MCCIP Marine Climate Change Impacts Partnership

Climate change and marine conservation

Supporting management in a changing environment

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Saline lagoons

- Saline lagoons have been identified as one of the most vulnerable habitats to climate change impacts, with their physical, chemical and ecological characteristics all likely to be affected.
- The biggest climate change threats to saline lagoons are relative sea-level rise, and changes in seasonal temperature, storminess, and rainfall patterns. As these climate change impacts are predicted to vary between geographic regions, so the effects of climate change on saline lagoons will be different across the UK.
- Due to their ephemeral nature, the characteristics of saline lagoons differ between sites and can change over time. As a result, the impacts of climate change are also likely to be variable. Some saline lagoons may remain relatively unaffected by climate change impacts where others may be lost completely. It is important to assess the vulnerability of each lagoon and/or habitat complex to climate change.
- Naturally formed lagoons have considerable ability to adapt to climate change impacts provided there is space for adaptation with minimal human interference. However, coastal processes rarely operate in their fully natural state. Artificial lagoons will be entirely dependent on continued human intervention to manage the impacts of relative sea level rise and changes in storminess.
- Coastal lagoons do not exist in isolation but are part of a wider coastal habitat network. Adaptation responses may therefore need to consider the coast as a whole.

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Saline lagoons

Saline lagoons are areas of typically (but not exclusively) shallow, coastal saline water, wholly or partially separated from the sea by sandbanks, shingle, man-made structures such as sluices, or other hard substrata.

They retain a proportion of their water at low tide and may develop as brackish, fully saline or hyper-saline water bodies[1]. They are found around the UK coast (see Figure 1).

Saline lagoons may be permanent or transient. They can form naturally through percolation of sea water through sand or shingle barriers, or artificially through development of man-made barriers that separate a part of an estuary or the sea from direct tidal influences. Freshwater input to saline lagoons usually occurs from drainage of surrounding land or through groundwater seepage. The substrate of saline lagoons can vary[2], but most commonly contain soft sediments.

Saline lagoons are complex and dynamic habitats that support a number of rare species of invertebrates and plants adapted to withstand the stressful and often highly variable conditions typical of this habitat. Such specialist species include the lagoon sand shrimp (*Gammarus insensibilis*), tentacled lagoon worm (*Alkmaria romijni*), lagoon sea slug (*Tenellia adspersa*), starlet sea anemone (*Nematostella vectensis*), trembling seamat (*Victorella pavida*), foxtail stonewort (*Lamprothamnium papulosum*) and bearded stonewort (*Chara canescens*). Despite their limited extent compared to many other coastal habitats, saline lagoons provide a highly important resource for large numbers of birds that use the habitat for feeding, nesting and roosting at high tide. The avocet *Recurvirostra avosetta* is considered to be a saline lagoon specialist. Islands in non-tidal saline lagoons are an important nesting habitat for a few species with very restricted breeding distributions, including several species of tern. Saline lagoons are of considerable conservation interest, and in the UK many are protected under various national and international designations.

Scientific evidence for climate change impacts

Relative sea-level rise and changes in storminess

Effects: Altered coastal dynamics and changes to sediment supply

Climate change impacts such as rising sea levels and changes in storminess will lead to increased erosion rates and inundation in already eroding, low-lying coastal habitats including saline lagoons[3,4]. Movement of sediment will be affected by accelerating rates of sea-level rise and more frequent severe storm events, but the impacts will differ between sites, depending on their topography and sediment supply[5].

Saline lagoons with natural barriers may be able to migrate landwards with rising sea levels by barrier overtopping and the transfer of sediment from the front to the rear of the barrier[2,6], but there are many lagoons where this process is restricted by artificial barriers such as hard sea defences. Where such structures are in place, natural coastal realignment is prevented and saline lagoons may be lost as they become incorporated in marine coastal waters. Table 1 describes the effects of sea-level rise and changes in storminess at various sites around the coast, and further illustrates the importance of natural processes in providing resilience to climate change impacts. Artificial lagoons are entirely dependent on continued human intervention to manage the impacts of relative sea-level rise and changes in storminess[7].

Effect: Increased seawater inundation

Increase in relative sea-level rise and changes to storminess may result in increased frequency of seawater inundation. Seaward enclosing barriers may become more susceptible to breaching and extensive morphological collapse[8]. Even if barriers remain in place, changes in wave height and/or force may result in increased frequency of barrier over-washing.

Increased seawater inundation may lead to higher and/or less variable salinity levels in saline lagoons[1]. While most lagoon organisms have optimal salinity regimes, they tend to have wide salinity tolerance, especially as adults. However, most lagoon specialist invertebrate species have marine counterparts occupying a similar niche that are likely to out-compete them if salinity levels become more stable and close to that of sea-water. Lagoon community composition and diversity may thus be altered as a result of changes in salinity regime (Table 1).

Increased temperatures and changing rainfall patterns

Effects: changes in water quality and quantity

The impact of changing weather patterns on saline lagoons is likely to vary between sites based on their geographic location. In southern Britain, where summers are likely to become drier and warmer, hypersaline conditions in saline lagoons due to water evaporation may become more frequent. Changes in lagoon community composition may occur as species with hyper-saline tolerances become more common. Drier and warmer summers may also lead to higher water temperatures and increased levels of desiccation in the intertidal area of saline lagoons, with potential impacts on the distribution of intertidal species[10] (Table 1).

Many climate change models for northern Europe have projected that most regions will experience wetter winters in the future, with increased frequency of flooding events in coastal areas[11]. Saline lagoons may experience changes in the volume and timing of freshwater input, which could alter the salinity regime of a lagoon[12], although many Scottish lagoons tend to have fresh water inflow even during summer droughts due to the high proportion of water-storing peat in their catchments; these same lagoons can have significantly higher surface levels in winter due to high rainfall. Lagoon water quality may also be reduced as a result of increased nutrient runoff from the surrounding land caused by changing precipitation and more frequent flooding[13]. These impacts, combined with the potential for more frequent over-topping of the seaward enclosing barrier during storms, rising temperatures, changing water chemistry (especially salinity) and reduced levels of dissolved oxygen, may affect lagoon species diversity and composition.

What is already being done to support management of saline lagoons in a changing climate?

Currently, evidence is still being gathered on the impacts of climate change and potential management responses are at an early stage of development.

Some work is underway to identify suitable locations for reinstatement or creation of saline lagoons where appropriate. Three potential courses of action have been suggested as adaptation responses to climate change for saline lagoons[1]:

1. Non-intervention, i.e. allowing processes to operate naturally. This option may mean that lagoons are formed, lost or relocated, or new and different coastal habitats are formed.

2. Manage the impacts of sea-level rise by raising the height of the isolating barrier (if appropriate).

3. Translocation of vulnerable species to analogue sites. The success of this method is yet to be proven.

While the first option is generally favoured, there is a risk that this could result in the local extinction of vulnerable lagoon species with limited dispersal abilities. Further research is required to inform options 2 and 3[1].

It is also important to acknowledge that lagoons are typically managed for more than one feature.

Due to their ecological importance and sensitivity to climate change it has been suggested that saline lagoons could be used as sentinel ecosystems in Northern Europe. In practice, this means they could be used for monitoring ecosystem responses to climate change and for trialling proactive management[19]. In the UK, sentinel ecosystems may become worthwhile in some locations[20], although a general lack of scientific understanding of lagoon functioning and variability[21] needs to be addressed through targeted research and monitoring before this type of management approach can be adopted[1].

Saline lagoon cockle *Cerastoderma glaucum* and stonewort *Tolypella nidifica*. Sue Scott © SNH

Figure 1. Map showing the locations of saline lagoons (EMODnet and regional administrations) and the distribution of Marine Protected Areas (MPAs) (JNCC) around the UK, including those which are designated to protect saline lagoons.

Table 1. Site level examples demonstrating the vulnerability of saline lagoons to climate change impacts.

Climate change driver	Effect	Site level examples of vulnerability
Relative sea-level rise, changes in storminess	Altered coastal dynamics and changes to the amount of sediment supplied	The Beacon Lagoons SSSI is a saline lagoon complex near Easington on the North Yorkshire coast. The northern lagoon at the site is bounded by man-made flood defence embankments that were breached and overtopped in the 1950s. The southern lagoon is formed by tidal inundation of a former borrow pit. The presence of the flood banks and an artificial dyke at the landward side of the lagoons mean that as sea-level rises and storminess changes, the morphology of the site, and the species and habitats it supports, are unable to evolve and move inland naturally in response to the eroding shoreline[14].
Relative sea-level rise, changes in storminess	Altered coastal dynamics and changes to the amount of sediment supplied	The Lymington – Keyhaven sea wall is located within the Western Solent on the Hampshire coastline. Reconstruction of the sea wall system followed extensive damage and flooding caused by the winter storms of 1989/1990. However, while the wall protects against flooding from the sea, the sea-wall pipes are not capable of coping with the freshwater volume when the sluices are closed, and sea-water ingress is negligible, allowing the salinity of these lagoons to approach zero at times. The seawall also restricts the natural migration of the saltmarshes and mudflats[15].
Relative sea-level rise, changes in storminess	Altered coastal dynamics and changes to the amount of sediment supplied	Several percolation lagoons behind Blakeney Spit on the Norfolk coastline were affected by the storm-breaching of the sea defences early in 1996. Some percolation lagoons within the site are thought to have been lost during the subsequent reconstruction of the shingle bank at Blakeney Spit, both due to movement of heavy machinery through the shallow lagoons during construction and by excavation of the shingle at the lagoons[15].
Relative sea-level rise, changes in storminess	Altered coastal dynamics and changes to the amount of sediment supplied	The North Norfolk coastline was heavily impacted by a storm surge event in December 2013. Monitoring the impacts of the storm surge using novel remote sensing techniques has revealed drastic physical changes to the saline lagoons and the nearby freshwater ecosystems. The affected coastline encompasses the Wash and Norfolk Coast European Marine Site (EMS) which contains several lagoons, including those at Cley Marshes. Remote sensing techniques have enabled mapping of the storm surge breaches and the sediment transport on man-made and gravel barriers that separate the saline lagoon from the sea. This has revealed widespread, long-term changes to parts of the coastline, including damage to the man-made and natural defences and saltwater flooding in the lagoons. Sediment was transported inland over 100m, in places infilling protected saline lagoon habitats. The high-resolution maps produced will serve as a baseline to investigate habitat resilience to flooding and salt-water ingress in the longer term. They can also be used to identify and predict the locations of vulnerable coastal habitats.
Relative sea-level rise, changes in storminess	Increased seawater inundation	Monitoring of lagoons using sediment cores has revealed diatom evidence of a gradual increase in salinity levels in the Loch of Stenness in Scotland since the 1930s[7]. Two rare charophyte species were lost during the same time period, and another charophyte species has been lost more recently[7]. These charophytes are brackish-water species with optimal salinity ranges typical of saline lagoons, and therefore it is possible that their disappearance from Loch of Stenness could be attributed to the observed changes in salinity levels.
Changes in water temperature	Changes in species range	The non-native species *Ficopomatus enigmaticus*, is an annelid tubeworm which is thought to be at, or close to, its temperature minimum for maintaining populations and for successful reproduction, along southern coasts of Britain[17,18]. It is believed to only be able to survive in artificially heated northern waters but it is now colonising lagoons along the south coast such as Cockle Pond near Portsmouth Harbour.

What wider management options could feasibly be considered?

Saline lagoons do not exist in isolation but are part of the wider coastal system, which consists of a series of interconnected habitats including saltmarsh, coastal grazing marsh and estuaries as well as more discreet features such as shingle bars. Adaptive management of interconnected coastal habitats should take a more holistic view of the coast as a whole. It should be recognised that gains for some coastal habitats may mean the loss of others, but that there is also potential for the creation of new habitats to offset habitats that have been lost. It should also be noted that there are many competing social and economic pressures in the coastal zone and managing these, as well as environmental issues that occur as a consequence of climate change remains a challenge.

Table 2 outlines some recent projects that have adopted landscape scale approaches to managing coastal habitats affected by climate change impacts such as sea level rise and more frequent severe storm and flooding events. Whilst many of these schemes have managed to create lagoon habitat, it is still to be seen whether lagoon restoration can be successfully done without losing lagoon specialist species such as lagoon cockles (*Cerastoderma glaucum*) and the starlet sea anemone (*Nematostella vectensis*) that make saline lagoons unique.

Practical actions to support management

Identifying the pressures that a site is subjected to is of key importance and will enable the collection of relevant evidence, for both habitats and species. This should include assessments of the vulnerability of sites to climate change.

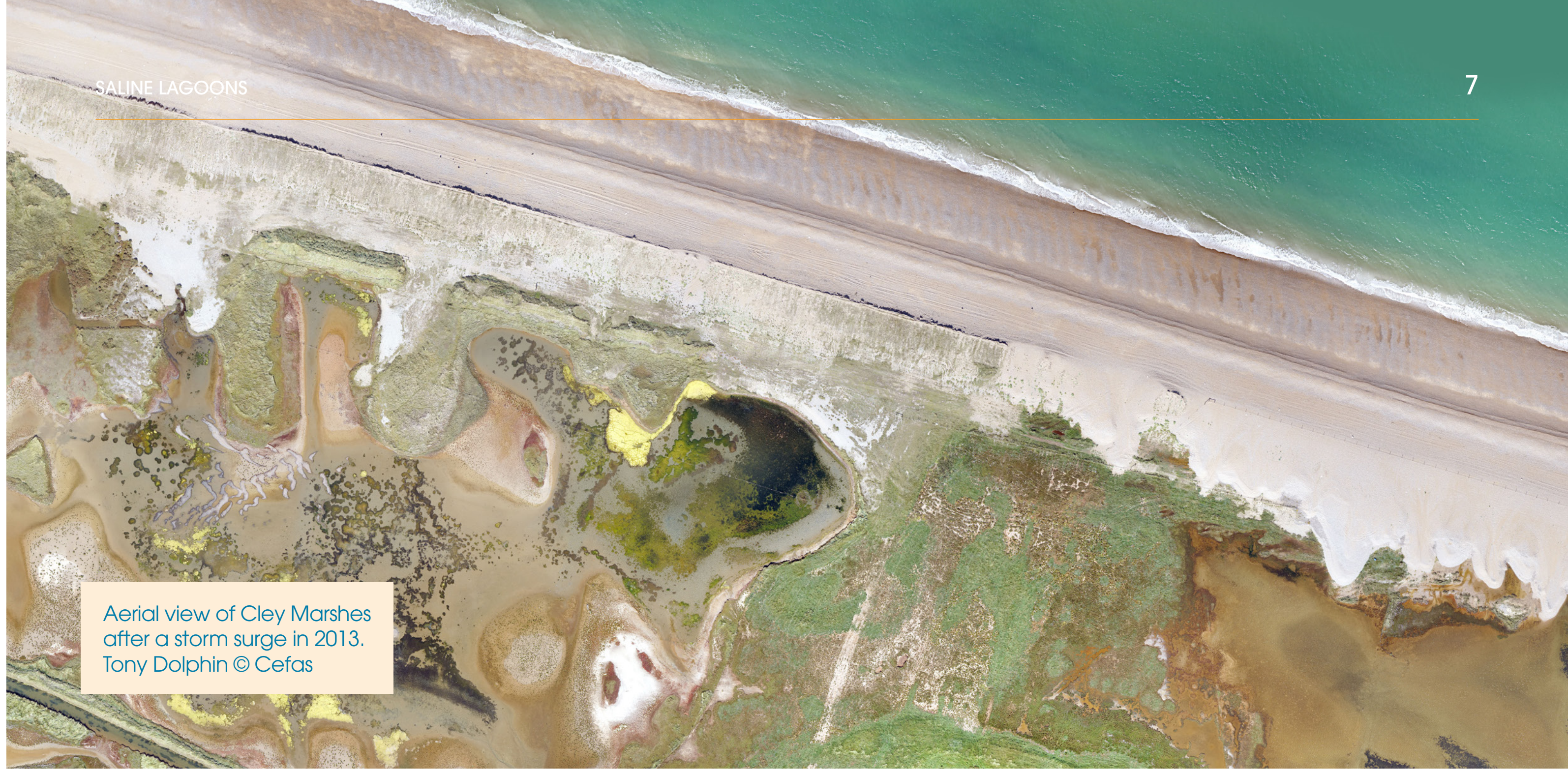
Appropriate management can then be put in place for lagoons and their associated species, taking into account the following:

- Designated saline lagoons should be maintained or restored (when necessary) so that they are in the best possible condition to withstand external pressures caused by climate change.
- Resilience of a saline lagoon to climate change impacts can be increased by developing approaches to protect and manage the land adjacent to the lagoon from human pressures such as infrastructure development and intensive agricultural practices. Sensitive land management practices that take account of nature conservation will help to reduce nutrient runoff to the adjacent lagoon and could help to secure space for the lagoon to retreat naturally as the sea level rises.
- Protected site boundaries could be more flexible to accommodate change in coastal habitats, including lagoons, due to climate change. Change may include loss of lagoons, changes in lagoon location and also the formation of new lagoons or other coastal habitats.
- Sediment recharge may be considered on vulnerable areas, for example where the isolating barrier of a lagoon is a shingle ridge. However, the impact of sediment recharge on other coastal habitats needs to be carefully considered before proceeding with this option.
- Pressures on saline lagoons other than those associated with climate change should also be addressed, including erosion caused by altered drainage flows or removal of sediment, eutrophication, heavy metal and synthetic contaminant exposure, marine litter and recreational pressures.

Development and implementation of management plans that can respond to projected changes along the whole coast should be considered instead of managing individual sites in isolation. As a part of a wider coastal management scheme, a lagoon may need to be allowed to move naturally or even to be lost entirely, and, if appropriate, new lagoons may be created elsewhere, in locations where seawater inundates freshwater areas. However, habitat compensation should never be considered as being equivalent to the natural lagoon habitat, as it is highly unlikely that newly created lagoon habitat could provide the interest and quality of a site it replaces.

There may be a need to identify, and then safeguard, possible new lagoons that will be formed by climate change, for example by new marine inflow to a former fresh water loch or lake.

Deliberate breach at Strangford Lough, Northern Ireland to create habitat. Hugh Edwards © DAERA



Aerial view of Cley Marshes after a storm surge in 2013. Tony Dolphin © Cefas

Table 2. Examples of site level management of saline lagoons.

Project name	Site name and location	Description
The Beacon Lagoons Habitat Creation Project	Kilnsea Wetlands adjacent to The Lagoons SSSI, North Yorkshire	This partnership project was set up in 2013 with the aim to create and improve open wetland bird roosting habitat in order to replace the habitat being lost in the nearby Holderness coastline and The Lagoons SSSI. Although saline lagoon habitat is one of the target habitats to be created, the focus of the project is to provide roosting and feeding habitat for birds at high tide. It is unlikely that the created saline lagoon habitat will be of equal quality to the original lagoon habitat that will soon become incorporated in the marine coastal waters of the Holderness coast.
Wallasea Island Wild Coast Project	Wallasea Island near Southend, Essex	This project is run by the RSPB and focuses on landscape scale adaptive management of interconnected coastal habitats. Saline lagoons have been created as part of a wider project following a deliberate sea wall breach. This project aims to combat the threats from climate change and coastal flooding by recreating a wetland landscape of mudflats and saltmarsh, lagoons and pasture. Wetland restoration began on Wallasea in 2006 when sea walls were breached on the northern edge of the island. By 2025, the RSPB's Wallasea Island Wild Coast Project plans to have created 148 hectares of mudflats, 192 hectares of saltmarsh, and 76 hectares of shallow saline lagoons[22,23].
Freiston Shore Managed Realignment Scheme	Freiston Shore on the north-western bank of the Wash SSSI/ SAC/ SPA/ Ramsar site	Freiston Shore is the largest managed realignment site in the UK. The scheme started in 2000 with the aim to enhance the coastal defence through set back of the primary defence and the establishment of fronting saltmarsh, but also to create a new wetland habitat, supporting a salt marsh community and a brackish lagoon landward of the embankment. This ongoing scheme has to date resulted in the creation of 66ha of new saltmarsh and 15ha of saline lagoons[24].
Data logger project	Loch Bee, South Uist	High flood levels in Loch Bee have led to the installation of water level recorders at five stations in Loch Bee, the second largest saline lagoon in the UK. These measure water level, salinity and temperature. The project is a partnership between Scottish Natural Heritage, Comhairle nan Eilean Siar (the Local Authority) and Storas Uibhist (the community landlord), following the repair of flood gates at the sea exchanges (one on the west coast of South Uist and the other on the east). Results so far suggest that winter water salinity levels can be close to those of fresh water, but both water exchanges leak sea water, so that when rainfall and fresh water run-off decline in the spring and summer salinity levels increase, so that lagoon organisms continue to thrive.
Breach to enlarge and modify SAC	St. Anne's Lagoon in Strangford Lough, Northern Ireland	Sea level rise in particular will change the salinity of some lagoons and turn other fresh water lakes into saline lagoons. In some of these cases there is a role for coastal retreat with adaptive management of the physical environment, but this has implications for the boundaries of the designations. At St. Anne's Lagoon in Strangford Lough, Northern Ireland, an existing small, saline lagoon owned by the National Trust (within the SAC) was modified by deliberately breaching the rock armour. This enlarged and substantially changed the salinity and tidal regime creating saltmarsh and wading bird habitat, and will allow for managed retreat in response to climate change. However, with the enlarged lagoon area created, only half of the lagoon is now in the SAC.

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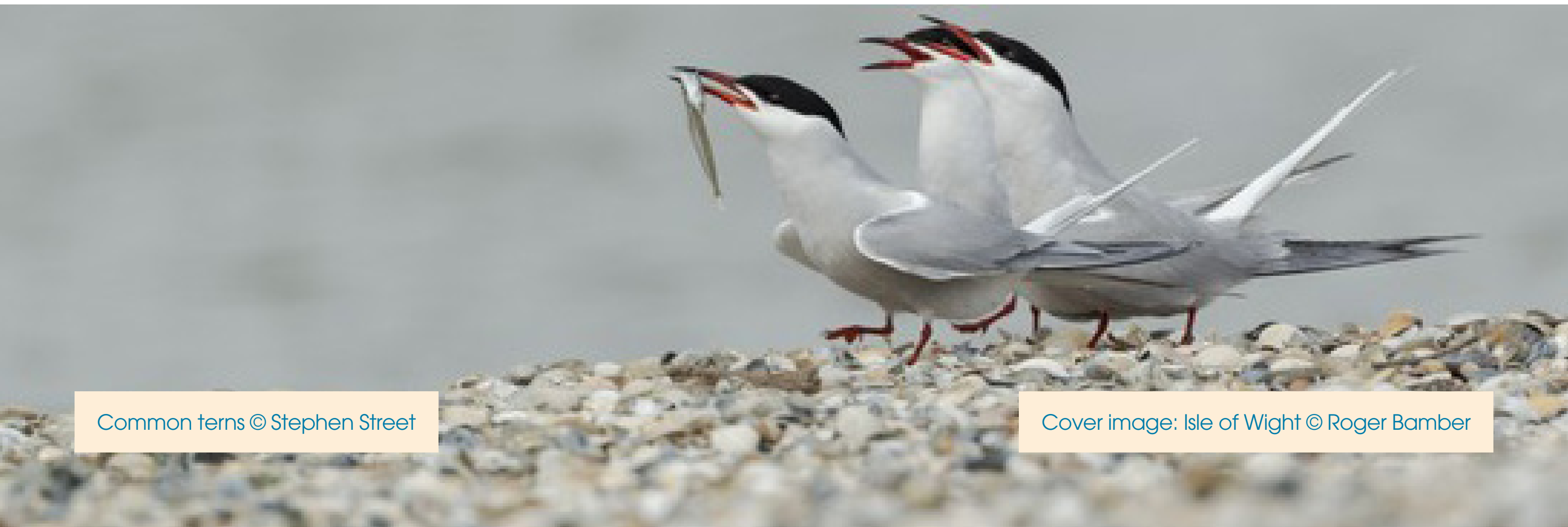

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