project design along-side experts and scientists. Scientific knowledge is often framed as objective while stakeholder preferences are viewed as subjective. In reality, scientific knowledge, and the focus of scientific enquiry, is equally subjective and makes assumptions about the preferences of people for how spaces are managed and how those spaces are valued (Owens, 2004).

Coastal management, and natural resource management more generally, is increasingly relying on 'user pays' approaches to establish and maintain infrastructure, practices, and projects that are perceived to serve the public good (Kauffman, 2015). The success of these projects can be undermined if local communities are unwilling to support schemes. Projects are more likely to succeed if stakeholder preferences are incorporated into project development in a way that promotes agency; facilitating a positive experience of engagement and allowing meaningful stakeholder-expert relationships to develop is as vital to the success of co-production as involving stakeholders in appropriate phases of decision-making.

We envisage six steps for effective co-production to optimize the success of MR sites (Fig. 3):

1) Establish links to relevant stakeholder and community groups in proximity of a potential MR scheme. This first step involves identifying relevant stakeholders and community groups and getting to know them personally. Rather than having a pre-determined list of stakeholders and community groups, these should be identified through individual discussion with initial and further contacts.
2) Define with community and stakeholder groups what a 'successful' MR project would deliver. The definition of success is thereby expected to considerably vary between different communities. Differences in success definitions will likely vary between communities based on their geographic location, socio-economic and demographic structure, experience with past coastal flooding and previous experiences with natural resource management projects.
3) Develop possible scenarios to be considered. For the informed scenario development, scientists will provide the "building blocks", or design elements, that may be used to develop MRs. Examples of such design elements include the nature of the breach in the sea defence (open or through a sluice), the size and number of breaches (which could determine, if it was possible to build bridges across them), the number, size and structure of the drainage network (potentially determining the nature of any possible walking paths within the site and maintain current access routes around the site), and the use of landscaping techniques, such as sediment infilling (allowing for the creation of a more bio-diverse area).
4) The co-produced MR designs are used to model coastal flood risk reductions for selected climate scenarios. Objective flood risk mitigation metrics, such as ratio of water levels within and outside MRs, overtopping, tidal prism and seiche formation (Christie et al., 2018). Some of the original stakeholder and community interests (step 2) and the associated design elements (step 3) may prove inefficient in reducing coastal flood risks, or in extreme cases may event exacerbate them.
5) By evaluating the objective flood risk mitigation metrics for different scheme designs (satisfying different community values and interests), so-called cohesion matrices are developed to map the compatibility of various community values and interests with the objective to mitigate coastal flood risks. Testing different co-produced scheme designs against the coastal protection function, now and in the long-term, will educate stakeholders and communities about possible benefits and limitations of any one scheme design and provide novel scientific insights into the flood mitigation function of MRs.
6) Considering the outcome of the produced cohesion matrix, community values and interests may (or may not) shift in priorities, allowing for the potential development of alternative designs, which in turn are modelled and evaluated until a consensus for the scheme design is reached.

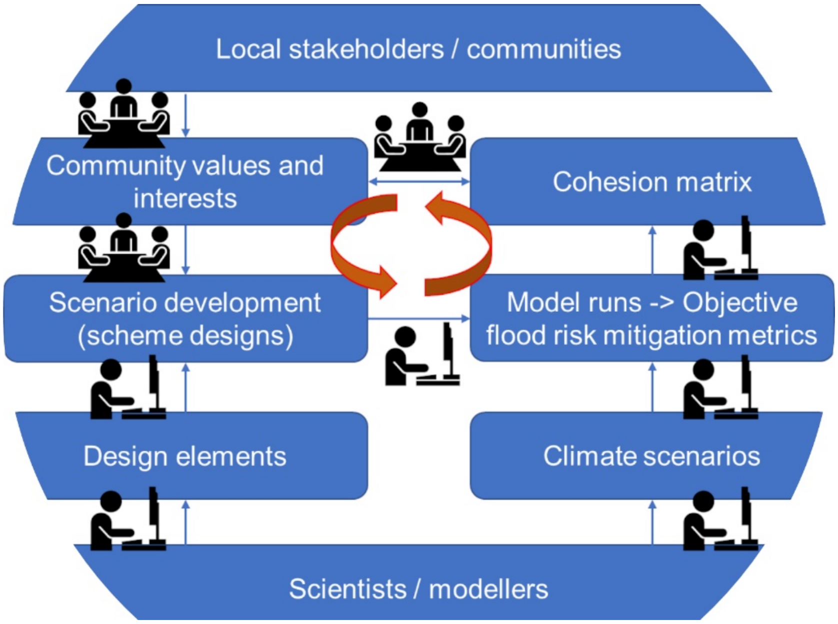

Figure 3: Schematic representation of the proposed co-production process to plan and develop Managed Realignment schemes. Some workflows are completed through traditional academics knowledge production (scientist working on computer), whereas other workflows will be completed through focus groups with stakeholders, communities and scientists (three people sitting around a table).

6 Conclusions

Despite significant political ambitions to implement nature-based solutions and MR for reducing coastal flood risks in the coastal zone, now and under future climate change and sea level rise scenarios, significant knowledge gaps with regards to the efficiency of MR schemes for coastal flood mitigation remain. This is surprising as the MR efficiency in mitigating coastal flood risks often constitutes (one of) the key argument(s) of scientists and coastal managers to convince local stakeholders and communities to give up their land. However, local support for MR implementation is often lacking as stakeholders and communities lose access to (valuable) land, and trust in the coastal protection function of MRs is low. This is becoming increasingly important, not least because the little available evidence there is, suggests that only larger MR schemes may contribute the flood risk mitigation, whereas smaller schemes do not. We, therefore, argue that new approaches of stakeholder and community engagement are needed, and that involving stakeholders and communities in the knowledge production process allows for the participating individuals to design a scheme that suits their purpose and is efficient in doing what it is supposed to do.

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Author contributions

MS brought together the author team and structured the initial draft. MS, HLM and HEM all contributed to the writing and proof-reading of the manuscript.

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