Assessing the implications of current understanding of saltmarsh environments for managed realignment: a literature review

Summary Report

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Executive Summary

Saltmarshes are important coastal fringe habitats providing multiple ecosystem services benefits to coastal communities. Understanding saltmarsh development associated with managed re-alignment is vital, given the promotion of this management process for coastal defence of lowlying estuaries in England and Wales. An extensive literature review was undertaken to inform the development of research relevant to managed alignment in the Bristol Channel. Content analysis was used as part of an extensive systematic review of literature published since 2000. Following scoping and screening, 56 documents from across the natural science, bioengineering and social science literature were further analysed using bespoke key word searches. This identified a number of key barriers and limitations to saltmarsh research relevant to managed realignment practice. These included a lack of standardisation of methods and terminology along with limitations associated with the short-term nature and limited scope of relevant field research and soil geochemical studies respectively. There were also issues associated with overly simplistic models of saltmarsh behaviour, which do not address the complex interactions between physical processes and the ecology of the system. Of particular note, however, were gaps in our understanding of public attitudes towards managed realignment and the implications of these for science communication and associated policy making. A clear disparity exists between some of the very recent findings within the social science literature which have investigated public attitudes towards restored habitats and the results of previous dedicated public perception surveys related to specific managed realignment projects. A pilot study in the Severn Estuary substantiates the need for further research. This suggested a focus on public views, opinions and feelings as well as research into how public interactions with saltmarshes may influence public acceptance of managed realignment as a coastal defence option.

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Context

Saltmarshes are important coastal fringe habitats providing multiple ecosystem services benefits to coastal communities (Barbier *et al*. 2011; Garbutt, 2013; Jones *et al*., 2011; Luisetti *et al*., 2008). Understanding saltmarsh development associated with managed re-alignment is vital to ensure that the many planned future re-alignment schemes along the coasts of England and Wales not only deliver compensatory requirements under the EC Habitats Directive (92/43/EEC), but also deliver these wider ecosystem service benefits to coastal communities (Barbier *et al*., 2011).

Building on Gedan *et al.* (2009) and French (2006), this literature review sought to inform the development of research relevant to managed alignment, identifying trends in research as well as key gaps and limitations in our understanding of saltmarsh processes and management.

Approach

An extensive and systematic global review of relevant saltmarsh literature published since 2000 was undertaken. After an initial scoping and screening process, fifty six documents from across the natural science, bioengineering and social science literature were analysed in depth using bespoke key word searches within a content analysis similar to that employed by Tang *et al.* (2013). This approach enabled a clear categorisation of recent literature using statistical analysis which provided the context and structure for a more detailed qualitative analysis of the gaps and limitations of current research. The study of further, supplementary grey literature sources was undertaken to inform this latter discussion.

An overview of the saltmarsh literature

The initial literature review identified roughly similar numbers of papers from natural science (26) and social science (21) perspectives with slightly fewer (15) papers within the bioengineering literature. Figure 1 below summarises the thematic focus of the literature. Whilst consideration of the ecological aspects of saltmarshes was well addressed across all three categories of the literature, climate change matters were much less common, particularly within US social science literature. Such findings are of concern given managed re-alignment's important role in climate change adaption, particularly in light of sea level rise (Morris 2012; Luisetti *et al.* 2011; French 2006; Pethick 2002). However, given that Willems (2003) and The Royal Society (2006) indicate that scientists tend to report their findings almost exclusively within their specific research communities, it is suggested here that the new findings in climate change science may take awhile to percolate into coastal environmental science, and even longer to reach and inform the policy and management process.

The level of detail on each theme varied considerably, as might be expected, from cursory references to 'human uses' in most of the natural science and bioengineering literature, to much more expansive consideration of such matters in the social science literature. The coastal protection function of saltmarshes was referenced in about 20% of the papers, with slightly more and greater consideration in papers within the bioengineering literature, as expected.

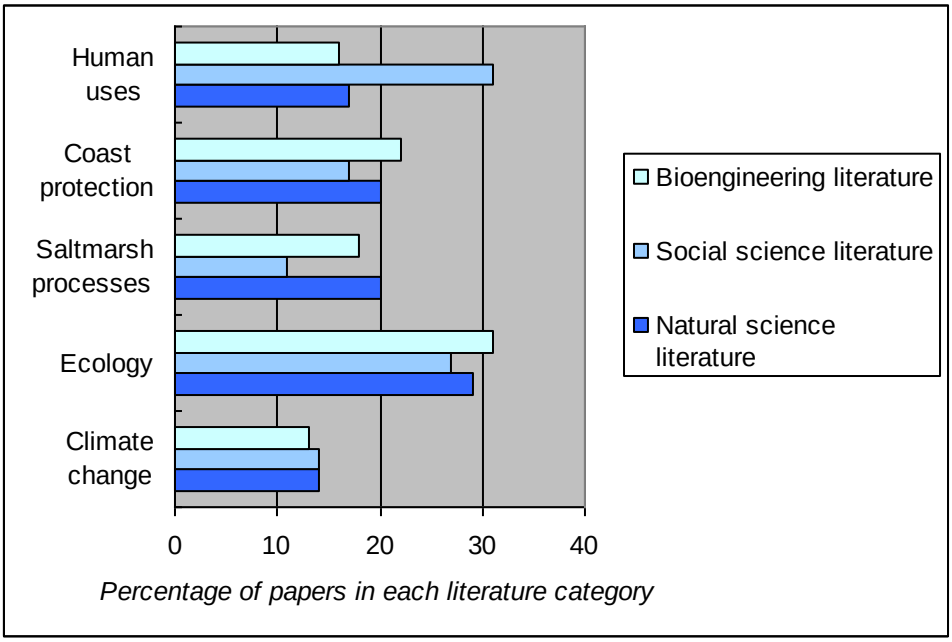

Figure 1 Thematic focus of literature

In contrast to the wider coastal and environmental literature where there is concern around science-policy interactions (see Petes *et al.,* 2014; Nursey *et al*., 2014; Dilling and Lemos 2011; Tribbia and Moser 2008; Sarewitz and Pielke 2007), the literature review identified a limited acknowledgment of science-policy interactions here. Granek *et al*. (2010) suggest such a weak science-policy relationship may be caused by scientists not presenting their findings in a form that is understandable or easy to use by end-users (including policy makers, stakeholders, and the public) or may be as a consequence of research progressing at a different rate to policy development. Consideration of science-policy implications was considered in just over half of the social science literature, albeit not always in much detail (Figure 2). In contrast a relatively small proportion of the bioengineering and natural science literature made scant reference to such matters, suggesting a possible relative lack of engagement of such scientists with end-users. These findings support research outcomes elsewhere which suggest a barrier between knowledge exchange between coastal science and policy cycles (McFadden 2007). This research suggests that if policy plans are not informed by best available science from the design stage, then there is the risk of problems being escalated across the whole coastal zone.

Consideration of science-policy aspects within UK saltmarsh research, however, was much stronger than that based in other geographical regions. This could be expected given the increasing adoption of managed realignment as a shoreline management option in the UK (ABPmer, 2015). However, there was only very limited focus on public perception of saltmarshes and barriers to science-policy interactions within this literature.

This contrasts markedly with the increase in literature related to perception of climate change and climate change adaptation (see Capstick *et al*. 2015, for example). Further aspects related to science-policy issues are considered below.

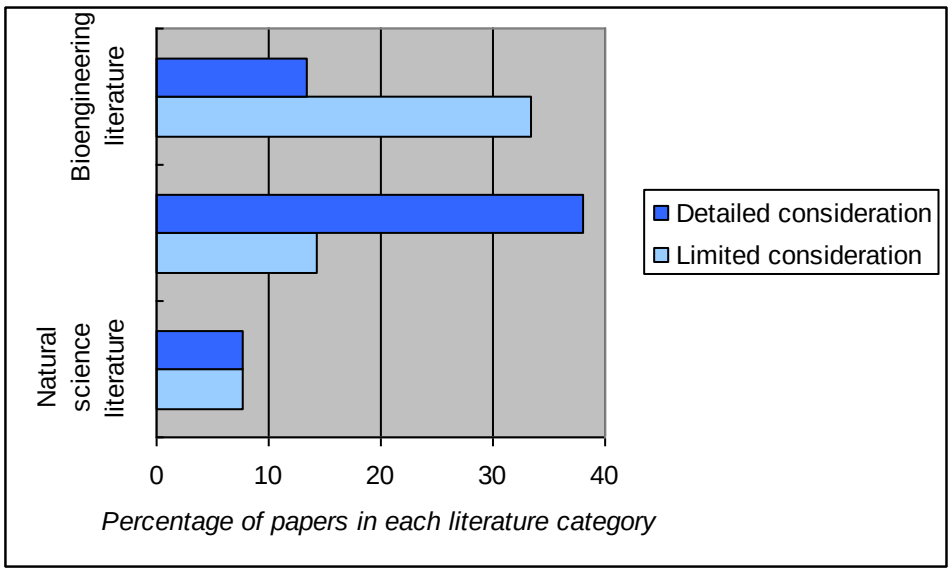

Figure 2 Acknowledgement of science-policy implications

As Figure 3 shows many of the reviewed papers were based on one-off site specific studies, but few considered future long-term temporal changes in any detail. Such issues were slightly more pronounced in the bioengineering and social science literature where there was also very limited discussion of climate change impacts.

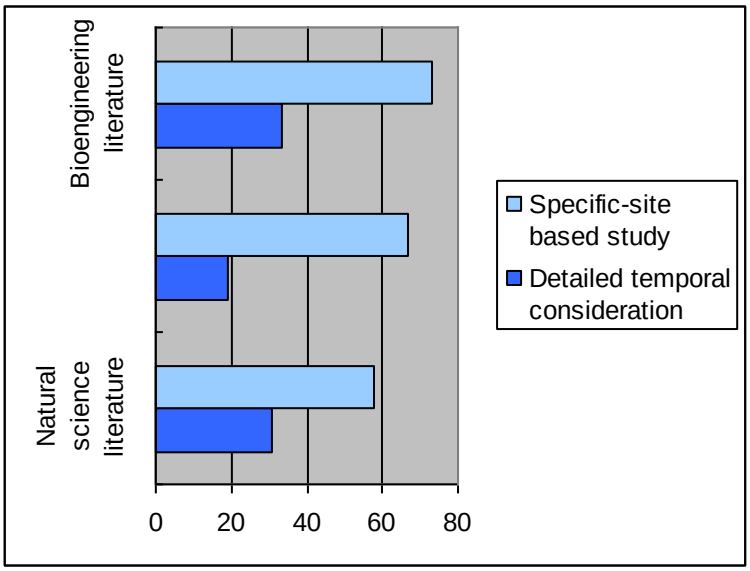

Figure 3 Spatial and temporal focus of the literature

Although this study focused on peer-reviewed academic journal outputs, there was a surprisingly low consideration of knowledge and research limitations within the papers studied, as shown in Figure 4. There was a slightly higher attention on such matters in the natural science literature, where it could have been expected such practice would have been more commonplace. The knowledge gaps and future research priorities identified within these papers are discussed in further detail in the following section.

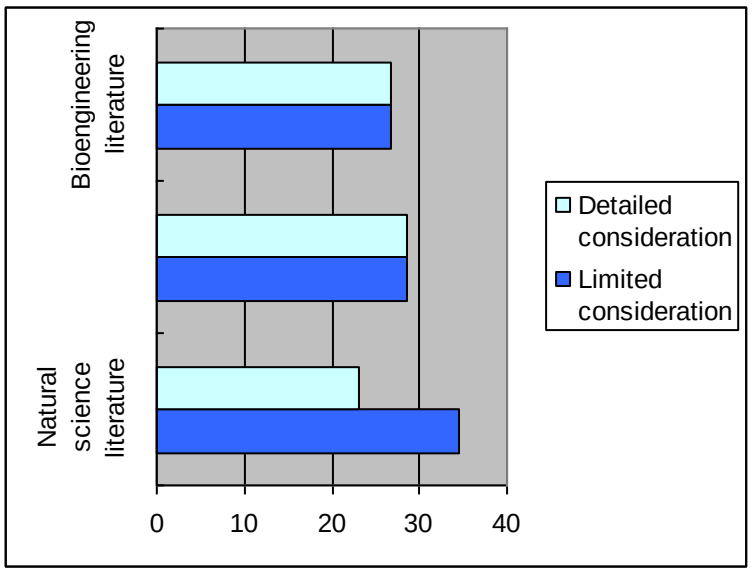

Figure 4 Consideration of research gaps and limitations

Current research gaps and limitations

The literature review identified the following barriers and limitations to saltmarsh research which are relevant to managed realignment in practice:

- Standardisation of methods and terminology
- Limited, short-term field case studies
- Limited understanding of species impacts on saltmarsh behaviour
- Limited research on soil geochemistry
- Modelling issues
- Poor understanding of science communication
- Weak understanding of public perception aspects of managed realignment

In the context of the modelling, issues are associated with over reliance on generic models with limited specific data input and the need for more specific understanding of 'threshold values'. The following sub-sections explore the nature and implications of these issues in more detail.

Standardisation of methods and terminology

There is a clear lack of standardisation of terminology in wetland science and management (Borsjea *et al*., 2011) which may impede understanding across disciplines and between scientists and policy makers. This lack of standardisation includes key definitions for the term 'wetland' itself as well as for key management processes and the ecosystem functions. In the context of the former, the term 'wetland' is used to refer to a wide variety of permanent to semi-permanent habitat covered by vegetation and partially covered by water. This reflects the broad definition within Article 1.1 of the RAMSAR convention: "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*" (RAMSAR, 2013). In terms of key management processes, Kentula (2000) suggests that the interchangeable use of terms such as compensatory habitat, habitat creation, habitat re-creation, restoration and mitigation may confuse, as may do the similarly careless use of the phrases used to describe the similar, but not identical processes of managed re-alignment, managed retreat and set-back (French, 1997). Given the relatively recent development of saltmarsh/ wetland restoration and associated science, this lack of standardisation is not that surprising. Indeed the formal establishment and professionalization of restoration science only came about in 1993 with the publication of the journal *Restoration Ecology.* The need to standardise ecosystem

functions to allow site comparisons and strengthen the scientific discourse on wetland site restoration was called for in 2000 (Zedler, 2000) and more recently by Borsjea *et al*. (2011). Such standardisation is, however, difficult to progress given the broad range of disciplines involved in saltmarsh studies, from engineers and geomorphologists to ecologists, economists and social scientists.

Alongside contrasting approaches to saltmarsh science in the different schools of academia, major technological advances in data collection and associated ICT have resulted in limited standardisation of approaches over recent years. This is a particular issue in England, where comparability between historic and even relatively recent national datasets is somewhat problematic. In this particular case, there are issues comparing the Environment Agency's recent 2011 dataset with the early Burd (1989) survey and even the Environment Agency's 2006-2009 aerial GPS saltmarsh survey.

Limited, short-term field case studies

Simenstad *et al*. (2006), French (2006) and Zedler (2000) all suggest limited availability of data from field sites over long time periods hampers our understanding of long-term changes to saltmarshes. Murray *et al.* (2008) argue that field data is required at landscape levels in order to improve our understanding of biomorphodynamic processes, and to better inform and build biomorphic prediction models. However, issues associated with limited field data are a particular problem in providing predictions of future long term outcomes of restored and managed re-alignment sites. Indeed, Simenstad *et al*. (2006) have suggested that demonstration sites be established to aid the development of tools to improve planning for coastal restoration. These authors argue that by building models representing different restoration processes, such research can help identify what can and cannot be realistically achieved by restoration projects. These authors suggest that such models would need to be highly sensitive to the specific type of saltmarsh required.

Limited understanding of species impacts on saltmarsh behaviour

There is some concern over our current limited understanding of the influences of specific species on bioengineering processes and associated saltmarsh behaviour as well as ongoing and related discussion into the drivers of saltmarsh establishment and zonation. In relation to the latter for example, whilst Silvestri *et al*. (2005) conducted research into the relationship between saltmarsh plant zonation, tides and salinity, they were unable to prove that plant zonation was controlled by tides or salinity. In relation to the former Borsje *et al*. (2011) suggest there is a debate over the effectiveness of saltmarsh environments as a means of coastal protection within the natural science and bioengineering literature as a result of contrasting data inputs producing different outcomes. In this context, these authors suggest a program of continuous monitoring of test sites to provide species data, but warn that standardisation in monitoring of bioengineering effectiveness will be required (*op. cit*.). Zedler (2000) also highlights a 'considerable need for more habitat specific advice' when considering the limitations of current wetland restoration models, noting that different wetland types require different models.

Limited research on soil geochemistry

As the study of geochemical changes within re-aligned marsh soils is a fairly new area of study, there is a lack of case studies particularly at the landscape scale. It is also not well understood how old soil and vegetation (from pre-alignment) may influence saltmarsh succession at managed realignment sites over long time periods. Questions remain as to whether or not to retain the old vegetation from such a site. Indeed, French (2006) identifies both benefits and challenges associated with keeping such vegetation in situ. Whilst he highlights the role of such vegetation in providing protection of the land from erosion during the early inundation stages, he also suggests some serious and potentially long-lasting negative impacts at later stages caused by changes in soil biogeochemistry (*op. cit*.). This is demonstrated by referring to Macleod *et al.*'s (1999) Orplands managed re-alignment case study. A later study by Spencer *et al*. (2008) found lower

biodiversity at this site than at other re-alignment sites around the UK. They attributed this to poor drainage caused by relic agricultural soil left *in situ* prior to inundation and suggested the creation of an aquiclude under such conditions prevented tidal flushing of the marsh soils (*op. cit*.). This process clearly has implications for the achievement of biodiversity goals for managed re-alignment sites under the Habitats Directive and also reduces the ability of saltmarshes to provide other key ecosystem services, including pollutant reduction and carbon sink roles.

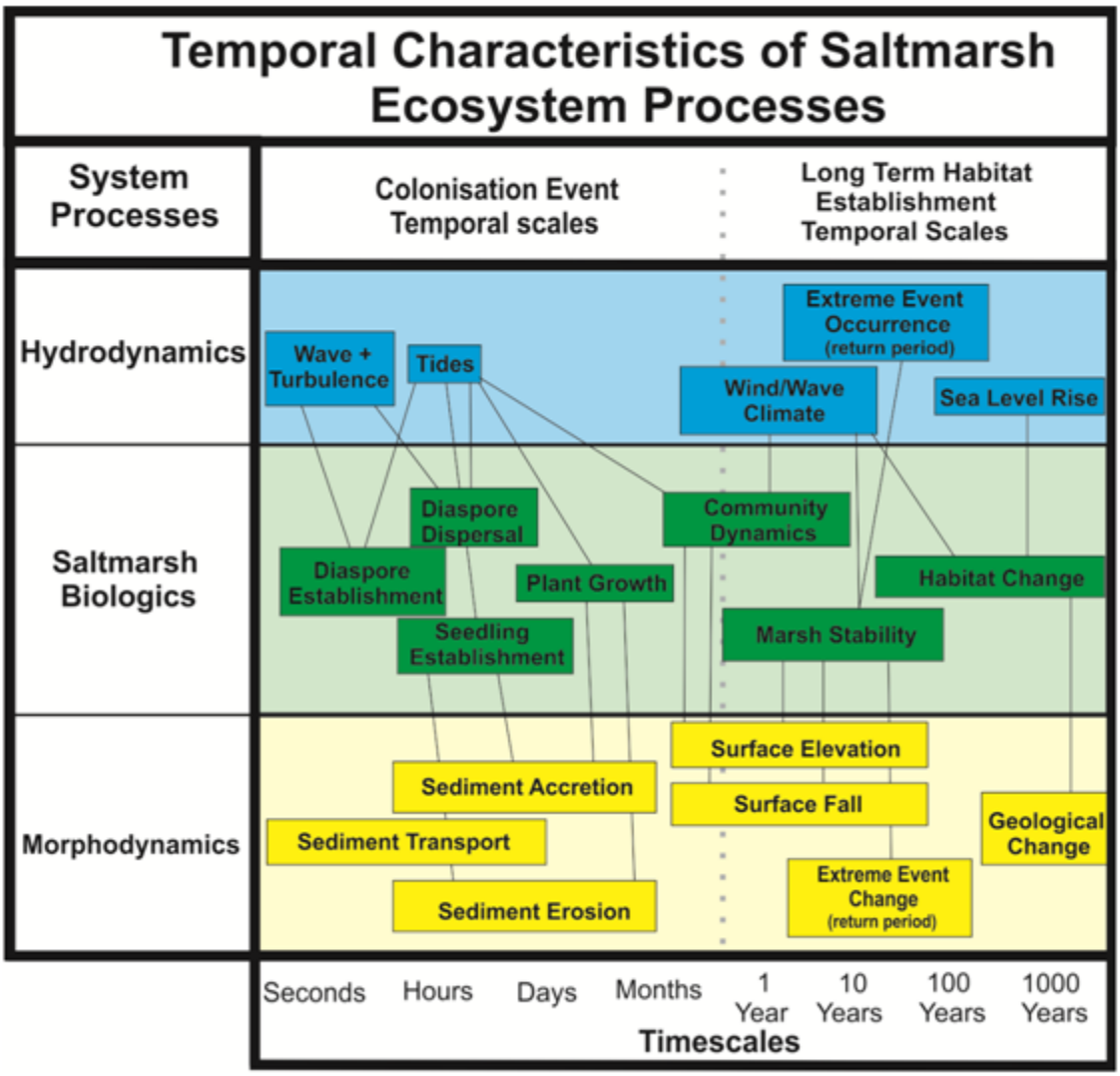

Figure 5 **The complexity of the saltmarsh ecosystem**

Modelling issues

References to modelling of saltmarsh processes were present throughout the literature. However, the literature generally calls for better and more data-informed models to better understand and predict outcomes of saltmarsh managed re-alignment. Although models on estuarine processes have been produced, they generally focus on hydrodynamic processes without modelling the interaction between these physical forces and the ecology of the system, which is often complex (Figure 5). Existing models have significant limitations as illustrated by the numerical model built by van de Koppel *et al*. (2005) to investigate processes of vegetation collapse in saltmarshes. This pioneering model used generalised saltmarsh data, and therefore has limited usefulness, having not included all relevant saltmarsh processes and vegetation species. In a similar vein, Mudd *et al*. (2009) suggest further data requirements and understanding of key processes to

enhance their analytical and numerical models to illustrate the relationship between sedimentation, sea-level rise, and biomass production of saltmarshes. They suggest further insights are required related to the relationship between biomass and depth below Mean Higher High Water (MHHW), particularly the relationships between different vegetation species, biomass, growth and root depth below MHHW (*op. cit*). Finally, it should be noted that knowledge gaps associated with the modelling of saltmarsh processes are present at both micro (e.g. specific species) and macro data (e.g. saltmarsh communities) scales.

Gedan (2009) identified the need for further research to understand the multiple driving forces behind saltmarsh degradation and highlighted the issue that multiple stressors are rarely researched in saltmarshes, resulting in inadequate modelling of the interconnectness of saltmarsh systems. Granek *et al*. (2009) also highlight how science often neglects to quantify specific 'threshold values' in the saltmarsh ecosystem, associated with sudden changes in the delivery of particular ecosystem services; clearly, potentially highly important to decision makers as well as being vital to saltmarsh environmental modelling.

Poor understanding of science communication

The literature review recognised issues related to the limited understanding of science communication within academic research related to saltmarshes and the possible impact of this on public engagement with managed realignment schemes.

Given little research is undertaken with public engagement in mind (Willems 2003), poor communication of science is commonplace. Indeed, there are some suggestions that sometimes official bodies, through misunderstanding public views and reasoning, may even exacerbate issues associated with science communication (Johnson and Chess, 2006). As a result these authors also suggest there are issues associated with the public adopting ill-informed and emotive rather than science-based reasoning. In the coastal management field, inadequate public and stakeholder understanding of the science behind saltmarsh habitat management may have negative implications particularly for managed re-alignment. Indeed, Dalton (2006) suggests poor understanding of saltmarsh ecosystem processes and associated concepts can reduce public engagement levels in coastal decision making. In the case of the Blyth Estuary Plan (2008) it is suggested that such poor understanding lead to mistrust amongst the public and the eventual rejection of the managed re-alignment plans. Other papers by Curado *et al.* (2014) Hoehn (2003) and Myatt (2002; 2003) all highlight issues associated with the limited public understanding of wetland and saltmarsh environments, particularly with regards to ecosystem services. Hoehn in discussing public understanding of wetlands in Michigan, highlights the disjuncture between the scientific and grey literature on wetlands, which frequently refers to the ability of these systems to act as pollutant sinks, and poor public knowledge on such matters.

However, Smith (2013) suggests that good relationships between the public and the management communities are also required for the public to be willing to actively participate in management discussions, engage with the relevant science and therefore to eventually accept realignment schemes. The literature review, however, pointed to little research on how science and management communities perceive public opinions, and how such views may influence public engagement and acceptance of coastal management decisions.

Weak understanding of public perception aspects of managed realignment

Within the social science literature there are mixed views about public attitudes towards and perceptions of managed realignment projects. Over a decade ago, Myatt (2002; 2003) argued that although coastal managers and scientists view managed re-alignment and the establishment of associated saltmarsh as a suitable coastal defence option, the public appeared less convinced. Defra and the Environment Agency at about the same time (2002) expressed concern over a lack of public support which they regarded as a major constraint to progressing managed re-alignment projects. However, some recent evidence suggests attitudes towards restored saltmarsh and wetland habitat may gradually be becoming more positive (Waddington,

2016). A study by Curado *et al.* (2014) found that, while the public generally had a low level understanding of saltmarsh habitats and their ecosystem functions, the majority of respondents viewed the saltmarshes as beneficial. This recognition of local environmental benefit through restorative techniques has also been noted in river restoration research (Junker and Buchecker 2008).

Dalton (2006) has suggested that an individual's perception of an environment is likely to be formed from not just their knowledge of an environment, but also from their direct experiences. It has also been found in other studies that interaction through conservation activities generates strong positive influences on willingness to pay to conserve habitat values (Yao *et al.* 2014). Current research on saltmarsh and wetland environments focuses on studies of public knowledge of the environment rather than people's views, opinions and feelings. This is a major oversight, posing potential limitations on our understanding of the implications of public values on engagement with and acceptance of relevant coastal management processes. Indeed, McFadden and Green (2007) have argued that coastal management should encompass an understanding of both the biophysical and social contexts if such decisions are to generate benefits to the coastal system.

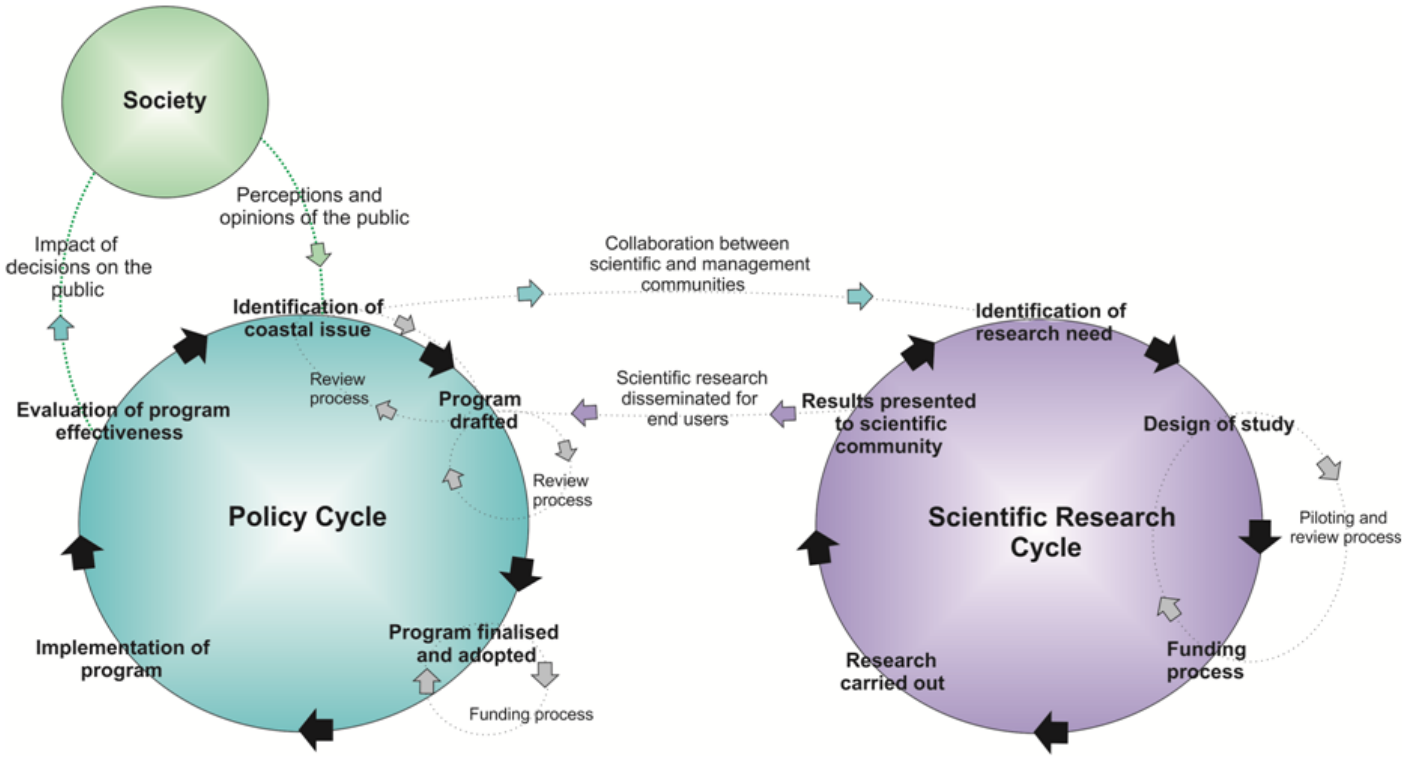

Figure 6 **Linkages between policy and scientific research cycles** (*Waddington, original*)

Conclusions and future research needs

The literature review has provided a useful overview of research relevant to managed alignment, having identified trends in research as well as key gaps and limitations in our understanding of saltmarsh processes and management.

A wide range of relevant papers were reviewed from across the natural science, bioengineering and social science literature. These addressed a wide range of themes from ecological aspects of saltmarsh

development through to aspects relating to the coastal protection service provided by these habitats. It was revealed that the academic and geographical background of the literature had some effect on topic content, particularly acknowledgment of science-policy relationships.

The findings suggest a few limitations of current research. These include issues associated with limited understanding and research on saltmarsh natural processes, to problems associated with over-generalised and over-simplistic models, to other issues associated with relatively weak understanding of science-policy interactions and particularly the influence of public perception on engagement with and acceptance of managed realignment. To improve science-policy interlinkages, the authors suggest that better engagement mechanisms are needed to allow climate and coastal change research to transfer from science to policy and management.

The following recommendations are suggested to address the key issues identified in this study:

- **Standardise methods and terminology**
    - Some of these inconsistencies reflect the relatively young, immature nature of the science associated with managed realignment. It is envisaged that with the increasing availability of fast and accurate field data collection technology (such as handheld GPS devices and LiDAR equipped drones), the rapid adoption of standardised saltmarsh data collection methods will take place over the next decade.

- **Invest into research to improve understanding of ecological and soil geochemical processes**
    - Further research into species impacts on saltmarsh behaviour is required to inform ongoing academic debate on to how effective saltmarshes are as coastal defences. Such data would also help build more effective models of saltmarsh behaviour.
    - As part of this research, it is suggested that the number and length of field case studies is increased
    - To improve understanding of the influence of subsurface water flows and sediment on above-ground saltmarsh vegetation processes, further studies into soil geochemistry associated with managed realignment schemes are required. Such research could provide boundary conditions for successful marsh establishment by emphasising correct soil and sediment management for managed re-alignment sites.

- **Develop landscape scale biomorphic and more locally sensitive models**
    - As saltmarsh functioning depends on a wide range of environmental factors across multiple timescales, the building of landscape scale biomorphic models would be useful for identifying risk factors, as suggested by Murray *et al*. (2008). The importance of having locally sensitive models supporting environmental management decisions has also been highlighted by the Tide Tidal River Development (2013).

- **Improve understanding of science communication**
    - In particular research is needed to inform communication of managed re-alignment schemes between science-centric communities (academia) and policy-centric communities (managed re-alignment practitioners and coastal policy makers). Further research, based on informal action research of specific case studies, is required to inform the development of a new communication framework between these communities.
    - Researching the challenges associated with the time frames of coastal research and policy cycle development will be necessary (Figure 6). This should enable improved incorporation of science within the wider coastal decision making processes not only managed re-alignment.

- **Improve understanding of the public perception and societal contexts of managed re-alignment.**
    - Whilst the social perspective of managed re-alignment is likely to change over time, it is an area greatly in need of further research, as few studies currently exist on this topic (Ledoux 2005). Given perceptions may differ between locations and types of saltmarshes, such further research is strongly recommended.
    - As noted above, further research into understanding the current public attitudes and perceptions towards managed re-alignment will be central in developing methods to involve members of the public in the projects and fostering trust in the schemes.

References

ABP Marine Environmental Research Ltd. 2015. *The costs of undertaking managed realignment schemes in the UK.* Briefing Note.

Barbier, E., Hacker, S., Kennedy, C., Koch, E., Stier, A. & Silliman, B., 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81 (2), 169-193

Borsjea, B.W. Bregje K. van Wesenbeeck, Frank Dekker, Peter Paalvast, Tjeerd J. Bouma, Marieke M. van Katwijk, Mindert B. de Vries. How ecological engineering can serve in coastal protection. *Ecological Engineering* 37 (2011) 113–122.

Burd, F. 1989. *The saltmarsh survey of Great Britain: an inventory of British saltmarshes*. Nature Conservatory Council, Research and Survey in Nature Conservation no. 42. Peterborough: Nature Conservancy Council.

Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N. and Upham, P., 2015. International trends in public perceptions of climate change over the past quarter century. *Wiley Interdisciplinary Reviews: Climate Change*, *6*(1), pp.35-61.

Curado, G. Manzano-Arrondo, V. Figueroa, E. & Castillo, J.M. 2014. Public Perceptions and Uses of Natural and Restored Salt Marshes*. Landscape Research* 39, pp.668-679.

Dalton, T.M. 2006. Exploring Participants' Views of Participatory Coastal and Marine Resource Management Processes. *Coastal Management* 34, pp. 451-367.

Dilling, L. Lemos, M.C. 2011. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change* 21, pp. 680–689.

French, P. W., 2006. Managed realignment—the developing story of a comparatively new approach to soft engineering. *Estuarine, Coastal and Shelf Science* 67: 409–423.

French, P.W. 1997. *Coastal and estuarine management (Routledge environmental management series). Routledge*. Abington, Oxon.

Garbutt, A., 2013. *Ecosystem goods and services provided by salt marshes*. Presentation prepared for: Wadden Sea Trilateral Conference, Wilhelmshaven, 29th August 2013. NERC Centre for Ecology & Hydrology, UK.

Gedan, K.B. Kirwan, M.L. Wolanski, E. Barbier, E.B. Silliman, B.R. 2011. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climatic Change* 106, pp. 7–29.

Granek, E.F., Polasky, S., Kappel, C.V., Reed, D.J., Stoms, D.M., Koch, E.W., Kennedy, C.J., Cramer, L.A., Hacker, S.D., Barbier, E.B. and Aswani, S., 2010. Ecosystem services as a common language for coastal ecosystem - based management. *Conservation Biology*, *24*(1), pp.207-216.

Hoehn, J.P., Lupi, F. and Kaplowitz, M.D., 2003. Untying a Lancastrian bundle: valuing ecosystems and ecosystem services for wetland mitigation. *Journal of Environmental Management*, *68*(3), pp.263-272.

Johnson, B.B. and Chess, C., 2006. From the inside out: Environmental Agency views about communications with the public. *Risk analysis*, *26*(5), pp.1395-1407.

Jones, L., Angus, S., Cooper, A., Doody, P., Everard, M., Garbutt, A., Gilchrist, P., Hansom, J., Nicholls, R.J., Pye, K. and Ravenscroft, N., 2011. *Coastal margins*. JNCC report.

Junker, B. Buchecker, M. 2008. Aesthetic preferences versus ecological objectives in river restorations. *Landscape and Urban Planning* 85, pp. 141–154.

Kentula, M.E. 2000. Perspectives on setting success criteria for wetland restoration. *Ecological Engineering* 15, pp. 199–209.

Ledoux, L. Cornell, S. O'Riordan, T. Harvey, R. Banyard, L. 2005. Towards sustainable flood and coastal management: identifying drivers of, and obstacles to, managed re-alignment. *Land Use Policy* 22, pp. 129-144.

Luisetti, T., Turner, K. & Bateman, I., 2008. An ecosystem services approach to assess managed realignment coastal policy in England. CSERGE Working Paper ECM 08-04

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

Macleod, C.L., Scrimshaw, M.D., Emmerson, R.H.C., Chang, Y.-H., Lester, J.N., 1999. Geochemical changes in metal and nutrient loading at Orplands Farm managed retreat site, Essex, UK. *Marine Pollution Bulletin* 38, 1115-1125.

McFadden, L., 2007. Governing coastal spaces: the case of disappearing science in integrated coastal zone management. *Coastal Management*, *35*(4), pp.429-443.

McFadden, L. Green, C. 2007. Defining vulnerability: Conflicts, complexities and implications for coastal zone management. *Journal of Coastal Research* S150, pp. 120-124.

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

Mudd, S.M., Howell, S.M. and Morris, J.T., 2009. Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation. *Estuarine, Coastal and Shelf Science*, *82*(3), pp.377-389.

Murray, A.B. Knaapen, M. A.F. Tal, M. Kirwan, M.L. 2008. Biomorphodynamics: Physical-biological feedbacks that shape landscapes. *Water Resources Research*, 44.

Myatt-Bell, L.B., Scrimshaw, M.D., Lester, J.N. and Potts, J.S., 2002. Public perception of managed realignment: Brancaster West Marsh, North Norfolk, UK. *Marine Policy*, *26*(1), pp.45-57.

Myatt, L.B., Scrimshaw, M.D. and Lester, J.N., 2003. Public perceptions and attitudes towards an established managed realignment scheme: Orplands, Essex, UK. *Journal of Environmental Management*, *68*(2), pp.173-181.

Nicholls, R., Pye, K., Ravenscroft, N., Rees, S., Rhind, P. & Whitehouse, A., 2011. *Reports from the UK National Ecosystem Assessment. Technical report*. Chapter 11: Coastal Margins.

Nursey-Bray, M.J. Vince, J. Scott, M. Haward, M. O'Toole, K. Smith, T. Harvey, N. Clarke, B. 2014. Science into policy? Discourse, coastal management and knowledge. *Environmental Science & Policy 38,* pp. 107–119.

Petes, L.E. Howard, J.F. Helmuth, B.S. Fly, E.K. 2014. Science integration into US climate and ocean policy. *Nature Climate Change* 4, pp. 671-677.

Pethick, J., 2002. Estuarine and tidal wetland restoration in the United Kingdom: policy versus practice. *Restoration Ecology* 10 pp. 431–437.

Ramsar Convention, Secretariat, 2013. *The Ramsar Convention Manual: a guide to the Convention on Wetlands* (Ramsar, Iran, 1971), 6th ed. Ramsar Convention Secretariat, Gland, Switzerland.

Sarewitz, D. Pielke, R.A. 2007. The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy* 10, pp. 5-16.

Silvestri, S. Defina, A. Marani, M. 2005. Tidal regime, salinity and salt marsh plant zonation. *Estuarine, Coastal and Shelf Science* 62, pp. 119–130.

Simenstad, C. Reed, D. Ford, M. 2006. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. *Ecological Engineering* 26, pp. 27–39.

Smith, J.S., 2013. *Improving participation of the public in coastal flood management: A case study from the Suffolk coast, UK* (Doctoral dissertation, University of East Anglia).

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

Tang, Z. Brody, S.D. Quinn, C. Chang, L. Wei, T. 2010. Moving from agenda to action: evaluating local climate change action plans. *Journal of Environmental Planning and Management* 53, pp. 41-62

Tang, Z., Dai, Z., Fu, X. and Li, X., 2013. Content analysis for the US coastal states' climate action plans in managing the risks of extreme climate events and disasters. *Ocean & Coastal management*, *80*, pp.46-54.

The Royal Society. 2006. *Science communication: survey of factors affecting science communication by scientists and engineer*s. Report prepared by the Research Councils of the UK and The Wellcome Trust. The Royal Society, London.

Tide Tidal River Development. 2013. WP5 Measures. *Interestuarine comparison: Managed Realignment Measures*. Antwerp Port Authority (APA). European Regional Development Fund and The Interreg IVB North Sea Region Programme.

Tribbia, J. Moser, S.C. 2008. More than information: what coastal mangers need to plan for climate change. *Environmental Science and Policy* 11, pp. 315-328.

van de Koppel, J., van der Wal, D., Bakker, J.P. and Herman, P.M., 2005. Self - organization and vegetation collapse in salt marsh ecosystems. *The American Naturalist*, *165*(1), pp.E1-E12.

Waddington, E (2016) *Public use and perception of managed realignment sites on the Severn Estuary – 2016, A pilot study into the public use and perception of the Steart managed realignment site*, A report produced as part of the Marine Renewable Energy Exchange Programmes, 14pp.

Willems, J. 2003. Bringing down the barriers: public communication should be part of common scientific practice, *Nature*, 422, 470.

Yao, R.T. Scarpa, R. 2014. Turner, J.A. Barnard, T.D. Rose, J.M. Palma, J.H.N. Harrison, D.R. 2014. Valuing biodiversity enhancement in New Zealand's planted forests: Socioeconomic and spatial determinants of willingness-to-pay. *Ecological Economics* 98, pp. 90-101.

Zedler, J.B., 2000. Progress in wetland restoration ecology. *Trends in Ecology & Evolution*, *15*(10), pp.402-407.