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Managed realignment in Europe: a synthesis of methods, achievements, and challenges

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1. **Introduction**

In Europe there is a growing trend of ‘building with nature’ initiatives to improve the long-term, environmental and socio-economic sustainability of coastal management strategies (e.g. Luisetti et al. 2011; Rijkswaterstaat and Deltares 2013; Temmerman et al. 2013; Spalding 2014). In particular, managed realignment approaches are increasingly considered as a no-regret option (van Loon-Steensma and Vellinga 2013; Elliott et al. 2014) bringing social (improved flood risk management), economic (lowering costs of flood protection maintenance), and environmental benefits through habitat restoration (e.g. Defra 2002; Spencer and Harvey 2012; Committee on Climate Change 2013; Spalding 2014). These are common drivers underpinning the implementation of managed realignment in Europe. However, the form in which managed realignment has been implemented varies between countries as it will be illustrated by the examples presented in this chapter.

In the literature, the terminology used to describe managed realignment varies regionally, through time, and between authors. Many terms have been used as synonyms of managed realignment, including set-back, managed retreat, de-embankment and depoldering. A review of the terminology and definitions can be found in Esteves (2014). Here managed realignment means taking planned actions to create space for natural dynamic processes, usually involving relocation of river embankments, estuary or open coast shorelines to shorten the overall length of protected shores (therefore reducing maintenance costs) and to provide opportunity for habitat restoration (Defra 2002; Esteves 2014). Key objectives of this habitat restoration is the provision of (i) a range of ecosystem services, including natural storm-buffering capacity, and (ii) compensation for habitat loss resulting from land reclamation or coastal squeeze, as required by environmental legislation (e.g. Defra 2002; Esteves 2014).

The first managed realignment projects in Europe (implemented in France in 1981 and in Germany in 1982[1]) were isolated initiatives meeting local needs. At the end of 2015, 140 projects have been completed or are under construction, most of them driven by national and European environmental legislation. Technical capacity to improve projects design and the scientific understanding of physical and ecological changes at realignment sites have greatly advanced (see Section 5). However, the wider implementation of managed realignment is still hindered by a number of challenges, such as: public acceptance, funding constraints, availability of suitable land, and uncertainties related to natural coastal evolution.

Recent national and regional strategies (e.g. in the UK, Belgium, Netherlands, and France) give an important role to managed realignment. Therefore, it is timely and relevant to identify lessons learned and assess how to overcome current challenges. This chapter provides an overview of the current state-of-play related to managed realignment in Europe and demonstrate that a combination of project types can be implemented in both rural and urban areas as a long-term and sustainable strategy to reduce flood risk and promote the provision of other ecosystem services through habitat restoration. The first sections introduce and discuss basic concepts, including the main underlying drivers (Section 2), the five most common methods of

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[1] A list of managed realignment projects, providing date of implementation, location and references is provided in Esteves (2014).

implementation (Section 3) and examples of existing strategies (Section 4). Then, a summary of lessons learned (Section 5) is presented, followed by a summary of key findings (Section 6).

2. **Underlying Drivers**

There are two main drivers underpinning the need for managed realignment in Europe: (1) environmental legislation aiming to prevent the loss and degradation of coastal habitats and associated biota (and the consequent impacts on society); and (2) the need to reduce flood and erosion risk to people and property and manage the increasing maintenance costs, especially due to climate change impacts. The implementation of managed realignment in Europe is greatly influenced by EU Directives, in particular: (a) the Birds Directive[2], (b) the Habitats Directive[3], (c) the Water Framework Directive[4], and (d) the Floods Directive[5]. Each EU country is obliged to adopt the EU Directives into national legislation.

The Birds Directive and the Habitats Directive have been fundamental instruments for nature conservation in the EU, including the restoration of coastal habitats (Pontee, 2014). Under these Directives, each EU member state is responsible for taking all necessary measures to protect designated habitats and species of European importance, mainly through the establishment of an EU-wide network of designated conservation sites (called Natura 2000). Most intertidal flats and saltmarshes in Europe are within Natura 2000 sites. Therefore any human-induced loss or damage must be prevented. Exceptions exist due to imperative reasons of overriding public interest (i.e. when certain development is required for the greater benefit of society). In these

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[2] Directive 79/409/EEC (April 1979) of the European Parliament and of the Council on the conservation of wild birds is the oldest EU environmental legislation, amended in 2009, it became the Directive 2009/147/EC, http://ec.europa.eu/environment/nature/legislation/birdsdirective/.

[3] Directive 92/43/EEC of the European Council on the conservation of natural habitats and of wild fauna and flora, http://ec.europa.eu/environment/nature/legislation/habitatsdirective/.

[4] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, http://ec.europa.eu/environment/water/water-framework/. .

[5] Directive 2007/60/EC on the assessment and management of flood risks, http://ec.europa.eu/environment/water/flood_risk/.

cases, any damage or loss to designated habitats must be compensated by restoration or creation of habitats with equivalent ecological function.

Compensation is also required to offset long-term habitat loss due to coastal squeeze, which is the loss of intertidal habitat caused by rising sea levels in front of an artificially fixed shoreline (Pontee 2013; Esteves 2016). In practical terms, this means that any new or improved flood-risk management measures unavoidably causing habitat loss or degradation within Natura 2000 sites requires creation of habitat as a compensatory measure.

The extent of compensatory habitat that needs to be created takes into consideration direct and indirect historical and future losses expected to occur during the life-time of the development (Thomas 2014). For example, the Defra Flood Management Division (2005) estimates that an average of about 100 ha of intertidal habitat needs to be created per year to compensate loss due to coastal squeeze and development projects within Natura 2000 sites, especially in south and east England. Managed realignment is often implemented to create the habitats required as compensatory measures.

Under the Floods Directive, EU countries must map flood risk to people and assets from coasts and inland waters and establish flood risk management plans focused on prevention, protection, and preparedness. The Floods Directive must be implemented in coordination with the Water Framework Directive, taking due consideration of the potential impacts of flood protection measures on water quality and the ecological status of coast and estuaries. In the UK, for example, the River Basin Management Plans, in combination with Shoreline Management Plans (SMP), are key instruments supporting sustainable water management, with managed realignment being a preferred option to restore the natural functions of estuary and coastal systems (Thomas 2014).

3. Types of Managed Realignment Projects

A review of published literature enables the identification of different methods of managed realignment being implemented in Europe, which generally will fit into one of five types: (1) removal of coastal protection structures; (2) breach of seawalls; (3) realignment of the coastal protection line; (4) controlled tidal restoration; and (5) managed retreat (Esteves 2014). The primary characteristics of each category are summarized in Table 1. Categorizing the projects into these five types helped to quantify the preferred methods of implementation, how they relate to different objectives (Table 1) and how they vary geographically (Table 2). Details and examples of the relationships between the type of implementation, the primary project objective, and on the physical characteristics of the site are provided in sections 3.1 to 3.5.

Table 1. Primary and secondary characteristics of the five managed realignment methods of implementation (shading black=primary; gray=secondary; white=not applicable).

	Removal	Breach	Realignment	Controlled tidal restoration		Managed retreat
				RTE	CRT	
Large sections of coastal protection are removed	■		▨			▨
Seawalls/embankments are artificially breached		■	▨			▨
Coastal protection is allowed to breach naturally			▨			▨
Project design includes new or upgraded structures			■	▨	▨	
Tidal flow is restored through sluices/culverts			▨	■	■	
Project involves flood control areas				▨	■	
Planned removal of people and assets at risk	▨	▨	▨	▨	▨	■
Primary and secondary objectives						
Creation of habitat	■	■	■	■	■	▨
Improved flood risk management	* ▨	* ▨	■	* ▨	■	■
Other ecosystem services	▨	▨	▨	▨	▨	▨
Climate change adaptation	■	■	▨			■

* Improved flood risk management depends on the habitat that will be created and therefore it should be considered either a secondary outcome or a long-term primary objective.

Table 2. Number, type and size of managed realignment projects implemented or under construction in Europe (in Dec 2015).

Country	Number of projects	Types of Managed Realignment Projects	Area (ha)*
Belgium	18	Controlled tidal restoration: 7; Realignment: 10; Removal: 1	3,530
Denmark	2	Breach: 2	206
France	5	Breach: 1; Controlled tidal restoration: 2; Managed retreat: 1; Removal: 1	511
Germany	30	Breach: 13; Controlled tidal restoration: 3; Realignment: 3; Removal: 11	5,036
Netherlands	13	Breach: 9; Controlled tidal restoration: 2; Realignment: 2	1,090
Spain	3	Controlled tidal restoration: 1; Removal: 2	3,272
UK	69	Breach: 16; Controlled tidal restoration: 23; Realignment: 27; Removal: 3	2,162
Total	140	Breach: 41; Controlled tidal restoration: 38; Managed retreat: 1; Realignment: 42; Removal: 18	15,807

The categories are also a mean to standardize the terminology used to describe the projects. For example, in the literature, the terms ‘breach’ and ‘realignment’ have been used indiscriminately to describe projects implemented in the same way, independently whether the design involved the construction of new coastal protection structures or not. Using the five categories, a clear distinction is made as all projects involving the construction or upgrading of a new coastal protection line are categorized as ‘realignment’ (Table 1). On the other hand, the categories ‘breach’ or ‘removal’ will only be used to describe projects not involving the upgrade or construction of new structures. Some projects use a combination of methods, especially to better address multi-purpose objectives (e.g. creation of specific habitats and reduction of flood risk). A combination of managed retreat and other methods of managed realignment is probably the best alternative when considering the long-term sustainability of multi-purpose projects.

However, such combination has not yet been widely implemented due to complex socio-economic issues associated with long-term planning and private property rights, as discussed in Section 5.

3.1. Removal of coastal protection structures

At some locations, entire sections of coastal protection structures are removed to restore the space required for the coast to respond more dynamically to environmental change (waves, tides, and sediment supply). Often the structures removed are failing, poorly maintained or not offering the expected level of protection. It is expected that the removal of coastal protection will result in the landward or seaward realignment of the shoreline position, depending on site-specific conditions. For example, seaward displacement of the shoreline may occur where the removal of a seawall may reactivate cliff erosion restoring sediment supply to the adjacent beach (if the cliff is formed by beach-quality sediment).

This type of managed realignment may increase exposure to waves, tides, and storm surges to inland areas and it is important to take into consideration how erosion and flood risk may change in the future (e.g. due to sea level rise). Additionally, removal of coastal protection might not be the most suitable method if the objective is to create habitats requiring sheltered environments (e.g. saltmarshes), as higher energy conditions might prevent the development of such habitats (Nottage and Robertson 2005). Figure 1 illustrates some of the conditions more suitable for the removal of coastal protection structures: (a) risks are controlled by natural topography (e.g. higher grounds) or (b) by the presence of existing coastal protection further inland; or (c) the potential increase in erosion and/or flooding hazard can be tolerated (e.g. where critical infrastructure and people are not affected and/or they are resilient to the expected impact). On the other hand, depending on site specific characteristics, benefits created may include a wide range of ecosystem services, including: (a) provision of sediment to replenish adjacent areas; (b) creation of flood-water storage space to reduce risk of flooding elsewhere; (c) habitat creation; (d) enhanced biodiversity; (e) and improvement of recreation opportunities.

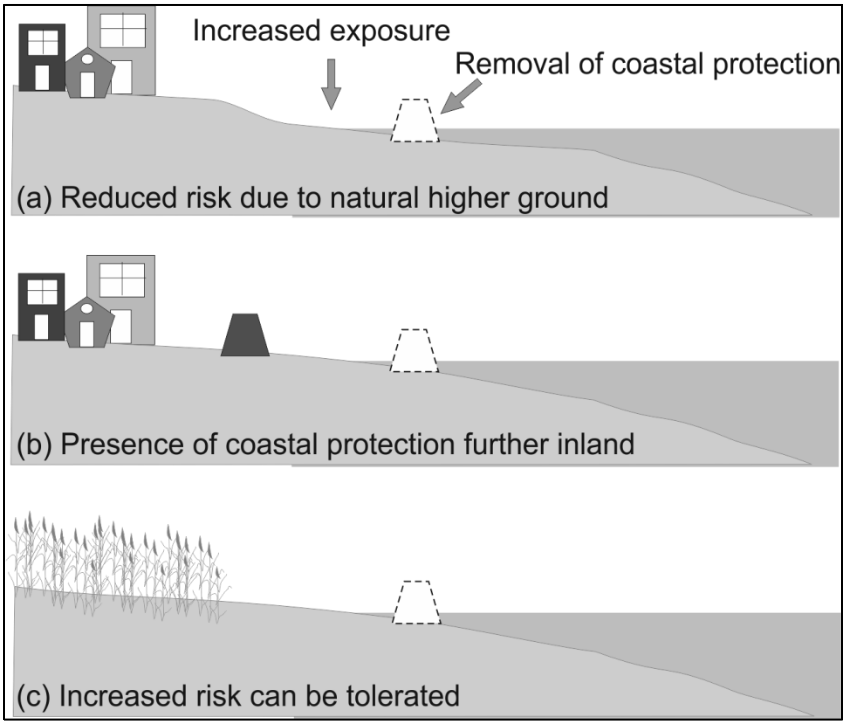

Figure 1. Managed realignment through the removal of coastal protection is more suitable for locations where flood and erosion risks are controlled either by (a) natural topography (e.g. higher grounds) or (b) the presence of existing coastal protection further inland and where (c) the potential increase in erosion and/or flooding hazard can be tolerated (e.g. where critical infrastructure and people are not affected and/or they are resilient to the expected impact).

Public and political acceptance of removing coastal protection is still challenging in Europe and elsewhere. Nordstrom and Jackson (2013) suggest that a number of demonstration projects may be required to evidence the benefits of such approaches before they become more widely acceptable. The involvement of willing landowners is an important facilitator. The National Trust[6] is a UK-based charity devoted to protect historic places and open spaces for the enjoyment of the public. Currently, the National Trust owns over 1,240 km of coastline across England, Wales, and Northern Ireland where they adopt a ‘making space for nature’ approach to coastal management (see Dyke and Flux 2014). An example of this management approach is the removal of coastal protection structures along the south shoreline of Brownsea Island (Dorset, UK), illustrated in Figure 2.

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[6] More about the National Trust is found at: http://www.nationaltrust.org.uk/what-we-do/.

Figure 2. (a) Failing coastal protection structures in Brownsea Island (b) were removed in 2011 and (c) by 2013 the shore profile was similar to pre-protection times (Photos: Tony Flux).

3.2. Breach of coastal protection structures

This method involves removal of one or more small sections of the existing coastal protection structures to restore tidal flow into previously protected land. Therefore, the considerations about the suitability of sites (illustrated in Figure 1) are also applicable to managed realignment through breaching. The remaining sections of the coastal protection line offer certain degree of shelter within parts of the realignment site (Figure 3a). The extent of the level of exposure within the realigned site will depend on the local topography, the width of the breach, the characteristics of tidal flow, wave conditions etc. Ideally, the sheltering effect can reduce flooding and erosion risk to inland areas, promote sedimentation, and favor the development of habitats, such as saltmarshes.

The long-term management of the remaining coastal protection will change with time and must be considered with care. A lack of maintenance will lead to structural degradation, which in turn will increase exposure within the realigned site, jeopardizing the habitat created under sheltered conditions. To avoid such undesired impacts, it may be necessary to provide regular maintenance of the remaining sections of the breached coastal protection (which will add additional costs to the project). However, to the knowledge of the authors, this type of measure has not yet been attempted.

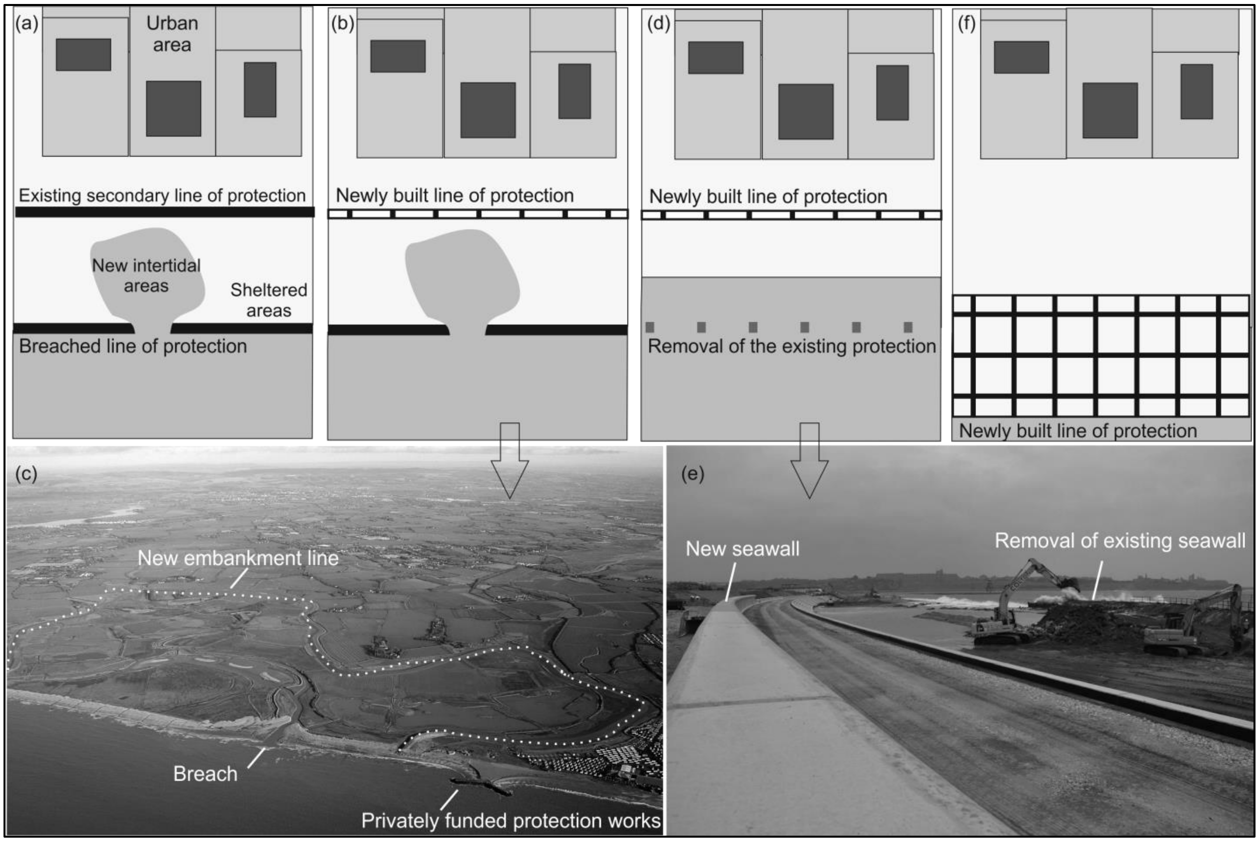

Figure 3. (a) Managed breaching of existing coastal protection creates new intertidal areas more exposed to tidal flow and waves, while offering more sheltered conditions in areas further away from the breach. Realignment of the coastal protection line involves the construction of a new line of coastal protection either inland, (b-c) through breach or (d-e) removal of the existing line of coastal protection, or (f) seaward. (c) Medmerry, West Sussex, England, illustrates inland realignment through breach (Photo by John Akerman) and (e) Littlehaven Beach, South Tyneside, England illustrates inland realignment through removal of existing coastal protection (Photo by Steve Burdett, courtesy of Royal HaskoningDHV).

The construction of a new line of coastal protection allows implementation of managed realignment in areas where the control of erosion and flood risk to inland areas requires active intervention. Tidal restoration can be implemented through breach (Figure 3b-c) or removal (Figure 3d-e) of the existing line of coastal protection. Realignment seaward (Figure 3f) can be achieved through mega-size sediment nourishment projects, which provide protection against storms and create space for the development of coastal habitats. An example is the 'Sand Motor'[7] project (also known as Sand Engine), built south of The Hague, in the Netherlands (De Schipper et al. 2014; Stronkhorst and Mulder 2014).

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[7] http://www.tudelft.nl/en/current/nieuwsartikelen/stw-perspectief-topsectoren/stw-naturecoast/

Inland realignment of the coastal protection line through breaching (Figure 3b) is the most common type of managed realignment in the UK (Table 2). Projects may involve one or multiple breaches; their dimensions and location control the tidal exchange and the level of exposure within the realignment site. The characteristics of the flow across the breaches determine the erosion and sedimentation patterns within the site and in the adjacent areas. The use of numerical modelling is essential to assess how breach design will alter the hydrodynamics and sediment dynamics at the site.

Not all realignment projects are designed to create habitats. Continued coastal erosion, or inadequate design/positioning of seawalls can result in shorelines too exposed to waves. Realignment of coastal protection structures may be implemented to reduce exposure and create opportunities for recreation. In Littlehaven Beach, South Tyneside, Northeast England, seawall realignment (Figure 3e) changed the shoreline from a protruding to a concave planform, reducing maintenance costs and increasing amenity value (Cooper et al. 2013). The Kreetsand project[8] along the River Elbe (Germany), combines flood risk reduction to the port of Hamburg with the creation of recreational areas.

3.4. Controlled tidal restoration

Controlled tidal restoration methods involve the maintenance of the existing line of coastal protection and the restoration of tidal flow into the protected area through the installation of culverts and sluices. The size and elevation of sluices and culverts determine the characteristics of the tidal inundation and sedimentation patterns within the site. In controlled tidal restoration, the high water line moves landwards within an embanked area. Therefore in this case, realignment refers to the position of the high water line. This method offers more control over erosion and flood risk than other types of manage realignment and is therefore a suitable

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[8] http://www.iba-hamburg.de/en/projects/elbe-islands-dyke-park/pilot-project-kreetsand/projekt/pilot-project-kreetsand.html

alternative at locations with high coastal development pressure and where land availability is scarce (Cox et al. 2006).

Two types of controlled tidal restoration methods are described in the literature: (a) regulated tidal exchange (RTE); and (b) controlled reduced tide (CRT). CRT schemes differ from RTE for having greater control on the tidal exchange to maximize the use of flood control areas to create intertidal habitat (Meire et al. 2005). Therefore, CRT allows managed realignment of coastlines heavily reliant on flood protection and where flood risk mitigation is a serious concern.

RTE schemes are widely implemented in France and the UK, often with the primary objective of habitat restoration and a secondary function of floodwater storage (Table 1). For example, the Polder de Sébastopol (Figure 4a), Vendée, France, was reclaimed from the sea in 1856, the existing dike breached during a storm in 1978, and the installation of culverts in 1999 restored tidal flows into the diked area. In 2008, the Polder de Sébastopol Regional Natural Reserve was created to protect 133 ha of wetlands that support protected migratory birds and other fauna and flora species of interest. The sheltered conditions and controlled tidal flow at RTE sites favor sediment deposition and the chances for saltmarsh development. Culverts can be designed to reduce the inundation depth at low-lying sites, but variations of water levels tend to be similar at neap and spring tides, limiting the restoration of the full spectrum of intertidal gradient (Beauchard et al. 2011).

CRT schemes are being implemented in Belgium as part of the Sigma Plan (see Section 4). Using a combination of high inlet culverts and low outlet gravitational valves (Figure 4b), the CRT creates a wide neap-spring range of inundation levels required for the establishment of the full spectrum of intertidal habitats within flood control areas (Cox et al. 2006; Maris et al. 2007). Flood control areas are enclosed by dikes, which are higher inland and lowered along the estuary or coast (Figure 4b). During high water level events, a large volume of water can overtop the lowered dike creating a temporary (one tide) floodwater storage area, alleviating flood risk to nearby areas (Cox et al. 2006).

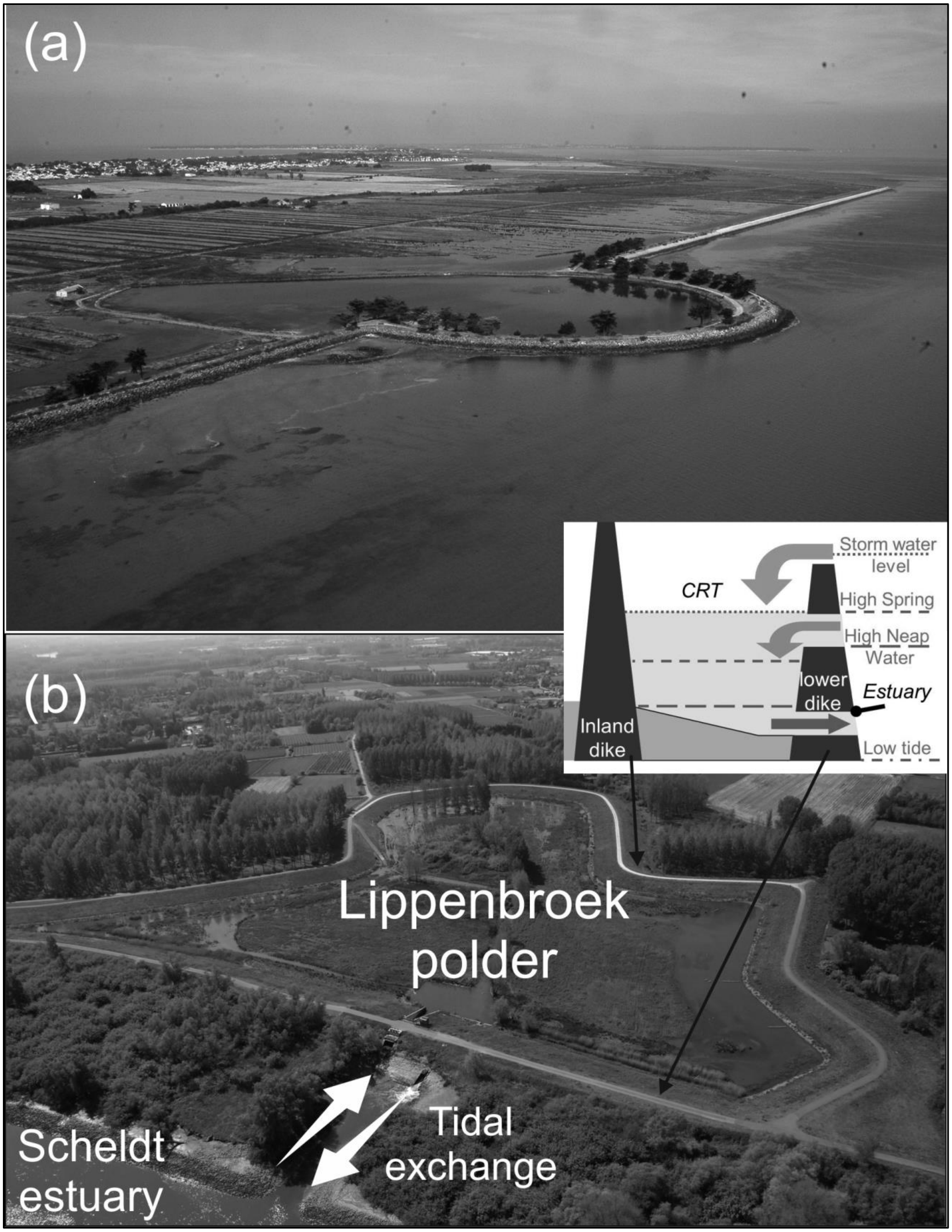

Figure 4. Two examples of controlled tidal restoration projects: (a) The Polder de Sébastopol (Vendée, France) illustrates a RTE scheme, in which tidal flows were restored into an embanked reclaimed land through culverts implemented in 1999 (Photo by Jacques Oudin, courtesy of Communauté de Communes de île de Noirmoutier); (b) Lippenbroek polder (Belgium) is a CRT pilot project where tidal flows enter a Flood Control Area through a high culvert during high water levels and site drainage is controlled by a gravitational valve installed in a low culvert (Photo from Olivier Beauchard).

Jacobs et al. (2009) summarize the tidal exchange in CRT sites as follows. During normal high tides, the volume of water entering the site is limited by the height and size of the inlet culvert. The water retained within the CRT site will start to drain only when the ebb tide lowers to the internal inundation level, allowing the low outlet culvert to open. The control of water levels allows saltmarshes to develop on elevations considerably lower than it would be possible under natural tidal conditions (Vandenbruwaene et al. 2011).

The Lippenbroek CRT (Figure 4b) construction started in 2004 and finished in March 2006 (Teuchies et al. 2012). The tidal amplitude is reduced from 5.2 m in the estuary to 0.9 m within the CRT site (Beauchard et al. 2011). Sediment accumulation was rapid, especially at lower elevations, where agricultural soils were covered by ~30 cm estuarine sediments in three years (Vandenbruwaene et al. 2011). Therefore, tidal inflow enhances sediment accumulation within the CRT, which may lead to (potentially undesirable) reduction of storage capacity through time. Conversely, emptying of floodwater may result in localized high erosion rates affecting habitat restoration (Cox et al. 2006). Numerical modelling simulations indicate that, due to differences in sedimentation patterns, CRT marshes may be less able to cope with rising sea levels than natural marshes, thus affecting their long-term sustainability (Vandenbruwaene et al. 2011).

3.5. Managed retreat

Managed retreat involves the relocation of people, property, and infrastructure from hazard-prone areas. If the objective is to reduce the number of people and assets at risk, managed retreat is perhaps the only option available for developed coasts threatened by rising sea levels (Alexander et al. 2012; Reisinger et al. 2015). However, its implementation requires long-term and strategic planning, which are difficult to achieve due to the complex nature of private property rights, social acceptance and uncertainties concerning future climate conditions. As a result, managed retreat initiatives tend to be slow and of limited scale, often not facilitating land-use changes within time scales that preclude the potential increase in risk (e.g. due to climate change and/or population growth). A typical example is the relocation of single structures at threat. For example, in 1999 the Belle Tout lighthouse (East Sussex, UK), then converted to a private home, was moved 17 m away from the edge of the eroding cliff, an effort privately funded.

Recently, a more strategic implementation of managed retreat has been promoted in national policies, such as the Protocol on Integrated Coastal Zone Management in the Mediterranean and the French national strategy for shoreline management (which is described in Section 4). Legislation supporting managed retreat usually involves alterations to private property rights based on defined thresholds of risk. It might include, for example, restrictions to restoration or reconstruction of properties affected by flooding or erosion if they are within high risk zones. Although setback lines are not direct instruments for managed retreat, they are often associated with some measures that facilitate its implementation.

In Spain, the Coastal Law of 1988 established an area of public domain (up to the most landward reach of waves during storms) and a ‘zone of protection’, in fact a setback, extending a further 100 m inland, or 20 m in areas developed before 1988 (Sanò et al. 2011). According to the Coastal Law, properties located within public domain would be considered illegal (and therefore requiring demolition). Properties within the zone of protection were granted a concession of use until 2018. Under the Coastal Law, these properties cannot be sold, transferred or upgraded. In the long-term this legislation has the potential to decrease the number of property and people in risk areas, reflecting a mechanism of managed retreat.

The Spanish Coastal Law was amended by Law 2/2013 on protection and sustainable use of the coast (ratified in 2014). This amend expanded the definition of public coastal domain causing many cases of appeal. However, it also increased the conditions in which the zone of protection is reduced from 100 m to 20 m and extended the concessions for a further 30 years, which allows a period of grace to request a permit to transfer the property deed. These amendments must comply with the Protocol on Integrated Coastal Zone Management in the

Mediterranean[9], which is part of EU law and is legally binding. The Protocol requires the implementation of a setback zone, at least 100-m wide, "*from the highest winter waterline…where construction is not allowed*". As the Protocol indicates certain conditions in which the setback zone may be 'adapted', national legislators have some flexibility to adjust their setback zones, and not necessarily to impose stricter measures.

The Spanish example illustrates the complexity involved in the implementation of managed retreat measures due to the influence of social and political pressures. Public support for managed retreat depends on a number of factors related to the underpinning cultural values of communities and individuals (Alexander et al. 2012) and social justice (e.g. Reisinger et al. 2015), including: (a) who will pay the costs; (b) how changes in existing rights of use are managed; and (c) who will benefit or loose with the changes.

4. Existing Strategies

Emerging national and regional strategies are driving the present day increase in managed realignment projects being implemented in Europe. The four strategies described here have the common objective of providing a more sustainable flooding risk management along coasts, estuaries and rivers, through innovative 'building with nature' approaches, including management realignment, as a sustainable climate change adaptation measure. Although other relevant initiatives exist (e.g. Cities and Climate Change programme promoted by IBA Hamburg, Germany), examples from the UK, Belgium, the Netherlands and France are selected to be detailed here as they illustrate the scale in which managed realignment is playing a role to achieve the strategies' objectives and the range of project types that are being considered.

4.1. Making Space for Water and Making Space for Nature, UK

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[9] http://ec.europa.eu/environment/iczm/barcelona.htm

In the UK, the public bodies most directly involved in managed realignment are: (a) the Department for Environment Food and Rural Affairs (Defra), responsible for policy-making concerning nature conservation and flood risk; (b) the Environment Agency (EA), responsible for implementing policy related to coastal erosion and flood risk management; and (c) local authorities, which are the designated Lead Local Flood Authority under the Flood and Water Management Act (2010), having the duty for managing local flood risk.

Defra (2005) published the Making Space for Water strategy with the aim to "*reduce the threat to people and their property*" and "*deliver the greatest environmental, social and economic benefits*". Managed realignment was promoted as the preferred approach for managing flood risk in rural areas and to create habitat to offset or compensate loss. Opportunities for managed realignment are identified by coastal management instruments, such as SMP and Catchment Flood Management Plans (Thomas 2014).

SMP are developed by coastal partnerships formed by local authorities and the EA and must consider four management policies: (a) no active intervention (no planned investment in coastal protection); (b) hold the line (investments on coastal protection will be made to maintain the shoreline position); (c) managed realignment; and (d) advance the line (new coastal protection will advance the shoreline seawards). Although not legally binding, SMP recommend the most suitable policy to be implemented at each coastal segment looking at three time frames into the future: 0-20 years; 20-50 years; 50-100 years. The most recent SMPs were published in 2012. Looking at the recommendations of the last SMPs, there is an 'ambition' to realign, in England and Wales, a total of 550 km by 2030 resulting in the creation of 6,200 ha of intertidal habitat at a cost of £10-15 million per year (Committee on Climate Change 2013). However, between 1991 and 2013, only around 66 km of coastline has been realigned. To achieve the target government plans require an eight-fold increase in realignment in the next 15 years.

The document 'Making Space for Nature' (Lawton et al., 2010) presents results from an independent assessment on the sustainability of natural environments in England. The report identifies that natural habitat sites are too small and fragmented and unable to provide all ecosystem functions, especially when climate change impacts on existing sites are considered. Additionally, the report makes 24 general recommendations that intend to steer future habitat restoration strategies without being prescriptive on how they should be implemented. Relevant to the context of this chapter, two key points are made by Lawton et al. (2010): (a) natural coastal protection will be critical to manage climate change impacts related to coastal erosion and flooding (e.g. sea-level rise and increased storminess); and (b) biodiversity offsetting and payment for ecosystem services should be considered as a way of enhancing nature and creating wider benefits through planning. It is possible to deduct from the report that habitat creation and a more effective ecological network is required if society is to benefit from ecosystem services related to water-quality, flood and erosion control and carbon storage. Managed realignment can deliver multiple functions that satisfy the need to adapt to climate change, compensate for habitat loss and provide sustainable coastal protection. The land-use changes resulting from managed realignment projects are an important element of the UK's National Adaptation Programme (Defra 2013) to provide improved climate and flood regulation. Implementation of managed realignment at the scale and rate planned by the UK government requires: (a) securing land at locations showing conditions favorable to the development of the habitats to be created; (b) better understanding how realigned sites evolve in the long-term; (c) increasing public acceptance; and (d) attracting external funding. Either collectively or individually, these challenges are known to delay or hinder the wider uptake of managed realignment projects.

4.2. Sigma Plan (Belgium)

Flood risk mitigation is a serious concern in Belgium, where estuarine and open coastlines are heavily engineered by flood protection structures. Restoration of intertidal habitats is a legal requirement as in other EU countries. The Sigma Plan[10] was devised in 1977 by the Waterways and Sea Canal (which is responsible for flood protection and navigation) in partnership with the Agency for Nature and Forests. It is a major regional strategy aiming to deliver improved flood risk management in the Flanders region through enhancement of environmental conditions along the river Scheldt and its tributaries.

The Scheldt Estuary Development Plan, a Netherlands-Flanders agreement, establishes an integrated long-term vision for the estuary's accessibility, environmental conservation and flood protection. Human interference in the Scheldt estuary has reduced intertidal habitat by 50% over the past century (Meire et al. 2005). The economic and ecological importance of estuary management interventions has caused historic cross-border conflicts between Belgium and the Netherlands due to enhanced flood risk and environmental degradation resulting, particularly, from land reclamation and channel dredging undertaken by the Netherlands (Esteves 2014). More recently, such conflicts involved the managed realignment of the Hedwige polder, which the Netherlands agreed to implement as a compensation measure for cross-border habitat loss (Stronkhorst and Mulder 2014).

A revision of the Sigma Plan in 2005 aimed to integrate the 'Room for the River' concept (see Section 4.3) and its multi-functionality (i.e. recreation, nature restoration, climate change adaptation, and sustainability of economic activities). The Sigma Plan involves the construction or upgrading of 512 km of dikes to the agreed 'sigma' height (i.e. to provide protection against water levels with a return period of 1,000 years), including the creation of flood control areas and 15 CRT projects to be implemented by 2030 resulting in the creation of 4,000 ha of intertidal habitat. A good overview of the Sigma Plan is provided in Beukelaer-Dossche and Decleyre (2013). Lippenbroek (Figure 4b) was the first CRT project piloted in Belgium (Jacobs et al. 2009; Beauchard et al. 2011; Teuchies et al. 2012).

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[10] http://www.sbe.be/en/reference/sigma-plan-river-scheldt

Land availability and cost is a significant issue in Belgium. To reduce impact of the revised Sigma Plan on urban and agricultural areas, most of the CRT projects are planned to take place in pre-defined preferred areas. Nevertheless, the impact on land value in the preferred areas is considerable and the government has implemented a policy of expropriation and freehold purchasing that is currently being tested in the Kalkense Meersen (Van Rompaey and Decleyre 2013). Other measures to facilitate land purchase include: (a) creation of a land bank (so land is available to offer as exchange to owners affected by the Sigma Plan); (b) € 2,000/ha in financial incentives (above market value) for willingness to sell; (c) relocation; (d) compensation for loss of production; and (e) low interest loans etc.

4.3. *Room for the River* and the *Delta Programme* (The Netherlands)

Coastal management strategies in the Netherlands vary along the coast, with complex dike systems protecting the low-lying land around the Rhine-Meuse-Scheldt delta and a range of soft engineering and managed realignment methods implemented along the sandy coast of the North Sea and the silty shorelines of estuaries and the Wadden Sea (Stronkhorst and Mulder 2014). Flood protection is of paramount importance to the Netherlands, where about two thirds of the land area is below sea level (Brouwer and van Ek 2004). Dutch policies have evolved through time and recognize the importance of naturally evolving coasts by incorporating concepts of eco-engineering (Rijkswaterstaat and Deltares 2013). Many of the projects described as ‘building with nature’ in the Netherlands could be classified as managed realignment. However, the perception of ‘retreat’ associated with the term ‘managed realignment’ restricts its use in the Netherlands (Eertman et al. 2002). The Dutch experience demonstrates that a combination of managed realignment and other coastal protection approaches can be strategically implemented to provide the desired level of protection and coastal uses, taking into consideration physical characteristics and socio-economic objectives of the sites.

The Rijkswaterstaat (Ministry of Infrastructure and Environment) is responsible for the main waterways and water systems in the Netherlands, including flood protection. In the aftermath of the catastrophic 1953 floods, the Delta Plan was devised to enhance flood protection through the construction of a robust dyke-dam system. As a result of hard engineering conducted under the 'deltaworks', the Dutch shoreline was shortened by 700 km. From 1990, under the 'Dynamic Preservation of the Coastline' policy, the shoreline is not allowed to retreat inland of its 1990 position (Hillen and Roelse 1995; Van Koningsveld and Mulder 2004), with management efforts focusing on beach nourishment along the sandy coasts of the North Sea. Annually 12 million m^3 of sand are used in foreshore, beach and dune nourishments to keep pace with the present sea-level rise of 2 mm/year (Stronkhorst and Mulder 2014). This approach has resulted in a slight seaward shift of the Dutch coastline (Giardino et al. 2014).

Climate change adaptation and environmental concerns have led to new policy developments, such as the *Room for the River*[11] (2007-2016) and the *Delta Programme*[12]. The *Room for the River* comprises 30 projects (at a cost of €2.3 billion) aiming to restore floodplains and their marshlands to improve flood safety and environmental quality. Realignment of river dikes is one of the measures used to tackle the combined effects of high river discharge and rising sea level that exacerbate flood risk.

The *Delta Programme* aims to improve flood risk management, securing freshwater supply, and promoting climate-proof spatial planning for the delta area. Underpinning the Programme is the decision to reduce *"the probability of individual mortality due to floods anywhere in the Netherlands to a maximum of 1:100,000 per annum*" by 2050. The implementation of the Programme will be based on predefined preferential strategies and these include a combination of measures, for example, beach nourishment along the sandy coast, dyke realignment (and other measures identified in the *Room for the River*) along the rivers and reinforcement of dykes

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[11] https://www.ruimtevoorderivier.nl/english/

[12] https://www.government.nl/topics/delta-programme

in densely occupied or strategic areas. Up to 2028, the *Delta Programme* has a secured average annual budget of €1.2 billion.

4.4. National Integrated Coastline Management Strategy (France)

The French National Integrated Coastline Management Strategy[13] published in 2011 explicitly promotes managed retreat from areas at risk. The Strategy is based on eight principles, which include: (a) acknowledging that the coast is dynamic and cannot be fixed everywhere; (b) the need to stop occupation in coastal areas where risk of flooding and erosion are high; (c) planning for long-term relocation of activities and property exposed to coastal risks taking into consideration how risks will change due to climate change; and (d) wide dissemination of knowledge on coastal ecosystems and hazards to all stakeholders. The strategy was developed by the Ministry of Ecology, Sustainable Development and Energy and the responsibility for its implementation is shared with local authorities.

The strategy recommends that planning considers predictions of coastal evolution at time-frames of 10, 40 and 90 years and anticipate relocation of property and infrastructure as a medium- and long-term alternative to reduce coastal risks, where justified through cost-benefit and multi-criteria analyses. Additionally, hard engineering protection should be considered only for densely populated areas or sectors of national strategic importance. Generally, flexible management options, allied with opportunities for ecological engineering to enhance natural protection, are preferred. Other managed realignment measures, such as the extension of the 100 m setback and removal of coastal protection structures reaching the end of their concession time are included in the strategy's plan of actions.

A call for innovative ecological engineering was launched in July 2011 to select demonstration projects where recommendations of the national strategy could be tested. In 2013, five projects

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[13] An English version of the strategy is available at: http://www.developpement-durable.gouv.fr/IMG/pdf/12004_Strate_ugie_gestion_trait_de_co_ete_GB_140326_BD.pdf.

were selected, each representing a different coastal typology and receiving €600,000 from the central government; and with the task to identify and evaluate coastal relocation measures within two years. The selected demonstration projects are: (1) Ault (affected by a rapidly eroding cliff at the margins of the English Channel); (2) Hyères les Palmiers (low-lying coastal plain along the Mediterranean); (3) three locations along the Aquitaine coast (Lacanau, La Teste-de-Buch, and Labenne have sandy beaches affected by erosion and dune migration); (4) Petit-Bourg (in the Caribbean Guadeloupe affected by hurricanes); and (5) Vias (a rapidly growing coastal population at risk of flooding in the Mediterranean).

In May 2014, a seminar was organized in Paris to discuss mid-project progress [14] and results indicate that the main issues so far include: (a) public acceptance (associated with poor understanding of coastal risks and how they may change in the future); (b) the definition of temporal and spatial scales in which the projects costs and benefits should be evaluated, (c) how to incorporate the uncertainty of predictions; and (d) the lack of governance instruments that support the types of actions required to relocate properties and infrastructure. Lack of awareness, poor acceptance of coastal communities, and mistrust of government actions are often cited as constraints to the implementation of managed realignment in France (Bawedin 2004; Goeldner-Gianella 2007; SOGREAH 2011) and in other countries (e.g. Roca and Villares 2012).

At present, the *Conservatoire du Littoral*[15] is a main player in nature conservation and habitat recreation in France, usually through implementation of RTE projects. It is a government agency with an action plan based on the philosophy of the British charity National Trust. In its 40th anniversary, the *Conservatoire du Littoral* has an annual budget of €50 million and currently owns 1,450 km of coastline and 160,000 ha, a good part managed as areas of conservation.

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[14] Documents (in French) describing the five projects and results of the seminar are found at: http://www.developpement-durable.gouv.fr/Strategie-nationale-de-gestion.html. At the time of writing, no further information was found about these demonstration projects in the scientific literature available in English.

[15] http://www.conservatoire-du-littoral.fr/

5. Lessons Learned

‘Building with nature’ approaches are now underpinning an increasing number of national and regional strategies as described above. Considering the increase in flooding and erosion risks associated with climate change, the benefits from natural coastal protection and other ecosystem services are becoming increasingly important to the sustainability and resilience of coastal communities (Temmerman et al. 2013). Managed realignment offers great opportunities for the creation of multi-functional areas that are able to benefit the wider society through a range of ecosystem services (e.g. Luisetti et al. 2011). The provision of these services depends on the size and type of managed realignment project, its adjacent environments, connectivity with water (Schleupner and Schneider 2013), and the previous land use in the realigned site (Spencer and Harvey 2012). The range of conditions in which managed realignment has been implemented makes each project almost unique and site specific. Therefore, generalizations of lessons learned need to be considered carefully, and adjusted to specific needs, as they may not necessarily be a good recipe for success elsewhere.

Considering the important role of managed realignment in existing coastal management policies, it is timely to identify lessons that may be more widely applicable to improve current practices and maximize social, economic and environmental benefits. These lessons are listed in Table 3 in three broad groups, factors important at the (a) high strategic level, and (b) project level, and key aspects concerning (c) public perception and stakeholder engagement. There are overlaps in the factors identified in Table 3, as some aspects are important both at the strategic and local level. In particular, aspects of public and stakeholder engagement are fundamental to the wider uptake of managed realignment at the strategic and local level, and therefore these are emphasized as a separate group in Table 3. This section describes the key aspects identified at the strategic and project level, including the importance of public perception and stakeholder engagement in each.

Table 3. Requisites for facilitating the implementation and wider uptake of managed realignment.

Governance and high-level strategy	Adaptive management (i.e. based on regular assessments) Clear and well-justified strategic vision (targets and time-frames are widely disseminated and understood) Availability of suitable land to deliver regional and local targets Funding and institutional mechanisms that facilitate the implementation of the strategy across the national to local levels (e.g. land purchase; to fund educational campaings) Ensure implementation mechanisms do not conflict with private property rights Strong knowledge basis about associated uncertainties and potential benefits accruing from the strategy Robust public dissemination and stakeholder engagement strategy
Delivery at the project level	Clear targets and well-defined time-frames for each project Capacity building for practitioners concerning project uncertainties, socio-economic implications and how to transfer this knowledge to the public Tailor project design to maximize benefits relevant to local communities Project design based on modelling outputs considering worst-case scenarios Better understanding of long-term evolution of realigned sites Systematic monitoring of relevant parameters until rates of change/conditions stabilize Independent and science-based data analysis to provide evidence of performance
Public perception and stakeholders engagement	Good understanding of national, regional and local targets Transparent decision-making and a legitimate participatory process to increase trust in government and non-government players Education efforts to reduce negativity associated with ‘give in to the sea’ perception Increased awareness about ecosystem services, climate change adaptation needs, the concept of managed realignment Long-term dissemination and engagement plan to reduce the ‘novelty effect’ Bottom-up approach to determine local targets Focus on multiple-functions and benefits (to reduce not-in-my-backyard attitude) Dissemination of evidence about the wider benefits gained from existing projects Working with the media to disseminate consistent messages and reduce influence of misinformation or unfounded perception

5.1. Governance and high level strategy

Adaptive management is often considered a good practice, particularly when outcomes of decisions may be affected by inherent uncertainties (Williams 2011), including time and magnitude of climate change impacts, sea-level rise etc. A key element of adaptive management is a systematic assessment of performance, so gained knowledge can be used to inform adjustments or changes where and when required. To ensure that performance can be properly evaluated, it is essential that clear targets and their time frames are defined both for the overall strategy and for individual projects (Garbutt et al. 2006; Williams 2011).

Strategies should be guided by a well-justified strategic vision aiming to achieve clearly defined targets and time-frames, which are widely disseminated and understood (e.g. the *Sigma Plan* and the *Room for the River*). Although strategic targets are often set out, it is less common that strategies identify the time-frames in which specific targets must be achieved and the criteria that should be used to measure performance. For example, the French National Integrated Coastline Management Strategy indicates that coastal local authorities should have plans developed by 2020, but does not identify exact targets (and time-frames) that should be achieved by the plans (e.g. the level of protection to be provided or the number/percentage of properties that should be removed from high risk areas). It is understandable that targets are less prescriptive due to the difficulty in predicting the course of nature and the variability of socio-economic, physical and environmental conditions along the coast. However, if objectives are unclear and not linked to time-frames, performance cannot be adequately measured; thus, adaptive management becomes impractical.

The success of national strategies depend on governance capacity; existing legislative mechanisms facilitating land acquisition, the licensing process, and controls related to individual property rights; and public acceptance. Clearly, the success of strategies largely depends on how well individual projects are delivered and managed at the local level, and these aspects are discussed in Section 5.2.

Land availability is a common issue in Europe, both in urban and rural areas (e.g. high-grade agricultural land), due to the increasing demand for locally sourced produce and the strong cultural values related to farming found in many countries, such as the UK, the Netherlands, Spain and others. Not only legal and financial mechanisms must exist so land can be acquired, the land must have suitable conditions for managed realignment to deliver the desired strategic objectives. The locations where managed realignment may be the most sustainable option are often identified at the regional/national level. However, the delivery of the strategy depends on the willingness of landowners to sell the land or to form partnerships with relevant government or non-governmental organizations at the local level.

Compulsory purchase mechanisms have been used in France in the aftermath of the Xynthia storm to force relocation from high risk areas. In Belgium, some incentives are identified in the Sigma Plan to stimulate interest of landowners (see Section 4.2). In England, land purchase is negotiated case-by-case and subjected to high price variability; sometimes resulting in acquisition of less suitable sites if willing landowners are identified in areas of high demand for habitat compensation (Esteves and Thomas 2014). In support of managed retreat strategies, it is paramount that existing legal mechanisms deal effectively with private property rights (e.g. the Coastal Law in Spain) and the time-frames of execution are faster than the increased risk posed by climate change or population growth. Otherwise, the strategy may not effectively reduce the number of people at risk.

In the UK, the Environment Agency has formed partnerships with the Royal Society for the Protection of Birds and The Wildlife Trusts to deliver projects focusing on nature conservation and able to provide wider environmental and socio-economic outcomes (e.g. Abbotts Hall, Freiston Shore and Wallasea Island). Working in partnership with landowners and relevant organizations can reduce the overall costs (e.g. eliminating the need for land purchase) and expedite implementation (e.g. less local opposition). Partnerships are facilitated when landowners can see the potential benefits on offer, such as diversification of land use; lower costs to maintain flood protection; or grants/subsidies offered by the government (e.g. payment for ecosystem services schemes).

Most projects in the UK have been implemented in areas where flood protection structures are in poor state of repair and land prices are lower. However, if site conditions are not ideal, managed realignment may not offer the best return for the investment of public money (Thomas 2014). Additional issues arise where managed realignment may result in flooding of freshwater habitats within designated areas of conservation, as these will need to be compensated through habitat recreation to comply with the EU Habitats Directive.

Farlington Marshes (Portsmouth, southern England) were reclaimed in the 1770s and the protection of a seawall allowed the development of marshes and other freshwater habitats that are now within Natura 2000 sites. A plan to realign the seawall at Farlington Marshes is favored by the local authority (the land owner) but has faced strong public opposition due to impacts on locally important recreational space, habitats supporting internationally important bird populations, and flood risk to more than 500 homes, a major access road, and the rail line. The creation of intertidal habitats cannot be considered as offering ‘equivalent value’ to the freshwater habitats that will be lost.

Managed realignment in such areas creates conflict between the uncertain gains (which will depend on the type and quality of intertidal habitats that might develop) and the certain loss of the services provided by the established freshwater habitats (which cannot be re-created locally or in the short-term). Such a conundrum is well described by Maltby (2006, p.93): “*We are then confronted by the contradictory situation of ecosystem destruction and re-establishment both featuring prominently in society’s agenda. The challenge is to manage the processes of change so that we do not irretrievably lose assets difficult or impossible to replace*”.

As in Farlington Marshes, public opposition has delayed or prevented the implementation of managed realignment at other locations, such as Donna Nook on the Humber estuary (UK); Bas-Champs de Cayeux in Picardy, France (SOGREAH 2011); and in the Ebro Delta in Spain

(Roca and Villares 2012). In the UK, public acceptance may delay or prevent the implementation of managed realignment projects, especially when projects involve loss of access rights to existing footpaths or there is a perception that increased flood risk will occur elsewhere in their area. The recent demonstration projects of managed retreat in France have exposed the lack of awareness of certain community groups about coastal risks and how existing coastal protection works may exacerbate risks under certain conditions.

Public perception is clearly a knowledge and communication issue (e.g. Goeldner-Gianella 2007; Esteves and Thomas 2014) that needs to be addressed as part of strategies (e.g. through robust educational campaigns) and delivered at the local level (i.e. where projects will be implemented). At the strategic level, it is important to convey a consistent message through educational campaigns and clearly explain why managed realignment is needed here and now, the expected gains and losses, supported by quantitative evidence of benefits realized from existing projects. This evidence-based and consistent message is particularly necessary to convince and engage stakeholders in situations involving a change in practice, such as where the government moves from a hard engineering hold-the-line policy toward managed realignment.

Gathering quantitative evidence of benefits requires projects to be systematically monitored through time and results measured against the intended objectives. Typically, monitoring of vegetation and macro invertebrates colonization, bird counts and sedimentation rates is undertaken in most projects. Often surveys and data analyses are conducted by the parties involved in project design resulting in restricted data availability and very few published independent studies. In fact, published studies and data monitoring reports are available for only a small number of management realignment projects; thus results disseminated in peer-reviewed publications tend to be limited in scope, space and time (Esteves 2013). Fortunately, the CRT pilot project Lippenbroek (Belgium) has been extensively studied and published by researchers of the University of Antwerp and collaborators (e.g. hydrology, sedimentation, nutrient cycling, vegetation, macroinvertebrates, fish habitat, metal concentration etc.), providing a good background for future CRT projects.

5.2. Project design and site evolution

The lack of pre-determined targets and performance indicators greatly compromises the sign-off of projects designed as compensatory measures for habitat loss or damage. The complications to achieve the sign-off of compensatory managed realignment are a concern of consultancies involved in project design and monitoring and stakeholders who want to ensure that compensation has actually being achieved[16]. It is in the public interest that measures are in place to ensure that individual projects are fulfilling their objectives (e.g. actually compensating habitat loss) and contributing to the overall impact of national strategies.

Although 140 managed realignment projects exist in Europe, they vary greatly in their method of implementation and local specificity. The design of the first managed realignment projects were relatively simple, involving mainly the planning of how coastal protection structures were going to be removed or breached. More recently, projects also involve the design of drainage channels and landscaping of the realigned area to produce a range of elevations and topography that would facilitate the creation of the desired types of habitats.

Technical expertise and modeling capability are key to project design and considerable advances have been achieved in the last decade. However, important challenges remain, such as: modeling hydrodynamic-sediment-vegetation interactions in mixed-grain size environments; dealing with uncertainties related to the changing physical environment (e.g. due to climate change and climate variability) and how it will affect restoration of ecosystems and the services they provide. These challenges associated with a deficient field-based knowledge still limit our

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[16] This topic was discussed in the 2013 ABPmer Conference 'Coastal Habitat Creation - Are We Delivering?', conference presentations can be downloaded from: http://www.omreg.net/conference-papers/.

understanding of and ability to predict the long-term evolution of realignment sites (e.g. French 2006; Rotman et al. 2008; Esteves and Thomas 2014; Ni et al. 2014).

Depending on project location, type and size, managed realignment can cause important changes to local hydrodynamic conditions, altering the tidal prism, and the erosion and deposition patterns in the intertidal zone. After breaching, the drainage system evolves rapidly; the main channel usually deepens and enlarges until a dynamic equilibrium with the new tidal prism is reached. Predictions of channel evolution depend on empirically defined coefficient and exponent (e.g. Hughes 2002), which vary with the scale of the system, tidal range, salinity, vegetation, and sediment characteristics (e.g. Williams et al. 2002). The required field data rarely exist (Vandenbruwaene et al. 2011) and values defined for other areas are often applied for largely different systems (e.g. cohesive vs. non-cohesive). Such practice may lead to large errors in the prediction of optimal breach width and channel cross-sectional area in managed realignment projects, as reported by Friess et al. (2014) for Freiston Shore.

The design of the managed realignment scheme at Freiston Shore was informed by modelling which included: three breaches (each 50-m wide), upgrading of an existing embankment further inland and the creation of an artificial tidal creek system. Two years from breaching, tidal creeks were still growing landward at rates of 400 m/year or about 20 times greater than observed at natural conditions (Symonds and Collins 2007). The rapid erosion and deposition associated with the evolution of the tidal creeks at Freiston Shore was not anticipated by model results. Perhaps model runs did not include the extreme water levels experienced few days after breaching. Considering the availability of suitable data (e.g. Symonds and Collins 2007; Friess et al. 2014; Ni et al. 2014), it would be relevant to test whether models are able to reproduce the observed hydrological-sediment response to the extreme conditions at Freiston Shore.

An increasing number of publications discuss the functional equivalency of recreated sites compared with natural ecosystems concerning vegetation (e.g. Mossman et al. 2012) and macroinvertebrates (e.g. Beauchard et al. 2013; Pétillon et al. 2014); the potential for nutrient cycling and carbon storage, metal mobility (e.g. Teuchies et al. 2012, 2013). Although there are large variations in site conditions and results, it is possible to briefly summarize the current state-of-the-art as follows.

Colonization by macroinvertebrates occurs fast in areas of new sedimentation (i.e. the new layer deposited on top of more consolidated old soils), where in few years following tidal restoration assemblages may be similar or richer than control sites (e.g. Beauchard et al. 2013). However, the size of individuals may be smaller and biomass lower (e.g. Mazik et al. 2010), which is likely to affect the diversity of bird assemblages using the realigned sites (e.g. Atkinson et al. 2004) or requiring greater feeding effort from individual birds (e.g. Mander et al. 2013). Additionally, compaction and geochemistry of older agricultural soils might slow or prevent colonization by invertebrates (Garbutt et al. 2006). Looking at arthropods, results reported by Pétillon et al. (2014) indicate that complete functional equivalency (including structure of trophic guilds and the potential for fish nursery) was not achieved at managed realignments.

Colonization of saltmarsh species within realigned sites can be fast (within 1-2 years). The types of assemblages are controlled by site elevation in relation to the tidal level, with pioneer and low marsh species dominating in lower areas (Garbutt et al. 2006) and even in higher ground (Mossman et al. 2012). Even after a long time species diversity tends to be lower than adjacent natural saltmarshes (Wolters et al. 2005); influencing factors include: poor drainage and seed availability (Spencer et al. 2008); the small extent of sites and poor range of elevations between mean high water of neap and spring tides (Wolters et al. 2005). The functioning of re-created saltmarshes was found to be “significantly impaired” when compared with natural systems affecting their ability to deliver ecosystem services (Spencer and Harvey 2012). Therefore, they may not satisfy the requirements of the EU Habitats Directive (Mossman et al. 2012).

Concerning nutrient cycling and metal mobility, results are geographically variable due to site-specific conditions and change through time as realigned sites evolve. The nitrogen and carbon storage capacity depends on vegetation density and sedimentation rates (Adams et al. 2012) and the chemistry of the floodwaters and soils (Blackwell et al. 2010). As an example of the variability across sites, realignment sites on the Blackwater Estuary were found to be net sources of methane and nitrous oxide (Adams et al. 2012), while on the River Torridge (southwest England) they are a net source of nitrous oxide and a sink for methane. The chemistry of the soils and the floodwater also determine whether the realigned sites may act as a sink (e.g. Teuchies et al. 2012) or source (e.g. Emmerson et al. 2001) of metal contaminants; however, metal availability and release are expected to occur within the first months after tidal restoration (e.g. Teuchies et al. 2013) and expected to change through time.

Only a few publications refer to long-term morphological evolution of managed realignment sites (Spearman 2011; Vandenbruwaene et al. 2011; Ni et al. 2014). Very little attention has been given in the literature to how site evolution may affect flood risk (Esteves and Williams 2015). In the UK, both the media and the published literature places a greater focus on ecological aspects of managed realignment, while there is a lack of evidence on other potential benefits. This imbalance has created a public perception, often detrimental, that managed realignment is an expensive nature conservation measure aiming to create habitats for birds while not enough effort is made to reduce flood risk to people (e.g. Esteves 2014). Morris (2012) argues that managed realignment will only attract wider public support if there is a shift in focus towards wider societal benefits, especially related to coastal erosion and flood risk management. Indeed, public perception is influenced by the lack of understanding about the benefits local communities might accrue from managed realignment. Demonstrating the multiple functions and ecosystem services that can be provided through managed realignment is likely to be more appealing to the public than emphasizing single objectives or achievements. By engaging with local communities to identify how they are likely to benefit from future managed realignment, a greater sense of ownership might be created leading to increased uptake of managed realignment in general and a better acceptance of projects near homes and businesses.

6. Concluding remarks

In Europe, managed realignment is increasingly promoted as a more sustainable coastal management approach able to deliver improved flood risk management and creation of habitats. In practice, the term managed realignment reflects a number of initiatives aiming to create space to restore the natural adaptive capacity of coastal environments and their ability to provide a range of ecosystem services. A total of 140 managed realignment projects have been implemented or are underway in Europe, which generally involve at least one of the following: removal, breach or realignment of existing coastal protection; controlled tidal restoration; and managed retreat (i.e. relocation from risk areas).

European Directives (e.g. Habitats, Birds, Floods and Water Framework) and climate change adaptation needs are the key drivers leading to the wider promotion of managed realignment approaches in recent national strategies. The French National Integrated Coastline Management Strategy, for example, supports relocation of economic activities and assets from high risk areas. In the UK, Shoreline Management Plans suggest that removal, breach or realignment of existing coastal protection may be the best management option for about 550 km of the coast by 2030. In Belgium, the Sigma Plan includes 15 controlled reduced tide projects to be implemented along the Scheldt estuary, resulting in the creation of 4,000 ha of intertidal habitat by 2030.

It is of paramount importance that managed realignment projects are carefully planned taking into account local characteristics (social and environmental) and site evolution is systematically monitored. Impact of managed realignment must be objectively measured against objectives set for each individual project and at the high strategic level. Evidence of benefits gained will help attract public support and lessons learned can be used to improve future practice.

The effective implementation of managed realignment requires the integration of: (a) improved scientific knowledge, (b) efficient mechanisms of governance, and (c) robust public engagement. The knowledge about how the many social, economic and technical aspects interact is evolving fast as new policies are formulated, more projects are implemented, and new monitoring data become available.

7. References

Adams, C.A., Andrews, J.E. and Jickells, T., 2012. Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. *Science of the Total Environment*, 434(15), 240-251.

Alexander, K.S.; Ryan, A. and Measham, T.G., 2012. Managed retreat of coastal communities: understanding responses to projected sea level rise. *Journal of Environmental Planning and Management*, 55(4), 409-433.

Atkinson, P.W., Crooks, S., Drewitt, A., Grant, A., Rehfisch, M.M., Sharpe, J. and Tyas, C.J., 2004. Managed realignment in the UK - the first 5 years of colonization by birds. *IBIS*, 146, 101-110.

Bawedin, V., 2004. La dépoldérisation, composante d’une gestion intégrée des espaces littoraux ? Prospective sur le littoral picard et analyse à la lumière de quelques expériences: Baie des Veys (Normandie), Aber de Crozon (Bretagne), Tollesbury (Essex) et Freiston shore (Lincolnshire). *Cahiers Nantais*, 6, 11-20.

Beauchard, O.; Jacobs, S.; Cox, T.J.S.; Maris, T.; Vrebos, D.; Van Braeckel, A. and Meire, P., 2011. A new technique for tidal habitat restoration: evaluation of its hydrological potentials. *Ecological Engineering*, 37, 1849–58.

Beauchard, O.; Jacobs, S.; Ysebaert, T. and Meire, P., 2013. Sediment macroinvertebrate community functioning in impacted and newly-created tidal freshwater habitats. *Estuarine, Coastal and Shelf Science,* 120, 21-37.

Blackwell, M.S.A., Yamulki, S. and Bol, R., 2010. Nitrous oxide production and denitrification rates in estuarine intertidal saltmarsh and managed realignment zones. *Estuarine, Coastal and Shelf Science*, 87(4), 591-600.

Brouwer, R. and van Ek, R. 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics*, 50, 1-21.

Committee on Climate Change, 2013. Managing the land in a changing climate. Chapter 5: Regulating services – coastal habitats. Available from: http://www.theccc.org.uk/publication/managing-the-land-in-a-changing-climate/, 92-107.

Cooper, N.J.; Wilson, S. and Hanson, T., 2013. Realignment of Littlehaven Sea Wall, South Tyneside, UK*. Proceedings Institution of Civil Engineers Coastlines*, *Structures and Breakwaters Conference*, 10p.

Cox, T., Maris, T., De Vleeschauwer, P., De Mulder, T., Soetaert, K. and Meire, P., 2006. Flood control areas as an opportunity to restore estuarine habitat. *Ecological Engineering*, 28, 55-63.

De Beukelaer-Dossche, M. and Decleyre, D. (eds.), 2013. Bergenmeersen, Construction of a Flood Control Area with Controlled Reduced Tide as Part of the Sigma Plan. Available from www.vliz.be/imisdocs/publications/250657.pdf, last accessed on 18 Sep 2015.

Defra (Department for Environment, Food and Rural Affairs), 2002. Managed Realignment Review. Policy Research Project FD 2008, Flood and Coastal Defence R&D Programme. Available from: http://randd.defra.gov.uk/Document.aspx?Document=FD2008_537_TRP.pdf, last accessed on 4 January 2015.

Defra, 2005. Making space for water - Taking forward a new Government strategy for flood and coastal erosion risk management in England. First Government response to the autumn 2004 consultation exercise. London.

Defra, 2013. The National Adaptation. Programme. Making the country resilient to a changing climate. Norwich: The Stationery Office, 182p. Available from:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf/.

Defra Flood Management Division, 2005. Coastal Squeeze Implications for Flood Management, the requirements of the European Birds and Habitats Directives. Defra Policy Guidance.

De Schipper, M.A., De Vries, S., Stive, M.J.F., De Zeeuw, R.C., Rutten, J., Ruessink, B.G., Aarninkhof, S.G.J. and Van Gelder-Maas, C., 2014. Morphological Development of a Mega-Nourishment: First Observations at the Sand Engine. Proceedings of 34th International Conference on Coastal Engineering (ICCE 2014), doi.org/10.9753/icce.v34.sediment.73.

Dyke, P. and Flux, T., 2014. The National Trust Approach to Coastal Change and Adaptive Management. , *In*: Esteves, L.S., *Managed realignment: is it a viable long-term coastal management strategy?* New York: Springer.

Eertman, R.H.M.; Kornman, B.A.; Stikvoort, E. and Verbeek, H., 2002. Restoration of the Sieperda Tidal Marsh in the Scheldt Estuary, The Netherlands. *Restoration Ecology*, 10, 438-449.

Elliott, M.; Cutts, N.D. and Trono, A., 2014. A typology of marine and estuarine hazards and risks as vectors of change: A review for vulnerable coasts and their management. *Ocean & Coastal Management*, 93, 88-99.

Esteves, L.S., 2013. Is managed realignment a sustainable long-term coastal management approach? *Journal of Coastal Research*, SI 65, 933-938.

Esteves, L.S., 2014. *Managed realignment: is it a viable long-term coastal management strategy?* New York: Springer.

Esteves, L.S., 2016. Coastal squeeze, *In*: Kennish, M.J. (ed.), *Encyclopedia of Estuaries*, Dordrecht: Springer.

Esteves, L.S. and Thomas, K., 2014. Managed realignment in practice in the UK: results from two independent surveys. *Journal of Coastal Research*, SI 70, 407-413.

Esteves, L.S. and Williams, J.J., 2015. Changes in coastal sediment dynamics due to managed realignment. *Coastal Sediments 2015* (11 – 15 May 2015, San Diego, USA), doi: 10.1142/9789814689977_0165.

Emmerson, R.H.C., Scrimshaw, M.D., Birkett, J.W. and Lester, J.N., 2001. Solid phase partitioning of metals in Managed Realignment soils: laboratory studies in timed soil sea-water batch mixtures. *Applied Geochemistry*, 16(14), 1621-1630.

Friess, D.A.; Möller, I.; Spencer, T.; Smith, G.M.; Thomson, A.G. and Hill, R.A., 2014. Coastal saltmarsh managed realignment drives rapid breach inlet and external creek evolution, Freiston Shore (UK). *Geomorphology*, 208, 22-33.

Garbutt, R.A., Reading, C.J., Wolters, M. Gray, A.J. and Rothery, P., 2006. Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Bulletin*, 53(1–4), 155-164

Giardino, A.; Santinelli, G. and Vuik, V., 2014. Coastal state indicators to assess the morphological development of the Holland coast due to natural and anthropogenic pressure factors. *Ocean & Coastal Management*, 87, 93-101.

Goeldner-Gianella, L., 2007. Perceptions and attitudes towards de-polderisation in Europe: A comparison of five opinion surveys in France and in the UK. *Journal of Coastal Research*, 23(5), 1218-1230.

Hillen, R. and Roelse, P., 1995. Dynamic preservation of the coastline in the Netherlands. *Journal of Coastal Conservation*, 1, 17-28.

Hughes, S.A., 2002. Equilibrium cross sectional area at tidal inlets. *Journal of Coastal Research*, 18, 160–174.

Jacobs, S.; Beauchard, O.; Struyf, E.; Cox, T.; Maris, T. and Meire, P. 2009. Restoration of tidal freshwater vegetation using controlled reduced tide (CRT) along the Schelde Estuary (Belgium). *Estuarine, Coastal and Shelf Science*, 85(3), 368-376.

Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.A., Tew, T.E., Varley, J., and Wynne, G.R., 2010. Making Space for Nature: A review of England's Wildlife Sites and Ecological Network. Report submitted to Defra. Available from: http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf, last accessed on 15 January 2014.

Luisetti, T., Turner, R. K., Bateman, I. J., Morse-Jones, S., Adams, C. and Fonseca, L. 2011. Coastal and marine ecosystem services valuation for policy and management: Managed realignment case studies in England. *Ocean & Coastal Management*, 54(3), 212-224.

Maltby, E,. 2006. Wetland conservation and management: questions for science and society in applying the ecosystem approach. *In*: R. Bobbink; B. Beltman; J.T.A. Verhoeven and D.F. Whigham (Eds). Wetlands: Functioning, Biodiversity Conservation, and Restoration. *Ecological Studies*, 191(2), 93-116.

Mander, L.; Marie-Orleach, L. and Elliott, M., 2013. The value of wader foraging behaviour study to assess the success of restored intertidal areas. *Estuarine, Coastal and Shelf Science,* 131, 1-5.

Maris, T., Cox, T., Temmerman, S., De Vleeschauwer, P., Van Damme, S., De Mulder, T., Van den Bergh, E., Meire, P. 2007. Tuning the tide: creating ecological conditions for tidal marsh development in a controlled inundation area. *Hydrobiologia*, 588, 31-43.

Mazik, K., Musk, W., Dawes, O., Solyanko, K., Brown, S., Mander, L. and Elliott, M. 2010. Managed realignment as compensation for the loss of intertidal mudflat: A short term solution to a long term problem? *Estuarine, Coastal and Shelf Science*, 90(1), 11-20.

Meire, P., Ysebaert, T., Van Damme, S., Van den Bergh, E., Maris, T., Struyf, E., 2005. The Scheldt estuary: a description of a changing ecosystem. *Hydrobiologia* 540, 1–11.

Morris, R.K.A., 2012. Managed realignment: a sediment management perspective. *Ocean & Coastal Management*, 65, 59-66.

Mossman, H.L.; Davy, A.J. and Grant, A., 2012. Does managed coastal realignment create saltmarshes with ‘equivalent biological characteristics’ to natural reference sites? *Journal of Applied Ecology*, 49, 1446–1456.

Ni, W., Wang, Y.P., Symonds, A.M. and Collins, M.B., 2014. Intertidal flat development in response to controlled embankment retreat: Freiston Shore, The Wash, UK. *Marine Geology*, 355, 260-273.

Nordstrom, K.F. and Jackson, N.L., 2013. Removing shore protection structures to facilitate migration of landforms and habitats on the bayside of a barrier spit. *Geomorphology*, 199, 179-191.

Nottage, A. and Robinson, P., 2005. The saltmarsh creation handbook: a project manager’s guide to the creation of saltmarsh and intertidal mudflat. London: RSPB and CIWEM.

Pétillon, J.; Potier, S.; Carpentier, A. and Garbutt, A., 2014. Evaluating the success of managed realignment for the restoration of salt marshes: Lessons from invertebrate communities. *Ecological Engineering*, 69, 70–75.

Pontee, N., 2013. Defining coastal squeeze: a discussion. *Ocean & Coastal Management*, 84, 204–207.

Pontee, N., 2014. Factors Influencing the Long-Term Sustainability of Managed Realignment. *In*: Esteves, L.S., *Managed realignment: is it a viable long-term coastal management strategy?* New York: Springer.

Reisinger, A., Lawrence, J., Hart, G. and Chapman, R., 2015. From coping to resilience: the role of managed retreat in highly developed coastal regions of New Zealand. *In*: Glavovic, B., Kaye, R., Kelly M. and Travers, A. (Eds.), *Climate Change and the Coast: Building Resilient Communities*. London: CRC Press.

Rijkswaterstaat and Deltares, 2013. *Eco-engineering in the Netherlands: Soft interventions with a solid impact*, 44p. Available from: http://dtvirt35.deltares.nl/products/30490.

Roca, E. and Villares, M., 2012. Public perceptions of managed realignment strategies: The case study of the Ebro Delta in the Mediterranean basin. *Ocean & Coastal Management*, 60, 38-47.

Rotman, R.; Naylor, L.; McDonnell, R. and MacNiocaill, C., 2008. Sediment transport on the Freiston Shore managed realignment site: An investigation using environmental magnetism. *Geomorphology*, 100, 241–255.

Sanò, M., Jimenez, J.A., Medina, R., Stanica, A., Sanchez-Arcilla, A. and Trumbic, I., 2011. The role of coastal setbacks in the context of coastal erosion and climate change. *Ocean & Coastal Management*, 54, 943-950.

Schleupner, C. and Schneider, U.A., 2013. Allocation of European wetland restoration options for systematic conservation planning. *Land Use Policy*, 30, 604-614.

SOGREAH, 2011. Etude de Faisabilite – Depolderisation partielle et eventuelle des Bas-Champs du Vimeu – La recherché d'un avenir sur un territoire perenne. Phase 1: Etat des lieux – diagnostic du territoire. Chapitre 8: Approche géographie sociale – perceptions.

Spalding, M.D., McIvor, A.L., Beck, M.W., Kock, E.W., Möller, I., Reed, D.J., Rubinoff, P., Spencer, T., Tolhurst, T.J., Wamsley, T.V., van Wesenbeeck, B.K., Wolanski, E. and Woodroffee, C.D., 2014. Coastal Ecosystems: A Critical Element of Risk Reduction. *Conservation Letters*, 7(3), 293–301.

Spearman, J., 2011. The development of a tool for examining the morphological evolution of managed realignment sites. *Continental Shelf Research*, 31(10), S199-S210.

Spencer, K.L., Cundy, A.B., Davies-Hearn, S., Hughes, R., Turner, S. and MacLeod, C.L., 2008. Physicochemical changes in sediments at Orplands Farm, Essex, UK following 8 years of managed realignment, *Estuarine, Coastal and Shelf Science*, 76(3), 608-619.

Spencer, K.L. and Harvey, G.L., 2012. Understanding system disturbance and ecosystem services in restored saltmarshes: Integrating physical and biogeochemical processes. *Estuarine, Coastal and Shelf Science*, 106, 23-32.

Stronkhorst, J. and Mulder, J., 2014. Considerations on managed realignment in the Netherlands. *In*: Esteves, L.S., *Managed realignment: is it a viable long-term coastal management strategy?* New York: Springer.

Symonds, A.M. and Collins, M.B., 2007. The establishment and degeneration of a temporary creek system in response to managed coastal realignment: The Wash, UK. *Earth Surface Processes and Landforms*, 32, 1783-1796.

Temmerman, S.; Meire, P.; Bouma, T.J.; Herman, P.M.; Ysebaert, T. and De Vriend, H.J., 2013. Ecosystem-based coastal defence in the face of global change. *Nature*, 504, 79-83.

Teuchies, J.; Beauchard, O.; Jacobs, S.; and Meire, P., 2012. Evolution of sediment metal concentrations in a tidal marsh restoration project. *Science of the Total Environment*, 419, 187-195.

Teuchies, J.; Singh, G.; Bervoets, L. and Meire, P., 2013. Land use changes and metal mobility: Multi-approach study on tidal marsh restoration in a contaminated estuary. *Science of the Total Environment*, 449, 174–183.

Thomas, K., 2014. Managed realignment in the UK: the role of the Environment Agency, *In*: Esteves, L.S., *Managed realignment: is it a viable long-term coastal management strategy?* New York: Springer.

Vandenbruwaene, W.; Maris, T.; Cox, T.J.S.; Cahoon, D.R.; Meire, P., and Temmerman, S., 2011. Sedimentation and response to sea-level rise of a restored marsh with reduced tidal exchange: Comparison with a natural tidal marsh. *Geomorphology*, 130, 115-126.

Van Koningsveld, M. and Mulder, J.P.M., 2004. Sustainable coastal policy developments in the Netherlands. A systematic approach revealed. *Journal of Coastal Research*, 20(2), 375-85.

van Loon-Steensma, J.M. and Vellinga, P., 2013. Trade-offs between biodiversity and flood protection services of coastal salt marshes. *Current Opinion in Environmental Sustainability*, 5, 320–326.

Van Rompaey, M. and Decleyre, D., 2013. Public Support. *In*: De Beukelaer-Dossche, M. and Decleyre, D. (eds.), 2013. *Bergenmeersen, Construction of a Flood Control Area with Controlled Reduced Tide as Part of the Sigma Plan*. Available from: www.vliz.be/imisdocs/publications/250657.pdf, last accessed on 1st Sep 2015.

Williams, B.K., 2011. Passive and active adaptive management: approaches and an example. *Journal of Environmental Management*, 92(5), 1371-1378.

Williams, P.B.; Orr, M.K. and Garrity, N.J., 2002. Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. *Restoration Ecology*, 10(3), 577-590.

Wolters, M., Garbutt, A. and Bakker, J.P. 2005. Salt-marsh restoration: evaluating the success of de-embankments in north-west Europe. *Biological Conservation*, 123(2), 249-268.