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Lessons in applying adaptive management on a dynamic coastline: a case study at the inlet to Pagham Harbour, UK[1]

C.R. Scott, E. Harris, and I.H. Townend

Abstract: Many of the world's coastlines are vulnerable to erosion and at risk from tidal flooding. Addressing and managing these risks presents major challenges especially when seeking to sustainably balance the requirements for coastal protection with other economic, environmental, and societal objectives. The nature and scale of these challenges varies greatly from site to site and can often be magnified on dynamic shorelines that are subject to a high degree of physical and ecological change. Applying an ongoing process of adaptive management is widely agreed to be a key mechanism for dealing with such dynamic conditions and issues of uncertainty. However, under this process it can be difficult for different stakeholders to reach a consensus about the most suitable intervention actions. In part, this can arise because there is an incomplete understanding about past, present, and, especially, future environmental processes. It can also occur due to differences in the perceptions and priorities of the relevant stakeholders. This paper reviews some of these complexities using, as a case study, recent developments of a shingle spit and tidal inlet at Pagham Harbour, on the south coast of the UK. This example provides lessons in the application of adaptive management and working with nature concepts in a particularly complex coastal setting. This paper considers these lessons in the context of the site's history, the legal and policy framework, and established understanding about the natural environment.

Key words: adaptive management, working with nature, tidal inlet, shingle spit, stakeholder engagement.

Introduction

The risk of tidal flooding is a major issue for many coastal communities around the world. This risk is only expected to increase in response to rising sea levels and changing climatic conditions. At the same time, the number of people living in low-lying vulnerable coastal areas is rising (Neumann et al. 2015). Therefore, the damage from future floods and the risks of flooding occurring are both expected to increase in tandem. This increases the need to anticipate these events and identify the most appropriate management strategies.

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The process of identifying appropriate strategies, and general perspectives for coastal management, have also been changing over time. During the early 20th century, building sea walls was viewed as the sole solution for hinterland protection but by the 1960s the potential value of soft engineering methods was increasingly being recognised (Nicholls et al. 2013). Over the last few decades there have been increasing ambitions to implement more sustainable shoreline management actions and erosion risk measures. These are measures that do not focus on single coastal protection objectives but aim to achieve a range of environmental, societal, and economic gains. In the context of such ambitions, there is an increasing recognition that coastal habitats and natural systems can be central to the development of solutions and that proposals that work with nature can achieve multiple gains or win-win opportunities (de Vriend et al. 2014; Environment Agency 2017*a*).

The globally recognised mechanism for achieving sustainable actions involves Integrated Coastal Zone Management (ICZM). This process, developed after the 1992 UN Rio Conference (Cicin-Sain et al. 1995), seeks to balance the needs of the many coastal users by joining up "the different policies which have an effect on the coast as well as bringing together stakeholders from local to national levels to inform, support, and implement these policies" (Atkins 2004). In Europe, ICZM was trialled and advocated during the 1990s (Townend 1994; European Commission 1999). Although not introduced into legislation, the European Union (EU) directed Member States to adopt eight ICZM principles for good coastal zone management (European Commission 2002). These principles involved having broad and long-term perspectives; applying adaptive management, including local specificity; working with natural processes; involving all parties; having support and involvement from relevant administrative bodies; and using a combination of instruments to facilitate planning and management coherence. In recent years, the European Commission has further progressed a combined initiative that links Integrated Coastal Management (ICM) and Maritime Spatial Planning (MSP) with a view to promoting the "sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources" (European Union 2014). This was adopted as a directive in 2014 and is to be implemented across European Member states by 2021.

ICZM, ICM, and MSP approaches set out the principles, aims, and best practices for coastal management at international, national, and regional scales. However, to then underpin such strategies and identify the most appropriate and site-specific management practices, a further sequence of increasingly localised studies is required. In many countries, a key mechanism for identifying management actions involves the preparation of shoreline management plans (SMPs). These provide an "assessment of coastal risks (principally flooding and coastal erosion) and present a long-term framework (including concrete actions) to reduce these risks to people and the coastal environment in a sustainable manner" (European Climate Adaptation Platform 2015).

In England and Wales, non-statutory SMPs have been produced over the last two decades. These provide a high-level evaluation of coastal risks and indicate how the coastline should be managed for the next 100 years. As an outcome of these SMPs, four possible strategic options are proposed for given stretches of the coast. These are the following: advance the existing defence line; hold the existing defence line; managed realignment; and no active intervention.

The regional-scale SMPs are developed over lengths of coast considered to be discrete sediment cells (Brampton 1993). There is then a nested sub-set of strategies and management action plans covering individual estuaries or discrete lengths of coast. These provide necessary detail on the localised morphological conditions, societal needs, and proposed mechanisms for implementing the SMP strategy. In recent years, "adaptive management" has been proposed as a fifth type of management option (in addition to the four set out in

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the SMPs). This was adopted on the south coast of England, under the Pagham to East Head Coastal Defence Strategy, as a way of "managing complex coastal areas by monitoring changes and acting on them in a planned but flexible way, increasing our understanding over time" (Environment Agency 2009).

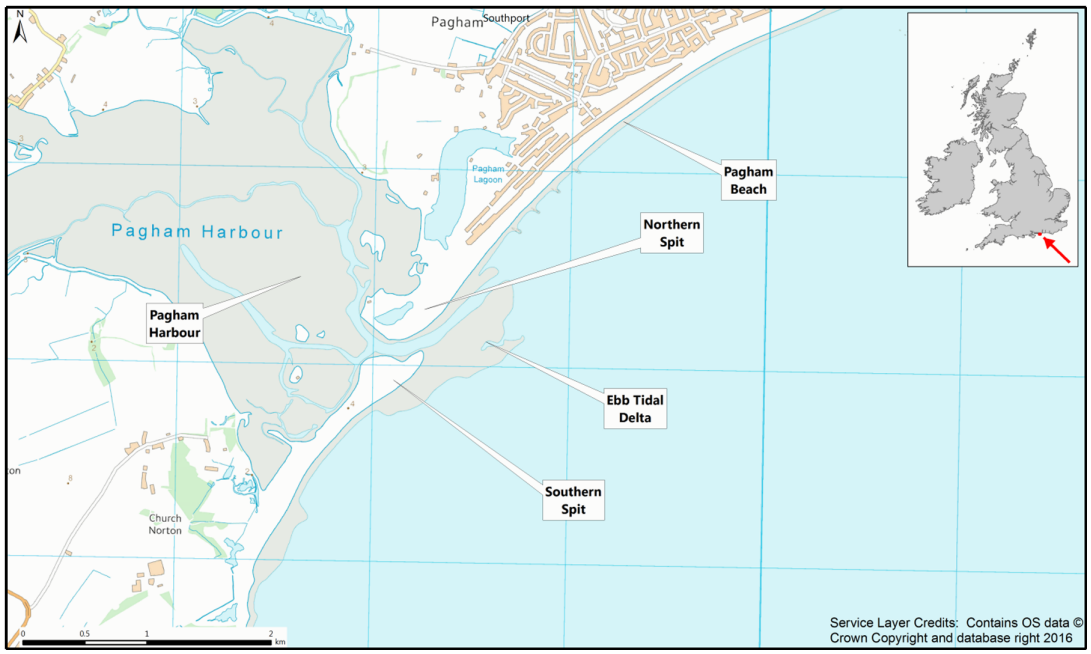
Adaptive management emerged as a mechanism for natural resource management in the 1970s. It is an evolving process of learning and adaptation that fundamentally anticipates the need for ongoing environmental and management changes over time (Williams and Brown 2014). It is a central tenet of the ICZM/ICM approach and is increasingly recognised, internationally, as a solution for dealing with uncertainty and complexity across all environments and not just the coast. It is seen as being "joined at the hips with ecosystem management" (Craig and Ruhl 2010) and fundamental to delivering an ecosystem approach for the integrated, sustainable, and equitable management of land, water, and living resources (Secretariat of the Convention on Biological Diversity 2004). "Adaptive management on the basis of the ecosystem approach" is similarly embedded in the EU's recent Marine Strategy Framework Directive (European Commission 2012). It is also a recognised mechanism for pursuing developments and activities in areas of conservation value while having certainty that important ecological features will not be adversely affected (European Commission 2011; CIEEM 2018). The concepts of sustainable and adaptive management are also closely aligned with the principles of working with nature because there is often an inherent expectation that the coastal environment should be allowed to continue to develop as naturally as possible.

Although there is an increasing desire to adopt integrated coastal management, apply adaptive management principles, and work with nature, it can be difficult for interested parties to reach a consensus about the best intervention actions along a given section of coastline. Each new location presents its own issues and challenges and there is rarely an off-the-shelf sustainable solution that coastal managers can draw upon. Instead, the available options will vary with each stretch of the coast. Also, perceptions and priorities may change over time for a given section of shoreline due to the variability of the morphological conditions or lessons from monitoring. There can also be differences in the views of different stakeholders leading to tensions between interested parties.

One of the main obstacles to agreeing to intervention approaches is uncertainty of outcome and this can be particularly evident in dynamic and ever-changing coastlines due to limitations in understanding about coastal behaviour. Even though adaptive management is designed to address uncertainty and be flexible, its implementation can be impeded by inflexible legal frameworks (Craig and Ruhl 2010; Frohlich et al. 2018). Uncertainty can also present difficulties with securing funding or accepting elements of risk across all stakeholders in relation to their own interests. These challenges are often magnified when seeking to work with nature because of the need to rely on natural processes rather than building higher seawalls or other measures that achieve more knowable or fixed outcomes, at least in the short term.

Previous reviews of adaptive management (Creed et al. 2018; Frohlich et al. 2018) have called for increasing empirical evidence to help understand how to better apply this policy. This paper therefore reviews an illustrative case study from Pagham Harbour on the south coast of the UK (Fig. 1). The environment at the mouth of Pagham Harbour is particularly dynamic. It is a tidal inlet with a mobile double spit and a long history of inlet migration, spit development, and anthropogenic interventions. For these reasons an adaptive management policy is in place. Change has always occurred at this site but over the 15 years from 2003 to 2018 there was a period of substantial morphological adjustment and rapid growth of the southern spit (which prograded in a north-easterly direction with the prevailing littoral drift). As this major change occurred, over a comparatively short timeframe, many

Fig. 1. Location of Pagham Harbour, UK, and key features (produced with ArcGIS 10.6 and using Ordnance Survey data base map © Crown copyright and database right 2016 (Ordnance Survey Data 2016)).



efforts were made to identify the best intervention actions in the context of the adaptive management policy and tensions arose between stakeholders about what was required. This experience provides useful lessons for the future management of this site and other locations in dynamic situations.

To review this case example, we provide a brief history of the inlet's evolution, followed by a summary of the approaches adopted to deal with the rapid growth of the spit in the context of the planning and decision-making framework. We then consider the lessons learned about adaptive management practices, as informed by a range of monitoring studies and review exercises.

Brief history of the Pagham Harbour inlet

Site characteristics

The Pagham Harbour entrance is characterised by a coarse-sediment double spit system. Typically, it has shingle spits on both its north-east and south-west sides. Littoral drift occurs in a net north-easterly direction as it passes across, and is interrupted by, the harbour inlet. This drift is a key factor influencing inlet behaviour and historically has often led to a growth of the southern spit.

The inlet is ebb-dominant and fronted by a mixed shingle and sand ebb delta feature. The coastal frontage is exposed to wave action between the south-east and south-west directions due to the south-west to north-east orientation of the coastline. The Selsey Bill headland to the south offers some sheltering, but this coastline is still subjected to locally generated storm waves and swells from the Atlantic. Data from the nearest offshore wave buoy (managed by the Channel Coastal Observatory, www.channelcoast.org) gives the maximum significant wave height as 5 m, with a mean direction just to the west of due south.

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Tides in the area are semi-diurnal, with spring and neap tidal ranges of 4.9 and 2.4 m, respectively (levels provided by UK Hydrographic Office). The channels within the harbour are small but there is an extensive area of intertidal flats and saltmarsh (ratio of the area of flat to channel is about 18). This gives a tidal prism that varies between 2.8 and 0.6 Mm^3 for spring and neap tides, respectively (ABPmer 2015).

To the south-west of Pagham Harbour, there is a divergence in the littoral drift feed from offshore, marking a littoral sediment cell boundary formed by the protruding headland of Selsey Bill (Bray et al. 1995). To the east of Selsey Bill there is then a net littoral drift along the shoreline to the north and then east. The sediment that supplies the harbour entrance is therefore predominantly derived from beaches and mobile nearshore shingle banks in the up-drift zone to the south-west of the harbour. Analysis of the wave climate suggests that the annual drift potential varies between 12 000 and 40 000 m^3/year and this is consistent with observations from sediment bodies moving along the shore (ABPmer 2015). Similar values of 10 000–40 000 m^3/year (and 50 000 m^3/year when the spit was once closed) were estimated by Barcock and Collins (1991).

Numerous studies have reviewed the history of the inlet (Robinson and Williams 1983; Bray et al. 1995; ADC 2009; ABPmer 2015; Dornbusch 2018) and there is now a well-documented record of landscape changes and previous anthropogenic interventions at the harbour mouth from a variety of sources stretching back over 400 years. These summaries of the geology and landscape are supported by more in-depth studies of the prevailing processes and sediment transport pathways (Barcock and Collins 1991; Bray et al. 1995) and responses of sediments within the harbour (Cundy et al. 2002).

Over recent times, aerial photographs were taken annually until a more detailed topographic monitoring programme was initiated in 2003 (www.channelcoast.org). These studies collectively provide a valuable description of historical and contemporary spit and inlet morphologies, allowing the landscape of the harbour entrance to be schematically mapped on various occasions from 1587 to the present day. Figure 2 describes observed spit and inlet morphologies between 1587 and 1999 and Fig. 3 shows recent morphologies between 2003 and 2018.

Broad-scale spit and inlet changes from 1587 to 2003

The earliest reliable map (from 1587) identifies two spits across the harbour mouth. Subsequent charts in 1672, 1724, 1785, and 1874 all show an elongated southern spit extending in a north-east direction. Care needs to be taken with any assumption of net trends from these intermittent records but, on their own, they suggest the southern spit grew steadily in the 1700s and then more rapidly in the 1800s. It was over 2 km long by 1874 and as it grew, the northern spit became much reduced and the Pagham foreshore to the north-east of the harbour entrance was being eroded in the late 1800s.

In 1876, the inlet was situated on the north-eastern side of the harbour before being deliberately closed to prevent further erosion of the Pagham shore. During the next 34 years of closure (1876–1910), Pagham Beach extended seawards as ebb delta deposits were eroded and moved onshore. Then, in 1910, the barrier beach ridge was breached by a storm at the south-western end of the harbour (Cundy et al. 2002).

Over the next few decades, the position and size of the inlet changed in response to a combination of anthropogenic and natural factors. Pagham Beach continued to grow and, in the 1920s, properties were first constructed on the beach, initially as beach huts and later as permanent housing. Between 1910 and 1934, the southern spit again prograded in a north-easterly direction by some 700–800 m towards Pagham Beach and deflected the tidal inlet in that direction. In 1937, attempts were made to adjust and stabilise the inlet,

Fig. 2. Charts showing spit and inlet morphological variations between 1587 and 1999 (produced by ABPmer Ltd. with ArcGIS 10.6 using maps (for 1587–1978) presented in Robinson and Williams (1983) and Barcock and Collins (1991) and using monitoring data (for 1999) collated by the Channel Coastal Observatory (www.channelcoast.org) and made available under the National Regional Coastal Monitoring Programmes).

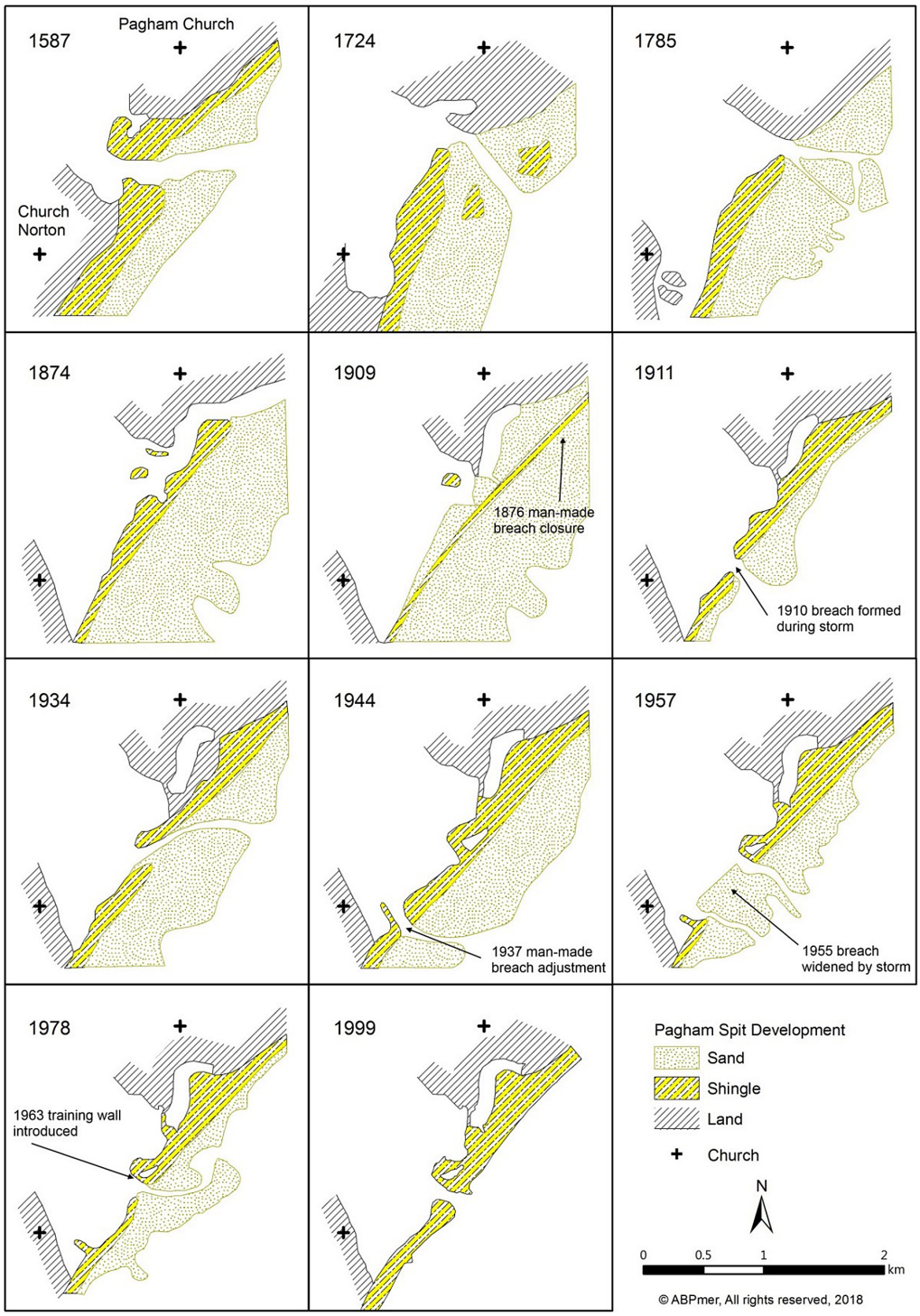

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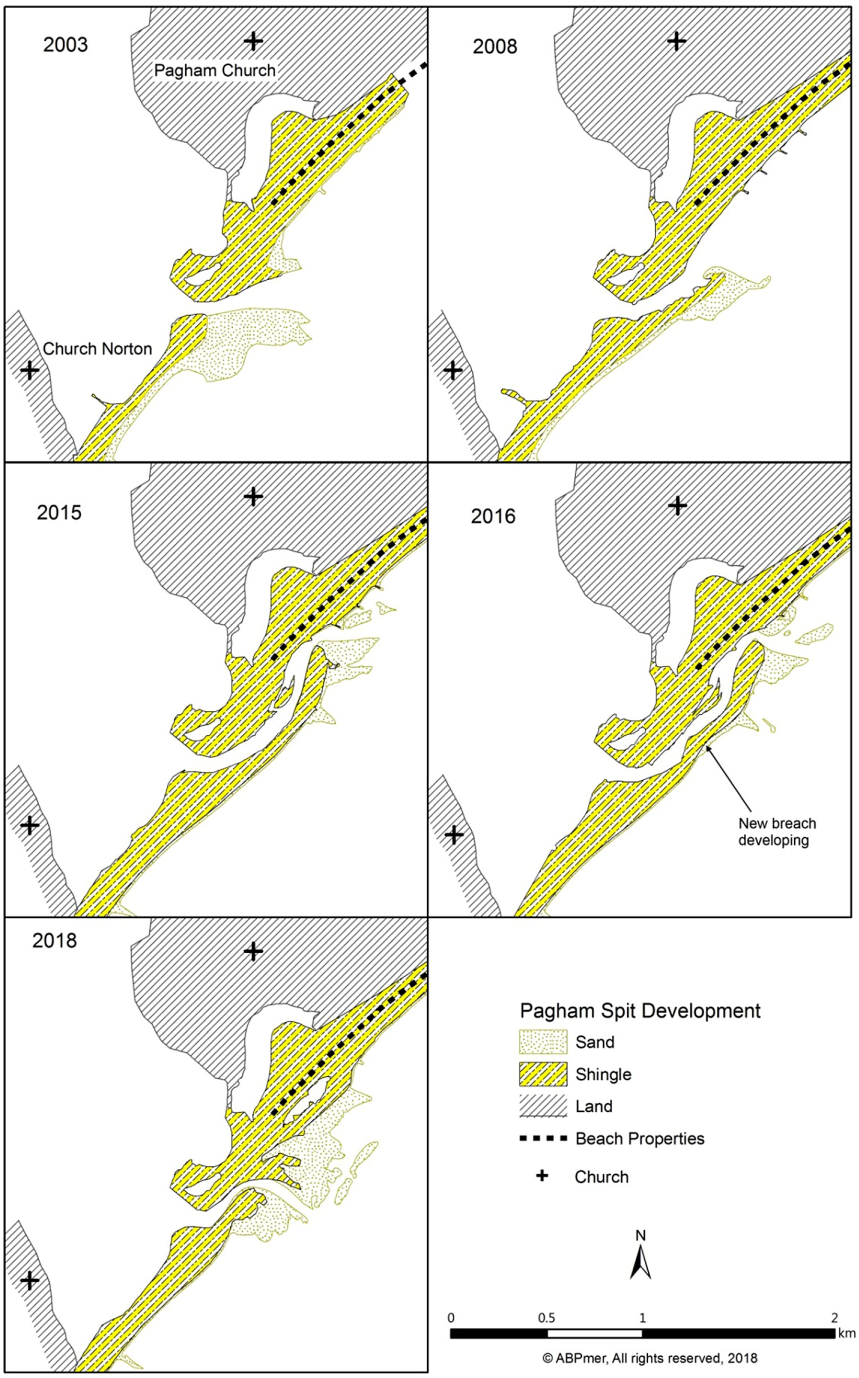
Fig. 3. Charts showing spit and inlet morphological variations between 2003 and 2018 (produced by ABPmer Ltd. with ArcGIS 10.6 using monitoring data collated by the Channel Coastal Observatory (www.channelcoast.org) and made available under the National Regional Coastal Monitoring Programmes). Sources: Channel Coastal Observatory monitoring data.



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including the creation of a new entrance near to where the 1910 breach occurred and then introducing concrete and sheet piles to try and stabilise it in 1944.

There was a further storm breach in 1955 and the inlet widened and migrated 900 m to the north-east during the 1950s and 1960s. A training wall was introduced to stabilise the northern side of the entrance in 1963. This sheet-piled wall (reconstructed in the 1980s following a collapse) provided a degree of stability to the harbour entrance. It also assisted in fixing the north-eastern spit in a more seaward position than had been the case historically. In the 1950s, a groyne field was also installed on the coastline to the south of the harbour that had the effect of stifling sediment supply to the southern spit from this up-drift zone. Further groynes were installed and extended on the spit and Pagham Beach during the late 1980s and 1990s.

Towards the end of the last century this area was relatively stable with a spit maintained to the south-west and the northern spit fixed by the training wall. An ebb-tidal delta was also a consistent feature to seaward of the inlet, with channel switching and bar migration enabling sediment to bypass the inlet (Barcock and Collins 1991). During this time, the National Rivers Authority and later the Environment Agency regularly excavated shingle (around 15 000 m^3/year) from the ebb delta and used it to build up and stabilise the southern spit after storms (Bray et al. 1995; Environment Agency 2017*b*). This recycling was carried out between 1991 and 2004, and would have influenced inlet and spit behaviour. However, this artificial nourishment became unnecessary after 2004 because the southern spit had started to grow.

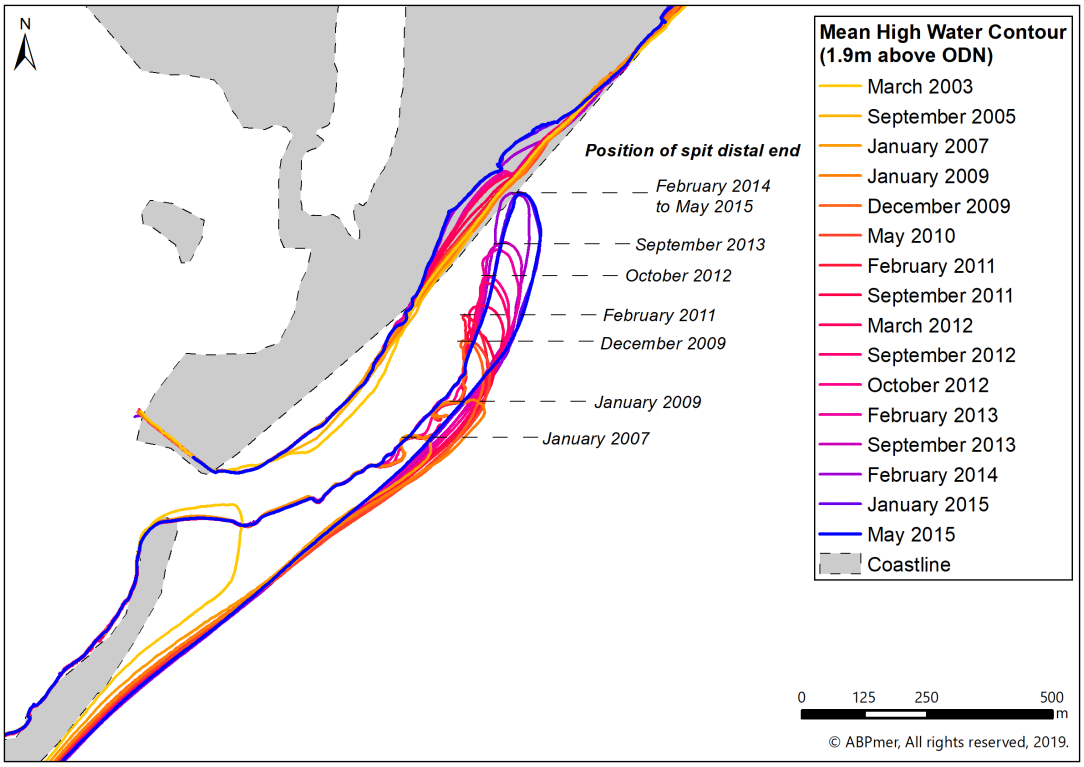
Southern spit growth and tidal channel migration from 2003 to 2015

From 2003, the southern spit began to grow and extend seawards, prograding along the coast in a north-east direction. This change was evidently influenced by an increasing sediment supply that had also rendered the Environment Agency shingle recycling activities unnecessary. The precise reasons for this change occurring at that time are not well understood but there was evidently no significant by-passing of sediment across the ebb delta and the shoreline began to mimic the elongated southern spit morphologies that had been observed in the historical records (especially in 1874). The mechanics of this southern spit's growth between 2003 and 2015 was captured through detailed monitoring work and recently reviewed by Dornbusch (2018). It generally occurred as distinct phases or pulses, each one beginning with an extension of the subtidal-platform in a north-easterly direction from the entrance. This platform filled the accommodation space and allowed the ebb delta to migrate. This was then accompanied by development of the channel behind (landward of) the spit towards the new ebb delta location. Once established, the spit then prograded quickly towards the ebb delta, extending the inlet channel and promoting further alongshore movement of the ebb delta (Scott and Townend 2017).

Three different spit and inlet morphologies from this period are included in Fig. 3, and the spit's evolution is illustrated in more detail in Fig. 4. These plots show the formation of an elongated spit morphology similar to, but seaward of, the 1874 alignment. A notable adjustment in the pattern of the spit's development also occurred from 2009 onwards when it started to prograde in a more northerly direction. This can be seen in the sequence presented in Fig. 4.

As the ebb delta and spit developed, the tidal inlet channel was diverted north-eastwards causing erosion of Pagham Beach (i.e., the northern spit). The build-up of the subtidal sediment platform on which the delta and spit are built, also locked up a substantial amount of sediment (up to around 390 000 m^3) and the limited amount of sediment bypassing the entrance also starved the supply to Pagham Beach. This northern spit erosion became particularly rapid, and presented the greatest risk to residential beach-side

Fig. 4. Evolution of the southern spit and erosion of Pagham Beach from 2003 to 2015 (produced by ABPmer Ltd. with ArcGIS 10.6 using monitoring data collated by the Channel Coastal Observatory (www.channelcoast.org) and made available under the National Regional Coastal Monitoring Programmes).



properties, towards the end of 2013 and early 2014. During that winter the spit grew rapidly towards the beach in response to a sequence of severe storms (Wadey et al. 2015).

To address the erosion at Pagham Beach, a range of management measures were pursued. During the 2009/2010 winter and then again in the 2012/2013 winter, these included local shingle recycling and the importation of shingle from offshore sources to feed and adjust the beach profile. At the end of 2013, in response to severe beach erosion, rock armouring and other emergency beach protection measures were carried out. Extra reinforcement measures were also needed following a break-through of a cross-shore groyne on the beach front.

Throughout most of 2014 and 2015, the southern spit was 1.1 km long and remained relatively stable. It was unable to prograde further in a north-east direction, or roll back, because of the emergency revetment works protecting homes on the beach. The works included a reinforced cross-shore groyne, which deflected the tidal channel seawards across the distal end of the spit and halted its progression (Fig. 5).

Southern spit breach and tidal channel change from 2016 to 2018

After two years of relative stability, and towards the end of 2015, a breach started to develop in the prograded southern spit. Initially there was over-washing of the spit for part of the tidal cycle but then the breach matured during the early months of 2016 (Fig. 6). This occurred as a comparatively rapid, and self-perpetuating, sequence of events in which shingle was washed into the channel behind the spit at high water and then carried away

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Fig. 5. Aerial view showing the shape of the southern spit in January 2014 (photograph courtesy of John Akerman).

from the breach towards the eastern end of the separating section of the spit on the ebbing tide. As the newly forming breach became larger, and a greater proportion of the harbour's tidal exchange volume passed through it, the tip of the spit started to move in a north-easterly direction into the old channel that had previously been halting its advance.

This breach formation and the north-easterly migration of the severed spit were most visibly evident between February and April 2016. Thereafter the relic part of the spit to the north-east formed an island for much of 2016 as the main tidal flow switched from the original channel to the new outlet through the breach. It then took until February 2017 for the island formed from the relic spit to roll landwards and attach to the beach. This final migration was probably stalled by the tidal channel that had formed between the spit and the revetment works and the residual flows that were occurring through it. Once that channel closed, the migrating island joined up with the northern spit (Pagham Beach) at two locations creating a small lagoon in the position of the relic channel. This process of the spit breaching and the island migrating onto Pagham Beach during 2017 and into 2018 are also shown in Fig. 6.

After the breach in early 2016, the tidal channel emerging from Pagham Harbour was shorter but with a larger meander amplitude than was the case before the breach. This more sinusoidal shape caused erosion along both the landward side of the southern spit and seaward side of the northern spit. From field observations in May 2017 there were signs of a new proto-creek forming at the end of the shorter southern spit and an expanse of low-elevation shingle in front that indicated the potential formation of a new ebb delta. By early

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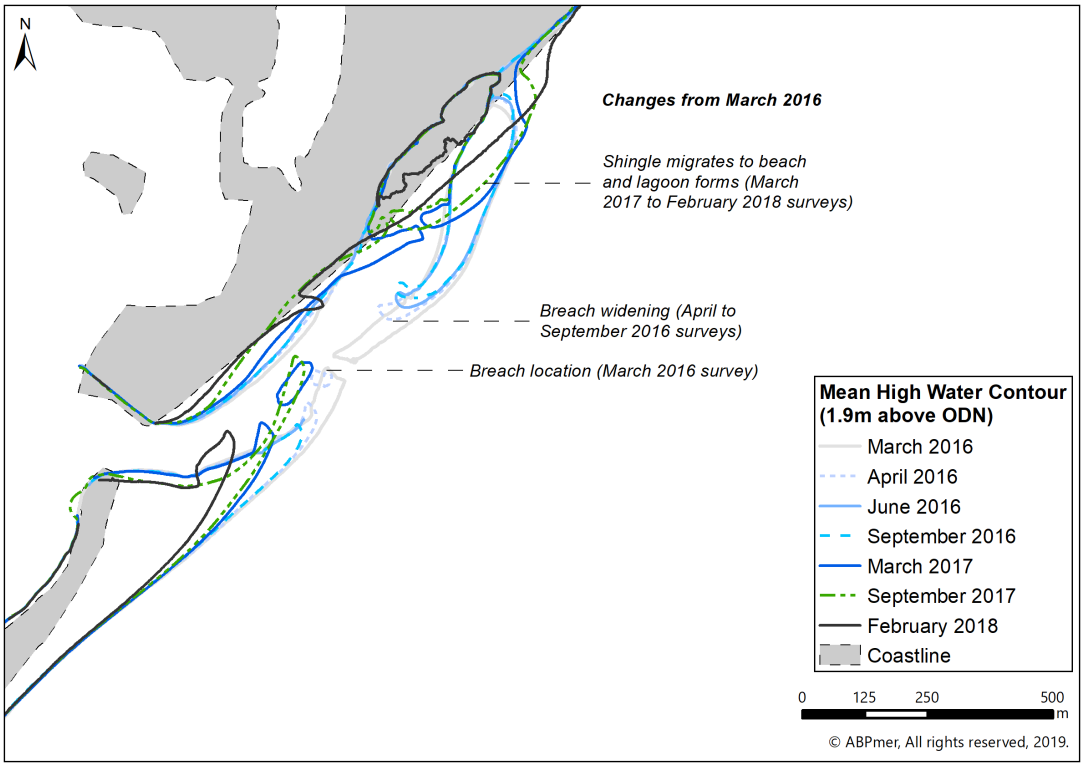
Fig. 6. Breach of southern spit and its migration onto Pagham Beach (2016–2018) (produced by ABPmer Ltd. with ArcGIS 10.6 using monitoring data collated by the Channel Coastal Observatory (www.channelcoast.org) and made available under the National Regional Coastal Monitoring Programmes).



2018 the channel had moved closer to the harbour inlet, as controlled by the training wall, creating an inlet morphology and ebb delta position similar to that observed in the early 2000s (Dornbusch 2018).

After the breach, and up to early 2018, the tidal exchange with the harbour was constrained (especially on the ebb tide) by the new inlet morphology, whereas there had been no such effect during the spit's growth phase. Post-breach there were lower high-water levels and higher low-water elevations in the harbour, with a prolonged ebb-tide drainage phase (Dornbusch 2018). These new morphologies of the channel, delta, spit, and the tidal exchange characteristics continue to change.

Identifying interventions in the context of coastal policies

In response to the substantial morphological changes that occurred in front of Pagham Harbour from 2003 onwards, and the evident risks to homes located on Pagham Beach, a lot of work was done to identify the most appropriate intervention measures. This was a complex process that included several reviews and stakeholder discussions.

This process is outlined here by first considering the international, national, and local planning and policy considerations that apply to the Pagham foreshore. Setting out this policy context then helps with understanding how coastal management interventions were considered and adopted at this location.

The second stage of this review outlines the approach that was taken to identify and implement management interventions. This process ultimately resulted in two quite

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different types of intervention being identified of which one was actively pursued. These two options, and the reasons why one was preferred over another, are then compared with this comparison providing useful lessons about how adaptive management was perceived and implemented at this location.

Planning and policy context

Coastal management polices

The management policies for Pagham Harbour and the adjacent shoreline are directed by a sequence of nested guidance documents. In 2006 the first revision of the Beachy Head to Selsey Bill SMP was produced by the cell coastal group, led by Arun District Council. This SMP identified a managed realignment policy for Pagham Harbour and a "hold the line" policy for Pagham Beach. The SMP was followed, in 2009, by the Pagham to East Head Coastal Defence Strategy, which was developed in collaboration with the Environment Agency and Chichester District Council. This strategy built on recommendations made in the SMP, with the aim of identifying a sustainable approach for flood and coastal management, over the next 100 years. It recommended "adaptive management" as the policy for Pagham frontage, including the harbour and the beach (Defra 2015). This was because a single definitive management approach was not deemed appropriate in the context of prevailing uncertainties about these two complex areas of the coast. A stakeholder group was set up to inform the implementation of this plan (the Pagham Harbour Coastal Issues Advisory Group).

Nature conservation value and sensitivity

In addition to the shoreline management policies, another key planning consideration for this section of the foreshore is that Pagham Harbour and the adjacent coastline to the north are environmentally valuable. They support a range of protected habitats including shingle spits/islands, saltmarshes, mudflats, seagrass beds, and coastal lagoons as well as protected species such as breeding Little and Common Terns (that nest on the shingle habitats) and a diverse range of overwintering birds such as Ruff and Brent Geese. The area is therefore designated under international and national environmental law as a Ramsar site (Convention on Wetlands of International Importance), a special protection area (SPA) (Directive 2009/147/EC), a site of specific scientific interest (SSSI) (*Countryside and Rights of Way Act*, 2000), and a marine conservation zone (MCZ) (*Marine and Coastal Access Act*, 2009). The site also forms part of the Pagham Harbour Local Nature Reserve. In addition, during 2016, Pagham Harbour and its fronting coastal waters were included within a larger potential SPA that, when designated, will protect foraging Sandwich Tern, Common Tern, and Little Tern, which breed in neighbouring coastal SPAs (including Pagham Harbour). These designated areas are shown in Fig. 7.

Pagham Harbour and the open coast (as well as the large lagoon behind Pagham Beach and the rifes (streams) that drain into the harbour) are also separately categorised as distinct water bodies under *The Water Environment (Water Framework Directive) (England and Wales) Regulations* (2003) (which transposes the Water Framework Directive (2000/60/EC)). Under the Water Framework Directive legislation, ecological as well as chemical targets (objectives) are set for these sites in the context of their status as either heavily modified or artificial water bodies. The harbour is also designated a sensitive area (eutrophic) under the Urban Waste Water Treatment Directive (91/271/EEC) and areas surrounding Pagham Harbour are designated nitrate vulnerable zones so that the areas is sensitive to excessive nutrient availability and potential eutrophication.

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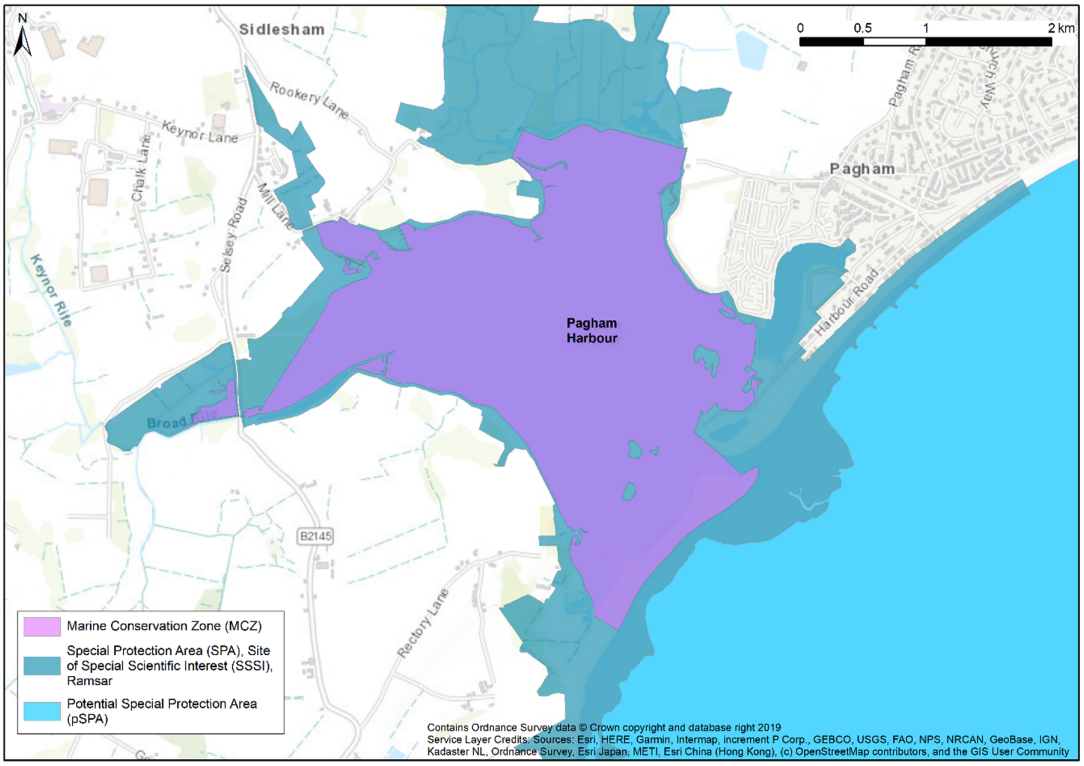
Fig. 7. Type and extent of protected nature conservation areas at Pagham (produced with ArcGIS 10.6 using © Natural England copyright designated sites map with © Ordnance Survey data Crown copyright and database right 2019 (Natural England 2019) and © ESRI, HERE, Garmin, USGS, NGA base map (ESRI 2019)).



Key legal drivers and responsible authorities

In England, the *Flood and Water Management Act* (2010) provides the overarching legislation for flood and coastal erosion risk management. Under this act, responsibility for coastline management typically falls to either the coastal Local Authority or the Environment Agency who have permissive power for coastal defence under the *Coast Protection Act* (1949), *Land Drainage Act* (1991), and *Water Resources Act* (1991) (Defra 2015). At Pagham, the Environment Agency is responsible for defences inside the harbour while Arun District Council manages the coastline (ADC 2018).

The flood and coastal erosion risk management process is necessarily underpinned by a legislative framework that must be adhered to before permission can be obtained for a preferred course of action. At Pagham, planning permission for any intervention is required from Arun District Council and also, in some instances the neighbouring Chichester District Council, as the planning authorities under the *Town and Country Planning Act* (1990). Also, because all intervention proposals would involve work below the mean high-water spring level, a marine licence is required from the Marine Management Organisation under the *Marine and Coastal Access Act* (2009).

The legislation that governs flood management, planning, and marine licencing influences the requirements for supporting information and assessments. In particular, depending on the type of proposed intervention and the nature and scale of the potential environmental effects, an environmental impact assessment (EIA) is required under the *Town and Country Planning (Environmental Impact Assessment) (England and Wales)* and under

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the *Marine Works (Environmental Impact Assessment) Regulations* (2007). An EIA has been required for major proposals at Pagham and in instances where this has not been needed an environmental appraisal has still been required to inform the planning and marine consents.

Due to the potential effects on internationally designated Ramsar and SPA sites, a habitat regulations assessment (HRA) is required for almost all interventions of any size under the *Conservation of Habitats and Species Regulations* (2017). This legislation transposes the EU Habitats Directive (Council Directive 92/43/EEC) on the conservation of natural habitats and of wild fauna and flora and the EU Birds Directive (Council Directive 2009/147/EEC) on the conservation of wild birds into UK law (JNCC 2017). Where an intervention could affect the MCZ or the Water Framework Directive water bodies, relevant assessments of impacts to these sites are also needed.

Under the planning and marine licencing processes, Arun District Council, Chichester District Council, and the Marine Management Organisation must consider the comments made by the statutory consultees (The Solent Forum 2016). These include the Environment Agency, which is the statutory consultee responsible for assessing proposals based on the impact to flood risk as well as, separately, helping to evaluate projects for the allocation of Governmental funds and the need for contributory payments from local residents. Natural England is the statutory advising body for the natural environment providing advice on the potential impacts to designated sites and wildlife interests (ADC 2018). Further consent was also required from Natural England under the *Countryside and Rights of Way Act* (2000) due to works being within a SSSI.

Identifying and adopting intervention measures

During the years that the southern spit was prograding, and properties on the eroding Pagham Beach were at risk of flooding, several reviews were carried out and many discussions held between stakeholders to identify appropriate intervention measures in the context of the planning and policy framework outlined above. A simplified tabular timeline of this detailed review and consultation process is shown in Table 1. This table describes key events in each year including the morphological changes that took place to the spit and on Pagham Beach alongside the main stakeholder meetings and governmental reviews that occurred. The main events are also summarised below.

During this process several different interventions were considered. Arun District Council (as the lead coastal management authority) conducted an initial review of options in 2007 and then, from 2009, carried out a series of interventions with requisite assessments, consents, and licences. These measures became increasingly urgent during the 2013/2014 period, when major beach erosion events occurred.

As this process took place, an increasingly clear distinction emerged between the approaches that Arun District Council was implementing and an approach that the local community wanted to see adopted. In simple terms, these two positions were either to manage Pagham Beach and protect properties where the erosion was occurring (the adopted Arun District Council approach), or to intervene on the spit itself (the approach preferred by the local community). Further details about these two strategies are set out below.

Adopted interventions on Pagham Beach

The approach implemented by Arun District Council involved a series of measures to manage the beach and protect homes at the site of the beach erosion. During 2009 and 2010, this involved recycling shingle from within the local area (including from the spit and delta) or importing shingle from offshore to build up the beach. From late 2013 to early

Table 1. Timeline showing the key events related to the evolution of the spit at Pagham between 2004 and 2018.

Date	Morphological developments of spit and beach	Key stakeholder meetings and technical/option reviews	Interventions on Pagham Beach by Arun District Council	Proposals for intervention on spit by community
2004 Spit starts growing.	Spit which has been building up to south of Pagham Harbour starts to prograde.	—	—	—
2005–2008 Spit grows, coastal policies developed.	Spit continues to prograde.	In 2006, a shorline management plan is produced. In 2007, Arun District Council review the intervention options. In 2008, the Pagham to East Head Coastal Defence Strategy is consulted on.	—	—
2009 Coastal policy finalised, beach erodes, intervention measures begin.	Beach has now narrowed by 5.2 m on average from March 2003 to January 2009 (0.9 m/year). Spit starts prograding more directly towards beach and properties.	Geomorphological study of Pagham completed by Arun District Council in February. Pagham to East Head Coastal Defence Strategy is approved.	In November, 10 000 m^3 of shingle is recycled from the ebb delta at the end of the spit to recharge narrowing beach crest at Pagham (at cost of £43 000).	—
2010 Intervention measures continue, beach stabilised briefly.	Following beach nourishment work in 2009 and 2010, beach widened by 3.4 m on average from January 2009 to February 2011 (1.7 m/year).	Pagham Harbour Coastal Issues Advisory Group set up around this time to oversee challenges with adaptive management implementation.	In March and April, a further 20 000 m^3 of shingle is imported to recharge Pagham beach (at cost of £600 000).	—
2011, 2012, and early 2013 Spit growth, beach erosion, and intervention measures continue, other intervention options reviewed.	Spit continues to prograde. Scour from migrating tidal inlet causes rapid beach erosion. Warning crest level reached, indicating need for measures to address erosion.	In 2011, Environment Agency produce framework for adaptive management. A new multiagency meeting held in January 2013 to consider options for addressing spit growth and beach erosion.	Shingle is recycled on three occasions (November 2012, January 2013, and February 2013) although this material is lost during subsequent storms (£25 000).	—
Late 2013 and early 2014 Severe storms accelerate spit growth and beach erosion, intervention measures and options review continue.	Severe storms occur over this winter period. After being stalled by a cross-shore groyne in January 2014 the spit breaks through the groyne.	In January 2014, a second multiagency meeting is held to consider options. Wide range of options reviewed.	In November and December 2013, rock revetment is placed along the most significantly eroding part of Pagham Beach to stabilise the beach and westernmost groyne (at cost of £500 000).	Pagham Parish Council set up the Pagham Flood Defence Steering Group to explore alternatives and consider the efficacy of the community's preferred option of creating a managed breach and new channel through the spit.
Rest of 2014 Spit more stable against the groyne. Community begins to actively explore alternatives.	Spit more visibly stable against groyne and tidal channel.	Stakeholder workshop held in October 2014 as part of Pagham Flood Defence Steering Group review.	Range of remedial actions carried out in February and August including relocation (cannibalisation) of rock revetment, shingle recycling, and use of geobags to urgently address erosion/scour. Additional rock imported in November to support revetment and groyne (at cost of £360 000 over 2014 and also February 2015).	Pagham Flood Defence Steering Group commission consultants to review intervention measures. A defined recommendation is not obtained. Pagham Flood Defence Steering Group commission second consultancy to review measures. On this basis a natural-style managed breach is proposed.

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Table 1. (*concluded*).

Date	Morphological developments of spit and beach	Key stakeholder meetings and technical/option reviews	Interventions on Pagham Beach by Arun District Council	Proposals for intervention on spit by community
2015 Spit remains relatively stable but ongoing intervention measures needed on the beach. Community actively pursues alternatives.	Spit remains visibly relatively stable against groyne and tidal channel.	In response to community and political concerns, in January, the UK Department for Environment Food & Rural Affairs (Defra) reviews coastal management practices at Pagham.	During February 2015 further maintenance and shingle recycling work is undertaken.	Pagham Flood Defence Steering Group commission consultants to pursue a planning application for managed breach approach. This is submitted and validated in December.
2016 Spit breaches without direct intervention. Community proposal continues through planning process.	In February, the spit breached and the separated section migrated east until it was stopped by groyne and tidal channel.	—	—	Pagham Flood Defence Steering Group planning application continues with further requests for information, consultations, and referral to the Secretary of State.
2017 Separated spit begins to feed the beach. Permission granted for community proposal that is now no longer urgent.	The gap between the separated section of the spit and the groyne slowly closes. It then migrates into the west of Pagham Beach.	In August, a new regional-scale beach management plan is produced. In November, the community-led Pagham Flood Defence Community Interest Company organises the first meeting of the new Pagham Coastal Issues Advisory Group.	—	In June, planning permission for the Pagham Flood Defence Steering Group granted for managed breach. Pagham Flood Defence Community Interest Company set up to oversee project, planning conditions, as well as community's funds held in trust (PFDT).
2018 Separated spit continues to feed beach. A community-led stakeholder group formed to oversee future management.	The separated section of the spit continues to integrate with Pagham Beach.	The community-led Pagham Flood Defence Community Interest Company organises further meetings of the Pagham Coastal Issues Advisory Group in May and October. A new proposal is in place to develop a local and bespoke beach management plan.	—	In April 2018, the Pagham Flood Defence Steering Group is disbanded to avoid duplicating roles with the new Pagham Coastal Issues Advisory Group.

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2015, as erosion of the beach and threat to properties increased, it involved using imported protective rock armour (3–6 tonne blocks) with geotextile bags and further shingle recycling, along with other remedial measures as necessary in response to observed changes on site. Planning and marine licence applications were needed for these interventions which had to be accompanied by an environmental appraisal for the urgent revetment in 2013, and a full EIA for the shingle recycling in 2009 while an HRA was needed for both (Royal Haskoning 2009, 2013).

Proposals for an intervention on the spit itself

The alternative approach proposed by the community involved cutting through the spit to restore the inlet to its pre-2004 position. This was designed to move tidal channel away from the beach (Fig. 8) and then allow the separated end of the spit to migrate eastwards and re-supply the eroded beach through natural processes. In late 2013, during the period of severe change on Pagham Beach, Pagham Parish Council set up its own Pagham Flood Defence Steering Group to consider the viability of this approach and, if appropriate, seek permissions for a preferred option.

During 2014, the Pagham Flood Defence Steering Group commissioned consultancy firms to carry out option reviews, consultations, and feasibility studies. Several variants of the managed breach approach were considered during this process and also by Arun District Council, which typically included plans to fix the inlet with training walls. The preferred proposal identified by the Pagham Flood Defence Steering Group involved mimicking a natural barrier breach condition without any associated infrastructure. In 2015, the Pagham Flood Defence Steering Group prepared and submitted planning and marine licence applications for this proposal. These applications had to be supported by detailed studies including field surveys, numerical modelling analyses, scheme design reviews, an EIA, an HRA, an MCZ impact assessment, a Water Framework Directive compliance assessment, and a range of other planning documentation and consultation work (ABPmer 2015).

To address the effects on designated nature conservation sites (including changes to the spit and the possible implications on the tidal functioning of the harbour) it was necessary, under the HRA process, to meet a range of legal tests and develop compensatory measures to offset known or potential ecological effects. The compensation measures involved creating a shingle island inside the harbour to provide nesting habitat for migratory terns, which nested on the spit (especially on the flattened and un-vegetated landside spit recurves) as it developed.

The application was validated by the planning authority in December 2015 but it took 18 months to obtain consent. This protracted application period occurred because of the complexity of the process and, especially, challenges associated with the HRA process. The HRA required a particularly detailed evidence base and necessitated referral to the UK Secretary of State to provide agreement that the necessary legal tests were met. During the time that the application was being determined, the breach in the spit occurred without direct intervention (during early 2016 particularly). This meant that, although permissions were in place, an active intervention to replicate such a breach was not immediately needed.

The situation in 2018 and the way forward

In the months and years after the spit breached, the severed distal section gradually re-supplied the shore in front of the Pagham Beach properties and a new shallow lagoon formed on the beach (Fig. 9). However, the remaining groyne field inhibited this re-supply process. Although concerns still exist about beach erosion, these changes helped to reduce the risk to beach proprieties.

Fig. 8. Comparison of modelled tidal flows (2 h after high water) through the inlet for the 2015 morphology (*a*) and the proposed, but not yet implemented, managed breach (*b*) (model images derived from by ABPmer (2015) and inset aerial image in (*a*) from Google Earth dated 22 April 2015).

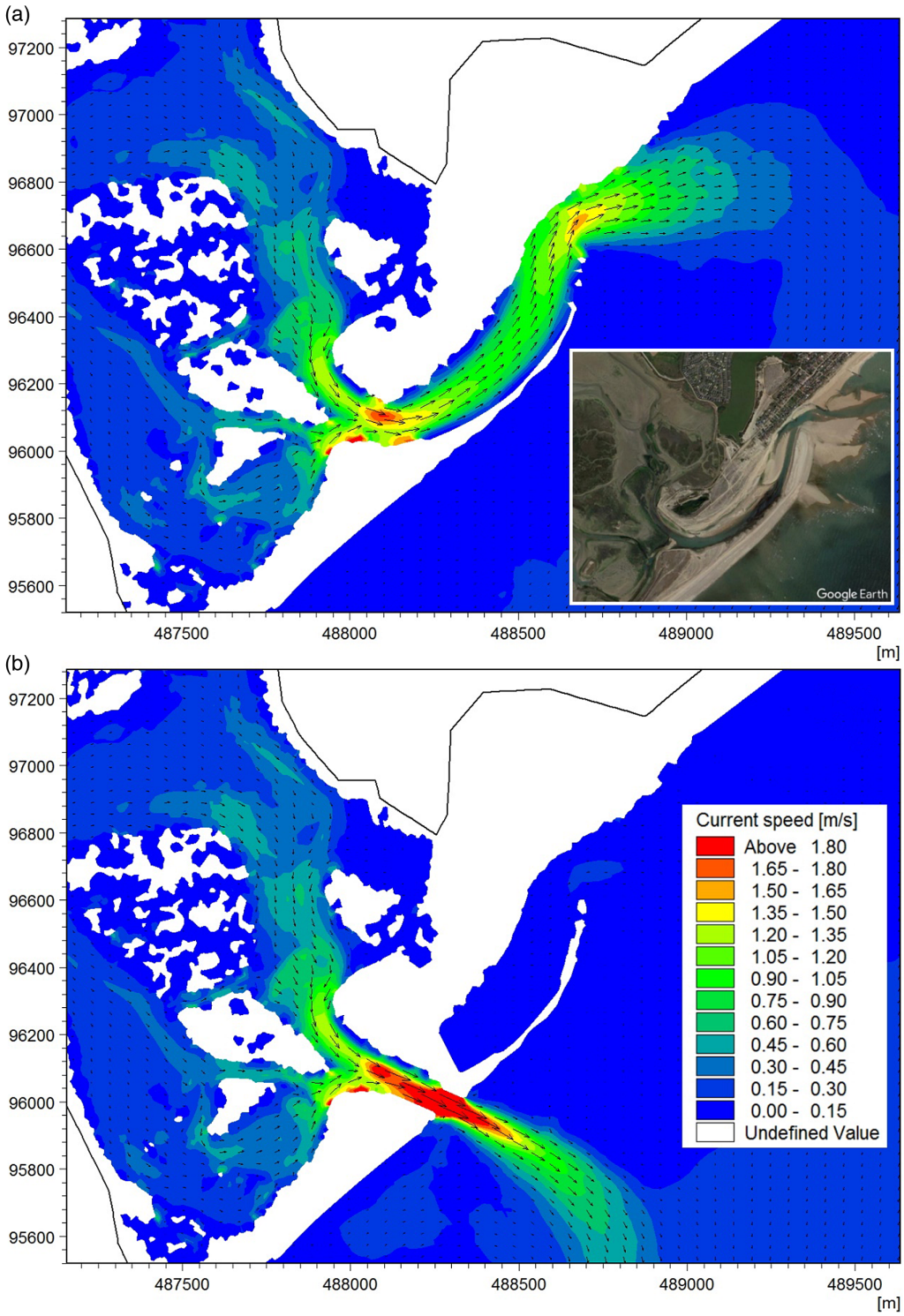

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Fig. 9. Aerial view of the inlet morphology and new lagoon feature in February 2017 (photograph courtesy of Robin Henderson).

By the end of 2018, there was still no obvious need to carry out a deliberate managed breach and a new community-led stakeholder group (the Pagham Coastal Issues Advisory Group) had been established. The Pagham Coastal Issues Advisory Group meets regularly to review conditions on site and discuss the next tasks in the context of the site's history and the extant planning consent for a managed breach of the spit (Henderson and Barter 2017).

A new regional Beach Management Plan was produced in August 2017 (Environment Agency 2017*b*). This provides advice on the management of the shingle beaches based on the existing standards of protection and recommended beach levels. However, this document makes no particular reference to local management opportunities at Pagham in light of recent experiences and morphological changes. However, it is anticipated that this Beach Management Plan will be complemented by a bespoke/local Beach Action Plan addressing such specific issues and lessons for the Pagham Harbour and Beach frontage. On behalf of this group, preparation of the beach plan is being led by Arun District Council working closely with key stakeholders including community members. The Channel Coastal Observatory Regional Coastal Monitoring Programme is also continuing, which will help inform future decision making.

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Comparison between the two main approaches

This case study highlights the challenges that can arise when seeking to implement intervention options under an adaptive management policy. These are illustrated particularly by the way in which there was a divergence of approach between the one pursued by the managing authority and that sought by the local community. This divergence led to further uncertainties for locals as well as increased costs and enhanced workloads for all the many parties involved.

A useful way to describe some of the issues that emerged from this process is to clarify why one approach was preferred over the other and then compare their outcomes (whether positive, adverse, actual, or potential). In the first instance, there were many reasons why the beach management and revetment approach was adopted over the alternative of breaching the spit. These include the following:

- **It adhered to a set of pre-determined and objective decision-making criteria:** To inform the implementation of the coastal defence strategy adaptive management process, a review to inform a review of approaches was carried out (Environment Agency 2011). This identified a set of measurable criteria in the form of minimum beach crest heights and widths that could be used for the management of Pagham Beach. Thus, if the beach narrows and the houses become vulnerable, this triggers either warnings of a future need for action or, in severe cases, requirements for immediate urgent action. Using such criteria is helpful and attractive for site management because it provides objective and measurable values that then make the processes of agreeing the need for, and the funding of, interventions much clearer. However, this approach also has the effect of narrowing the range of possible options that are available for intervention. It focusses solely on delivering coastal protection with little, if any, consideration to wider sustainability objectives and community needs, and it leads to a strong preference for interventions that occur on the beach in reaction to events rather than other more proactive responses to anticipated future needs.
- **It had lesser perceived effects on nature conservation and protected sites:** The protected SPA and SSSI nature conservation areas extend across the harbour and the beach area and these play a crucial role in decision-making processes. These sites were designated before the spit developed but their site boundaries were defined by the low-water mark. Thus, as the spit grew and extended the low-water boundary, the extent of the protected areas is extended. As a result, the spit was deemed to be protected and any intervention on the spit needed to consider the effects on the designated sites in the context of relevant legal drivers and especially Habitats Regulations. The spit was also viewed as a geological feature under the SSSI designation. Although the beach was also within these protected areas any interventions affecting the beach directly were viewed as having lower, and more localised, environmental effects than any intervention on the spit.
- **Interventions on the spit would require a longer planning process:** As a consequence of the environmental protections, any major intervention on the spit required more detailed impact assessments and evidence gathering (including field surveys and detailed numerical modelling work). The HRA process was an especially key issue as this encompassed additional legal tests, which included the need for assurances that there were no alternatives having lesser environmental effects and requirements to compensate for any damage to the protected sites. It was therefore simpler in planning terms to implement smaller-scale initiatives on the beach that were seen to have lesser ecological consequences.
- **The costs of any spit adjustment were perceived to be very high:** Proposals to sever the spit were thought to be expensive. In the early stages of the process it was envisaged that one or more training walls would need to be added to maintain the inlet position where the spit was severed that would themselves need maintaining for many years thereafter

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(estimated to be around £1.75–2 million). Therefore, it was considered easier to secure funds, and make funding applications, for smaller-scale initiatives on Pagham Beach. The eventual planning application did not include a training wall, relying on the formation of an ebb delta to maintain the entrance, thus greatly reducing the potential cost. However, this took a considerable time to agree and so also favoured the alternative option.

- **The benefits of a spit adjustment would take time to materialise:** Adjusting the spit was designed to change the position of the tidal channel and move it away from the eroding beach and this would have happened quickly. However, the secondary objective was to release shingle locked in the end of the spit but this benefit would take time to be realised. Coupled with the delays that would come from having a protracted planning process for such an approach, it was considered better to do protective actions directly on the beach. As the spit and channel grew and as greater pressure was placed on the beach, the need for such direct measures became increasingly urgent and the opportunities for pursuing alternative options with longer benefit lead-in times became less viable.
- **Issues of uncertainty, indemnity, and risk:** A pivotal consideration throughout the options review process was the need for certainty of outcome. This need is understandable especially when large sums of money are to be spent but it does have the effect of reducing the scope of available options to only those that would provide instant and quantifiable value (often using fixed structures) rather than potential longer term gain that is less quantifiable. This quest for certainty also influenced many of the previously listed reasons for the preferred option selection. It means that the costs of a spit adjustment were projected to be high because of a tendency to envisage large-scale measures (including possible training walls and ongoing future maintenance activities) rather than smaller initiatives whose outcome might be less uncertain. The planning process was also protracted because, under the Habitats Regulations in particular, there is a requirement to have certainty of outcome both in terms of the impacts and the benefits from measures to offset those impacts. Some other illustrations of this thinking where they apply to the concept of a managed breach were as follows:
    - **Concerns about managing, and paying for, breach closure risks:** One view promulgated throughout the options review process was that the spit would close-up naturally due to the littoral drift of shingle or that if the spit was cut it would then close. This led to concerns about changes to the tidal conditions in the harbour and the need for regular maintenance activities to keep the breach open.
    - **Concerns about the efficacy of proposed compensation measures:** The extent to which the proposed habitat restoration work would deliver its objectives was debated. This habitat needed to provide nesting habitat for birds, and tern species particularly, in the same way that the developing spit was providing this function. This habitat would also need to be managed on an ongoing basis. In the end, the breach that occurred in 2016 removed this nesting habitat without compensation.
    - **Challenges with making cost:benefit applications for coastal protection funding:** To inform the funding allocations for coastal defences in England and Wales, a set of cost:benefit funding formulae are used to inform requests for Government funding and identify the level of community contributions. Applying these calculations is generally simpler where a proposed initiative will achieve more definable and relatively well understood durations of benefit for known numbers of properties (with the property owners then contributing to the funding). This leads to a preference for coastal defence measures that protect defined stretches of the coast for relatively known periods of time. In this case, timescale and spatial extent of the benefits arising from a spit intervention option were less quantifiable than protecting sections of the beach.

- **Difficulties with agreeing insurance and liabilities:** To provide requisite certainty of outcome, the regulators required assurances that monies and insurances would be in place and that the community representatives would take on legal liabilities for any ongoing restorative measures. Pagham Parish Council, who led this initiative, were not able to take these liabilities on and so Pagham Flood Defence Community Interest Company was set up to oversee the project, the planning conditions, and the community's funds held in trust. As part of this process, there were detailed discussions about the nature and scale of the insurances and the liabilities required in the context of scientific understanding about the nature and scale of the risk of unforeseen events arising.

In terms of the actual and potential outcomes of the two approaches, the adopted beach management and revetment measures (which are understood to have cost over £1.5 million) were successful in protecting the vulnerable homes and the rock armouring can also be moved and re-used if required. This approach did however cause stress to, and an alienation of, the local community who were concerned about the flooding risk to their homes and house value depreciation. The revetment work also caused environmental and visual damage to the beach and altered the evolution of the spit and channel by forcing the mouth of the channel and ebb delta offshore.

As of the end of 2018, the consented managed breach approach had not yet been implemented. However, costs were estimated to be around £1 million with the works themselves estimated at £700 000 while the further consenting requirements were around £100 000 and the projections for compensatory habitat restoration work were approximately £200 000. Higher costs of £1.75–2 million were anticipated for an initial breach design that included costly training walls. This was later rejected in favour of an approach that worked with nature.

That a planning consent was eventually secured for a managed breach concept, demonstrates that it was possible to achieve permission for such an approach with the uncertainties that come with it. However, it also confirms that this process was complex and protracted. This was one of the reasons for not adopting this approach previously. This process took so long that the changes to the spit overtook the consenting process and, by the time a decision was reached, the spit had breached without direct intervention. Indeed, it may be that this assisted with the consenting process because the breach had taken place and the outcome of it was visible to decision makers.

The breach that occurred in 2016 functioned in a similar manner to that which had been envisaged for the managed breach proposal. This demonstrated the efficacy of the technique. In this case though, the aims were achieved at no extra cost and without any liability being placed on the community (Pagham Flood Defence Community Interest Company). The breach also caused environmental damage by removing nesting grounds for Little Terns. Although measures to compensate for such damage were included in the planning application for the managed breach there was no requirement for this offsetting measure to be implemented in response to the breach that occurred without direct intervention.

The offsetting measure would have involved creating a shingle island for nesting Little Terns in the harbour. This would have been similar to other recent, and successful, management projects carried out by the Royal Society for the Protection of Birds. The Pagham Coastal Issues Advisory Group has decided to explore options for carrying out this valuable conservation measure in its own right. However, this concept of separating the compensatory action from the consented proposal is raising further legal questions and possible obstacles (under the HRA process) that, as of the end of 2018, were being reviewed.

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Discussion

The spit development at Pagham, and responses to it, provide a valuable illustration of the difficulties associated with adaptively managing, and living beside, a dynamic coastline. This case example highlights, particularly, how different stakeholders (coastal managers, regulators, statutory advisors, and the local community) encounter difficulties with identifying and agreeing the best and most appropriate management intervention in an ever-evolving and environmentally important location.

These difficulties were thrown into sharp relief at Pagham for several reasons. In part, it was because the morphological changes were visually dramatic and happened over a relatively short timeframe. This meant that the risks and the need for a response were clearly defined in contrast to situations where change is more gradual and there is more time to foresee issues and adapt. It is also because two very distinct solutions were ultimately proposed. Differences in the way these two solutions were considered provides broader insights into the ways that adaptive management is perceived and implemented. These insights, in turn, provide useful lessons for coastal management that are transferable to other locations and adaptive management practices. In particular, this example illustrates:

- how the need for complete certainty of outcome plays a pivotal role in decision making and can restrict the number of available options (while also potentially being at odds with concepts of sustainability and working with nature);
- how interpretations are made about perceived natural and human influences that affect decision making;
- how important it is to have effective, inclusive, and informed community engagement as well as clear leadership; and
- how the planning regime is insufficiently flexible to allow for adaptive decision making in a dynamic situation.

These four issues are discussed further below.

The need for absolute certainty

Judgements about the intervention options at Pagham were strongly influenced by the need to have definitive ecological and coastal protection outcomes. This desire for certainty is understandable and is embedded in legislation, planning processes, and funding mechanisms. It is also an inherent function of the way we think individually and as a society. However, seeking absolute certainty regarding all outcomes can often be at odds with policy aspirations for sustainable development or working with nature, which typically requires the inclusion of a degree of uncertainty because, whether in whole or in part, they rely on the action of natural forces.

This need for absolute certainty of outcome, and the challenges of achieving it, were particularly evident at Pagham because of the area's high environmental value and the multiple conservation designations. The Habitats Regulations are particularly influential in this respect because, under this legislation and associated case-law, there is the need to prove with reasonable scientific certainty that there will be no adverse effect on the ecological integrity of the designated nature conservation sites.

Providing certainty is also difficult because of the dynamic nature of the environment, which makes it challenging to achieve a consensus view on the baseline coastal processes acting on the shoreline, let alone the expectations for future change. This was the case at Pagham, despite there being a relatively rich source of survey data and a good understanding of historical morphological change. At Pagham, for example, residual uncertainties

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included the source and reliability of the shingle supply, the risks of inlet closure, the risk of change to tidal patterns in the harbour, or the precise conditions that trigger either inlet bypassing or shingle growth processes.

The outcome of this thinking is that options that involve working with nature, and which are typically accompanied by a degree of uncertainty, tend to be eschewed. Instead there is a tendency to favour options that fix environmental conditions in place by introducing physical structures or undertaking comparatively costly and large-scale interventions. For example, expensive training walls were thought to be needed when the idea of a managed breach was first mooted. Even when a managed breach option was advocated by the community, with no such walls included, their proposal still involved substantial volumes of shingle excavation and translocation to reshape the spit to exert a high degree control on the environment and its future evolution from this adjusted morphology. No one involved in the management decisions and reviews of options at Pagham recognised the potential for the spit to be slightly adjusted at low cost and then allowed to breach and evolve on its own. If there is an especially obvious lesson from the breach that happened in 2016, it is that this small-scale and low-cost option for truly mimicking a natural breach scenario exists.

This tendency to seek fixed outcomes through comparatively large and costly approaches can then count against certain solutions during the options selection process or present challenges with securing funds even for the preferred option. Also, beyond just the costs of project implementation (including fees needed to secure necessary consents), the need for certainty regarding all eventualities at Pagham also meant that the community proposal was required to underwrite the risk of this initiative having unexpected consequences and requiring extra ongoing management. This was a major additional issue for the community group advocating the managed breach approach and added a further challenge with respect to securing the funding needed to progress the proposal.

Alongside requirements for certainty of environmental outcomes, there was also a perceived need for definable coastal protection cost:benefit projections (i.e., quantifications regarding the number of houses protected and the duration of that protection) to underpin a funding application. This led to a preference for projects that deliver coastal protection objectives only, without a broader recognition of the societal, amenity, and aesthetic benefits or impacts of a proposed intervention.

The funding criteria therefore need to align better with the concepts of working with nature, and it is recognised that the Environment Agency are exploring ideas to bring ecosystem service valuations into these cost:benefit metrics. This could result in better decision making by broadening the spectrum of interventions that can be funded and including projects that are more sustainable and can achieve multiple benefits.

The perceptions of natural and anthropogenic influence

The decisions made at Pagham also illustrate how a binary distinction is made between natural processes and human interventions as part of planning and options review processes. In reality, the distinction between the two is often unclear, and it is generally true that a combination of both factors (with different levels of influence over a range of spatial scales and over historical and contemporary timescales) contributes to ongoing coastline change.

At Pagham, for example, the evolving spit was viewed as a natural process despite the long history of human intervention. Therefore, any further human intervention on the spit was seen as problematic. The preferred approach of reactively managing the beach as opposed to proactively altering the spit in any substantial way was the outcome of this thinking. The beach management approach was viewed as having much less impact on

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natural processes than the managed breach alternative; although it did cause adverse environmental, societal, aesthetic, and amenity change in its own right. Furthermore, it also ultimately halted the evolution of the spit and will have contributed to the spit's inability to morphologically adjust and therefore to its degradation.

This distinction between natural processes and human interventions is embedded in planning processes and environmental legislation where the aspiration is to preserve protected features in an existing and natural condition. Under the Habitats Regulations, for example, this desire to maintain natural functioning is enshrined in the conservation objectives for protected sites against which the adverse effects of a project are judged. For the Pagham case-study, this tendency to preserve a perceived natural state applied notwithstanding the fact that the protected spit feature did not exist at the time of its designation and is a feature that is always changing in response to both natural and human factors. As with the need for certainty, this need to simplify complex environments by making such binary distinctions between natural and anthropogenic influences is understood because it contributes to auditable decision making. But this thinking also limits the range of options that are available for intervention by placing higher burdens on the proof of outcomes from active human interventions in environmentally sensitive locations, and favours leave-as-is or react-only-when-urgent scenarios. One key principle of adaptive management though is to not lock a feature into an existing size, shape, and location (Creed et al. 2018).

This binary approach is applied notwithstanding that active human interventions can enhance the conservation management of environmentally important areas, or even that leaving an environment to the fate of perceived natural process can be detrimental to some ecological interests. In this case, the process of trying to undertake a natural-style managed breach intervention led to commitments for ongoing conservation management such as the creation of an island to offset the loss of Tern nesting habitats (as well as ongoing breach shape management work to preserve the existing tidal functionality in the harbour). However, the adopted processes of beach revetment work, which acted contrary to natural processes, did not include such commitments and, ultimately, Tern nesting habitat was lost anyway when the spit breached without deliberate intervention.

Based on these lessons, it will be valuable for future decisions to be based more upon the delivery of natural capital gains as advocated in the UK's 25-year environmental plan (HM Government 2018) alongside social gains in the context of existing site variability. This is as opposed to being based on perceptions regarding the degree to which human intervention changes an existing condition.

The importance of actively involving the community

During the years covered by this case example, stakeholder groups were assembled and regular meetings held to inform and engage with the local community. It is known that stakeholder engagement is important for adaptive management (Williams and Brown 2014) and that having a stakeholder group has been critical for implementing the adaptive management policy at nearby East Head, at the mouth of Chichester Harbour (Creed et al. 2018). At Pagham however, increasing tensions, differences of opinion, and confrontation still arose between the community and those charged with managing the coastline. This is probably because there was no consistent overarching group and because, crucially, while the community was informed through these groups and other activities it did not have any active involvement or ownership of the processes.

This aspect was illustrated by Evison (2017) who carried out community surveys and interviews with authorities to investigate the role of social justice, as an element of UK sustainability policy (HM Government 2005, 2018), in the decision-making process at Pagham. This study found that the adaptive management policy had not been well received

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by the community. It also indicated the lack of a consensus view and an inconsistency of understanding about the situation at Pagham and about what social justice means. It concluded, with reference to the ladder of citizen participation (Arnstein 1969), that while the community was informed, consulted, and placated (collectively seen as degrees of tokenism), there was no community partnership, or any degree of citizen power, ownership, or control in the process. Edwards et al. (1997) also records that "coastal management can only become a truly participatory process when it involves bottom-up approaches, including provision for the formulation and implementation of plans with the full and active participation of local communities".

These engagement issues had been highlighted early in the process, when community views were sought on the coastal defence strategy. During the consultation in 2008 those responding expressed concerns regarding the meaning of adaptive management. There was a belief that it offered no clear policy commitment and that "[the strategy] is evasive, fosters a feeling of uncertainty and appears only to underline indecision by the authorities" (Environment Agency 2008). This led to requests to be assured that adaptive management would be proactive, as well as reactive, and a perception (that persisted throughout the years that followed) that "wildlife interests were placed above those of the local community" (Environment Agency 2008). This project therefore illustrates how perceptions and misperceptions can combine to sow seeds of doubt that can be interpreted as a lack of social justice in decision making. This will have contributed to the divergence of approach that was observed and to the local community seeking planning permission for their preferred solution because they did not buy into the adopted strategies and the constraints and limitations that led to them.

In response to these lessons, the Pagham Coastal Issues Advisory Group stakeholder group is now led by the community in the form of the Pagham Flood Defence Community Interest Company. A series of Pagham Coastal Issues Advisory Group meetings have been held and Terms of Reference for ongoing co-operation have been agreed (PCIAG 2018). This group will now oversee the development of a new local Beach Action Plan to inform future interventions. The Pagham Coastal Issues Advisory Group is also actively involving the local community in citizen science monitoring and drawing upon residents' lived experience (Evison 2017) to inform decisions and reinforce the participatory nature of this new group.

One factor to highlight is that leadership by a key individual has been a common factor in previous adaptive management success stories (Schultz and Fazey 2009). In the future, the Pagham Coastal Issues Advisory Group will probably need to fulfil such a championing role to deliver effective adaptive management.

The inflexibilities of the planning regime

In addition to difficulties that can be encountered with identifying adaptive interventions and securing necessary permissions under established planning and licencing regimes, even once a project is consented it is still subject to fixed conditions with defined outcomes and timelines. Such fixed approaches are an understandable necessity for most developments but can be ill-suited to adaptive management on a dynamic coast. In the years after the managed breach was consented at Pagham, for example, the Pagham Coastal Issues Advisory Group has encountered challenges with meeting fixed conditions and consenting deadlines while the shoreline, and the scope of what is needed, continues to change.

For example, the Pagham Coastal Issues Advisory Group explored the idea of pursuing trial spit excavations and creating the Tern nesting island in advance of any full managed breach. However, there appeared to be no opportunity for adjusting the scope of the works

in this manner. This starkly illustrates how more flexibility is needed in the planning regime if opportunities to learn and provide ecological enhancement cannot be taken.

One possible solution is a trigger-based approach, as described by Barnes et al. (2017), where planning outcomes are conceptual rather than locked in and there are interim actions linked to monitoring over an extended timeline. Embedding adaptive management in the planning process in this way is likely to be an advancement on the current situation and allow for more rapid responses to changing conditions. However, it would also be important under such a regime to actively involve all key stakeholders and recognise ecological and social needs and not just focus on coastal protection objectives.

Conclusions

The Pagham case example illustrates the difficulties associated with managing dynamic coastlines and seeking sustainable intervention solutions. It highlights these challenges because such large, dramatic, and visibly obvious changes occurred at this site and because the environment is so highly valued and protected. The complexity of the environment understandably led to the adoption of a flexible adaptive management policy. However, the selection of intervention options under this policy is, in reality, comparatively inflexible and greatly influenced by the need to preserve an existing and perceived natural state and to have a high degree of certainty in the outcomes. These issues and other legal, planning, and funding constraints limited the scope of possible corrective measures and led to a preference for actions which reactively addressed symptoms while an approach that sought to proactively address the cause and (or) work more sustainably with natural process was avoided.

This case study also shows how the process of seeking a solution can become protracted and incurs extra costs and stress to all parties (especially the local community). It also demonstrates how, when the environment is in a state of continual flux, it is not really clear what preserving a natural state actually involves. Critically, it illustrates how the local community can become alienated from the decision-making process where, despite efforts of regulators to communicate and engage, there was no single and coherent engagement mechanism that allows the community to be actively involved and to have an ownership of the problem.

The case study further emphasises that there are no simple solutions for dynamic coastal management but that there are mechanisms that can be put in place to assist with decision making and communication. It is hoped that the future management of this site will be improved by the setting up of a new single stakeholder group, as well as new proposals for the development of a bespoke and localised beach management plan. The future management of this site will also be assisted by the monitoring work that is carried out by the Channel Coastal Observatory. It will be important to continue developing an understanding of the system's dynamics, informed by the monitoring data, to make more robust decisions in the future.

In the future, at this and other sites, it will be valuable to find ways of accepting a degree of uncertainty and placing greater credence on, and ideally giving priority consideration to, natural management solutions that deliver a broader and more balanced range of social, economic, and environmental gains (i.e., the three pillars of sustainable development). This could allow more flood protection measures to be undertaken that work with nature, rather than fight against it. More generally, a greater consensus is needed on what adaptive management and working with nature mean and the scope of what can be achieved within such policy aspirations. It is hoped that this can be informed by referring to this and other case examples.

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