Restoration, creation and management of salt marshes and tidal flats

A collation of evidence-based guidance

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Advisory group

This document has been reviewed by a group of advisors, each with expertise of some or all aspects of salt marsh and tidal flat restoration. The advisory group gave feedback on the structure and the content. They also provided additional information and recommendations based on their own experience. Errors or omissions from the document remain the responsibility of the authors.

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Section 1 Introduction

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Salt marshes and tidal flats serve as vital habitat for biodiversity and provide extensive and highly valuable ecosystem services. Yet, they have undergone substantial loss and transformation over millennia with impacts increasing in recent decades. Their loss and degradation have impacted species of high conservation concern, including migratory shorebirds and other waterbirds, as well as ecosystem functions and services they provide to humans more broadly. There is increasing recognition of the importance of these systems, and the impact of their loss, and increasing concern and effort in managing and restoring them.

These intertidal areas are vital in protecting the coast from erosion, especially during on-shore storm tides, and act as a natural flood defence that can protect built areas such as housing and industry, and other human land uses such as agriculture. As such they can reduce the costs of hard engineering-based coastal protection, and will have an increasing importance as sea levels rise as a result of climate change.

Scope of the document

This document collates evidence-based guidance for site managers and decision makers involved in salt marsh and tidal flat restoration with an ecological focus on shorebirds, a highly threatened group of broad conservation concern. Here, we consider shorebirds in a rather general sense, including all species of the order Charadriiformes. Shorebirds that commonly use or heavily depend on intertidal habitats include waders (e.g. plovers, stilts, oystercatchers, sandpipers), gulls and terns.

This document is a collection of smaller stand-alone pieces of guidance, each focusing on a different conservation action. They can therefore be used singularly, or as a collection, depending on the management needs of the user.

This document was initiated by concerns about salt marshes and tidal flats in the Yellow Sea region, particularly as habitats for birds. The Yellow Sea is a critical bottleneck for migratory shorebirds and other waterbirds that have suffered extensive loss and degradation of tidal flats and salt marsh (see also Box 1). Therefore, the collated guidance relates to selected actions most relevant to salt marsh and tidal flat restoration, and bird conservation therein, in the Yellow Sea region. The content of each guidance document is, however, global in scope.

The guidance does not provide strict protocols that must be followed or detailed practical instructions about how to implement interventions or specific techniques (e.g. how to install a culvert, how to transport sediment, required permits and the application process). Rather, it highlights interventions and restoration techniques that have been demonstrated to be effective in at least some situations. Application and implementation of these techniques requires a thorough understanding of the natural system, both its biotic and abiotic aspects. Interventions that were successful at one site may not be at another because of different local conditions or implementation methods.

Evidence for the guidance was gathered primarily from the literature. For evidence on the effects of interventions on biodiversity (focusing on shorebirds, benthic invertebrates and vegetation), we drew from Conservation Evidence syntheses (Sutherland *et al.*, 2019) where available, i.e. the Bird Conservation Synopsis (Williams *et al.*, 2013) and the Marsh and Swamp Conservation Synopsis (Taylor *et al.*, 2021). These syntheses are based on systematic literature searches of studies that test the effectiveness of conservation actions (see www.conservationevidence.com). We complemented these with ad hoc searches for further literature, especially on invertebrates. In addition to evidence from the literature, we contacted experts and practitioners to record their experiences of the effects of salt marsh and tidal flat restoration efforts and practical information about implementation. New evidence is continually emerging, and readers should take into consideration that this guidance document is currently underpinned by available evidence up until 2023.

Who is this document for?

This document is for practitioners and policy planners who are responsible for managing intertidal habitats, especially those that may be responsible for overseeing/managing restoration projects on tidal flats and/or salt marshes, and who are looking for practical guidance. The information provided focuses on how these systems can be managed as habitats for shorebirds, but this will also be useful for the conservation management of these habitats more generally.

The aim is to allow practitioners to easily consult and evaluate existing evidence and implementation knowledge before considering the practical implications relating to the situation at their site when deciding about future management and restoration.

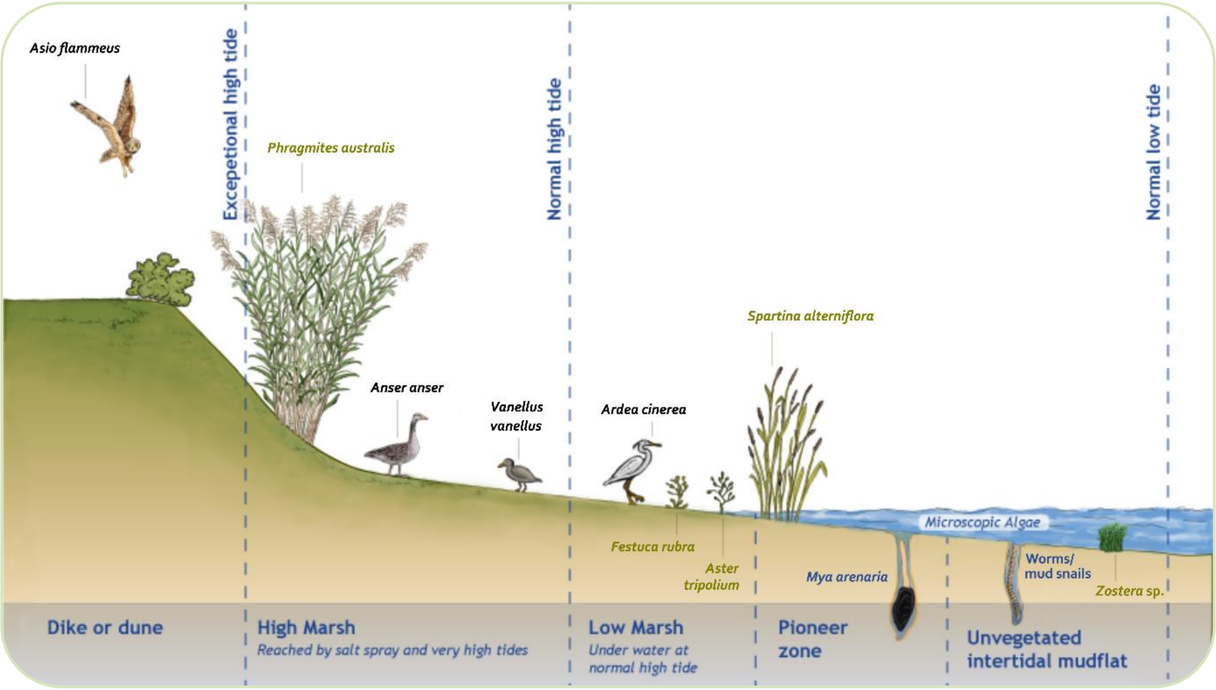
Structure of guidance

The guidance documents in sections 3 & 4 follow a set structure:

- **Objective:** A concise statement of the desired outcome of the intervention.
- **Definitions:** Of key technical terms used in the guidance document
- **Description:** A definition of the intervention and what it involves, explanation of the logic behind the intervention, and why the intervention is needed.
- **Evidence for effects on biodiversity:** Evidence, largely drawn from the scientific literature, about the effects of this intervention on biodiversity and the timescales over which they may occur. There is a focus on three groups that are key indicators of the state and functioning of coastal ecosystems (birds, invertebrates and vegetation) and, where possible, on quantitative evidence.
- **Factors that can affect outcomes:** A list of some major factors that may affect the outcomes of the intervention: generally related to (a) the local context and (b) how the intervention is done.
- **Implementation:** Notes about practical implementation to achieve the overall objective, for example, specific techniques that can be used, and practical issues to consider when carrying out the intervention. This is based on published reports, the experience of practitioners, and scientific literature.
- **Case study:** A specific illustrative example of the implementation of the intervention and its observed effects.
- **Other useful sources of information:** Sources that provide further detail and/or complement information in the guidance.
- **References:** Published sources referred to in the preceding text.

Description of salt marshes and intertidal flats

Salt marshes and tidal flats are found in the intertidal zone, the area between the reach of the highest high tide and the lowest low tide, and are subject to varying amounts of flooding by seawater. The ratio of salt marsh to tidal flat in the intertidal zone can vary (Atkinson *et al.*, 2001) but together, they provide a variety of different habitats for wildlife, including benthic invertebrates, fish and birds. They also provide important ecosystem services to people through coastal protection, water purification, carbon sequestration, food production and recreation (Barbier *et al.*, 2011).



An example of a coastal system showing variation in habitat and species present across the tidal range [Credit: Petra Dankers. Adapted from: EcoShape].

Tidal flats are large expanses of temporarily exposed soft substrates (sand or mud) that form where sediment deposits, often at the edge of estuaries or in sheltered sections of coasts. A key feature of tidal flats is that they are regularly inundated with water (Healy *et al.*, 2002), have sufficiently high mud content for the sediment to exhibit cohesive properties (Dyer *et al.*, 2000) and have no vegetation cover other than occasional seagrass. The International Union for Conservation of Nature (IUCN) classifies tidal flats as shoreline systems within the marine-terrestrial biome (MT1.2; Bishop *et al.*, 2020).

Salt marshes (also known as tidal marshes) are vegetated areas, typically found in the upper parts of the intertidal zone, experiencing less frequent flooding than tidal flats. Salt marshes naturally occur globally but are more well studied in temperate and northern regions. A key feature of salt marshes is the 'zonation' of the vegetation, whereby different plant communities establish in bands following bathymetric patterns, depending how tolerant they are of being submerged by saltwater (Davy, 2000). Vegetation is dominated by salt-tolerant forbs, grasses and shrubs, such as *Phragmites* spp. and *Sueda* spp., but not seagrasses (Keith *et al.*, 2020a). The IUCN classifies salt marshes as brackish tidal systems within the marine-freshwater-terrestrial biome (MFT1.3; Keith *et al.*, 2020b).

Salt marshes and tidal flats attract shorebirds for feeding, roosting and nesting. Different degrees of vegetation cover, fluctuating water depths, and varied sediment composition provide habitats that meet the needs of a wide variety of shorebird and other waterbird species, which have different requirements for foraging, roosting and nesting. Tidal creeks (networks of small drainage channels in tidal areas) provide foraging habitat for fish and invertebrates (Olmstead & Fell, 1974; West & Zedler, 2000). During high tide, these animals are able to invade the salt marsh via tidal creeks in order to feed and are subsequently preyed upon by larger fish and birds (Olmstead & Fell, 1974). Tidal flats have therefore been described as 'the supermarkets of the sea' because of their abundance of food that shorebirds can feed on, such as polychaete worms, molluscs and crustaceans. Many migratory shorebirds use intertidal areas as stepping stones to re-fuel before embarking on, or during, their long migrations and during the non-breeding period. Resident species of shorebirds and other waterbirds depend on these food sources throughout the year.

Tidal flats and salt marshes occur in estuarine systems worldwide, providing both ecological and economic value. However, these systems are vulnerable to a range of threats, which overall have led to a significant reduction in their extent. ***Top:*** Salt marshes at Saeftinge, Speelmansgat, The Netherlands [Credit: Edwin Paree]. ***Left:*** Shorebirds feeding on a tidal flat on the west coast of South Korea [Credit: Peter Prokosch, www.grida.no/resources/4394].

Why and how are they threatened?

Salt marshes and tidal flats are under pressure from a range of threats (Melville *et al.*, 2016). It has been estimated that 16% of tidal flats were lost globally between 1984 and 2016 (Murray *et al.*, 2019), while salt marshes are being lost at a rate of 0.3% per year (Campbell *et al.*, 2022).

Some of the main threats include:

Coastal development (including land reclamation): The expansion of human populations on coastlines has put increasing pressure on developing infrastructure and housing in these areas (Charlier *et al.*, 2005; Lai *et al.*, 2015; Murray *et al.*, 2019).

Reduced sediment supply: Activities upstream, such as river damming, limit the amount of sediment reaching estuaries, therefore the rate at which sediment is replenished is reduced relative to the rate it is eroded (Syvitski *et al.*, 2005; Dethier *et al.*, 2022). Similarly, the removal of sand from rivers is a major global environmental issue (Rentier & Cammeraat 2022) that reduces sediments reaching the coasts, including in the Yangtze and Yellow Rivers (Yang *et al.*, 2006; Yi *et al.*, 2022).

Sea level rise: Coastal areas are vulnerable to sea level rise, which leads to the erosion of shorelines and increased risk of flooding (Fujii, 2012; Passeri *et al.*, 2015). The combination of rising sea levels with coastal development, which prevents the landward movement of salt marshes and tidal flats, means there is simply less space available for these habitats. The resulting loss of intertidal habitats is called coastal squeeze (Pontee, 2013).

Sinking river deltas: Due to sediment compaction and reduced sediment supply, it is estimated that 85% of the world's deltas have experienced subsidence (Syvitski *et al.*, 2009). This impacts salt marshes and tidal flats by increased wave exposure, altered tidal inundation characteristics and increased erosion.

Habitat degradation: Intertidal habitats can become degraded from human activities such as bottom trawling, dredging and digging, which impact the benthic fauna (Dieter & McConnaughey, 2003). Many pollutants including heavy metals, pesticides, plastics and excess nutrients end up in estuaries from agriculture, aquaculture and domestic waste (Islam & Tanaka, 2004; Bessa *et al.*, 2018).

Invasive species: Invasive species spread through a variety of routes infiltrating coastlines and outcompeting native species (Reise *et al.*, 2023). The highly invasive Smooth Cordgrass *Spartina alterniflora* is a considerable threat to tidal flats and salt marshes on many shorelines including the Chinese (Zuo *et al.*, 2012; Stokstad, 2023) and Korean (Kim *et al.*, 2015, 2023) coasts. The deliberate introduction of native species for commercial purposes, for example molluscs, can be a threat to other native species by taking over ecological roles (Peng *et al.*, 2021).

Importance of salt marsh and intertidal flat restoration

The movement to restore salt marshes and tidal flats has been driven by increasing recognition of their value (Casagrande, 1997; Barbier *et al.*, 2011). Their protection and restoration benefits biodiversity by conserving and reinstating habitats, while maintaining vital functions required by people. Around 27% of the human population live near the coast (Kummu *et al.*, 2016) and depend on a range of services provided by coastal ecosystems. Most recorded coastal restoration projects occur in the USA, Europe and Australia, but this may be a reflection of data availability – more data about the successes and failures of restoration projects are urgently needed (Bayraktarov *et al.*, 2016). Restoring these habitats can be a cost-effective, nature-based solution to biodiversity loss and climate change.

Important functions and services of these habitats include:

Coastal defence: Salt marshes and tidal flats defend the coastline by slowing the incoming tide and dissipating wave energy, thereby reducing coastal erosion and protecting vulnerable human settlements from flooding (Arkema *et al.*, 2013; Pontee *et al.*, 2016; Reed *et al.*, 2018). They can form part of "green-grey" infrastructure, which mixes natural restoration with structures of the built environment such as seawalls and dikes (Green-Gray Community of Practice, 2020).

Carbon storage: Salt marshes and tidal flats are a major contributor to the amount of carbon sequestered in the marine environment, particularly due to their ability to store carbon in their soils and sediments (Duarte *et al.*, 2005; Chen and Lee, 2022; Maxwell *et al.*, 2023). As such, they have been identified as important blue carbon ecosystems (Macreadie *et al.*, 2021).

Many species are almost entirely dependent on coastal habitats during the migration season such as these Whimbrels *Numenius phaeopus*, Sundarbans, Bangladesh. [Credit: Sayam Chowdhury].

Biodiversity: Being at the interface between the terrestrial and marine worlds, salt marshes and tidal flats support a unique variety of wildlife, which function together as a large ecological complex (Daiber, 1986; Boorman, 2003). Salt-tolerant plants and benthic microalgae that live in the sediments are primary producers (Cloern *et al.*, 2014), which means they are at the base of the food chain. They support organisms at higher trophic levels, such as fish and mud-dwelling invertebrates, which subsequently provide food for foraging shorebirds and humans. Salt marshes and tidal flats are critical stepping stones in the flyways of migratory shorebirds, connecting breeding grounds at high latitudes with non-breeding grounds at lower latitudes.

The loss of intertidal habitats has caused declines in shorebird populations (Piersma *et al.*, 2016; Studds *et al.*, 2017) and is a key driver for the focus on their restoration.

Filtering of nitrogen pollution: Salt marshes can act as a buffer from nitrogen pollution, caused by run-off from agricultural areas where fertiliser has been applied. The uptake of nitrogen by salt marsh plants can increase their biomass and reduce the amount of nitrogen entering the ocean (Nelson & Zavaleta, 2012). The presence of filter feeders in tidal flats can significantly reduce nutrient and pollution loads in the water column (Officer *et al.*, 1982).

Supporting human livelihoods: Living in coastal areas provides opportunities for specific economic activities and trade (Kummu *et al.*, 2016). This is reflected in the fact that many large cities are close to the coast. Many communities are dependent on coastal ecosystems for food. For example, subsistence fishing provides protein-rich food and income in many countries (Bell *et al.*, 2009) and gleaning (the collection by hand of marine organisms from intertidal areas) is an economic activity specifically dependent on healthy tidal flat systems (Grantham *et al.*, 2021). Coastal areas also support tourism and recreational activities, although these can have negative consequences on sensitive coastal landscapes (Gormsen *et al.*, 1997).

Intertidal invertebrates are a key human food supply globally, with many communities being dependant on coastal systems for their livelihood. ***Left:*** A crab catcher searches for mud crabs at a tidal flat in Sonadia Island, Cox's Bazar, Bangladesh. [Credit: Sayam Chowdhury]. ***Bottom:*** Traditional shellfish harvesting on the former tidal flats of Seamangeum in South Korea. These tidal flats, along with the shellfish harvesting grounds, have been lost due to the embankment at Seamangeum. [Credit: Ju Yung Ki, www.grida.no/resources/4418]

Feeding, roosting and nesting sites for shorebirds

The availability of feeding, roosting and nesting sites in coastal habitats is essential for shorebirds. Many migratory shorebirds use coastal habitats as stepping stones in their migratory flyway. They use them as stopover or staging sites, where they stop for a period of days to weeks during migration to feed and refuel before a (often long-haul) flight (Warnock, 2010). Shorebirds mostly forage on tidal flats during low tide, following the tide as it moves across the flat. During periods of high tide they must leave their feeding grounds in intertidal areas. They move to areas where they are safe from high water and threats like predators, mostly to roost, but sometimes to continue feeding. They roost in so-called high-tide roosts (Rogers, 2003), either on exposed ground or in shallow water. The availability of both suitable high-tide roosting sites and feeding sites in a given area will affect bird abundance (Rogers *et al.*, 2006).

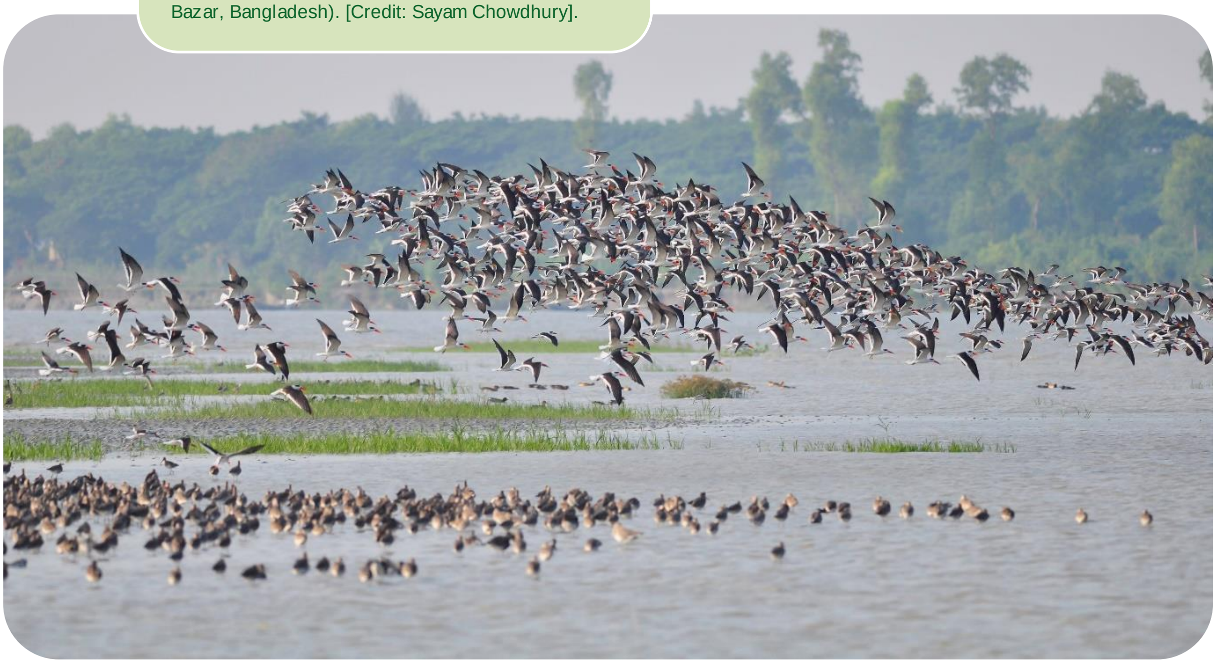
Some shorebirds prefer to roost in the upper portion of the tidal flats where they feed, in areas above the water level, but will also roost (and forage) in man-made features in intertidal wetlands (Rosa *et al.*, 2006; Fidorra *et al.*, 2015; Scarton & Montanari, 2015), such as aquaculture ponds (such as fish or crab ponds) (Li *et al.*, 2013) or salt production ponds (Sripanomyom *et al.*, 2011). Some species actually show a preference for such artificial habitats (Green *et al.*, 2015). It has been suggested that artificial habitats provide a buffer, a secondary role, or a complementary habitat for shorebirds when natural sites are not available (Li *et al.*, 2013; Rocha *et al.*, 2017; Jackson *et al.*, 2019). There are some concerns about the reliance of shorebirds on artificial wetlands in coastal areas (Jackson *et al.*, 2020). For example, if aquaculture or salt ponds fall out of use, or if they are converted to other land uses, shorebirds may be at risk. Therefore, management of artificial habitats should be considered alongside natural habitat creation and restoration.

In addition to providing valuable stop over sites for migratory birds, many coastal areas also provide nesting habitat to birds. As roosting and nesting are vulnerable behaviours, shorebirds prefer sites that are safe from disturbance from humans or predators (Rogers *et al.*, 2006; Rosa *et al.*, 2006). However, with the continuing loss of coastal habitat, safe and accessible roosting and nesting sites are becoming fewer (Studds *et al.*, 2017). This means that birds may spend more time flying between foraging and roosting sites, which uses up their precious energy reserves needed for migrating or reproducing.

Maintaining undisturbed roosting sites is essential for shorebirds. Here, Whimbrels *Numenius phaeopus* are roosting during high tide in the upper tidal flats that have not been covered by seawater in Moreton Bey, Queensland, Australia. [Credit: Micha V. Jackson].

Land reclamation has led to the loss of non-breeding stopover sites and subsequent population declines for shorebird species such as the endangered Great Knot *Calidris tenuirostris* (pictured above). Here they are feeding on the former Saemangeum tidal flat in South Korea. Developments on coastal wetlands has led to declines of non-breeding populations in South Korea. [Credit: Ju Yung Ki, www.grida.no/resources/4409].

Maintaining habitat for coastal birds can require sustaining both prey in the water column, as for the globally endangered Indian Skimmers Rynchops albicollis (top photo, Nijhum Dwip National Park, Bangladesh), and prey once the tide has receded, as for the critically endangered Spoon-billed Sandpiper Calidris pygmaea (right photo, Sonadia Island, Cox's Bazar, Bangladesh). [Credit: Sayam Chowdhury].



Box 1: The Yellow Sea ecoregion

The Yellow Sea is bordered by eastern China, Democratic People's Republic of Korea (North Korea) and the Republic of Korea (South Korea). Salt marshes and tidal flats are the principal coastal ecosystems in this region (Murray *et al.*, 2015), yet nearly 65% of tidal flats and nearly 60% of salt marshes have been lost since the 1950s and 1980s, respectively (Murray *et al.*, 2014; Gu *et al.*, 2018). The Yellow Sea tidal flats are now considered an endangered ecosystem under the IUCN Red List of Ecosystems due to the decline in their extent, the severity of their degradation and biotic disruption (Murray *et al.*, 2015).

Land reclamation is one of the main drivers of intertidal habitat loss in this region but existing intertidal habitats also suffer from degradation (Melville *et al.,* 2016; Gu *et al.*, 2018). In South Korea, around half of the tidal flats have been embanked since the 1970s (Koh & de Jonge, 2014) and in China, the seawall stretches for 13,830 km along the coast (Luo *et al.*, 2015). A typical salt marsh community in North and South Korea is dominated by *Phragmites communis* and *Suaeda japonica* (Kolbek *et al.*, 1989; Ihm *et al.*, 2001; Chung *et al.*, 2021), while in China the most extensive species are *Suaeda salsa, Phragmites australis, Aeluropus littoralis, Zoysia maerostachys* and *Imperata cylindrica* (Yang & Chen, 1995). However, there is evidence to suggest that reclamation and embanking could change the distribution of vegetation from a zonal pattern to a mosaic pattern by altering the salinity gradient (Feng *et al.*, 2018). Now, in parts of the Yellow Sea, there is next to no salt marsh, even in areas where a tidal flat remains (Melville *et al.*, 2016).

The Saemangeum Seawall on the southwest coast of South Korea separates the former Saegmangeum estuary from the Yellow Sea. Its construction caused controversy and opposition from some citizens and environmental groups. [Credit: Ju Yung Ki, www.grida.no/resources/4415].

The damming of both the Yellow and Yangtze rivers has drastically reduced the sediment supply to the coastline (Yang *et al.*, 2006; Wang *et al.*, 2012). Water use for irrigation and human consumption in the upper reaches of the Yellow River has also considerably reduced the fresh water flow to its delta (Yang *et al.*, 2020). Coastal groundwater extraction is associated with subsidence of up to 25 cm/year (Higgins *et al.*, 2013). In China, sewage disposal and the movement of chemical industries to the coast increases the risk of chemical pollution (Melville 2018). There are also huge outbreaks of macroalgae (e.g. *Ulva prolifera*) in China and South Korea, thought to be a result of multiple factors, including climate change, rising sea temperatures and eutrophication caused by increased nitrogen pollution (Zhang *et al*., 2019)

Coastal areas in the Yellow Sea are threatened by the invasive Cordgrass (*Spartina sp.*), a group of grasses native to Atlantic, European and African coasts. *Spartina* species have been introduced intentionally and unintentionally to many coastal areas globally. *Spartina* occupies large areas of open tidal flats and can facilitate the accumulation of sediment (Crooks, 2002; Civille *et al*., 2005). *Spartina* can be detrimental to shorebirds, making tidal flats and salt marshes inaccessible (Gan *et al.*, 2009; Jackson *et al.*, 2021; Lyu *et al.*, 2023), as well as by reducing the diversity of benthic macroinvertebrates. Research from the Wadden Sea and Australia shows that the diversity of arthropods and macrobenthos is higher in open tidal flat and native salt marsh than in *Spartina*-invaded marshes (Tang & Kristensen, 2010; Cutajar *et al.*, 2012). *Spartina* can outcompete native plants, including *Zostera* (Madden *et al.*, 1993), *Suaeda* (An *et al.*, 2007), *Phragmites australis*, and *Scirpus mariqueter* (Li *et al.*, 2022), decreasing the amount of food resources and nesting habitats for birds. The loss of intertidal benthic fauna, such as shellfish, can negatively impact human livelihoods (Gan *et al.*, 2010; Goss-Custard & Moser, 1988; Jackson *et al.*, 2021). *Spartina* is a well-known invasive, but it is not the only species to cause problems in intertidal habitats. For example, Black Swans (*Cygnus atratus*) are increasing in numbers in at least two coastal national nature reserves: Yellow River Delta and Chongming Dongtan (David Melville, pers. comm.).

The coastline of the Yellow Sea is a critical area for migrating birds and their reliance on this habitat as a migration stop over is a major cause of their decline (Studds *et al.*, 2017). The East Asian-Australian Flyway (EAAF) is a major bird migration route, where birds travel from Russia, China and Alaska to South East Asia, Australia and New Zealand. The Yellow Sea stopover accounts for around 40% of the birds travelling on the EAAF, with a yearly influx of around 3 million individual birds (Studds *et al.*, 2017). It is a critical staging region where the birds stop to feed and refuel while they prepare for next steps in their long-haul migration flight. In response to human population growth, many coastal areas have been converted to aquaculture ponds for food production (Sun *et al.*, 2015), with China being the leading aquaculture producer in the world (FAO, 2020). Although artificial, aquaculture ponds can in fact provide roosting and foraging sites for shorebirds, depending on how they are managed (e.g. Bohai Bay in China, Lei *et al.* 2018). Therefore, integrating waterbird conservation with economic productivity is something to be considered (Ma *et al.*, 2010). A healthy intertidal zone will benefit both birds and commercially important benthos.

Overall, the coastal ecosystems in the Yellow Sea ecoregion, and the species within, are under immense anthropogenic pressure. In 2018, China introduced strict regulations on land reclamation, whereby general land reclamation projects will no longer be approved (Miao & Xue 2021). In South Korea, opposition by citizens has had some success, for example a lawsuit by environmental groups was brought against the Saemangeum Reclamation Project, forcing the development to take the environment into account (Koh & de Jonge 2014; Song *et al.*, 2014). According to IUCN (2023), despite efforts to strengthen protection for habitats in the Yellow Sea, most especially in the intertidal zone, the trends for most species continue to decline (IUCN, 2023).

Other sources of information

Documents

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Videos

An example of the wider benefits of salt marsh and tidal flats: Cowden B. (2022, November 08) *Rewilding the Essex coast* [video]. Vimeo. www.vimeo.com/768722918

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Section 2 Planning

Guidance on…

Making evidence-based decisions for conservation management

Planning coastal restoration and setting targets

Conservation Guidance Series No. 1, v1.0

Guidance on making evidence-based decisions for conservation management

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Definitions

- **Evidence** = relevant data, information, knowledge and wisdom used to assess an assumption (Salafsky *et al.*, 2019).
- **Evidence-based practice** = the consideration of evidence in the decision-making process.
- **Evidence-based guidance** = a trusted source of information and recommendations based on the best available, up-to-date evidence to help decision-making (Downey *et al.*, 2022).

The aim of this section is to outline how evidence can aid decision-making. It comprises three elements. Firstly, describing the importance of guidance being evidence-based and the principles for creating evidence-based guidance. Secondly, listing a range of possible sources of evidence and finally briefly outlining the principles for evidence-based decision-making.

Creation of evidence-based guidance

To ensure guidance is trustworthy, Downey *et al.* (2022) provided a set of "Principles for the production of evidence-based guidance" (see Box 1 below). Key elements are that guidance is based on up-to-date, relevant evidence and integrates the knowledge and experience of experts and practitioners. An important consideration is that guidance is transparent about its sources with a comprehensive effort to include evidence to support the claims and assumptions made. This creates transparency by allowing the reader to locate the original source (if needed) that formed the basis for each claim. Using evidence to write guidance in this way can ensure that effective decisions are made based on the information that is currently available.

Besides informing us about the effectiveness (or ineffectiveness) of actions, evidence use also helps identify knowledge gaps. These knowledge gaps are revealed when there is no (or very little) documented information, for example for a certain species group, country or action. Consulting practitioners can help to fill these gaps, but practitioner knowledge should also be referenced. Understanding where gaps in our knowledge lie enables the prioritisation of future research (Christie *et al.*, 2021).

Much existing guidance relating to conservation is not evidence-based: few guidance documents include a reference list and even fewer provide sources to justify recommended actions (Downey *et al.*, 2022). This creates a problem when guidance influences decision-making, particularly if those decisions lead to heavy investment of time, money and labour into actions for which there is no evidence of their effectiveness.

Box 1 Principles for the production of evidence-based guidance

(taken from Downey *et al.*, 2022)

Collating evidence

1. *Scientific evidence should be reviewed and where available incorporated when formulating recommendations.*

Review the available scientific evidence on conservation actions (either from peer-reviewed studies, databases, grey literature or expert consultation) and extract key messages to inform the development of recommendations. There are now many databases available that synthesise relevant evidence, such as conservationevidence.com, environmentalevidence.org, and databases that collate grey literature such as Applied Ecology Resources (www.britishecologicalsociety.org/applied-ecology-resources). These can drastically reduce search, reading and interpreting time as well as overcoming access barriers. The evidence should be considered by stakeholders to judge its strength and relevance (Salafsky *et al*., 2019) and assessed alongside the experience and knowledge of stakeholder groups, which must include relevant experts. The date, search terms, and databases used for searching for evidence should be stated (Haddaway *et al*., 2015). Non-English language papers should also be considered in the search to avoid bias (Konno *et al*., 2020).

2. *Conduct repeated searches of the literature regularly and update guidance to include new studies when required.*

To ensure that guidance is based on the most up-to-date information, guidance should state when the evidence was searched and set review dates. We suggest reviewing the evidence every five years. When critical new information is available, guidance should be updated. Out-of-date guidance should be updated and then archived, with clear links to the updated version provided. If the original evidence synthesis clearly specifies its references and justification for recommendations, then updating the guidance will be easier and faster.

3. *Presentation and interpretation of evidence should be neutral.*

The information should be presented factually and objectively and those engaged in collating and synthesising the evidence should operate as neutral brokers. This can be difficult for some authors or organisations involved in the production of guidance, particularly where there is an advocacy objective or when they have been involved in producing the relevant evidence. It may therefore be beneficial to have guidance peer-reviewed or produced collaboratively across communities of practice, to avoid bias affecting the presentation of the evidence. Some organisations may find it hard to remove all advocacy of their agenda from guidance. Such conflicts of interest should be stated explicitly.

4. *Bias and limitations of the reviewed literature should be stated explicitly.*

State the problems (such as publication bias) and uncertainty that are inherent in any study or synthesis. Any potential bias or limitation in evidence searching and collation strategies should also be clear (Dicks *et al*., 2017).

5. *Where possible, assess and report on the cost (financial and other), cost-effectiveness, and side effects of potential interventions.*

Information on the costs and outcomes on factors other than biodiversity should be collected where possible. This should include possible areas of conflict, for example, with other biodiversity or socioeconomic priorities. This can help inform the recommendation process.

Making recommendations

6. *Specify the type and source of evidence used to make recommendations.*

Make clear what evidence has been used. Document the review process and sources (e.g. scientific papers, grey literature, expert opinion, indigenous knowledge). Details of methods should be provided either in the guidance document or in a linked source (e.g. weblink or QR code) that explains how the evidence was identified and extracted. This allows the details of the original studies to be available to those who are interested in further research.

7. *The strength of the evidence behind recommendations should be transparent.*

If there is uncertain or conflicting evidence this should be made apparent, either by explicitly describing the evidence or using appropriate terms (strong evidence, some evidence, weak evidence, studies predominantly support, etc.). The scale of inference should also be clear, such as if the evidence is based on a subset of conditions or varies with context (e.g. species, location).

8. *Make explicit where statements have been made in the absence of effectiveness information.*

Make cases explicit where no evidence exists and recommendations are based upon first principles, theory or common sense. Consensus recommendations are still valuable when made without scientific evidence, for example, based on practitioner knowledge and experience. Explicitly labelling these cases reveals gaps in evidence-based guidance that inform future research.

9. *Make explicit where recommendations are based on factors besides the evidence of effectiveness (e.g. costs, social acceptability).*

Some recommendations are derived from a range of factors beyond the available evidence base, such as financial costs or the acceptability of outcomes and side effects to different stakeholders. This logic and the key factors should be made clear in the guidance. For example, there may be good evidence for the effectiveness of an action, but it may be too costly or socially unacceptable and so is not recommended.

Making evidence-based decisions

There is no suggestion that users should simply follow the content of any guidance. Instead, the recommended practice is to combine the available scientific evidence (if using guidance, also updating with more recent material) with experience and local knowledge as well as with values; this process is shown in Figure 1.

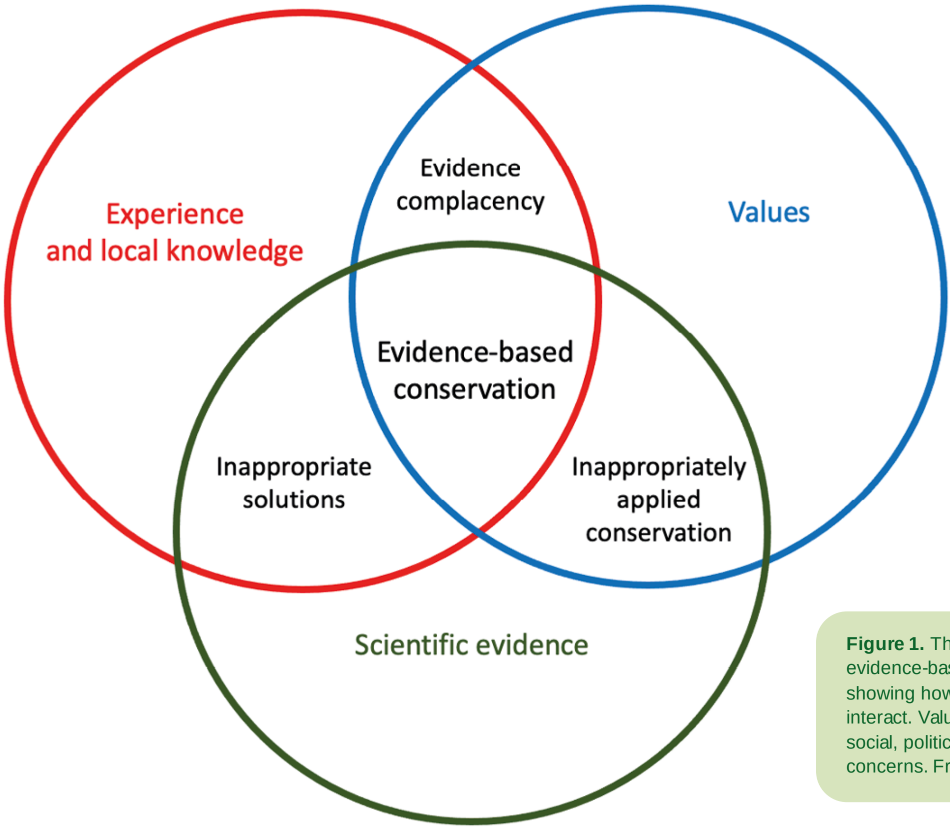

Figure 1. The role of evidence in evidence-based conservation, showing how the components interact. Values incorporate ethical, social, political, and economic concerns. From Sutherland (2022).

There are eight main stages of decision-making listed below with descriptions of good practice (Sutherland in prep). For details of approaches for carrying out each stage rigorously see Sutherland (2022).

Identify and frame the challenge: Formulate the issue, or issues, where there are problems or opportunities resulting in a need for decisions. Frame the issue in terms of what is being decided, including what is not being decided and the goals that are being sought.

Identify who to consult: Consider who should be involved in making decisions, overseeing decisions, consulted or informed. A stakeholder analysis is a good starting point.

Research the problem: Research the causes and consequences of the problem. The research may result in modifications of the challenge, for example by making it more specific.

Identifying options: One study showed that practitioners were only aware of 57% of the possible options for a particular topic (Walsh *et al.,* 2015). Solution scanning, in which options are extracted from the literature and practitioners followed by wide consultation to collate further options, is an approach for ensuring a reasonably comprehensive list.

***Identifying relevant evidence*:** Identification of relevant studies if already extracted or search of literature if not. The below section suggests sources of evidence.

Assessing evidence: Each piece of evidence is assessed according to its reliability and relevance. The assessed evidence is then combined to summarise the conclusions. For an action this would be the strength of the effect and confidence in the result.

Using experts appropriately: Experts providing and assessing statements (rather than making decisions, which requires combining with values that may differ from the decision maker). The literature shows there are numerous sources of bias that seriously impair the accuracy of experts. There are a range of techniques for reducing these biases including tools such as the Delphi Technique and IDEA protocol. Key elements are for scoring to be anonymous.

***Using a structured decision-making process*:** Structured approaches vary according to the issue but include multi-criteria analysis, argument maps, theories of change and cost-benefit analysis.

Sources of evidence

Listed below are some sources of evidence that apply to many conservation projects.

- Conservation Evidence database: This database collates and summarises documented evidence about the effectiveness of conservation actions (Sutherland *et al.*, 2019). All of the actions relevant to a specific subject are grouped into a subject "synopsis". As of February 2024, evidence for 24 different taxa or habitats had been collated.
- What Works in Conservation: An annual update of the information within the Conservation Evidence database on the effectiveness of actions is produced as a book, What Works in Conservation (Sutherland *et al*., 2021). All the information within each update is also presented within the searchable database.
- CEEDER (The Collaboration of Environmental Evidence Database of Evidence Reviews): Lists 1,920 reviews and systematic maps across the environmental field.
- PANORAMA: Allows practitioners to share and reflect on their experiences, by describing their projects and any lessons learnt.
- RESTOR: Database to share insights from nature conservation and restoration projects.
- Metadataset: A collection of open data from scientific publications. Provides over 15,000 effect sizes, mostly related to invasive species management.
- Specific papers, books, reports and other documents relating to the particular issue.

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Conservation Guidance Series No. 2, v1.0

Guidance on planning coastal restoration and setting targets

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A site should be thoroughly assessed and understood before developing a restoration plan [Credit: Edwin Paree].

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Restoration projects in coastal habitats are successful when they effectively reinstate the ecological values identified as having been lost or degraded due to human activities or natural events and successfully maintain it over time. Setting clear targets is the cornerstone of any successful restoration initiative, providing a reference point for achieving ecological, conservation, and community-related goals. In the context of shorebird conservation, the success of restoration depends on the ability to recreate vital habitats with specific ecological functions that are specific to the needs of shorebirds. For instance, if the objective is to restore a tidal flat crucial for shorebirds' feeding, the restoration process must ensure that the restored tidal flat can effectively serve this purpose. This involves respecting the morphological features of a natural tidal flat, preventing the growth of vegetation, as well as fostering the return of benthic fauna, ensuring appropriate and adequate food source for the birds. In addition to target setting, establishing a common and shared vision can increase ownership and participation of key stakeholder groups.

It is crucially important to understand the threats that have caused the degradation of the natural habitat and ensure that they have been addressed and eliminated. Restoring a natural ecosystem while the threats are still present would only lead to failure. Mangrove restoration, for instance, should only start after illegal logging and mangrove clearance has been stopped, otherwise it is much more beneficial and cost effective to ensure the conservation of existing natural ecosystems.

The guidelines presented here advocate for a stepwise approach to coastal habitat restoration, with target setting at its core. This approach provides a structured and systematic methodology, facilitating informed decision-making and adaptive management practices for sustainable ecological outcomes.

A stepwise approach to coastal habitat restoration:

1. **Identify the area/habitat/landscape:** Site selection considerations: Assess historical ecosystem distribution, current characteristics, and future landscape changes.
2. **Get to know the area:** Comprehensive site assessment: evaluate geomorphological, hydrological, and ecological features.
3. **Stakeholder engagement:** Identify and engage stakeholders and experts throughout the process, cultivating local ownership and expert involvement.
4. **Set SMART targets:** Identify conservation and restoration priorities and objectives, based on measurable and achievable targets.
5. **Identify ways to achieve targets:** Develop strategies based on scientific evidence and understanding.
6. **Design a restoration project:** Synthesise site assessments and stakeholder input to formulate detailed project proposals.
7. **Develop a restoration plan:** Detailed plan of action to achieve targets, outline tasks, responsibilities, and timelines.
8. **Develop a monitoring strategy:** Define indicators, protocols, and timelines for monitoring.
9. **Start implementation of restoration:** Putting the plan into action, execute interventions.
10. **Evaluate the success of interventions:** Restoration success assessment: evaluate outcomes against ecological restoration targets.
11. **Adapt the restoration plan:** Monitoring-informed adjustments: use monitoring data for adaptive management.
12. **Document the steps:** Maintain records of assessments, strategies, and implementation.

1. **Identify the area/habitat/landscape**

When selecting a restoration site, it is important to recognise the occurrence of natural processes that can either facilitate or impede successful restoration. Optimal sites for restoration are those where natural processes support and complement engineering interventions and other man-made restoration actions. This harmonious work with nature aligns with the principles of “Building with Nature” (van Eekelen & Bouw, 2020), ensuring that restoration work complements natural dynamics and local stakeholder interests.

Building with Nature principles:

“Building with Nature" is an approach that integrates Nature-based Solutions as a fundamental aspect of designing water-related infrastructure for coasts, rivers, deltas, and cities. It harnesses natural forces to benefit biodiversity recovery, the economy, and society as a whole. Adhering to the principles of Building with Nature, restoration efforts should strategically leverage the inherent dynamics of the selected site rather than contrasting them.

A practical example of this approach is evident in coastal restoration. In this context, a viable method to replenish an eroding coast involves depositing sediment in one location, allowing gradual and natural redistribution by wind, waves, and currents. This strategy minimises disturbance to local ecosystems while creating new areas for both nature and recreation (De Vriend *et al*., 2014; Ecoshape, 2020).

Another practical example comes from the approach followed under the Building with Nature Indonesia project in Demak. The flooding risk on an eroding coastline that once hosted a mangrove forest was addressed by constructing permeable dams made of brushwood. These dams are deployed to capture sediment and help establish a healthy sediment balance. Once the nearshore bed level has sufficiently risen, mangroves begin regenerating naturally, forming a natural water defence against flooding and further erosion (Wetlands International & Ecoshape, 2022).

Key considerations for site selection include the historical distribution of natural ecosystems, current geomorphological and ecological characteristics, and predictions of future landscape changes. Managed realignment is often particularly effective in areas with sediment accretion, where natural deposition processes can be encouraged to create or enhance coastal habitats (Atkinson, 2001). However, in sites experiencing erosion, where maintaining traditional coastal defences can be costly, managed realignment offers an alternative approach that may be more financially sustainable. Furthermore, an action may require continual maintenance (e.g. the expected inland movement of the shoreline as a result of subsidence and change of the relative sea level). Therefore, the cost–benefit trade-off needs to be considered alongside site suitability. This practical insight underscores the importance of site-specific features, guiding the restoration approach based on the inherent characteristics of the ecosystem.

Of course, it is important to consider the current state and functioning of the habitat. If the habitat is degraded and suboptimal for target species, then habitat creation could have ecological benefits. If the existing habitat is functioning well, creating additional tidal flat or salt marsh may be unnecessary or an inefficient use of resources (Yozzo *et al.*, 2004). This may also depend on the availability of sufficient roosting habitat to accommodate increased numbers of birds.

2. **Get to know the area: Detailed assessment of natural and socioeconomic conditions**

Conduct a comprehensive assessment of the selected site, considering its geomorphological, hydrological, and ecological characteristics. Understanding the natural dynamics of the area informs subsequent restoration decisions. Key aspects requiring assessment include the tidal range and positioning of the chosen site, sediment characteristics, the level of wave exposure, the amount of erosion and sediment deposition, topographic features (e.g. the distribution of tidal creeks), vegetation composition, benthic structure in tidal flat areas, the present and historical wildlife occurrences, and the predicted relative sea level change. These factors are pivotal in comprehending the site's ecological complexities, predicting its response to restoration interventions and communicating with stakeholders.

Assess the area while considering the wider landscape. It is important to learn of larger landscape-scale development plans, such as building of harbours, breakwaters or other construction in the intertidal areas in the vicinity that may affect volumes of sediment and flow patterns and local currents, as well as changes to river water flows into the area, through construction of upstream barrages that may affect sediment flows to the coast.

3. **Identify and engage stakeholders and experts throughout the process**

What works and does not work is critically dependent on understanding and responding to the socioeconomic environment. Therefore, stakeholder involvement is essential for sustainable success of a restoration project. Understanding stakeholder perceptions, misconceptions and areas of concern may influence planning.

Stakeholder groups should be identified through a stakeholder analysis (Golder & Gawler, 2005), categorising them based on industry, function, socioeconomic factors, and their stance on the restoration project. This classification prepares for potential hurdles and facilitates effective planning.

Engage professionals from diverse fields in an interdisciplinary manner to enrich the restoration plan with varied viewpoints and expertise. Additionally, it is vital to promote meaningful engagement through capacity-building endeavours, ensuring that local stakeholders and underrepresented groups possess the knowledge and skills to actively contribute. Capacity development may be necessary to secure agreement among all local communities and authorities concerning several aspects of the restoration project (FAO *et al.,* 2023).

Aligning with the “4 Returns Framework” enhances stakeholder engagement by fostering landscape-level partnerships and collaborative planning efforts. By embracing this approach, restoration initiatives become more than just ecological endeavours: they become catalysts for social, economic, and inspirational returns. Through a shared understanding of the landscape's challenges and opportunities, stakeholders co-create a vision for restoration, ensuring that projects are aligned with broader landscape goals. Moreover, the framework's emphasis on monitoring and learning enables adaptive management, allowing restoration plans to evolve in response to changing conditions and stakeholder feedback. This iterative process fosters greater stakeholder buy-in and long-term commitment to restoration efforts, ultimately enhancing project sustainability and success (Sterling *et al.*, 2017; Dudley *et al.*, 2021).

4 Returns Framework

The 4 Returns Framework is an approach for evaluating restoration feasibility at landscape scales (e.g. >100,000 ha) and for assessing how smaller projects fit within and contribute to the wider landscape. This conceptual and practical framework helps stakeholders to achieve returns in four areas – social returns, natural returns, financial returns, and inspirational returns. The framework follows five process elements:

1. Landscape partnership
2. Shared system understanding
3. Landscape vision and collaborative planning
4. Taking action
5. Monitoring and learning.

The elements are implemented within a multifunctional landscape (including natural zones, economic zones, and combined zones) over realistic time periods (indicative: minimum 20 years). Multiple restoration projects across several ecosystem types must go through an alignment and planning process that may take up to 2 years.

4. Set SMART targets: Specific Measurable Achievable Realistic and Time-bound

When setting targets for restoring habitats, it is necessary to take an approach focused on reinstating ecological functions rather than concentrating on delivering individual attributes (Atkinson *et al.*, 2001) or actions. In the field of restoration ecology, a crucial distinction is made between (real) ecological targets and management actions. The former pertains to the overarching goal of restoring an ecological function, such as transforming a degraded tidal flat into a thriving foraging habitat for waterbirds. On the other hand, the latter involves specific management actions, like removing invasive cordgrass *Spartina*, managing native vegetation, repositioning sediment, etc., which should be regarded as means to achieve the ecological target rather than targets themselves (Bakker *et al.*, 2000).

Reinstating an ecological function in a site through a restoration or conversion intervention may involve reducing or terminating another ecological function. Such trade-offs should be clearly identified and carefully considered. For example, creating a mangrove forest with fish nursery and wave attenuation functions on an open tidal flat may contravene or reduce the function of that tidal flat as a feeding habitat for shorebirds or for mollusc collection by local communities. Historic function of the site, next to scarcity and desirability of the target functionality, may help decide where to aim in such trade-off situations.

The identification of a clear and specific target becomes the cornerstone for selecting appropriate restoration actions to restore the desired ecological function.

SMART criteria

To enhance the effectiveness of restoration efforts, targets should adhere to the SMART criteria: Specific, Measurable, Achievable, Realistic, and Time-bound. Examples of well-formulated targets could include:

1. Restore 50% of the tidal flat to support the foraging and roosting habitat for waterbirds in the next 5 years.
2. Increase salt marsh extent by 50% to provide nesting sites for an endangered shorebird species in 5 years.
3. Improve sediment composition to ensure that the benthic fauna recolonises the target area, and that the community consists of species suitable for shorebirds to feed on.
4. Restore two effective high tide roost sites by converting aquaculture ponds into open, shallow water areas suitable for high tide roosting for waterbirds within 1 year.

5. Identify ways to achieve targets: Developing strategies based on scientific understanding

Craft a strategy outlining the specific actions required to achieve the set targets. Identify those actions that will deliver the necessary results as steps towards the targets, based on evidence. Identify any assumptions and risks associated with such actions. The actions that are part of such a strategy may involve landscape modification, vegetation management, or other interventions tailored to the identified needs of the ecosystem.

Several restoration actions are mentioned in the sections below. It needs to be stressed again that these individual actions themselves are not the target, but one or more of these actions lead to the achievement of the ecological restoration target.

6. **Design a restoration project**

In order to craft an effective restoration plan, first a project design should be developed. The design integrates findings from the site assessment and the stakeholder consultation process. This phase involves synthesising scientific understanding and stakeholder input to develop a comprehensive framework for restoration efforts. By tailoring interventions to address the site's ecological complexities and aligning with local interests and priorities, the design ensures that restoration actions are effectively targeted. Additionally, this phase facilitates proactive planning to identify potential challenges and opportunities, enhancing the sustainability and success of restoration initiatives.

Importantly, the design should incorporate the adoption of an adaptive-management approach, allowing for modifications informed by the evaluation of monitoring results. Thus, the design should inherently facilitate adaptive management to accommodate evolving circumstances and optimise restoration outcomes.

7. **Develop a restoration plan: Detailed plan of action to achieve targets**

Drawing from the strategies identified in the project design, the next critical step in the restoration process involves the formulation of a comprehensive restoration plan. This plan should delve into the specifics, outlining detailed tasks, assigning responsibilities, and establishing timelines for the implementation of each identified strategy. If possible, it is helpful to determine the necessary resources, encompassing aspects like labour, equipment, and materials. The formulation of the plan should also account for potential challenges that may arise during implementation, offering a proactive approach to handling unforeseen circumstances.

The development of a restoration plan should be a collaborative effort, co-created with stakeholders and partners who were identified during steps 2 and 3. The participatory approach ensures that diverse perspectives are considered, enriching the plan with a comprehensive understanding of the project. The restoration plan functions as a crucial document, serving as a comprehensive guide for all those involved in the project. Its clarity enables anyone engaged with the initiative to grasp the project's objectives, understand the necessary actions, identify decision points, and gauge the financial requirements essential for the project's success (Beeston *et al.,* 2023).

8. **Develop a monitoring strategy**

To track the progress and success of the restoration plan, a comprehensive monitoring strategy is indispensable. This strategy involves defining key indicators, measurement protocols and timelines.

Defining targets and monitoring for ecological restoration are intricately intertwined. Monitoring serves as an essential tool to evaluate whether targets are met within a specified timeframe. The methods employed should align with the project's targets (step 5), emphasising simplicity, participatory processes and costs.

The selection of monitoring indicators must be tailored to the project's objectives, the specific ecosystem under restoration, and the site's unique conditions. Monitoring should take place before and after intervention. In addition, monitoring should compare indicators between the intervention and control sites, where restoration activities occur and do not occur, respectively. This comparative analysis aims at measuring the net difference the project makes toward achieving the desired ecological state.

Data collection should be conducted according to standard and scientific approaches, including, for instance, vegetation surveys, benthos surveys, assessment of bird (roosting) numbers and (feeding) densities and habitat use monitoring. It may also be important to consider human use of sites in instances when a restored area contains commercially important species that may be harvested.

Where available, species and habitat monitoring should be carried out according to coordinated and standardised monitoring protocols. In this regard, the East Asian-Australasian Flyway Partnership (EAAFP) encourages the development of a coordinated waterbird monitoring and reporting protocol to be adopted by the EAAF countries.

Securing dedicated funding streams or budget reservations for monitoring activities is essential. Collaboration with relevant governmental departments, policymakers, and stakeholders is crucial to highlight the importance of monitoring in achieving restoration objectives. Clarifying roles and responsibilities for monitoring within the governance framework ensures efficient resource allocation and governance alignment, enhancing project effectiveness and long-term sustainability.

Examples of indicators for assessing coastal wetland ecosystems restoration projects. These indicators are most informative when a restoration site is compared to a pre-restoration baseline and/or a reference site. Adapted from Cadier *et al*., (2020) and Atkinson (2001).

Attribute category	Indicators
Biological conditions	• Species richness and diversity • Species abundance, percentage area cover and biomass • Presence of threatened species
Physical conditions	• Soil and sediment physiochemical conditions • Water physiochemical variables • Bathymetry • Current intensity
Absence of threats	• Biological threats (e.g. invasive species) are absent from the restoration area • Extraction of resources by people is sustainable • Pollution levels

9. **Start implementation of a restoration plan: Putting the plan into action**

   Begin the implementation of the restoration plan, carefully executing the outlined interventions while considering the ecological sensitivities of the habitat.

10. **Evaluate the success of interventions: Comparing outcomes with set targets**

   Consistent evaluation of restoration outcomes against predetermined targets is pivotal for success. The efficacy of restoration efforts is intricately linked to the identified targets. Assessing outcomes at the target level, rather than merely the means level, is crucial. For instance, monitoring the success of *Spartina* removal solely informs about the presence or absence of *Spartina,* yet it does not provide insights into the broader restoration of the tidal flat's health, for example as a foraging habitat for shorebirds, such as the re-establishment of the native salt marsh community.

   Functional success is an important concept that assesses whether the ecological functions of the system have been restored (Atkinson, 2001). This encompasses, for instance, the restoration of intertidal habitats' ability to support food chains, attenuate wave action, and improve water quality. Monitoring efforts must extend beyond the immediate factors to encompass broader ecological indicators. In the case of tidal flat rehabilitation through *Spartina* removal, alongside tracking the invasive species' presence or return, it is imperative to monitor the benthic composition of the restored tidal flat and the return of foraging bird populations. The continuing success of an action, as well as its initial success, is key. This comprehensive approach ensures a holistic evaluation, aligning with the restoration's overarching goals and contributing to the long-term success of the intervention.

   A practical tool to aid in the evaluation of restoration work is offered by the 5-star Recovery System (www.ser.org/page/SERNews3113) developed by the Society for Ecological Restoration and widely adopted to assess the success of restoration initiatives worldwide. This structured approach allows for assessing and ranking a site's progress towards ecosystem recovery. Using a 5-star scale, it evaluates the similarity of a restored ecosystem to a reference system, providing a comprehensive understanding of recovery. The system allows for overall assessments or individual evaluations of specific ecosystem attributes, promoting continuous improvement. While aimed at achieving full ecosystem recovery, the system is adaptable for projects focusing on specific functional attributes. However, its reliability depends on robust monitoring data, emphasising the importance of comprehensive monitoring plans tailored to each site (McDonald T. *et al.*, 2016).

11. **Adapt the restoration plan: Flexibility and adaptive management**

   Use monitoring data to inform adaptive management. If the outcomes deviate from expectations, be prepared to adjust the restoration plan accordingly, ensuring a responsive and dynamic approach. This may involve liaison meetings with stakeholders (e.g. annual reviews) to assess the progress, with the option of tweaking the restoration plan, while maintaining the overall objectives. In cases where the predefined target is not attained, further investigation is required to understand whether the discrepancy results from inappropriate restoration actions, insufficient implementation, unrealistic, targets or unforeseen external factors, such as changes in government policy or catastrophic events.

12. Document the steps: Thorough documentation for future reference

Maintain detailed documentation throughout the entire process. This includes records of assessments, target setting, strategies, implementation procedures, resources required, and any adjustments made. Monitoring efforts should be recorded and both the successes and failures of interventions should be reported. The results of a restoration project should be summarised and translated in an accessible way, so that they are usable to decision-makers, such as practitioners and policy makers. Documentation provides a valuable resource for future reference and informs best practices for subsequent restoration projects. Consideration should be given to having data be open-access, or adding results to open access repositories including national or international databases.

Other sources of information

Public perceptions of coastal restoration: Yamashita H. (ed.) (2021) *Coastal Wetlands Restoration: Public Perception and Community Development*. Routledge: London. https://doi.org/10.4324/9780367863098

OMReg: A database of coastal habitat recreation schemes. Available at: www.omreg.net/

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Section 3 Restoration approaches

Guidance on…

Facilitating tidal exchange to restore/create salt marshes and intertidal flats

Using sediment to restore/create salt marshes and intertidal flats

Reprofiling salt marshes and intertidal flats

Restoring or creating salt marsh vegetation

Managing vegetation on intertidal flats

Chemical control of *Spartina* spp.

Physical control of *Spartina* spp.

Integrated control of *Spartina* spp.

Conservation Guidance Series No. 3, v1.0

Guidance on facilitating tidal exchange to restore/create salt marshes and intertidal flats

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Managed realignment in the Westerschelde, The Netherlands. [Credit: Edwin Paree]

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Objective: create or restore coastal habitat by reinstating or managing the tidal regime

Definitions

- **Benthic invertebrates** = invertebrates living at the bottom of the water column (macro: >1 mm; meio: < 1 mm; micro: < 0.1 mm).
- **Ebb** = period from high water to low water, i.e. when the tidal waterline is retreating.
- **Intertidal zone** = area between high and low tide.
- **Managed realignment** = a technique where coastal defences (e.g. sea walls) are breached or removed to reinstate tidal exchange, allowing an area previously protected to become flooded. Also known as 'managed retreat'.
- **Regulated tidal exchange** = allowing regulated flow of tidal water through existing coastal defences. Sometimes referred to as 'controlled reduced tide'.
- **Spring tide** = Extreme tides occurring when the Sun, Moon and Earth are aligned leading to strong gravitational pull. These produce the highest and lowest tides that regularly occur. Spring tides occur twice each month.

1. Description

Tidal exchange permits the periodic inundation with sea water that is a defining feature of tidal flats and salt marshes. Tidal exchange can be facilitated by breaching or removing the existing coastal defences, as in managed realignment, or controlling tidal flow through existing coastal defences, as in regulated tidal exchange (Ausden, 2007; Scott *et al.*, 2012). Often, the aim is to restore tidal exchange to impounded salt marshes, where roads or bridges, for example, restrict tidal flow (Ausden, 2007). New defences typically need to be built further inland to protect human infrastructure and farmland from flooding.

This intervention has been used extensively in Europe, namely the UK, Germany and the Netherlands (Wolters *et al.*, 2005; Rupp-Armstrong & Nicholls, 2007; Scott *et al.*, 2012). One of the major benefits of replacing hard coastal defences, such as sea walls, with salt marshes and tidal flats is that the natural defences provide protection from flooding with reduced maintenance costs. As such, economic benefits of intervention can exceed the costs, making funding decisions clear.

2. Evidence for effects on biodiversity

Effect on birds**:** Sites with restored tidal exchange are known to support shorebirds, with bird numbers beginning to increase within one to three years (Slavin & Shisler, 1983; Brawley *et al.*, 1998; Atkinson *et al.*, 2004; Natuhara *et al.*, 2005; Badley & Allcorn, 2006; Armitage *et al.*, 2007; Mander *et al.*, 2007; Elliot, 2015). The community may change after facilitating tidal exchange, compared to what it was before. For example, at Osaka Port, Japan, the number of shorebirds increased five-fold after tidal introduction on reclaimed land (Natuhara *et al.*, 2005), with ducks (e.g. Common Pochard *Aythya ferina*) being replaced by plovers (Charadriidae) and sandpipers (Scolopacidae). Habitat preference may differ among species. For example, at a restored site in California, USA, Willet *Catoptrophorus semipalmatus* and dowitchers (*Limnodromus* spp). preferred extensive tidal flats, while godwits (*Limosa* spp.) and sandpipers (*Calidris* spp.) preferred habitats with a mix of water and tidal flats (Armitage *et al.*, 2007). Note that there may be a trade-off when creating habitat for birds, between breeding and foraging space.

Effect on invertebrates: Macrobenthic invertebrates can colonise quickly, with biomass densities reaching similar levels to those in comparable areas of 'natural' tidal flat within two to five years (Mazik *et al.*, 2010; Malcom Ausden, pers. comm.), but it can take decades for the community structure to fully develop (Craft & Sacco, 2003; Reading *et al.*, 2008). In a restored tidal flat in Osaka, Japan, chironomids were replaced by polychaetes and gammarids after reinstating tidal flow, and there were fewer brachyurans and molluscs compared to natural tidal flats in Japan (Natuhara *et al.,* 2005). The time taken for invertebrates to reach natural levels will depend on the characteristics of the species and their requirements. For example, in created marshes in North Carolina, USA, species with dispersing larval stages reached natural levels within three years, while earthworms (oligochaetes) took 25 years to reach densities similar to natural marshes (Craft & Sacco, 2003).

Effect on vegetation**:** In many cases where tidal exchange has been facilitated (and where areas were of a suitable elevation), vegetation characteristic of salt marshes develops within one to two years (Barrett & Niering, 1993; Dagley, 1995; Brockmeyer *et al.*, 1996; Burdick *et al.*, 1996; Roman *et al.*, 2002; Thom *et al.*, 2002; Williams & Orr, 2002; Badley & Allcorn, 2006; Garbutt & Wolters, 2008; Wolters *et al.*, 2008; Hughes *et al.*, 2009; Howe *et al.*, 2010; Mossman *et al.*, 2012; Rochlin *et al.*, 2012; Elliot, 2015; Chang *et al.*, 2016; Flitcroft *et al.*, 2016; Clifton *et al.*, 2018). However, the vegetation community of restored areas may remain different from natural salt marshes after more than 30 and 50 years (Elphick *et al.*, 2015; Flitcroft *et al.*, 2016). In some cases, facilitation of tidal exchange is followed by little or no change in the amount of vegetation for up to four years (Buchsbaum *et al.*, 2006; Konisky *et al.*, 2006; Kadiri *et al.*, 2011).

3. Factors that can affect outcomes

Site area**:** Before facilitating tidal exchange, the amount of space available for intertidal habitat needs to be considered. If infrastructure is too close to the coast, new intertidal habitat and its associated wildlife will have limited space to develop behind the breached defences (Howe *et al.*, 2010; Morris, 2013). The size (and isolation) of a restoration site may also influence the species that establish there. Small sites may never develop the full range of biodiversity that is seen in large natural sites (Atkinson *et al.*, 2004; Wolters *et al.*, 2005). One review found that the highest species diversity occurred in sites over 100 ha (Wolters *et al.*, 2005). At a site in Japan, the population of large sandpipers and snipe (Scolopacidae) decreased even after the enlargement of the tidal flat and it is speculated that the area (2.6 ha) was too small for these species (Natuhara *et al.*, 2005).

Elevation: Elevation influences the amount of flooding on a site, therefore, the habitat that forms will be strongly influenced by the existing height of the land. One review found site-level species diversity was highest in salt marshes with the largest elevation range (Wolters *et al.*, 2005). At a site in England where a sea wall was breached, the area supported wintering waterbirds, but not breeding waders because the site was too low, meaning the entire area was flooded during spring tides (Badley & Alcorn, 2006). Maintaining sediment supply will, in turn, maintain the desired elevation. The size and number of breaches can influence the amount of sediment entering a site, and therefore the habitat that develops. Wider or more frequent breaches allow more sediment to enter the site, favouring development of salt marshes rather than tidal flats (Morris, 2013). Additional fill material may be added (see Cutts *et al.,* 2024), but it is generally sensible for the target state to be dictated by the existing elevation/topography of the site (Mark Dixon, pers. comm.).

Drainage: Well-drained salt marshes may be more resistant to erosion (Atkinson *et al.*, 2001) and can support a greater diversity of species (Wolters *et al.*, 2005). Poor drainage can affect the plant species that grow, favouring those tolerant of moisture and anaerobic conditions (Atkinson *et al.*, 2001). When restoring intertidal habitats, it is important to avoid permanent inundation.

Sediment: The development of tidal flat and salt marsh habitat will also depend on the transport paths of sediments and the stability of the substrate in relation to the prevailing hydrodynamic forces, including the amount of wave energy that can move through the breach (Williams & Orr, 2002; Morris, 2013). The grain-size composition, water-retaining capacity and degree of compaction of the sediment are also important factors to consider. The sheltered conditions within managed realignment sites on estuaries that have high levels of suspended sediment can result in high rates of sediment accretion, resulting in the rapid development of salt marsh at the expense of mudflat (Mazik *et al.*, 2010). Note that wave action within a site can re-suspend deposited sediment, slowing the process of sedimentation (Morris, 2013).

***Distance from natural sites*:** If a site with restored tidal exchange is left to revegetate naturally, the appearance of vegetation will depend on the distance from source populations of target species, which will determine how easy it is for them to colonise (Bakker *et al.*, 1996; Elsey-Quirk *et al.*, 2009). Seeds of salt marsh plants will arrive via tidal water (Malcom Ausden, pers. comm.). Experimental evidence found that bivalves colonised via the water column, while polychaete colonisation was hindered by fences, suggesting that lateral movement is important (Negrello Filho *et al.*, 2006). Note that the functional distance to source populations matters here, not the mathematical distance: a seed source 1 km upstream or up-current of a restoration site is functionally closer than a seed source 1 km downstream or down-current. Implementing this action before dispersal season may allow vegetation to colonise more quickly (Wolters *et al.*, 2005). Around much of the Yellow Sea in China, vegetation has been slow to colonise due to the reclamation of upper marsh areas (David Melville, pers. comm.). Slow colonisation by desirable vegetation presents an opportunity for invasive species, such as Smooth Cordgrass *Spartina alterniflora*, to do so.

Invertebrates: The presence of different species of invertebrates influences whether birds will use the site. For example, at a site in the UK, Eurasian Oystercatchers *Haematopus ostralegus* did not occur as there were no large bivalves, whereas Red Knot *Calidris canutus* used the site after four years coincidentally with the appearance of a saltwater clam *Macoma balthica* (Atkinson *et al.*, 2004).

Vegetation: The initial increase in the amount of surface water on a site may eliminate breeding habitat for specialised birds, but the eventual re-establishment of salt marsh vegetation can re-create ideal breeding conditions (Brawley *et al.*, 1998).

Proximity to man-made structures: Man-made structures could deter some birds by obstructing their view of predators (Erftemeijer, 2023). One study found shorebird species diversity at a restored site to be lower closer to man-made structures (Armitage *et al.*, 2007).

4. Implementation

Breaching coastal defences: The width of a single breach can range from 20 m to 150 m (Thom *et al.*, 2002; Mazik *et al.*, 2010; Elliot, 2015) but in some cases multiple breaches are dug (Hughes *et al.*, 2009). The number of breaches needed will depend on the tidal range and the bathymetry of the area to be flooded (Hand Winterwerp, pers. comm.). Breaches could be located where there is an existing sluice (Mark Dixon, pers. comm.). It is recommended to start excavation during neap tide, as the tide ebbs, with the final breaching undertaken in one ebb tide cycle on one day only (Mark Dixon, pers. comm.). Once the final breach is made there is no going back, so it is recommended that the material is loaded and carted at the same speed as it is excavated from the breach, and that there are escape routes for machinery to get off site as the tide comes in (Mark Dixon, pers. comm.).

If breaches are too narrow, tidal exchange can be restricted, limiting the amount of sediment entering the site (Williams & Orr, 2002), while larger breaches can be more costly. The size and number of breaches will influence the frequency and depth of inundation, and the amount of sediment entering a site. Be aware that scour holes can form around breaches at their base, caused by fast flowing water (Whitehouse, 2006). Extreme weather events caused by climate change could affect breaches, for example with the increase in typhoons in China (Huang *et al.*, 2022; David Melville, pers. comm.)

***Modifying culverts or other openings*:** Culverts channel water through or under a barrier or obstruction, such as a road. Culverts can be removed or their diameter increased to allow more tidal exchange (Streever & Genders, 1997). Where culverts have allowed sufficient tidal flow, their diameter has ranged from 0.75–2.10 m (Barrett & Niering, 1993; Burdick *et al.*, 1996; Brawley *et al.*, 1998; Roman *et al.*, 2002; Buchsbaum *et al.*, 2006; Wolters *et al.*, 2008). Culverts or other openings can be used for regulated tidal exchange by placing tidegates on them (Ausden, 2007). This consists of a hinged door that opens in a seaward direction, allowing the flow of water to be self-regulated as the force of the incoming tide pushes the gate closed. Floats can be used to open the gate based on changes in water level (e.g. Ridgway & Williams, 2021). Electronically operated gates can also be used (Ausden, 2007).

Drainage: Channels can be constructed to improve drainage and provide foraging habitat for fish and invertebrates (Olmstead & Fell, 1974; West & Zedler, 2000). Alternatively, it is suggested that a natural drainage system can develop following deep ploughing to crack existing land drains (Mark Dixon, pers. comm.).

Vegetation: It is suggested that existing terrestrial vegetation should be cut back or removed before flooding, to prevent rapid die off post-breaching, which can pollute adjacent tidal systems (Mark Dixon, pers. comm.). Furthermore, chemical application on vegetation should stop six months prior to breaching to prevent a 'pulse' of chemicals into tidal waters (Mark Dixon, pers. comm.).

Capturing fresh water: Constructing low-level bunds or excavating lagoons to capture any fresh water that is coming into the site pre-breaching can considerably improve the value of a site for birds by providing fresh water to drink and preen in (Mark Dixon, pers. comm.).

Counter walls: Tidal inundation can be limited to the target area by constructing new defences or 'counter walls' (e.g. Reading *et al.,* 2008). Consider using curved wall faces to better reflect wave energy (Mark Dixon, pers. comm.). Existing footpaths can be diverted onto counter walls (Mark Dixon, pers. comm.). The tide may naturally reach higher ground in some parts of the site, in which case counter walls may not be needed (e.g. Leeds, 2016). Counter walls can be expensive to build and maintain, so allowing the tide to move to higher land can keep costs down (Mark Dixon, pers. comm.).

Case Study: Meddat Marsh, Nigg Bay reserve, Scotland

Meddat Marsh in the Nigg Bay RSPB reserve was the first salt marsh created through managed realignment in Scotland. Over one third of the salt marsh in Nigg Bay had been lost between 1946 and 1977. The sea wall that was built in the 1950s had no salt marsh in front of it, which meant it was constantly being eroded by wave action, resulting in high maintenance costs.

Meddat Marsh was purchased by the RSPB from a local landowner to be used as the realignment site. In 2003, the existing sea wall was breached. Two breaches 20-m-wide were dug using a mechanical digger across sites of relict channels, which allowed fast incoming tide but slow outgoing tide. Secondary defences were built to prevent the neighbouring land from being flooded.

The rationale for breach design: Using two breaches provided sufficient inundation whilst retaining some sheltered conditions for vegetation to establish and for creeks to develop. Removing the entire sea wall was too expensive and would have provided no shelter. Allowing the sea wall to breach naturally was an option, but strategic placement of the breaches was preferred.

The site was repeatedly monitored before and after breaching the seawall. Salt marsh plants began to colonise within six months. Within 10 years, salt marsh vegetation was dominant and covered the majority of the site; mud-dwelling invertebrates that are eaten by birds were recorded, 25 species of waterbirds were recorded with up to 2,000 individuals using the site, and 20–30 cm of sedimentation occurred. Overall, this created 20 ha of salt marsh and 5 ha of pioneer salt marsh and tidal flat habitat, increasing these habitats by 23% in the Nigg Bay reserve. The sea wall required no maintenance during this time.

Sources: Elliot (2015); Video: Restoring salt marsh (youtube.com/watch?v=aiOl8bjctAw)

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Disclaimer: These guidelines have been developed through a thorough assessment of available evidence, including a literature review from various global sources, complemented by insights from experts in the field. Their aim is to provide practical insights and recommendations for coastal habitat restoration efforts worldwide. Practitioners and professionals are encouraged to apply their expertise and judgement when using this guidance, adapting it as necessary to address their specific contexts and requirements. It is important to note that stakeholders interested in replicating the approaches presented here assume full responsibility for the success and sustainability of their implementation.

Conservation Guidance Series No. 4, v1.0

Guidance on using sediment to restore/create salt marshes and intertidal flats

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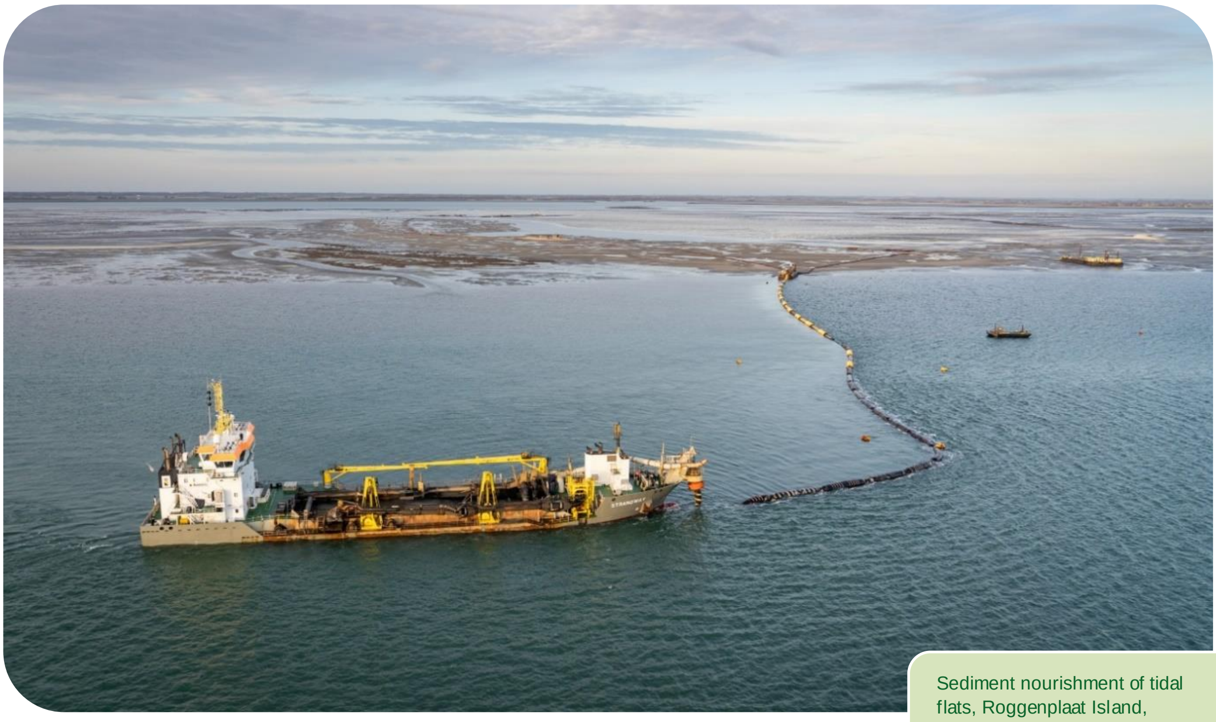

Sediment nourishment of tidal flats, Roggenplaat Island, Oosterschelde, The Netherlands. [Credit: Edwin Paree]

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Objective: create or restore intertidal habitat

Definitions

- **Benthic invertebrates** = invertebrates living on or in the substrate at the bottom of the water column (macro: >1 mm; meio: < 1 mm).
- **Biofilm** = a cluster of microorganisms that stick to each other and often to a surface.
- **Dredged sediment** = sediment/debris removed from the bottom of water bodies, such as harbours, lakes and rivers and sea.
- **Dredge islands** = artificial islands created with the controlled disposal of dredged sediment.
- **Intertidal recharge** = using dredged sediments to restore coastal habitats.
- **Intertidal zone** = area between high and low tide.

1. Description

This guidance describes the use of sediment to restore tidal flats and salt marshes by depositing large quantities of sediment to form the physical structure. Adding sediment can alleviate threats such as erosion, sea level rise, land subsidence and reduced sediment discharge from rivers or the sea. This guidance does not include manipulating sediment flows up stream (e.g. dam removal).

The successful creation of a functioning tidal flat or salt marsh ecosystem must aim to mimic (as much as possible) the morphology and composition of natural tidal flats and salt marshes, with a view of the prevailing hydrodynamic forces, tide and other environmental conditions in the area. Such considerations are important to ensure the long-term (dynamic) stability of these habitats. Study of historical topographic maps and satellite imagery can help to reconstruct former tidal flat and salt marsh areas.

2. Evidence for effects on biodiversity

Birds: The use of dredged material as habitat by shorebirds is well documented (Golder *et al.*, 2008; Yoon *et al.*, 2018; ABPmer, 2020). Both natural and created tidal flats can provide habitat for shorebirds, but it is not fully understood if they have the same bird communities (Atkinson, 2003). Whether, and how quickly, shorebirds will use artificially created tidal flats or islands depends to a large extent on the function that it has been designed for. Open dry or shallow water areas created for roosting may be used immediately if sufficient feeding habitat is available in the vicinity to already support populations of shorebirds. Distance to these feeding habitats and suitability for roosting (no access for predators, minimal disturbance) will be important determining factors in this. For dry nesting habitat the breeding season following the creation may already see birds using it if the required vegetation cover (ranging from none to substantial, depending on the target species) has been achieved (see Cutts *et al.,* 2024a). For feeding habitat, the created tidal flat needs to have been able to build up a population of invertebrates before the birds can start feeding on them, which may require a colonisation interval (Evans *et al*., 1999).

***Invertebrates*:** Macrobenthic invertebrates can colonise created tidal flats and reach similar overall abundance to that of natural tidal flats. For example, a study in Ago Bay, Japan, saw similar or even higher biomass of macrobenthic fauna develop over a 20-month period compared to nearby natural tidal flats. In Moune Bay, Japan, restored tidal flats (following an earthquake and tsunami) were found to be inhabited by a diverse and abundant benthic fauna dominated by juvenile clams within 14 months (Chiba *et al.*, 2015). However, sometimes it may take decades for the community structure to fully develop to a ‘natural’ state (Craft & Sacco, 2003; Bolam *et al.*, 2006; Reading *et al.*, 2008).

Polychaetes are typically among the first pioneers to colonise; they are habitat generalists (Diaz-Castañeda & Reish, 2009) but species in later successional stages can vary as their responses to disturbance differs (Zajac & Whitlatch, 1982) and may vary depending on differences between the existing sediment and the added dredged sediment (Imai *et al.*, 2008; Ishii *et al.*, 2008; Nasser *et al.*, 2019). A study in the UK that noted late colonisation of invertebrates suggested that it was due to too much compaction of the earth caused by heavy machinery (Evans *et al.*, 1999). The dispersal capacity of the species will influence the time taken for colonisation of a new site (Craft & Sacco, 2003).

***Vegetation*:** Salt marsh vegetation can develop naturally on dredged sediment, but the time taken has shown to vary among sites. For example, in Louisiana, USA, some salt marshes were created by pumping dredged sediment into open water (Edwards & Proffitt, 2003). The created marshes were colonised from nearby natural marshes, but it took between 4 and 17 years for the vegetation community to reach similarity to natural marshes. In South Carolina, USA, LaSalle *et al.* (1991) found that vegetation biomass on areas of deposited sediment reached similar levels to that of natural marshes within four years. Further research in South Carolina showed that it took between 6 and17 years for monospecific stands of vegetation to develop on areas of deposited sediment, with a minimum of 13 years for mixed communities to develop (Alphin & Posey, 2000). The vegetation community that develops on created marshes may be different from natural marshes, as Edwards & Proffitt, (2003) found in one of their sites, where the plant community was different eight years after creation.

3. Factors that can affect outcomes

***Sediment characteristics*:** Differences in sediment composition (e.g. grain size and organic:inorganic ratio) can affect how biodiversity develops and manifests. For example, using coarser sediment, or compacted sediment, can affect its suitability for benthic invertebrates (Evans *et al.*, 1999; Peterson *et al.*, 2006), and can make it more difficult for vegetation to establish (if the goal is to create a salt marsh) (Haltiner *et al.*, 1996). A pilot study creating two artificial tidal flats at mesocosm scale (3.6 m^2) in a tidal flat simulator in Japan, found that increasing the percentage of silt and clay increased the emerging number of macrobenthos (Ishii *et al.*, 2008). An experiment in the UK found that a higher organic content led to a slower recovery (Bolam *et al.*, 2004). The characteristics of the sediment in tidal flats and salt marshes can vary across the globe. For example, in the USA, coastal soils tend to be more peat-based than sediment-based compared to those in the UK (Atkinson, 2003).

***Wave action/sheltering of the coastline*:** How exposed the site is, and how strong the waves are, may influence the erosion rates of the sediment. Sites subject to high erosion rates may need regular placements of sediment. Alternatively, if a site composed of fine sediments is eroding, then replacement or protection by coarser material may reduce or prevent that erosion (but consider the effects of changing grain size on sediment properties and biodiversity; see above). In exposed sites, permanent or temporary breakwaters can help to disperse energy and/or trap sediment, thus controlling erosion (Zhang *et al.*, 2010; Pontee *et al.*, 2022). Note that sheltering tidal flats can facilitate seaward expansion of salt marsh vegetation (Chowdhury *et al.*, 2019). Sea currents can influence the migration of intertidal invertebrates (e.g. as seen in a 'mega-nourishment' project in the Delfland Coast, the Netherlands; Luijendijk & van Oudenhoven, 2019).

Elevation: The final elevation of the deposited sediment will determine the duration and frequency of inundation and exposure of the different parts of the flat. Most of the site should lie between the level of mean low water spring and mean high water spring tides, but with some variation to support a diversity of species (see Cutts *et al.,* 2024b).

Slope: Shallower slopes will allow for creation of a wider intertidal zone. Experience suggests a typical slope should preferably be around <0.04 or 1:1000 (WAVE, 2001).

Drainage: Well-drained marshes may be more resistant to erosion (Atkinson *et al.*, 2001) and can support a greater diversity of species (Wolters *et al.*, 2005). Poor drainage can affect the plant species that grow, favouring those tolerant of moisture and anaerobic conditions (Atkinson *et al.*, 2001).

Pollution: Biodiversity on restored/created intertidal habitats may be negatively impacted by pollutants. These range from chemical pollutants, such as aquaculture effluents, sewage and oil, to large solid waste, such as fishing nets (e.g. Melville, 2018). A study of Indonesian tidal flats found that decapod crustaceans and oligochaetes made up a greater proportion of the macrofaunal community in areas covered by litter, whereas polychaetes dominated litter-free areas (Uneputty & Evans, 1997). If pollutants are (or are likely to be) present, consider whether they can be managed on the tidal flat and/or at the source.

Temperature: Microbenthic invertebrate recolonisation tends to be faster in tropical areas due to higher water temperatures, in comparison with other regions (Dittman, 2002).

4. Implementation

***Obtaining the sediment*:** Dredging is common practice for maintaining navigation in infrastructure and transport corridors, such as ports and waterways (Sheehan & Harrington, 2012), and in such practices the disposal of the dredged sediment can be costly (Svensson *et al.*, 2022). Consequently, dredged sediment can be available at no or low cost but costs will be incurred for transportation. Sourcing sediment from nearby locations may be the most cost-effective in terms of transportation, and the sediment itself is more likely to resemble the natural sediment of the focal site (Erftemeijer, 2019). This could include harbours, lagoons, or sea inlets. If material has to be sourced far offshore, this can become expensive for large sediment deposits, such as De Zandemotor in The Netherlands (Stive *et al.*, 2013). Dredged sediment is typically silt, sand and clay (Costa-Pierce & Weinstein, 2002). It is important to realise that the area to be recharged is accessible to the ship that will deliver the material i.e., the water depth available for the dredger to operate in when laden with the cargo (Baptist *et al.,* 2019).

Amount/height of sediment**:** This will vary depending on the target habitat, i.e. a tidal flat or a salt marsh, but generally the elevation of the sediment should be such that it is covered by the sea during high tide but exposed during low tide. However, if the objective is to create a nesting area for shorebirds, then consider placing the material at a height above high tide level. Of 12 intertidal recharge projects in the UK, one-off sediment placements ranged from 800 m^3 to 550,000 m^3, while yearly placements ranged from 600 m^3 to 107,750 m^3 (Scott *et al.*, 2017).

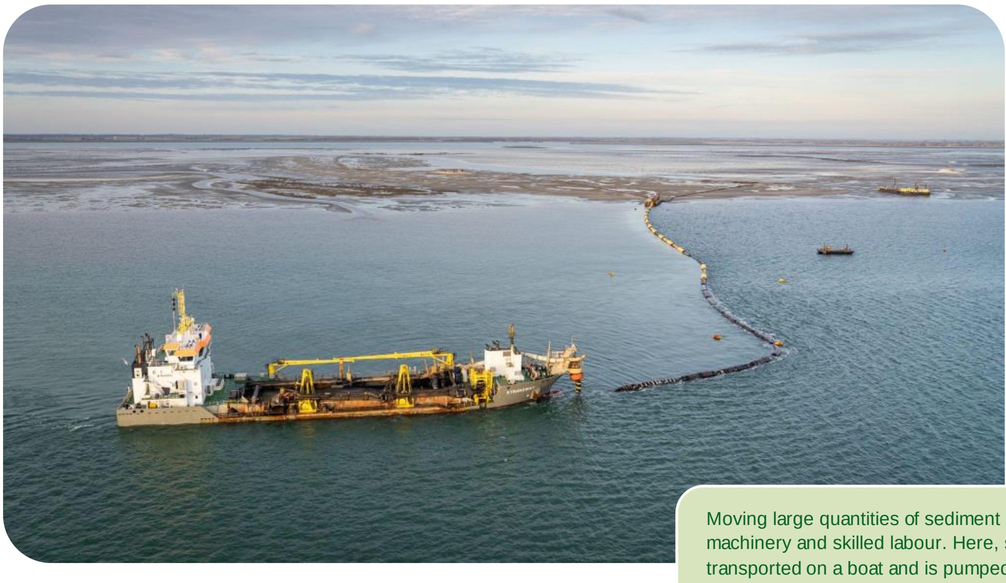
Moving and placing sediment**:** Moving large quantities of sediment requires heavy machinery and skilled labour. Sediment can be placed exactly where it is needed, or it can be spread by current and waves. In the latter case, adding the sediment at a dynamic location will allow it to spread more easily (Borsje *et al.*, 2012). Creating topographic diversity with the sediment (to ensure rich biodiversity) can be achieved in a number of practical ways, for example by using multiple discharge points from pipelines carrying dredged material slurry into the target area, or periodically moving the discharge point (end of pipeline) across the area to create multiple gradients in grain-size and achieving spatial variability in surface elevation (microtopography) across the flat (Erftemeijer, 2024). Consider the breeding times for birds as well as the dispersal of invertebrates as moving and placing dredged sediments cause sediment resuspension (Golder *et al.*, 2008; Van Der Werf *et al.*, 2015). Furthermore, care should be taken when using heavy machinery to spread sediment as it has been suggested this may cause too much compaction of the earth, inhibiting invertebrate colonisation (Evans *et al.*, 1999).

Drainage**:** Channels can be constructed to improve drainage and provide foraging habitat for fish and invertebrates (Olmstead & Fell, 1974; West & Zedler, 2000). Alternatively, it is suggested that a natural drainage system can develop by deep ploughing to crack existing land drains (Mark Dixon, pers. comm.).

Contamination of dredged material: Be wary that dredged material can be contaminated with heavy metals, which can be taken up by vegetation and other wildlife. Contaminated sediments are ideally to be avoided, but can, if unavoidable, be capped with clean substrate, ideally a minimum of 60 cm (Yozzo *et al.*, 2004).

Vegetation control: Prevention/removal of colonising vegetation may be necessary if the goal is to create tidal flats (e.g. manually, chemically using herbicides, or control by fire, flooding or salinity change). Tidal flats should not be planted with mangroves, as the mudflats are typically inundated for longer periods than the mangroves can tolerate (thus typically resulting in failure of the planting efforts). Even if successful, this would be substituting one habitat for another thereby losing the specific value provided by tidal flats (Erftemeijer & Lewis, 2000). Encroachment by other vegetation, such as the prolific colonisation of opportunistic algae *Agarophyton* (Besterman *et al.*, 2020)*, Ulva* (Zhang *et al.*, 2019) and *Lyngby* (Estrella *et al.*, 2011), should also be avoided (see Cutts *et al.,* 2024c).

Water: Regular tidal flushing with seawater will ensure an abundant supply of larvae (recruitment) to replenish macrobenthic populations and prevent encroachment of the tidal flats by vegetation (Jackson *et al*., 2021). While some freshwater inflow can boost nutrient supply and input of organic matter (favouring biofilm formation and increasing benthic biomass), effluent discharges and sewage outfalls are best avoided, as these can promote prolific algal blooms on the flats, which reduces diversity and attractiveness of tidal flats to some shorebirds (see Estrella *et al.*, 2011; Besterman *et al.*, 2020). Wetter areas on tidal flats provide habitat for macroinvertebrates, hence feeding habitat for shorebirds, while drier areas with some vegetation provide nesting habitat for birds and drier open areas may provide roosting habitat. But requirements vary across species, for example the Spoon-billed Sandpiper *Calidris pygmaea* seems to have a specific requirement for sandier substrates with shallow pools (Spike Millington, pers. comm.).



Moving large quantities of sediment requires heavy machinery and skilled labour. Here, sediment is transported on a boat and is pumped through a pipeline to the target area. Location: Roggenplaat island, Oosterschelde, The Netherlands. [Credit: Edwin Paree].

Pipes can be used on land and water to bring sediment to where it is needed. Location: Roggenplaat Islands, Oosterschelde, The Netherlands. See the photo on the next page for the result. [Credit: Edwin Paree].

The tidal flat pictured here was created from dredged sediment at Roggenplaat Island, Oosterschelde, The Netherlands (see the two photos on the previous page). [Credit: Edwin Paree].

Case Study: The Galgeplaat, The Netherlands

The Galgeplaat tidal flat is located in the Eastern Scheldt, a former estuary in the Netherlands. This is an important area for foraging birds, especially shorebirds, but is suffering from erosion. Galgeplaat was one of a number of pilot projects launched to investigate the effectiveness of erosion mitigation.

In 2008, 130,000 m^3 of sediment was added to an area of 150,000–200,000 m^2. The sediment was obtained from maintenance dredging in the tidal channels Brabantsche Vaarwater and Witte Tonnen Vlije. The sediment was less than 7% mud and was coarser than the surrounding, undisturbed sediment. After placing the sediment, the average nourishment height of the area was 0.65 m.

The initial plan was for the placed sediment to supply sand to the surrounding area. However, it did not spread much within the first two years. It was speculated that placing the sediment at a more dynamic location with varied topography would encourage the sediment to spread (Borsje *et al.*, 2012). The sediment volume decreased by 10% after four years, which equates to an erosion rate faster than the surrounding environment.

The sediment buried, and killed, a lot of the benthic macrofauna in the area, which in turn reduced the amount of time birds spent foraging. However, biological recovery began straight away. Recovery of invertebrates was highest at locations that were wet for a longer period of the tidal cycle. Two years after the sediment was placed, the overall average invertebrate biomass at Galgeplaat reached similar values to a reference site and the amount of time spent foraging by birds increased to the level before sediment addition. Eurasian Curlews *Numenius arquata* and Oystercatchers *Haematopus ostralegus* returned to the site but other shorebirds, such as Red Knot *Calidris canutus*, Bar-tailed Godwit *Limosa lapponica*, Grey Plover *Pluvialis squatarola* and Dunlin *Calidris alpina* did not, despite the abundance of food.

Sources: Borsje *et al.* (2012); van der Werf *et al.* (2015)

5. Other sources of information

Documents

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Conservation Guidance Series No. 5, v1.0

Guidance on reprofiling salt marshes and intertidal flats

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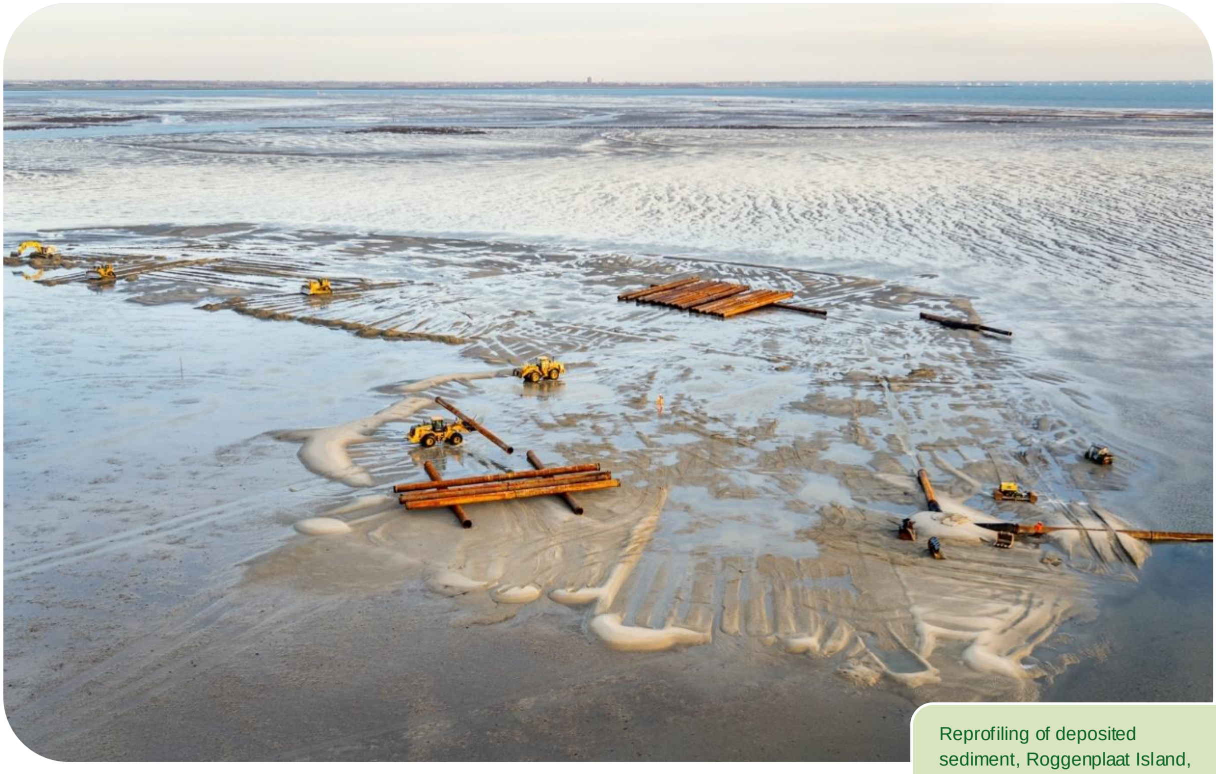

Reprofiling of deposited sediment, Roggenplaat Island, Oosterschelde, The Netherlands. [Credit: Edwin Paree]

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Objective: create habitat heterogeneity and/or restore hydrology

Definitions

- **Intertidal zone** = area between high and low tide.
- **Reprofiling** = changing the topography or landscape heterogeneity.

1. Description

Reprofiling intertidal habitats involves moving around the soil or sediment to create variation in the structure of a salt marsh or tidal flat. This includes excavating depressions or pools, creating mounds or ridges, or altering the slope. Moving and re-shaping sediment is a way of restoring the natural hydrology and topographic variation, to restore wetland function to support key species by creating a mosaic of sub-habitats and microhabitats. Depressions can provide shelter for colonising plants, while pools and islands can be used by birds for foraging, roosting and breeding. Variation in abiotic conditions (e.g. elevation and sediment grain size) drives variation in the species present, such as invertebrates and, consequently, birds (Cai *et al*., 2023).

2. Evidence for effects on biodiversity

Birds: Evidence from inland wetlands has shown that creating wet features, like ponds and pools, to restore the original habitat can increase bird abundance (Provost, 1948; Hoffman, 1970; Holton & Allcorn, 2006; Squires & Allcorn, 2006), although some species may prefer to use older ponds rather than newly created ponds (Provost, 1948). On a coastal wetland in south-eastern USA, Great Egrets *Ardea alba* used man-made ponds but, overall, they tended to use natural wetlands more (Fidorra *et al.*, 2015). A study in Italy found that created intertidal ponds were the most heavily used feature by birds, followed by dykes and mounds with vegetation (Scarton & Montanari, 2015).

Invertebrates: Benthic invertebrates both use and create microtopographic structures (Erftemeijer, 2023). They are sometimes referred to as 'ecosystem engineers' because of how they modify the substrate (e.g. by burrowing) (Jones *et al.*, 1994). A varied microtopography means there is variation in organic material, sediment and water across a site and thus more habitat options for different species (Desjardins *et al.*, 2012).

***Vegetation*:** Studies that have tested the effects of adding sediment to alter the elevation of a site, or to counteract subsidence, find that vegetation abundance increases to be higher than that in degraded sites (DeLaune *et al.*, 1990; Pezeshki *et al.*, 1992; Ford *et al.*, 1999; Schrift *et al.*, 2008; Stagg & Mendelssohn, 2012). A gentle slope provides a gradient that can aid the natural development of a salt marsh by generating areas that experience different amounts of flooding (Pitre & Anthamatten, 1981; Langis *et al.*, 1991; Pétillon *et al.*, 2010). A site in Belgium – from which buildings and fill material were removed and the remaining sediment reprofiled into an intertidal slope – developed salt marsh vegetation within one year but colonisation continued for 27 years, ultimately creating the typical zonation of the salt marsh plant community (Pétillon *et al.*, 2010). In the Yellow River Delta in China, positive recovery and growth of *Suaeda glauca* was noted near tidal creeks in the subtidal zone, whereas, for common reed *Phragmites communis,* being further away from creeks in the intertidal zone was conducive for recovery (Wu *et al.*, 2020).

3. Factors that can affect outcomes

Elevation/slope: The existing elevation and slope of a site will determine the feasibility of the action and the vegetation that develops (Han Winterwerp, pers. comm.). Shallower slopes will allow for creation of a wider intertidal zone. Experience suggests a slope could be around <0.04 or 1:1000 (WAVE, 2001).

***Topography*:** Variation in topography influences water depth and vegetation coverage (Ma *et al.*, 2010). Experimental evidence from a freshwater environment found that a varied micro-topography (changes in elevation of up 3 cm above- or below-ground) can support greater plant species richness and diversity, with many species showing preferences for hollows or hummocks (Vivian-Smith, 1997). Deeper depressions have been shown to trap more seeds and form larger vegetation patches than smaller ones (Wang *et al.*, 2018).

Water depth: Water depth will determine how accessible pools are for foraging birds, depending on their beak and leg length (Ma *et al.*, 2010). An average water depth of 0.5–15 cm across a relatively large area is generally recommended to maximise shorebird diversity (Rogers *et al.*, 2015). The amount of flooding can affect the rate at which vegetation establishes, with one study finding daily flooding to be the most successful (Pitre & Anthamatten, 1981).

4. Implementation

Create depressions/basins: Basins can be excavated by digging which, depending on the size, could involve the use of heavy machinery. One study in China found that larger, deeper basins (depth: 15 cm; width: 100–150 cm) trapped more seeds and formed larger patches of vegetation than smaller, shallower basins (depth: 5 cm; width: 20 cm) (Wang *et al.*, 2018).

Change site elevation/slope: Assuming there have been no other modifications (e.g. installation of dams or culverts), restoring the natural elevation can restore the natural hydrological regime. Raising or lowering the elevation of the whole site will reduce or increase, respectively, the frequency and duration of inundation. Altering the slope will affect the relative inundation across the site. A site in the IJzer estuary in Belgium that successfully created a salt marsh plant community with zonation created a slope with water inundation frequencies ranging from 0.01–70% per year (Pétillon *et al.*, 2010).

Use of heavy machinery: It can be challenging to use heavy machinery in wet, soft, intertidal sediments. Vehicles can displace or compress any vegetation present. Access can be facilitated and impacts reduced by using modified vehicles (e.g. with extra wheels, tracks and/or reduced tyre pressures), reducing the weight carried, using a few designated routes for access rather than driving across the whole marsh or tidal flat, accessing the site when the sediment is frozen, or using vehicles/equipment that doesn't actually touch the marsh surface (e.g. hovercraft, helicopters or drones) (Wolters *et al.*, 2017; Shotzberger, 2021).

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Conservation Guidance Series No. 6, v1.0

Guidance on restoring or creating salt marsh vegetation

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Volunteers carrying and planting marsh grass in South Carolina, USA. [Credit: South Carolina Department of Natural Resources].

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Conservation Evidence
Wetlands INTERNATIONAL

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Objective: (re)vegetate salt marshes with target vegetation

Definitions

- **Corm** = a swollen, underground stem base covered by scale-like leaves, capable of producing new growth in suitable conditions.
- **Seed bank** = the natural storage of seeds in soil or sediment, which can be dormant.

1. Description

Created or restored salt marshes may need a 'helping hand' if vegetation is not colonising naturally, or is colonising slowly. Target vegetation can be introduced by physically planting new plants, seeds or vegetation fragments, or by depositing plant material containing target species. Sites where active revegetation may be particularly useful include those with a depleted seed bank of target species (e.g. sites historically used for agriculture or created by placement of dredged material), those without a ready source of colonising vegetation (e.g. a long way from, or up-current of, existing salt marshes), and those susceptible to invasion by non-native species (which may readily colonise bare sediment but not sites with native vegetation cover; Tarsa *et al.*, 2022). Vegetation can also help salt marshes keep pace with rising sea levels (Davis *et al.*, 2017).

Note that there are several options available to stimulate growth of salt marsh vegetation without directly introducing it, which are not addressed here. These include adding fertiliser, adding mulch, planting nurse plants (see Taylor *et al.,* 2021) and reprofiling (see Cutts *et al.,* 2024). Managing any cause of vegetation loss – from recreational activity to livestock grazing to pollution – can also help (Taylor *et al.,* 2021).

Many coastal habitats naturally have little or no vegetation and provide important resources for shorebirds and other wildlife in this state. Managers should avoid the temptation to revegetate these habitats. For example, in parts of the upper tidal flats on the Yellow Sea coast, China, sparsely vegetated alkaline flats (mostly *Suaeda salsa*), rather than densely vegetated or completely unvegetated areas, provide nesting habitat for shorebirds such as Saunders's Gull *Saundersilarus saundersi* (David Melville, pers. comm.).

2. Evidence for effects on biodiversity

Vegetation: Planting seeds or whole plants has generally been shown to be successful for revegetating salt marshes (Taylor *et al.*, 2021). A global review of salt marsh restoration studies reported an average survival rate of 65% (range 0% to ≥95%) for planted and sown non-woody vegetation in 64 cases (Bayraktarov *et al.*, 2016). At a site in the Netherlands, adding a layer of driftline material, containing seeds and vegetative fragments of salt marsh species, increased the number of target species during the first four years. However, after six years, the number of species was similar to a control site where no material was added (Wolters *et al.*, 2017).

Planting can work well when combined with fertiliser (Taylor *et al.*, 2021), for example kelp compost (O'Brien & Zedler, 2006) or reed debris (Guan *et al.,* 2011). Another study found that rock phosphate increased overall salt marsh vegetation cover but that this was only effective when also introducing vegetation (Emond *et al.*, 2016). Using urea was found to increase Seablite *Suaeda salsa* biomass in China (Guan *et al.*, 2011).

3. Factors that can affect outcomes

Water levels: Plants have specific tolerances to flooding or waterlogging, which is influenced by the elevation of a site. Older plants may be better able to withstand waterlogging than young seedlings (Cao *et al.*, 2022). Therefore, consider planting species or individuals at appropriate elevations. Modifying the (micro)topography before planting may also increase survival (see Cutts *et al.,* 2024). Evidence suggests that seed retention of pioneer salt marsh plants is higher in depressions in the soil (Wang *et al.*, 2018).

Salinity: Coastal vegetation is salt-tolerant, but even the most tolerant species will struggle in hypersaline areas (Zedler, 2003). Equally, prolonged periods of low salinity, for example due to inputs of rainwater or runoff from urban areas, are not suitable for salt marsh vegetation and can favour invasion by undesirable species such as, in North America, cattail *Typha domingensis* (Beare & Zedler 1987) or Perennial Pepperweed *Lepidium latifolium* (Wiggington *et al.*, 2020).

Exposure: Physical disturbance from waves and currents may limit initial establishment and long-term persistence of vegetation. Attempting to establish vegetation in the highest energy sites will often be a losing battle. Moderate energy levels can be mitigated using barriers such as breakwaters. Species and life-stages appropriate to local energy levels should be chosen.

Animals: Establishing salt marsh vegetation may be consumed and/or trampled by animals such as mammals (Wasson *et al.*, 2021), birds (Zedler, 1993) or crabs (Liu *et al.*, 2020). High animal densities might prevent establishment. Cages or other exclosures can be used to protect young vegetation (Taylor *et al.*, 2021; Wasson *et al.*, 2021). Animals can also have positive effects. For example, planted *Scirpus mariqueter* suffered less grazing and reached higher densities in areas closer to Giant Mud Crab *Scylla serrata* burrows, because the crabs preyed upon grazers (Wu & He, 2023).

4. Implementation

Planting: Seedlings/plants can be transplanted from nearby marshes or can be reared in a nursery. Plants are often placed in depressions 5–10 cm deep in the soil, but the optimum depth depends on the species (Varty & Zedler, 2008; Guan *et al.*, 2011; Hu *et al.*, 2016). Studies where planting has been successful have typically planted 45–100 cm apart and planting usually occurs in spring to early summer (Taylor *et al.*, 2021). In several cases, planting was into fine-grained dredged sediment and sometimes the existing vegetation was removed. In the Yangtze Estuary, China, Zhang & Li (2023) tested different methods of planting

Scirpus mariqueter (a dominant salt marsh species in the estuary) finding that the most economically efficient treatment was to transplant low-density corm seedlings without sediment, costing ¥10,100 Chinese Yuan (about US$1,400; Feb 2024 conversion) per hectare.

Seeds can be collected from natural marshes or nurseries and are typically sown around 1.5–5.0 cm deep, but the optimum depth will vary between species (Groenendijk, 1986; Hu *et al.*, 2016). Although easier to handle than plants, seeds are more at risk of being washed away. The number of seeds planted will vary based on the species and the size of the site. Studies report a range of 80–4,000 seeds/m^2 (Groenendijk, 1986; Varty & Zedler, 2008; Guan *et al.*, 2011; Hu *et al.*, 2016). The survival of the new plants depends on the local conditions. For example, at a site in California, over 21,000 seeds were planted but only 17 seedlings grew (Zedler, 1993). This was attributed to the high salinity levels, sediment deposition that buried the plants, algal smothering and trampling by birds, such as American Coot *Fulica americana*.

Sods of salt marsh vegetation have also been successfully transplanted to restoration/creation sites (Green *et al.*, 2009; Sparks *et al.,* 2013). It has been suggested that this restores vegetation coverage more quickly, is more aesthetically pleasing and is more resistant to erosion than planting or sowing – but generally more expensive (Sparks *et al.,* 2013). It may not be necessary to completely cover a restoration/creation site with sods: one study in Mississippi, USA reported that 50% coverage was more cost effective (and required less material from the donor site) than 100% coverage (Sparks *et al.,* 2013).

Plant material can be collected from nearby sites that contain target plant species and spread on a restoration/creation site (Emond *et al.*, 2016; Wolters *et al.*, 2017). For example, to restore a brackish marsh in the Netherlands, plant material was collected from the foot of a nearby sea wall, using agricultural machinery. Portions of 10 cm^3 were put in a manure spreader and 200 m^3 was spread over two thirds of the site in a 5 cm layer (Wolters *et al.*, 2017).

If using vegetation from existing salt marshes, consider how to minimise impacts on donor sites, for example by leaving some vegetation in place and avoiding collecting vegetation during bird breeding periods. Any necessary permits should be secured before collection.

Actions to help planted vegetation: A wide range of actions could be done before or after introducing vegetation to increase survival and/or growth rates. These include reprofiling (creating mounds and/or depressions), removing polluted/dry/crusty surface sediment, using nurse plants, using fences or barriers to exclude animals that may damage young plants, adding lime and adding fertiliser (Taylor *et al.*, 2021).

If it is considered necessary to add materials, such as lime or fertiliser, these should generally be added when the site is not flooded to reduce the risk of it dissolving or being washed away. Additives can also be mixed into the sediment before planting. One study had success with kelp compost, mixing 40 L/1.5 m^2 of compost (two parts soil, one part kelp) into the top 30 cm of soil (O'Brien & Zedler, 2006), while another study found success ploughing 2 kg/m^2 of reed debris to a depth of 20 cm (Guan *et al.*, 2011). The addition of fertiliser alongside planting can speed the growth of new vegetation by balancing the nutrients available in the sediment. It should be noted that not all additives have proven to be successful; adding too much fertiliser, such as nitrogen, can do more harm than good by causing eutrophication, which is a great threat to coastal systems globally (Albornoz, 2016; Malone & Newton, 2020).

Case Study: Marconi salt marsh, The Ems Estuary, The Netherlands

The Marconi Buitendijks project was commissioned to address the deteriorating ecological condition of the Ems estuary in the Netherlands. A seawall along the coast of Delfjizl was relocated and reinforced and two salt marshes were constructed by raising the seabed to the mean high tide with dredged sand. One salt marsh is open to the public, while the other is a pioneer salt marsh open only to researchers. This pioneer salt marsh of 15 ha is a pilot and is being used for experiments to understand the development of salt marshes.

Researchers are testing the effect of enriching the salt marsh with mud and the effect of planting versus natural colonisation of vegetation. The pilot marsh consists of six 1 ha compartments each with different percentages of mud, sand, and fine sediments, some of which are seeded and some that are allowed to vegetate naturally. Heavy machinery was used to mix mud in the top 1 m of the sandy bed (note that this caused the machines to sink). From November 2018 to September 2020, the salt marsh was inundated approximately 70 times.

In May 2019, the research team manually sowed long-spiked glasswort *Salicornia procumbens.* Before sowing, the glasswort was dried, cut into pieces and soaked in fresh water for four days to allow the seeds to germinate. Glasswort plants appeared one and a half years after seeding (in July).

What has been learned from the project so far?

- The effect of seeding was temporary: seeded areas had a higher cover of glasswort plant than non-seeded areas but only in the first year.
- A higher percentage of mud (25–48%) in the top layer of sediment led to more total vegetation cover, while vegetation cover was significantly lower with less mud (7–9%).
- Higher mud content led to higher species richness.
- No vegetation was found in plots with high rates of erosion (>2.5 mm per month).
- Vegetation only developed with areas enclosed by brushwood groynes.
- Overall, the researchers conclude that mixing the top layer of the sandy bed with mud to 25% boosts vegetation cover and species richness and is practically feasible.

Sources: Baptiste *et al*. (2021); de Vries *et al*. (2021); Video: Research on the pioneer salt marsh Marconi Delfzijl (youtube.com/watch?v=V8zCrhG-jtY)

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Conservation Guidance Series No. 7, v1.0

Guidance on managing vegetation on intertidal flats

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The Humber estuary, UK.
[Credit: Mat Fascione]

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Objective: remove or contain vegetation to maintain open intertidal flats

Definitions

- **Intertidal zone** = area between high and low tide.

1. Description

Most migratory shorebird species require open areas of tidal flat habitat where they can forage and maintain unobstructed sight-lines to allow early detection of predators (Erftemeijer, 2023). The expansion of mangrove and salt marsh vegetation into shorebird feeding habitats due to sea level rise and increased sedimentation is a problem in estuaries such as in Hong Kong, Taiwan, New Zealand and eastern Australia (Straw and Saintilian, 2006; Jackson *et al*., 2021; Choi *et al.*, 2022). Planting of mangrove on open tidal flats (that were not mangrove before) should in general be avoided as this would be substituting one habitat for another, thereby losing the specific value provided by tidal flats (Erftemeijer & Lewis, 2000; Choi *et al.*, 2022; Beeston *et al.*, 2023).

Although some algae may be naturally present on tidal flats, prolific colonisation by opportunistic algae, such as *Agarophyton* (Besterman *et al.*, 2020), *Ulva* (Zhang *et al.*, 2019) and *Lyngby* (Estrella *et al.*, 2011) resulting from eutrophication can significantly reduce benthic diversity and attractiveness of tidal flats to some shorebird species (Estrella *et al*., 2011; Besterman *et al*., 2020). The same applies to colonisation by the invasive seagrass *Zostera japonica* (Durance, 2002). However, most native seagrasses (as well as seagrass wrack) seem to enrich benthic fauna in intertidal flats and enhance their attractiveness to feeding shorebirds (see: Unsworth and Butterworth, 2021).

Removal of such vegetation may be desirable (a) where the tidal flat is a particularly important habitat for other species, such as shorebirds, and/or (b) the vegetation is not native. There are separate guidance documents on removal of invasive cordgrasses *Spartina* spp. (see Cutts *et al.,* 2024a-c).

2. Evidence for effects on biodiversity

Birds: In the Danshuei River estuary, Taiwan, wintering shorebirds roosted in open mudflats created by removing mangroves. The expansion of mudflat habitat in the estuary increased the richness of wintering shorebirds (Huang *et al*., 2012). In Hawaii, the Hawaiian Stilt *Himantopus mexicanus knudseni* numbers increased once vegetation was managed to restore bare mud patches (Rauzon & Drigot, 2002). Invasive pickleweed *Batis maritima* was ploughed and mangroves were physically removed.

Invertebrates: Despite concerns prior to removal, adjacent shellfish beds appeared unaffected by mechanical mangrove removal in the Waikareao Estuary, New Zealand (Lundquist *et al*., 2012). Studies in Mangawhai Harbour, New Zealand (Alfaro, 2010) and Siangshan Wetland, Taiwan (Chen *et al*., 2018) reported increases in the abundance, richness and/or diversity of benthic macroinvertebrates after removal of mangroves. These invertebrates included crabs, snails and bivalves.

Problematic vegetation: We found few studies that quantified the effectiveness – on the vegetation itself – of vegetation control on tidal flats (other than for cordgrasses; see Cutts *et al.,* 2024a-c). Truman (1961) reported complete mortality of grey mangroves *Avicennia marina* var. *australasica* when a sufficient dose of herbicide was applied (4% 2,4-D or 2,4,5-T) – but note that use of these herbicides, especially the latter, is now prohibited or restricted in many countries.

In Mangawhai Harbour, New Zealand, mangrove removal (specific method unclear) was associated with an increased density of aerial roots (pneumatophores) over the following two years. Mangrove seedlings also gradually colonised the removal site (Alfaro, 2010). In the Waikareao Estuary, New Zealand, anoxic sediment and nutrient release resulting in algal blooms were also observed following mechanical mulching of mangroves (Lundquist *et al*., 2012).

Schlosser *et al*. (2010) suggest that eelgrass *Zostera japonica* on tidal flats can be removed by excavation and killed by covering with opaque material such as burlap fabric, but that flame heat treatment is not an effective control method.

3. Factors that can affect outcomes

Adjacent habitats: Upstream or up-current habitats can act as a source of organisms to colonise any cleared tidal flat. This colonisation might be desirable in the case of characteristic tidal flat organisms (e.g. benthic invertebrates). However, connected patches of undesirable vegetation can hinder the success and longevity of vegetation control in a focal site (Rauzon & Drigot, 2002; Wolters *et al*., 2008). Decisions to manage vegetation in a focal site might also be influenced by the presence of tidal flats nearby. For example, these might temper the value of creating a new area of tidal flat or justify vegetation control to prevent colonisation of existing flats.

Physical conditions: Local tide patterns, currents, waves and sediment characteristics can affect the physical consequences of vegetation removal. For example, erosion of muddy sediments is more likely in exposed sandy sites than in sheltered muddy sites (Lundquist *et al*., 2017). It may sometimes be prudent to retain vegetation in areas where removal could lead to significant erosion and instability of tidal wetlands (Qiang He, pers. comm.).

4. Implementation

Prevention: Consider managing the ultimate cause of problematic vegetation encroachment; this will often be more successful and cost-effective in the long term. For example, if algal blooms are linked to eutrophication from direct discharge of effluents and sewage outfalls onto tidal flats, consider managing this discharge. Active planting of mangrove propagules or seedlings on tidal flats, as previously widely practised across South East Asia, is now strongly discouraged due to low survival (inappropriate site selection) and adverse impacts on the tidal flat ecosystem, especially impacting its role as shorebird feeding ground (Erftemeijer & Lewis, 2000; Choi *et al.*, 2022; Beeston *et al.*, 2023).

Control: Options for management intervention include the controlled removal of accreting seedlings and saplings from key shorebird feeding grounds (see: Mai Po marshes case study below). Other more intrusive control methodologies are sometimes deployed, such as the use of herbicides in combination with mowing to control invasive *Spartina* (Jackson *et al.*, 2021). Periodic flooding with seawater, mowing or herbicides are some of the ways used to control colonisation and expansion of unwanted vegetation in ponds and other artificial habitats used by shorebirds in Australia (Erftemeijer, 2019). Management should be timed to avoid or minimise impacts on non-target species, for example avoiding bird migratory or breeding seasons. Other important considerations include selecting access points to removal areas that minimise or avoid trampling adjacent habitat types (Lundquist *et al.*, 2017).

In New Zealand, many methods of removing mangroves have been used with varying success (see review by Lundquist *et al.*, 2017). These include manually pulling small seedlings, removal using chainsaws and axes at above ground level, and mechanical removal. Manual removal of seedlings is cheapest and can be effective in containing local spread, whilst causing the least adverse environmental impacts, but must be conducted regularly to avoid re-establishment. Mechanical operations using tractors and diggers to remove vegetation and some below-ground root material from tidal flats are more expensive and rarely result in a return of tidal flats, whilst often having detrimental effects on the local ecosystem and amenity (sight and smell). Removal by hand or light equipment (pulling, shovels, chainsaws) may be preferable to use of heavy machinery in areas of archaeological interest (Rauzon & Drigot 2002).

Herbicide application by drone (as used in China for *Spartina* control) is a method that could also potentially be trialled to control mangrove expansion on mudflats if an appropriate herbicide can be identified (David Melville, pers. comm.). Some herbicides have been implicated in devastating mangrove dieback (see Duke *et al.*, 2005), so caution is warranted.

Other vegetation (e.g. low-growing herbaceous plants, shrubs or algae) can be controlled, at least temporarily, by covering it with sediment. This will reset succession. Deposition of shell and gravel debris has been tried as a means to help control thick vegetation at important shorebird sites in the USA (Plauny, 2000). Temporary reduction of vegetation cover can also be achieved by ploughing. In Tokyo Port Wild Bird Park (Tokyo-ko Yachoen), the tidal flats are ploughed before and after the shorebird season (SSS 2023). In Hawaii, Amphibious Assault Vehicles have been used to control invasive pickleweed *Batis maritima* growing on mudflats (Rauzon & Drigot, 2002). 'Checkerboard patterns' or 'donuts' of ploughed muddy sediment with islands of vegetation were created, which the authors suggested were attractive to Hawaiian stilts *Himantopus mexicanus knudseni*.

Also note that vegetation removal can affect physical processes, which in turn can affect local biodiversity. For example, mangrove removal can exacerbate estuarine infilling through landscape-scale bio-morphodynamic feedbacks, enhancing estuary-scale sediment trapping due to altered sedimentation patterns (Xie *et al.*, 2023). In the Waikareao Estuary, New Zealand, a gradual seaward erosion of salt marsh was observed following mechanical removal of the mangrove buffer (Lundquist *et al.*, 2017).

Compensation: If it is too difficult or expensive to manage problematic vegetation in a particular site, restoration or creation of tidal flats or saltmarshes elsewhere (ideally nearby) could be considered. If restored/created sites are near a site with problematic vegetation, consider how invasion of the new site will be prevented or managed.

Case Study: Mangrove seedling removal from intertidal flats at Mai Po Marshes

Removal of mangrove seedlings, and patches of grasses and sedges, from tidal flats at Mai Po Nature Reserve (Hong Kong) is carried out annually (in autumn) by World Wide Fund for Nature (WWF) Hong Kong. The aim is to maintain an area of open tidal flat, free of seedlings, for waterbirds to roost and feed, and to keep a clear open view for birdwatchers to observe the birds. The area being managed in this way (at least since 2001, when 5 ha was cleared) has increased over the years and is now some 43 ha. Mangroves on the tidal flats in front of the floating bird hides at Mai Po Nature Reserve have been managed in this way since 1986.

Each August–October, permission is obtained from the District Land Office (Yuen Long) to remove a pre-agreed number of mangrove seedlings over a set area of tidal flat (WWF Hong Kong, 2006). Removal of mangrove seedlings is achieved by pushing the seedlings into the mud, causing them to die. For the removal in 2007, a team of six people required a total of 65 person-days to clear approximately 31,000 mangrove seedlings from a 43-ha area of tidal flat. The removed seedlings consisted mainly of *Kandelia obovata* (75%) and *Aegiceras corniculatum* (22%), with the rest (3%) of *Acanthus ilicifolius* and *Sonneratia* sp. (an exotic species).

Source: WWF Hong Kong (2021)

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Conservation Guidance Series No. 8, v1.0

Guidance on chemical control of *Spartina* spp.

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Conservationists spraying *Spartina* with herbicide, British Columbia, Canada. [Credit: DUC]

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Objective: reduce the abundance of *Spartina* species already present in intertidal habitats

Definitions

- **Herbicide** = a chemical that kills or inhibits the growth of plants.
- **Intertidal** = the area between high and low tide.
- **Neap tide** = a period of moderate tides due to the position of the sun and the moon, with a high tide height substantially lower than that during spring tide period while a low tide height substantially higher.

1. Description

The use of chemicals to control *Spartina* involves applying herbicides to areas where *Spartina* has become invasive to manage and/or eradicate the species. The use of herbicides is a well-established method for controlling invasive plant species and can be effective in making habitat available for feeding and roosting of shorebirds on tidal flats and salt marshes but the effect on native wildlife itself must also be taken into consideration.

2. Evidence for effects on biodiversity

Birds: Using herbicide to remove invasive plants can benefit birds by increasing the availability of habitat. Studies on tidal flats in Willipa Bay, USA, found that following the control of *Spartina,* using glyphosate and imazapyr, more shorebirds used the sites, including sandpipers *Calidris* spp., with overall shorebird usage increasing from almost zero to around 800 birds/ha following herbicide application (Patten & O'Casey, 2007; Patten *et al.*, 2017). At a site in the UK, more individual shorebirds, particularly Redshank *Tringa totanus*, foraged in areas where *Spartina* had been recently cleared than in areas where it has been cleared three to four years before (Evans, 1986) – it is thought that the wetter, open habitat in the more recently cleared areas made invertebrates more visible. The long-term effect of herbicide on birds in the wild is uncertain (as far as we are aware). Experimental studies on Japanese Quail *Coturnix japonica* suggest there may be a cumulative effect of glyphosate exposure (Ruuskanen *et al.*, 2020a,b). Those fed with glyphosate-contaminated seeds from 10 to 52 weeks of age had a different gut microbiome, decreased levels of male testosterone and slightly lower embryonic development compared to a control group, but there was no clear effect on reproduction, in terms of testis size and egg production. Eggs collected from these species contained glyphosate residues but there was no effect on the egg quality.

Invertebrates: A study in Australia found no detrimental effects on molluscs, annelids and crustaceans of using Fusilade Forte® (Fluazifop-p-butyl) to remove *Spartina.* In fact, they found higher species diversity and more crustaceans (mainly the amphipod *Allorchestes compressa*) in areas treated with herbicide after six months (Kleinhenz *et al.*, 2016). Another study found that spraying with Fusilade Forte® had initial toxic impacts on benthic invertebrates but that the community recovered and by 12 years resembled that of natural tidal flat – there were fewer crustaceans but more molluscs, particularly gastropods (Shepherd, 2013). In Chongming Island, China, one month of spraying haloxyfop appeared to have no adverse effects on the meiofauna community (Zhao *et al.*, 2020).

Native vegetation: Global evidence about using herbicide to eradicate invasive species from brackish/saline wetlands shows it has neutral or positive effects on the native vegetation (Taylor *et al.*, 2021). However, some studies found the cover of native, non-target vegetation decreased as well as the target invasive species (Whitcraft & Grewell, 2012; Tobias *et al.*, 2016). A recent study in Laizhou Bay, China found that the native herbs *Salicornia* and *Suaeda* increased in density after spraying *Spartina* with haloxyfop-R-methyl (a grass-specific herbicide) for 10 months (Wei *et al.*, 2023).

3. Factors that can affect outcomes

Tidal flow: Large tidal ranges lead to the replacement of water (known as tidal flushing), which can wash herbicide from plants. When *Spartina* is submerged, this can reduce the absorption rate of herbicides. For example, in the Yangtze Estuary in China, the large tidal range leaves *S. alterniflora* submerged for long periods, which shortens the absorption time of herbicide (Zhao *et al.*, 2020). Therefore, applying herbicide during neap tides, when plants are submerged for a shorter period, will allow more of the herbicide to be absorbed (Peng *et al.*, 2022).

Density of* Spartina *vs. non-target plant population: How *Spartina* is distributed, and how close it is to native species, may influence the herbicide that is used. If *Spartina* is mixed with native species, it is more appropriate to use a grass-specific herbicide, such as haloxyfop, to project the native species. For large monospecific stands of *Spartina*, a broad-spectrum herbicide such as imazapyr can be used (David Melville, pers. obs.).

Site accessibility: The method of herbicide application will depend on how accessible a site is to both humans and vehicles. For example, soft mud can make a site inaccessible to humans (Hassell *et al.*, 2014), making precise treatment more difficult. In New Zealand, helicopters have been used to apply herbicides to overcome access issues (David Melville, pers. obs.).

***Time of application*:** The control efficacy of the same herbicide may differ depending on the time of year it is applied. For example, Zhao *et al.* (2020) found that applying herbicide in July/August resulted in 100% mortality, while *S. alterniflora* was able to recover rapidly when applied in May.

***Use of heavy machinery*:** Using heavy machinery to apply herbicide (e.g. boom sprayers) can be challenging in wet, soft, intertidal sediments. Furthermore, vehicles can displace or compress any vegetation present and could have potential adverse impacts on benthic invertebrates in the sediment (Evans *et al.*, 1999; David Melville, pers. obs.).

4. Implementation

What chemicals to use: Current global practice suggests that the two most effective herbicides are haloxyfop and imazapyr, with high kill rates shown in New Zealand, USA and China (Brown & Raal, 2013; Strong & Ayres, 2016; Patten *et al.*, 2017; David Melville, pers. obs.). In the New River estuary, New Zealand, haloxyfop (registered as Gallant) was shown to have a 95% mortality rate on its first application, decreasing *Spartina* cover from 800 ha to <1 ha (Miller & Croyhers, 2004). Imazypyr was used in Willapa Bay, USA, imazypr application reduced *Spartina* coverage from 3,440 ha to 0.36 ha over an 11-year period (Patten *et al.*, 2017). Other chemicals that negatively affect *Spartina* (from a recent meta-analysis of 26 studies), include: imazameth, glyphosate, 2,2-dichloropropionic acid (commercially Dalapon) and cyhalofop butyl (Reynolds *et al.*, 2023).

Given the small number of studies which have investigated the effectiveness of some individual herbicides, it is important to use caution when drawing conclusions about their ability to control *Spartina* at scale.

Chemical application: Ways to apply herbicide include using drones, quad bikes, aircraft, and backpack-mounted sprayers. This may be followed up with hand spraying to target small patches and reduce the impact on native vegetation. For example, in the Great Brak Estuary in South Africa, glyphosate was initially applied by backpack spraying but, as *Spartina* cover reduced, this was switched to bottle spraying (Riddin *et al.*, 2016). Similarly, in Willapa Bay in Washington, USA, *Spartina* was removed by boom spraying imazapyr with follow-up hand and backpack spraying, which involved intensive searching on foot by multiple searchers (spaced 4 to 20 m apart along 230 km of shoreline) at least twice a year (Patten *et al.*, 2017). Some control efforts have employed the use of drones carrying a 20–30 litre tank, which are operated with a pre-programmed GPS to ensure site coverage (David Melville, pers. obs.). On harder substrates, crawler tractors with spray booms may present the most effective herbicide deployment method (David Melville, pers. obs.).

Drones can be used to apply herbicide aerially. Pictured here are drones used for *Spartina* removal efforts in China. [Credit: David Melville].

Dose: Wang *et al.* (2023) compared four herbicides, three of which removed only 25–35% of *Spartina* with the highest tested dose: glyphosate (8.0 kg/ha), cyhalofop-butyl (0.8 kg/ha) or imazameth (0.4 kg/ha). Haloxyrop was the most effective, with a dose of 0.3-0.45 kg/ha removing 95% in the first year. In Chongming Dongtan, China, one study found the highest tested dose of haloxyfop, 2.70 g/m^2, to be the most effective, removing 100% of small patches at 92% of continuous swards, while lower doses (0.45–1.35 g/m^2) removed <40% (Zhao *et al*., 2020).

Surfactants in herbicides: Surfactants are chemicals that allow herbicides to disperse more easily in water. Evidence suggests that glyphosate-based herbicides can be toxic to aquatic organisms, such as amphibians, water fleas and fish and this toxicity has been linked to the concentrations of surfactants in the herbicide (Pless, 2005; Mikó & Hettyey, 2023).

Case study: San Francisco Bay, USA

*Spartina alterniflor*a was introduced to San Francisco Bay in the 1970s. *S. alterniflora* crossed with the native species *S. foliosa*, producing some hybrids that grew vigorously. The *Spartina* hybrids outcompeted the natives and expanded their range due to their higher tolerance to inundation and salinity. The presence of the native *S. foliosa*, which is valuable in structuring the shoreline, makes controlling invasive *S. alterniflora* more difficult. The spread of *S. alterniflora* led to an estimated loss of 27–80% of the foraging area for birds.

A federal state programme to eradicate *Spartina* was established in 2003 and herbicide application began in 2005. The herbicide used was imazapyr, which is one of only two herbicides permitted to be used in estuaries in California.

Imazapyr was applied using helicopters, all-terrain vehicles, boats, and on the ground with backpack sprayers. In 2005, *S. alterniflora* and *Spartina* hybrids covered 327 ha of the Bay. By 2019 coverage was 11.4 ha. This equates to a reduction of 96%.

From 2000–2001 the total cost of the Invasive *Spartina* Project was 21 million US dollars.

Lessons learned:

- Between establishing the programme in 2000 and implementing the programme in 2005, *S. alterniflora* spread extensively. Therefore, delaying treatment made *Spartina* removal even more difficult.
- Mapping *S. alterniflora* occurrence before herbicide application would mean applicators do not have to decide where to spray, saving time.
- The herbicide requires six hours of drying time (depending on the weather conditions), therefore the timing of application is critical in terms of weather and tides. It should also be applied during the growing season before seed set.

Source: Strong & Ayres (2013, 2016)

5. Other sources of information

Assessment of different management actions for *Spartina* control: Reynolds S., Aldridge D., Christie A., Choi C.-Y., Jackson M.V., *et al*. (2023) *Spartina* invasive management - A review of the evidence. OSF. https://doi.org/10.17605/OSF.IO/3BWZX

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Cutting Smooth Cordgrass *Spartina alterniflora* with a floating rotary hoe in Chongming Dongtan, China. [Credit: David Melville].

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<u>Objective</u>: reduce the abundance of *Spartina* species already present in intertidal habitats

Definitions

- **Intertidal** = the area between high and low tide.
- **Rhizomes** = underground plant stems that grow horizontally, producing roots and shoots. Rhizomes enable plants to survive underground through harsh seasons.

1. Description

The use of physical controls is a well-established method for controlling invasive plant species. Physical controls include uprooting the plant, cutting or mowing to reduce seed production, covering with fabric or soil to prevent photosynthesis, burning, and building dikes.

Physical measures can be effective at controlling *Spartina* (Reynolds *et al.*, 2023) but the effect on native wildlife must also be taken into consideration. A review by Wang *et al.* (2023) found that *Spartina* abundance was significantly reduced following physical interventions (25.5%), as was *Spartina* growth, but that the effectiveness of the interventions declined over time.

2. Evidence of the effects on biodiversity

Birds: Birds tend to be deterred from areas invaded by *Spartina*, but have been shown to use areas (to a similar degree to non-invaded areas) once *Spartina* has been eradicated (Lyu *et al.,* 2023).

Native vegetation: The global evidence base suggests that both cutting and burning are likely to lead to a significant increase in native plant diversity, while cutting is unlikely to have an effect on native plant abundance. On average, physical interventions enhanced native plant diversity by 72% (Wang *et al.*, 2023).

Invertebrates: A study in the UK found that physical disturbance of *Spartina* using a tracked vehicle in a tidal flat had no negative impact on benthic invertebrates (Frid *et al.*, 1999). However, using heavy machinery can have negative impacts on benthic invertebrates through soil compaction (David Melville, pers. obs.). Using a fully enclosed cement dike to control *Spartina* in the Yangtze Estuary in China had a negative impact on benthic invertebrates, as species richness declined by 50% after diking. However, a sediment dike that was only partially enclosed had a positive impact, increasing species richness and density (Wang *et al.*, 2021).

3. Factors that can affect outcomes

Site access: How easy it is to access all areas of the site will determine which techniques can realistically be used. For example, soft mud can make a site inaccessible (Hassell *et al.*, 2014).

Humans may need to manually intervene in areas where large machinery cannot reach. However, some areas may also be difficult, or unsafe, to access on foot.

Size of the site: The size of the area that requires *Spartina* removal will influence the methods to be implemented. For example, very small areas could be managed manually by removing plants by hand. However, this is a slow process and would therefore be impractical at a larger scale (Hedge *et al.*, 2003).

***Time of treatment*:** The time of the year the control measure is taken can influence its effectiveness. Evidence from China suggests that the optimal time for mowing is early June to early July, i.e. from the end of the vegetative growth period to the flowering stage (Xie *et al.*, 2019).

***Use of heavy machinery*:** It can be challenging to use heavy machinery in wet, soft, intertidal sediments. Furthermore, vehicles can displace or compress any vegetation present and could have potential adverse impacts on benthic invertebrates in the sediment (Evans *et al.*, 1999; David Melville, pers. obs.).

4. Implementation

Spartina has a strong capacity to withstand physical stresses and can therefore rebound quickly following physical controls (Wang *et al.*, 2023). This highlights the importance of planning a consistent removal effort and follow-up monitoring to quantify risks of reinvasion.

Cutting or mowing: Cutting/mowing creates open areas more quickly than herbicides (David Melville, pers. obs.). Cutting/mowing can be done with hand-held equipment or with machines (boats) capable of accessing both land and water. However, Hedge *et al.* (2003) reported that mowing machines were too fragile to use in estuarine environments. The timing of mowing needs to be considered (see above). Repeated mowing may be necessary, although Sheng *et al.* (2014) found that repeated mowing reduced *Spartina* stem height but did not eradicate it. It is noted that cutting may reduce abundance by 100% at the time of cutting, but may not reduce abundance thereafter (David Melville, pers. obs.).

Different machines can be used to cut *Spartina*. Pictured here is a mini harvester/cutting machine. [Credit: David Melville].

Uprooting: Hand removal of *Spartina* by uprooting the plant requires few resources but is labour intensive. The entire underground rhizomes need to be removed to prevent regrowth, but these can be over 1 m deep in the sediment (Hedge *et al.*, 2003). Uprooting can also be done by ploughing. Ploughing loosens and mixes the sediment and can damage *Spartina* rhizomes. A study in China found that ploughing at the end of the growing season prevented *Spartina* from reproducing (Xie *et al.*, 2019). Despite its effectiveness according to the evidence (Reynolds *et al.*, 2023), some practitioners urge caution when using ploughing due to the associated habitat disturbance and potential for regrowth if viable plant matter is not completely removed, which could facilitate the spread of *Spartina* (Bo Li, pers. comm). Furthermore, sediment consolidation from heavy machinery can negatively impact benthic invertebrates (David Melville, pers. obs.).

Covering: *Spartina* can be covered over temporarily with fabric to prevent photosynthesis and deter plant growth. Care should be taken to ensure the cloth is not washed away (Lyu *et al*., 2023). Alternatively, *Spartina* can be covered with inter- or sub-tidal soils, but this can increase the height of the treated areas. This may trigger an increased vegetation cover. Where this is carried out in the upper intertidal areas, it risks reducing the width of open tidal flat areas that are extremely important for feeding of migratory shorebirds (Mu & Wilcove, 2020).

Burning: Prescribed fire can be used to kill invasive plants, including *Spartina*. Studies where removal by burning has been successful at controlling salt marsh vegetation (including *Spartina*) used backfires, whereby the fire goes against the prevailing wind (de Szalay & Resh, 1997; Gabrey *et al*., 1999). This exposes the plant to higher temperatures for longer (DiTomaso & Johnson, 2006). Burning while the seeds are still on the plants can increase the chances of seed mortality (DiTomaso & Johnson, 2006); however, seed production can be quite variable – in the UK, it was found that flowers emerging in July/August will seed in November, but those emerging in September may not set seed (Mullins & Marks, 1987).

Smooth Cordgrass *Spartina alterniflora* is highly invasive in China and there are ongoing efforts to control it. The photo on the left shows an area of *Spartina* at Nanhui New Town, Pudong New Area, Shanghai in July 2022. The photo on the right shows the same location in September 2022, after the Spartina mown, leaving a stubble height of 20 cm. The soil was thoroughly turned over after mowing. Photos taken by Tianyou Li, a PhD student from East China Normal University.

Case Study: Guangdong Zhanjiang Mangrove National Nature Reserve (ZMNNR), South China

In 2006, *Spartina alterniflora* was found in Guangdong Zhanjiang Mangrove National Nature Reserve, covering over 18 ha. Efforts to control *Spartina* began in November 2019.

The surface layer (including the rhizome layer) was dug up and then buried 1.5 m deep. This was done using an excavator, which worked its way backwards to limit the amount of sediment compaction. In May to July 2020, further removal efforts involved cutting *Spartina* stems, breaking the roots with an excavator and covering it with two layers of black plastic shade cloth. The cloth covered 30 cm beyond the edge of where *Spartina* occurred and was removed the following year if the seedling regrowth from rhizomes was less than 5%. In cases when *Spartina* grew underneath mangroves, they were removed by manually digging the surface rhizomes.

What was the impact on *Spartina*?

The initial digging and burying removed 14 ha of *Spartina*. Further actions, cutting and covering, removed an additional 4 ha of *Spartina*. There still remained 2.7 ha of *Spartina*.

What was the impact on native species?

Shorebirds and benthic invertebrates were surveyed in the area where *Spartina* was removed, as well as an area of bare tidal flat. Shorebird sampling revealed that species richness of shorebirds, and their frequency of occurrence, was similar in eradicated areas compared to bare tidal flats one year after *Spartina* removal. Tracking of individual shorebirds revealed that nine out of fourteen tracked birds used the areas where *Spartina* was eradicated, particularly Common Redshank *Tringa tetanus*. Benthic invertebrates were surveyed 5–20 cm below the surface of the sediment. Density and biomass of benthic invertebrates was found to be lower in areas where *Spartina* had been eradicated compared to bare tidal flats. This suggests that, although shorebirds are present, their food resources may take longer than one year to recover.

Source: Lyu *et al.* (2023)

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Conservation Guidance Series No. 10, v1.0

Guidance on integrated control of *Spartina* spp.

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Smooth Cordgrass *Spartina alterniflora* in Fengxian District, China. [Credit: Tianyou Li]

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Objective: reduce the abundance of *Spartina* species already present in intertidal habitats

Definitions

- **Intertidal** = the area between high and low tide.
- **Herbicide** = a chemical that kills or inhibits the growth of plants.

1. Description

Integrated control most commonly refers to the use of multiple control methods and is generally related to the application of a second control method after cutting. Integrated measures have been found to reduce *Spartina* abundance by 91% and *Spartina* growth by 57%, on average (Wang *et al.*, 2023). Integrated measures may be effective at reducing *Spartina* but the effect on native wildlife must also be taken into consideration.

2. Evidence of effects on biodiversity

Birds: Birds tend to be deterred from areas invaded by *Spartina*, but have been shown to use areas (to a similar degree to non-invaded areas) once *Spartina* has been eradicated (Lyu *et al.,* 2023). Controlling *Spartina* by waterlogging and mowing led to a restored site having comparable species richness to a natural wetland (Fan *et al.,* 2021).

Invertebrates: Cutting or mowing machinery could have potential negative impacts on benthic invertebrates if heavy machinery leads to soil compaction (David Melville, pers. obs.). A study in China found that waterlogging and mowing had negative impacts on the macrobenthic community in the long term (Sheng *et al.*, 2014).

***Native vegetation*:** A review by Wang *et al*. (2023) observed that native plant species diversity on salt marshes was enhanced by 210% following integrated control measures. However, Sheng *et al.* (2014) found that a combination of waterlogging and mowing negatively impacted native reed *Phragmites* spp.

3. Factors that can affect outcomes

Site access: How easy it is to access all areas of the site will determine which techniques can realistically be used. For example, soft mud can make a site inaccessible (Hassell *et al.*, 2014). Humans may need to manually intervene in areas where large machinery cannot reach. However, some areas may also be difficult, or unsafe, to access on foot.

Size of the site: The size of the area that requires *Spartina* removal will influence the methods to be implemented. For example, very small areas could be managed manually by removing plants by hand. However, this is a slow process and would therefore be impractical at a larger scale (Hedge *et al.*, 2003).

Time of treatment: The time of the year the control measure is taken can influence its effectiveness. Evidence from China suggests that the optimal time for mowing is early June to early July, i.e. from the end of the vegetative growth period to the flowering stage (Xie *et al.*, 2019).

Use of heavy machinery: It can be challenging to use heavy machinery in wet, soft, intertidal sediments. Furthermore, vehicles can displace or compress any vegetation present and could have potential adverse impacts on benthic invertebrates in the sediment (Evans *et al.*, 1999; David Melville, pers. obs.).

4. Implementation

Cutting or mowing: Cutting/mowing creates open areas more quickly than herbicides (David Melville, pers. obs.). Cutting and mowing can be done with hand-held equipment or with mowing machines (boats) capable of accessing both land and water. However, Hedge *et al.* (2003) reported that mowing machines were too fragile to use in estuarine environments. The timing of mowing needs to be considered. Sheng *et al.* (2014) found that this mowing reduced *Spartina* stem height but did not eradicate it.

Herbicide: Current global practice suggests that the two most effective herbicides are haloxyfop and imazapyr, with high kill rates shown in New Zealand, USA and China (Brown & Raal, 2013; Strong & Ayres, 2016; Patten *et al.*, 2017; David Melville, pers. obs.). Other herbicides shown to negatively affect *Spartina* abundance include: imazameth, glyphosate, 2,2-dichloropropionic acid (commercially Dalapon) and cyhalofop butyl (Reynolds *et al.*, 2023). Given the small number of studies which have investigated the effectiveness of some individual herbicides, it is important to use caution when drawing conclusions about their ability to control *Spartina* at scale.

Flooding: Flooding areas where *Spartina* grow can kill the roots by decreasing the oxygen availability. A study in China found waterlogging at depths of at least 30–40 cm is the most effective at reducing *Spartina* (Xie *et al.*, 2019). This was effective when combined with mowing in either June or August. This can only be done in areas where the water levels can be controlled over a longer time, so not on open tidal flats. Sheng *et al.* (2014) found that waterlogging and mowing together were the most effective at reducing *Spartina.*

Covering: *Spartina* can be covered over temporarily with fabric to prevent photosynthesis and inhibit plant growth. Alternatively, *Spartina* can be covered with inter- or sub-tidal soils, but this can increase the height of the treated areas. Where this is carried out in the upper intertidal areas, it risks reducing the width of open tidal flat areas that are extremely important for feeding of migratory shorebirds (Mu & Wilcove, 2020). At a site in Xiaoyangkou, Jiangsu, China, placed sediment in fact provided roosting habitat for shorebirds. However, this was subsequently lost as *Spartina* grew up through dumped sediment (David Melville, pers. obs.).

Case Study: Chongming Dongtan National Nature Reserve, China

Chongming Dongtan National Nature Reserve is a Ramsar site located on the eastern tip of Chongming Island in Shanghai, China. It is situated on the East Asian-Australasian Flyway. Invasive cordgrass *Spartina alterniflora* was introduced in 1995 and by 2012 covered over 2,000 ha of the salt marsh in the reserve. This resulted in extensive ecological change across tidal flats, making them unsuitable for foraging and roosting shorebirds.

Various methods for controlling *S. alterniflora* were tested and evaluated in Chongming Dongtan. For example, in 2007, Yuan *et al.* (2011) tested the effect of waterlogging and cutting to control *S. alterniflora*. They found that managed waterlogging initially reduced *S. alterniflora* biomass and seed production, but that *S. alterniflora* later showed rapid adaptation to the long-term waterlogging stress. However, when three months of managed waterlogging was followed by cutting the above-ground part of *S. alterniflora* during the flowering period (July), *S. alterniflora* was successfully eradicated. There was no regrowth of *S. alterniflora* in the following years, however, when the hydrodynamic regime was restored to the area, *S. alterniflora* reinvaded from neighbouring areas.

In 2013, a large-scale restoration project covering 2,400 ha was launched in Chongming Dongtan NNR. This project cost ¥1.3 billion Chinese Yuan (US$ 186 million; February 2024 conversion), with one of the major goals being to eradicate *S. alterniflora*.

There were two main sites in the project region, one that was enclosed by a cement dike and another that was partially enclosed with a sediment dike. The dike was built as an attempt to guarantee the eradication of *S. alterniflora*. Within the enclosed area, *S. alterniflora* was controlled through cutting the plants and flooding the marshes. The plan is for the constructed levee to be allowed to deteriorate, or deliberately breached, so that the area can return to tidal inundation (Mark Dixon, pers. comm.). Barrier fences outside the engineering area stimulated sediment accretion, forming a tidal mudflat <2 m above sea level. This was used for revegetating *Scripus mariqueter,* a common native species.

What was the impact on *Spartina*?

From 2012 to 2016, *S. alterniflora* cover dropped substantially from 2,000 ha to 729 ha. However, large areas of *S. alterniflora* remain intact outside the reserve (over 1,315 ha in 2018) on Chongming Island (Zhang *et al.*, 2020).This serves as a source for subsequent *S. alterniflora* re-invasion and poses a threat to the restoration efforts in Chongming.

In 2016–2017, a field experiment was conducted using Gallant herbicide (Haloxyfop-R-methyl) as an emergency control for re-invading *S. alterniflora* (Zhao *et al.*, 2020). The researchers found the highest tested dose of 2.70 g/m^2 to be the most effective, removing 100% of small patches at 92% of continuous swards. Lower doses (0.45–1.35 g/m^2) were less successful, removing less than 40%. The researchers also found that applying herbicide in July/August resulted in 100% mortality, while *S. alterniflora* was able to recover rapidly when applied in May.

What is the impact on native species?

In the fully enclosed area, species richness and density of macrobenthic invertebrates decreased before and after *S. alterniflora* control. The species that disappeared included snails, bivalves, crustaceans and polychaetes, which are the important food sources for shorebirds. The polychaete *Heteromastus filiformis* and the bivalve *Glauconome chinensis* were the only species present both before and after the control measures. In the partially enclosed area, macrobenthic invertebrate richness increased and it is thought that the tidal flow brought in additional species, such as gastropods.

The number of shorebird species at Chongming Dongtan, and their individual densities, are comparable to a natural wetland and higher than artificial wetlands (fishponds and farmland) (Fan *et al.*, 2021).

Sources: Wang *et al.* (2021); Zhao *et al.*, (2020); Zhang *et al.*, (2020); Hu *et al.*, (2015); Mark Dixon (pers. comm.)

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Disclaimer: These guidelines have been developed through a thorough assessment of available evidence, including a literature review from various global sources, complemented by insights from experts in the field. Their aim is to provide practical insights and recommendations for coastal habitat restoration efforts worldwide. Practitioners and professionals are encouraged to apply their expertise and judgement when using this guidance, adapting it as necessary to address their specific contexts and requirements. It is important to note that stakeholders interested in replicating the approaches presented here assume full responsibility for the success and sustainability of their implementation.

Section 4 Management approaches for shorebirds

Guidance on…

Managing artificial ponds for shorebirds

Creating islands for shorebirds

Managing/clearing vegetation for shorebirds

Reducing disturbance of shorebirds

Conservation Guidance Series No. 11, v1.0

Guidance on managing artificial ponds for shorebirds

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Shorebirds using a partly dried up aquaculture pond for high-tide roosting in China. [Credit: Micha V. Jackson]

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Objective: maintain artificial ponds as roosting and foraging sites for shorebirds

Definitions

- **Intertidal** = the area between high and low tide.
- **Nesting** = when birds lay eggs and protect their chicks.
- **Roosting** = when birds are resting, sleeping or preening, i.e. this is an energy-saving behaviour.
- **Shorebirds** = birds of the order Charadriiformes; includes waders, gulls and terns that use coastal habitats for feeding, roosting and/or nesting.

1. Description

Many shorebirds will roost in man-made, artificial ponds, such as aquaculture ponds. Artificial ponds are not replacements for natural intertidal habitat, but it has been widely recognised that they act as supplementary roosting and feeding sites for shorebirds, especially when natural intertidal habitats are threatened by degradation or natural supratidal habitats (e.g. salt marsh, natural salt pans) have been lost (Ma *et al.*, 2010; Jackson *et al.*, 2020). Aspects of artificial ponds can be managed to improve their utility for shorebirds, such as the water level and vegetation cover.

With the growing human population and resulting food demands, coastal areas around the world are being converted to aquaculture and salt ponds (Sun *et al.*, 2015; FAO, 2020). This conversion involves taking control of water management by embanking, removing vegetation and creating free-standing water bodies in place of the free-flowing water that would occur naturally. Both of these types of artificial ponds are regularly used by shorebirds for roosting at high tide, and in some cases also for foraging or nesting (Sripanomyom *et al.*, 2011; Li *et al.*, 2013; Green *et al.*, 2015). Therefore, their management should be considered alongside natural habitat creation and restoration.

There are some concerns about the reliance of shorebirds on artificial wetlands in coastal areas (Jackson *et al.*, 2020). For example, if aquaculture or salt ponds fall out of use, or if they are converted to other land uses, shorebirds may be at risk (Green *et al.*, 2015; Jackson *et al.*, 2020). For instance, there is an increasing trend in China of placing solar farms over aquaculture ponds and tidal flats (David Melville & Spike Millington, pers. comm.). How these sites are managed for food production and economic benefit should be taken into consideration and integrated with shorebird conservation (Ma *et al.,* 2010). Spatial as well as temporal aspects of management may be considered in favour of the value these habitats can bring for birds.

2. Evidence for effects on biodiversity

Birds: A review of data and expert knowledge from across the East Asian-Australasian Flyway showed that use of artificial (i.e. human-created) wetlands is high throughout the region. The study documented records of 83 shorebird species, including all regularly occurring coastal migratory shorebirds, found at 176 artificial sites with eight different land uses (Jackson *et al.*, 2020). Across five important non-breeding regions of Australia, >50% of the average proportion of the regional population of 39 of 75 species-region combinations used artificial habitats at high tide (Jackson *et al.*, 2021).

Other studies have documented birds' use of specific types of artificial habitats. For example, in the Inner Gulf of Thailand drained aquaculture ponds are used by roosting and foraging birds, although to a lesser extent than salt ponds (Green *et al.*, 2015). Recently drained fishponds can be heavily visited by piscivorous birds, like herons (Ardeidae) and Black-faced Spoonbill *Platalea minor*. In both Hong Kong and Taiwan the majority of foraging by Black-faced Spoonbill *Platalea minor* is in drained down fish ponds (David Melville, pers. comm.) Another study in the Yellow Sea in China found that the banks of aquaculture ponds were used as roosting sites, with shorebirds preferring long banks with little vegetation cover (He *et al.*, 2016).

Salt ponds are used extensively by shorebirds for both roosting and foraging in the Gulf of Thailand (Sripanomyom *et al.*, 2011), Australia (Jackson *et al.*, 2020) and China (Lei *et al.,* 2018). The high usage of salt ponds by birds has been linked to high densities of invertebrates (Masero *et al.*, 2000; Rocha *et al.*, 2017). Rocha *et al.* (2017) found that salt ponds in Portugal that were drained for artisanal fishing led to a rapid increase in the number of foraging birds, suggested to be due to the high densities of polychaete worms. Some shorebirds use salt ponds more than others. A few studies have shown that small birds and short-legged birds use saltpans for roosting and foraging more so than larger birds (Masero *et al.*, 2000; Green *et al.*, 2015; Lei *et al.*, 2021).

3. Factors that can affect outcomes

Distance to feeding area: Shorebirds are more likely to roost in areas close to their feeding habitat (Zharikov & Milton, 2009), as this expends less energy travelling. One study of Nordmann's Greenshank in man-made ponds in the Gulf of Thailand found roosts to be around 1 km away from foraging sites (Yu *et al.*, 2019). A literature review of the importance of artificial roosts for shorebirds globally showed that across 12 studies shorebirds were documented roosting from <1 km to >20 km away depending on the species (with smaller species typically moving smaller distances; Jackson, 2017). However, distances of 2–9 km were more typical in studies where the mean distance across multiple individuals was presented (Jackson, 2017, see Table 1). Shorebirds also appear to travel longer distances to roost sites at nighttime, presumably because of perceived increased predation risk at night (Rogers, 2003).

Water depth: Some evidence suggests that water depth has the strongest influence on whether shorebirds are present (Bancroft *et al.*, 2002; Bolduc & Afton, 2004; Jackson *et al.*, 2019). A study of 94 sites containing man-made ponds found that roosts were, on average, 6 cm deep (Yu *et al.*, 2019).

Pond size: Some evidence suggests shorebirds are more abundant on larger ponds (Sánchez-Zapata *et al.*, 2005; Jackson *et al.*, 2019). Larger ponds have greater habitat heterogeneity and can therefore support a greater diversity of shorebirds. Preserving a range of pond sizes, but prioritising larger artificial ponds, will suit a larger number of shorebird species (Paracuellos, 2006).

Availability of prey: The abundance and accessibility of mud-dwelling invertebrates in the area (Bolduc & Afton, 2004) will influence where shorebirds choose to roost and nest. Bird morphology, such as beak length, influences their feeding preferences.

***Vegetation*:** In general, vegetation is a significant deterrent to most shorebird species using a site for roosting, especially if it is tall or dense (Rogers, 2003; Jackson *et al.*, 2019). Shorebirds rarely settle in areas with >50% total vegetation cover and most prefer vegetation to be less than half of their height (Jackson & Straw, 2021). Shorebirds will not use the edges (for example bunds or walls) around a pond if they have vegetation on them (Jackson & Straw, 2021). A preference for unvegetated roost sites is understood to be related to avoidance of aerial predation by maintaining good site lines around the roost site. It has been observed that vegetation can spread and grow very quickly in some dry patches of an artificial pond (Chi-Yeung Choi, pers. comm.)

Salinity: Salinity is an important factor for managing salt ponds. This affects the invertebrates and aquatic plants, which in turn influences shorebirds (Ma *et al.*, 2010). High levels of salinity can be harmful to waterbirds (Hannam *et al.*, 2003), but can also cause a superabundance of prey, such as brine shrimp, which shorebirds are greatly attracted to (Micha Jackson, pers. obs.). One study found that small birds use saltpans with higher salinity levels, while large birds use those with lower salinity levels (Velasquez, 1992). Shorebirds were found to forage in mid-salinity in San Francisco Bay, USA, with levels ranging from 81–150 ppt (Warnock *et al.*, 2002; Takekawa *et al.*, 2006), while shorebirds foraged in a wider range of salinities (25–220 ppt) in the Berg River Estuary in South Africa (Velasquez, 1992).

Disturbance: Shorebirds are highly sensitive to disturbance while roosting, which may cause them to take flight or abandon otherwise suitable roost sites. Disturbance can be caused by human recreational activities, for example dog-walking, off-road driving, birdwatching or photography too close to birds, or operating aerial devices like kites and drones. Disturbance can also be caused by human production activities like aquaculture harvest, vehicles and machinery, and helicopters.

Predation: The presence of predators will have a strong effect on the numbers of birds using ponds for roosting. Predator management may be considered, such as killing or exclusion using fences (Malcolm Ausden, pers. comm.). One study found that predator disturbance was higher in salt ponds compared to tidal flats, which was suggested as a reason why shorebirds preferred natural tidal flats for roosting (Rosa *et al.*, 2006).

4. Implementation

Water depth: Aquaculture and salt ponds can be managed for shorebird conservation by managing the water levels. Reducing the water levels (Velasquez, 1992; Rocha *et al.*, 2017;

Lei *et al.*, 2021) and exposing areas of mud (Sripanomyom *et al.*, 2011) tends to attract shorebirds. Water levels can be reduced by opening sluice gates (e.g. Rocha *et al.*, 2017). Reducing the water depth to 5–10 cm has shown to attract high densities of foraging birds (Velasquez, 1992; Yu *et al.*, 2019), or as low as 1–2 cm (Rocha *et al.*, 2017). Green *et al.* (2015) suggest that aquaculture ponds should be drained regularly to be used by shorebirds.

Salinity: In practice it can be difficult to regulate salinity in ponds since it is affected daily by factors like evaporation. By using a mix of seawater and freshwater inputs managers may be able to maintain an optimal salinity probably in the range of 80–150 ppt that both encourages the persistence of shorebird prey items while discouraging vegetation growth (Micha Jackson, pers. obs.).

Reduce disturbance: Signs can be erected to warn and encourage humans to avoid areas where there are shorebirds (Medeiros *et al.*, 2007). Areas can be closed off by installing fences: for example rope fences (Lafferty *et al.*, 2006) or temporary fences can be installed during the breeding season (Wilson & Colwell, 2010). Viewing platforms can be constructed so that tourists can view birds from a distance (Burger *et al.*, 2004). For more information see Cutts *et al.,* 2024.

Case Study: Tiaozini wetland roost site, China

Tiaozini wetlands lie on the East Asian-Australasian Flyway in Jiangsu province, China. Tiaozini was declared as the first intertidal wetland World Heritage site in China in 2019 and has since been made into a protected area and developed for ecotourism (Liang *et al.*, 2023).

A site of 48 ha was converted from aquaculture ponds to managed wetland. This was done specifically to create a high-tide roosting habitat for birds. Habitat was created to suit the needs of different species by managing and maintaining the water level, controlling the height of vegetation and restoring the micro-topography. Controlling the water level and altering the topography created areas with different water depths, while vegetation was managed to leave some areas of open mud. The roosting site is located near the intertidal zone within 0.3–0.9 km, meaning birds are close to their feeding area (Wu *et al.*, 2022).

In 2020 and 2021, the site was used by birds for high-tide roosting, including endangered and vulnerable species such as the Spoon-billed Sandpiper. Before this, birds did not use the site.

Source: Liang *et al.* (2023)

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Conservation Guidance Series No. 12, v1.0

Guidance on creating islands for shorebirds

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Dredged spoil island, tidal flats and mangrove vegetation created for waterbirds in Florida, USA. [Credit: Robin R. Lewis III].

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<u>Objective</u>: Create safe nesting and roosting sites for birds

Definitions

- **Dredged sediment** = sediment/debris removed from the bottom of water bodies, such as harbours, lakes and rivers.
- **Dredge islands** = artificial islands created with the controlled disposal of dredged sediment.
- **Intertidal** = the area between high and low tide.
- **Nesting** = when birds lay eggs and protect their chicks.
- **Roosting** = when birds are resting, sleeping or preening, i.e. this is an energy-saving behaviour.
- **Shorebirds** = birds of the order Charadriiformes; includes waders, gulls and terns that use coastal habitats for feeding, roosting and/or nesting.

1. Description

Historically, islands made out of dredged material were created as a by-product of sediment disposal, but have since proven to be valuable refuges for roosting, nesting and foraging shorebirds (Buckley & McCaffrey, 1978; Yozzo *et al.*, 2004; Scarton *et al.*, 2013). For example, in the USA, over 2,000 islands have been constructed in the Atlantic and Gulf Coast estuaries and are used extensively by shorebirds (Yozzo *et al.*, 2004). As islands are located away from the shore, they can provide nesting birds with some protection from disturbance, either from predators or humans (Goodship & Furness, 2022).

Depending on the target species, vegetation on created islands may require management (see Cutts *et al.,* 2024). Trees and shrubs that colonise islands can be useful for canopy-nesting birds (Yozzo *et al.*, 2004) but will be a deterrent to shorebirds, particularly gulls and terns which prefer dry ground and open space for nesting (Conway *et al.*, 2005; Ausden, 2007).

It has been suggested (Golder *et al.*, 2008) that creating artificial islands can stimulate loss of (semi-)natural sites (a) because artificial islands use sediment that might otherwise be used to recharge natural sites, and (b) because it gives the impression that any loss of natural sites can be easily compensated. We are not aware of any evidence supporting these assumptions.

2. Evidence for effects on biodiversity

Birds: Around the world, islands created from dredged material have been shown to support shorebird species as roosting or breeding sites (Buckley & McCaffrey, 1978; Landin & Soots, 1978; Parnell *et al*., 1986; Burton *et al*., 1996; Powell & Collier, 2000; Erwin *et al*., 2003; Yozzo *et al.*, 2004; Akers & Allcorn, 2006; Aulert *et al.*, 2012; Scarton *et al.*, 2013; Chan *et al*., 2019). Shorebirds known to breed on dredge-material islands include Little Ringed plover *Charadrius* *dubius* (Aulert *et al.*, 2012), Snowy Plover *Charadrius nivosus* (Powell & Collier, 2000), Great Black-backed Gulls *Larus marinus* (Aulert *et al*., 2012), and Caspian Terns *Hydroprogne caspia* (Martin & Randall, 1987; Quinn & Sirdevan, 1998). A study in France (Aulert *et al*., 2012) reported that although shorebirds used a constructed island and other constructed roosting areas these structures did not fully compensate (in terms of shorebird numbers) for the loss of an open-sea resting area due to development of a port.

At Mai Po Marshes, Hong Kong, low-lying islands were constructed in a shallow lagoon and provided a high tide roost site throughout the summer wet season. This resulted in first-year (subadult) Terek Sandpipers *Xenus cinereus* over-summering in the area. Previously, all aquaculture ponds around Deep Bay were maintained with deep water over summer and so although tidal flats were available for foraging there was no place to roost at high tide and the area held no over-summering waders (David Melville, pers. comm.).

3. Factors that can affect outcomes

Area: The optimum island size may vary depending on the species. Larger islands can support more birds, but smaller islands may act as refuges for solitary birds. Therefore, having a variety of sizes is ideal if creating multiple islands. Dredge islands in the Atlantic and Gulf Coast estuaries of the USA range in size from 1–80 ha (Yozzo *et al*., 2004).

***Elevation*:** If islands are intended to be used as roosting sites, they should be high enough so that they are not frequently inundated by tides. If islands are intended to be used as breeding sites, they should be high enough that they are never inundated by tides – at least during the breeding season. Consider the likely influence of future sea level rise and climate change (and related storms).

Profile: Shallow slopes provide opportunities for the creation or development of tidal flats or salt marshes. Open, flat-topped, gently sloping islands may be preferable for species that roost in large, tight flocks such as oystercatchers and knots (recommendation in Burton *et al.*, 1996). Steep-sided islands provide more shelter for species that roost in small or loose flocks, such as Common Redshank *Tringa totanus* (recommendation in Burton *et al*., 1996).

Sediment: The grain size of the sediment may influence if and how shorebirds use islands. Evidence from Least Terns *Sterna antillarum*, Gull-billed Terns *Sterna nilotica* and Black Skimmers *Rhyncops niger* nesting on dredged material suggests shell material within the substrate is beneficial as it may play a role in egg camouflage and vegetation control (Mallach & Leberg, 1999). Finer substrates may be invaded by weedy plants while coarser substrates may better resist plant invasion (Powell & Collier, 2000).

Vegetation: The amount of vegetation at a site will affect how birds use it, although the preferred amount varies between species and whether the site is used for nesting or roosting. One study on the use of islands as breeding habitat found that shorebirds were more likely to nest on sparsely vegetated islands than heavily vegetated ones (Burgess & Hirons, 1992). At a site in the UK with created gravel islands, the decline in their use by nesting shorebirds (gulls and terns) was thought to be due to increasing dominance of woody vegetation over 25 years (Akers & Allcorn, 2006).

Distance to feeding area: Shorebirds tend to roost in areas close to their feeding habitat (Zharikov & Milton, 2009) as this reduces expenditure of energy on travelling. For example, for Spotted Greenshank *Tringa guttifer*, roosts in man-made ponds were around 1 km away from foraging sites (Yu *et al.*, 2019). For Eurasian Oystercatchers *Haematopus ostralegus* in the Wadden Sea, roosting sites were around 2–4 km from foraging sites (Bakker *et al*., 2021).

Accessibility: Islands that are close to the mainland and/or in shallow water may be more accessible to terrestrial organisms, especially at low tide (Landin & Soots, 1978). This includes wild animals such as foxes and rats, domestic cats and dogs, and humans – which may prey upon and/or disturb shorebirds.

Competition and predation: Larger shorebird species can reduce the value of artificial islands for target shorebirds. Gulls, for instance, may establish breeding colonies earlier each year than terns, and consequently discourage terns from using the same island (Quinn *et al*., 1996). Gulls may also prey upon eggs and chicks of smaller shorebirds (Quinn *et al*., 1996). Various actions can be used to exclude problematic birds or protect nests (Williams *et al*., 2013). For example, in Canada, covering islands with plastic sheeting early in the breeding season discouraged gull nesting and maintained habitat availability for terns (Quinn & Sirdevan 1998). Mammalian predators can also be a problem for shorebirds. On dredge islands in Maryland, USA, fox predation of terns was mitigated by trapping, along with an education programme to address public concerns (Erwin *et al.*, 2007).

Existing habitat: In areas where there is already plenty of suitable shorebird habitat, there may be little to gain from creating new islands. Researchers in the USA suggested that dredge islands are used extensively only where alternative sites are not available (Landin & Soots, 1978).

Use of attractants: Shorebirds may be hesitant to use newly created sites. Decoys and/or vocalisations can be used as attractants (Williams *et al*., 2013). For example, a study in the USA reported that Forster's Terns *Sterna forsteri* only started nesting on artificial structures once decoys and vocalisations were added (Ward *et al*., 2011).

4. Implementation

Sediment is available from dredging practices for maintaining human infrastructure and transport corridors, such as ports and waterways (Sheehan & Harrington, 2012). Islands can be created by confining the dredged sediment in one place by using, for example, rubble, wooden cribs, or by planting vegetation around it (Yozzo *et al*., 2004; Scarton *et al.*, 2013). Careful planning is needed to make sure sediments do not get washed away within a few years (Chi-Yeung Choi, pers. comm.). It is generally sensible to invest in protection on the windward side of islands, for example in the form of dikes or breakwaters. Consider whether an absence of existing islands is an indicator of high energy levels that would lead to rapid erosion (Golder *et al*., 2008). Finer sediments (clay, silt or fine-grained sand) are more susceptible to wind erosion and will take longer to stabilise than coarser sediments (Golder *et al*., 2008). Fine sediments can be stabilised by mixing in coarser sediments or sand, or by depositing coarse material on top (Landin & Engler 1986; Golder *et al*., 2008). To maintain their size, it is suggested that dredge islands require deposits every three to seven years (Golder *et al*., 2008).

It has been suggested that feeding shorebirds are attracted to standing fresh water on dredge islands, if it contains lots of mosquito larvae (Parnell *et al*., 1986). Incorporating ponds into dredge island design may benefit shorebirds.

If islands are being created close to existing sites used by shorebirds, work should avoid the breeding season, when birds are particularly sensitive to disturbance (Golder *et al*., 2008). The presence of infrastructure, such as airports or wind turbines, which introduce a bird collision risk, can restrict the feasibility of island creation (Climate-ADAPT 2023).

Be wary that dredged material can be contaminated with heavy metals and persistent organic pollutants (POPs), which can be taken up by vegetation and other wildlife. Contaminated sediments can be capped with clean substrate, ideally to a minimum thickness of 60 cm (Yozzo *et al.*, 2004).

As an indicative cost of island creation, a single 200 x 325 m island off the north coast of France cost €8 million (about US$ 8 million; February 2024 conversion). in 2005 (Aulert *et al*., 2012).

Case Study: Marker Wadden, Markermeer, The Netherlands

Marker Wadden is a man-made archipelago consisting of five islands in the Markermeer lake in the Netherlands. The islands cover 1,300 ha (excluding two under construction in 2023). The islands are used recreationally but there are strict rules for visitors. There are jetties, walkways and bird observation points for visitors.

The Markermeer lake was created in 1976 when a dike was built connecting the two coastal cities Enkhuizen and Lelystad, leaving Markermeer cut off from open water. A lack of current led to a build-up of silt at the bottom of the lake. The silt is disturbed by wind-induced waves, leaving the water turbid with disastrous consequences for the food web. As a way to restore the ecological balance, five islands were created with dredged material, the goal being to halt ecosystem decline and restore native biodiversity.

How the islands were created

Construction began in May 2016. A total of 30 million m^3 of sediment (sand, silt and clay) was dredged from Markermeer lake to create the islands. Equipment used included a cutter suction dredger Edax, a spray pontoon, three crane vessels and earth-moving equipment. Firstly, ring dikes were built out of sand, into which the dredge material was sprayed. This material was deposited in layers, allowing the sediment to consolidate before adding a new layer until the islands were above sea level. The larger, sandier sediment particles settled closest to the spray nozzle, while the finer, siltier sediment spread further away, creating texture at the bottom of the lake. The top layer of sediment dried to form a crust. Sand hills were built in the water at the back of the islands creating a gradual transition from land to water, with creeks and swamps of clear water. There was initial subsidence of the sediment (1.7 m), mostly in the first three months after filling, but this continued for 2.5 years.

Silt has accumulated on the sheltered side of the archipelago, which can be used for future maintenance. The islands are protected from stormy weather by the sandy edges. However, some measurements revealed that the sand can be lost laterally, causing a landward shift of the islands.

Biological development

Reed *Phragmites communis* was established manually through sowing, planting rhizomes and spreading grass clippings. Reed rooted rapidly and had a strengthening effect on the soil. The pioneer plants Marsh Ragwort *Tephroseris palustris* and Red Goosefoot *Oxybasis rubra* developed almost immediately on the shallow tidal flats. Geese were able to walk on the dried crust layer within a few weeks. Submerged aquatic vegetation developed after roughly one year, including pondweeds *Potamogeton* spp., stoneworts *Chara* spp. and Eurasian Watermilfoil *Myriophyllum spicatum*.

In 2020 and 2021, four years after construction began, there were 43 and 47 species of breeding birds on the islands, respectively. Birds that breed on bare sand were the first to settle, for example Common Tern *Sterna hirundo*, Avocets *Recurvirostra avosetta* and Kentish Plover *Anarhynchus alexandrinus* (rare). Passerines and ducks were also recorded, including the first breeding pair of Long-tailed Ducks *Clangula hyemalis* in The Netherlands. The islands act as stepping stones between nearby marshland.

Nutrients released from the dredged material led to high densities of filamentous sulphur bacteria *Thioloca spp.* relative to the surrounding area. Their role in the food web is unclear.

Sources: KIMA (2022); Video: Marker Wadden – Positive impetus to the ecology of the Markermeer Lake (youtube.com/watch?v=3I0lJhZdUOc).

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Conservation Guidance Series No. 13, v1.0

Guidance on managing/clearing vegetation for shorebirds

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Encroachment of vegetation on the intertidal flats of the Inner Deep Bay, Hong Kong. [Credit: David S. Melville]

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Conservation Evidence

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Objective: maintain open space for birds

Definitions

- **Nesting** = when birds lay eggs and protect their chicks.
- **Roosting** = when birds are resting, sleeping or preening, i.e. this is an energy-saving behaviour.
- **Scrapes** = shallow depressions with gently sloping sides that hold water intermittently.
- **Shorebirds** = birds of the order Charadriiformes; includes waders, gulls and terns that use coastal habitats for feeding, roosting and/or nesting.

1. Description

Vegetation influences how shorebirds and other waterbirds use salt marshes and tidal flats. Shorebirds have different requirements for nesting, roosting and foraging and these requirements also vary among species (Ma *et al.*, 2010). Vegetation management may be needed to create suitable nesting, roosting and foraging sites if no alternatives are available.

Vegetation will develop when water levels are low, but this may be at odds with shorebirds' requirements for shallow water (for roosting) and for dry surfaces (for nesting). Therefore, depending on the target species/behaviour, regular clearing of vegetation may be necessary to maintain open space and this may need to be coupled with regular flooding and draining. But be mindful about the nesting period to avoid that nests are washed away.

There are some important things to consider and evaluate first before taking this action, such as the fact that salt marsh habitat may only be a suitable roost site for a few days in the entire tidal cycle because it will get inundated at high tide for most of the days (Chi-Yeung Choi, pers. comm.).

2. Evidence for effects on biodiversity

***Birds*:** When roosting, shorebirds are more abundant when there is less vegetation (Jackson *et al.*, 2019). When foraging, dense vegetation cover can prevent accessibility for foraging (Bancroft *et al*., 2002). When it comes to breeding, needs differ among species. Several species of shorebird prefer to nest in unvegetated, open areas and shallow scrapes on the ground in coastal areas (Conway *et al.*, 2005; Ausden, 2007), particularly gulls and terns. Others prefer light or even full cover, such as Arctic-breeding shorebirds, Black-tailed Godwits *Limosa limosa*, Lapwing *Vanellus vanellus* and Eurasian Curlew *Numenius arquata* (Ward Hagemeijer, pers. comm.). Dense vegetation is avoided. In coastal habitats like salt marshes and tidal flats, most species are towards the 'open' end of the scale for their breeding preferences. At a site in Texas, USA, an entire Caspian Tern *Sterna caspia* colony relocated to an area where the vegetation was cleared and the sand was smoothed with a tractor (Roby *et al.*, 2002). A study in Canada found that Common Terns *Sterna hirundo* nested at higher densities in sites where clumps of mossy stonecrop and driftwood had been added, while they rarely nested in sites layered with gravel or with bare ground. At a site in the UK, the number of Ringed Plover *Charadrius hiaticula*, Oystercatcher *Haematopus ostralegus* and Lapwing doubled after vegetation was removed from an area of 465 m^2 (Wilson, 2005). Studies from islands have found higher abundances of birds when vegetation is removed (Akers & Allcorn, 2006), or when vegetation is sparse (Burgess & Hirons, 1992). One study found that Sooty Terns *Sterna fuscata* did not nest when all vegetation was cleared, but did nest when vegetation was partially cleared (Saliva & Burger, 1989). Saunders's Gulls *Saundersilarus saundersi* at Shuangtaizehekou NNR, Liaoning, China, nested in areas where tall (around 1 m) dead stems of *Suaeda salsa* from the previous growing season had been cleared overwinter, but avoided areas where stems remained. Winter clearance of vegetation has continued at the reserve for >20 years (David Melville, pers. comm.).

Shorebirds often prefer to roost in open spaces, such as these Sharp-tailed sandpipers Calidris acuminata roosting in a salt marsh in Goolwa, South Australia. [Credit: Micha V. Jackson].

3. Factors that can affect outcomes

Water level: Water depth influences how much and what type of vegetation will grow. Some evidence suggests that bird abundance is more strongly related to the water level than it is to vegetation (Bancroft *et al.*, 2002), therefore water level should be considered alongside vegetation management.

4. Implementation

Manual removal: Vegetation can be cleared physically by hand or by using machinery. Heavy machinery can be used to scrape away vegetation, remove woody debris and clear vegetation, for example bulldozers (Roby *et al.*, 2002) or tractors (Wilson, 2005) can be used to create bare sand. Machinery may then be used to smooth bare sand surface to create attractive nesting habitat (Roby *et al.*, 2002).

Flooding: Vegetation can also be suppressed by flooding. Flooding benefits the macroinvertebrates in the mud, so when water is drained, they are readily available as food for shorebirds (Jackson & Straw, 2021). However, some plants can survive long periods of flooding, such as Common Reed *Phragmites australis* (unless it is completely submerged, which will eventually kill it; Malcolm Ausden, pers. comm.) or Smooth Cordgrass *Spartina alterniflora*, in which case physical removal may also be required (see Cutts *et al.,* 2024a-c). Reeds can be managed by regular mowing, but consideration should be taken for non-shorebirds that use reedbeds (Boulord *et al.*, 2012; Kubacka *et al.*, 2014). Nests washing away is a common cause of breeding failure in coastal habitats, therefore, if using flooding to reduce vegetation, this should occur outside of the breeding season (Ward Hagermeijer, pers. comm.).

Herbicide: Herbicide could be an option for problematic species. For example, at a site that was invaded by willow scrub *Salix* sp*.* in the UK, the willow were removed and their stumps treated with herbicide. Note that little is known about the long term effect of herbicide on birds in the wild (as far as we are aware). Experimental studies on Japanese Quail *Coturnix japonica* suggests there may be a cumulative effect of glyphosate exposure (Ruuskanen *et al.*, 2020a,b). Those fed with glyphosate-contaminated seeds from 10 to 52 weeks of age had a different gut microbiome, decreased levels of male testosterone and slightly lower embryonic development compared to a control group, but there was no clear effect on reproduction, in terms of testis size and egg production. Eggs collected from these species contained glyphosate residues but there was no effect on the egg quality.

Vegetation on islands: Vegetation on islands can be trickier and more intensive to manage than on the mainland. Lowering the elevation of islands so they are closer to the water level can help reduce vegetation growth (Akers & Allcorn, 2006), but be aware of the risk of flooding of nests at (occasional) high water levels. If removing vegetation from islands, equipment may need to be floated across on rafts (Akers & Allcorn, 2006).

5. Other sources of information

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Disclaimer: These guidelines have been developed through a thorough assessment of available evidence, including a literature review from various global sources, complemented by insights from experts in the field. Their aim is to provide practical insights and recommendations for coastal habitat restoration efforts worldwide. Practitioners and professionals are encouraged to apply their expertise and judgement when using this guidance, adapting it as necessary to address their specific contexts and requirements. It is important to note that stakeholders interested in replicating the approaches presented here assume full responsibility for the success and sustainability of their implementation.

Conservation Guidance Series No. 14, v1.0

Guidance on reducing disturbance of shorebirds

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Shorebirds taking flight in response to disturbance at an important high tide roost site at Lee Point (Darwin), Northern Territory, Australia. [Credit: Micha V. Jackson].

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Objective: create a safe environment for nesting, roosting and feeding shorebirds

Definitions:

- **Disturbance** = activity that causes an individual or group of shorebirds to alter their normal behaviour, leading to additional energy expenditure by the birds. Productivity and survival rates may also be reduced (Mengak & Dayer, 2020).
- **Flight initiation distance** = the distance at which birds take flight to avoid perceived danger.
- **Nesting** = when birds lay eggs and protect their chicks.
- **Roosting** = when birds are resting, sleeping or preening, i.e. this is an energy-saving behaviour.
- **Shorebirds** = birds of the order Charadriiformes; includes waders, gulls and terns that use coastal habitats for feeding, roosting and/or nesting.

1. Description

Roosting, nesting and feeding are vulnerable behaviours, therefore shorebirds prefer sites that are safe from disturbance from humans or predators (Rogers *et al.*, 2006; Rosa *et al.*, 2006). Disturbing birds while they are roosting, nesting or feeding causes them to expend energy. For nesting birds, disturbance may result in periods in which the nest is unguarded, therefore leaving it vulnerable to predation and temperature change. This may cause hatchlings to fledge prematurely or drive recently fledged chicks into danger (e.g. away from parents, into the water or into sight of potential predators). Preventative measures can be used to encourage people to avoid areas where birds may be nesting, roosting and feeding.

Disturbance by humans can be caused by cars, boats, aircraft, firearms, seafood collection, or simply by walking too close to shorebirds. In China, extensive collection of invertebrates by humans has been reported, with molluscs and shrimps being harvested at a rate of 100–150 kg/day (Melville 1997). Disturbance can also be caused by animals such as livestock (Sharps *et al.*, 2017), avian predators and domestic dogs. Note that some human presence may in fact be beneficial for coastal birds, acting as a predator deterrent. For example, in Sweden, the absence of tourists during COVID-19 lockdowns was associated with increased disturbance of breeding Common Murres *Uria aalge* by eagles, and consequently reduced productivity (Hentati-Sundberg *et al.*, 2021).

2. Evidence for effects on biodiversity

Birds: Closing paths and trails has increased reproductive success of Hooded Plovers *Thinornis rubricollis* (Dowling & Weston, 1999) and Snowy Plovers *Charadrius nivosus*

(Lafferty *et al.*, 2006; Wilson & Colwell, 2010). Using signs alone to warn people of nesting shorebirds reduced the probability that hooded plover eggs were crushed (Weston *et al.*, 2012).

Often, multiple specific measures are used *in combination* to reduce disturbance. In the north-east USA, a combination of signs, access restrictions, viewing platforms, patrols and penalties for infractions drastically reduced disturbance of shorebirds (Burger *et al.*, 2004). In Portugal, Little Tern *Sterna albifrons* nesting success was improved by a combination of signage and wardening nesting areas during weekends at peak disturbance times (Medeiros *et al.*, 2007). In New Jersey, USA, a combination of signage and education improved the reproductive success of Common Terns *Sterna hirundo* (Burger & Leonard, 2000). In Namibia, a combination of information boards, barriers, limiting quad bikers to one designated route and handing out information sheets to recreational users increased the overall number of chicks hatching from a Damara Tern *Sterna balaenarum* colony (Braby *et al.*, 2009).

Excluding predators can increase nesting success (e.g. Dinsmore *et al.*, 2014), however, the use of exclusionary fences may also lead birds to abandon their nests (Vaske *et al.*, 1994).

Harvesting seafood from tidal flats can disturb roosting and foraging shorebirds. Here, people are searching for invertebrates on the tidal flats of Sonadia Island, Cox's Bazar, Bangladesh [Credit: Sayam Chowdhury].

3. Factors that can affect outcomes

Bird species: Tolerance to disturbance varies between shorebird species. For example, one study found Bar-tailed Godwits *Limosa lapponica* to be more susceptible to noise disturbance than other shorebirds (van der Kolk *et al.*, 2020). Species- and disturbance-specific 'flight initiation distances' can be used to inform positioning of measures such as signs, fences and viewing platforms (Livezey *et al.*, 2016).

Type of disturbance: The costs and benefits of human presence on shorebirds will depend on factors such as the proximity, frequency and intensity of any disturbance. The specific method used to manage disturbance will need to be tailored to the type of disturbance. For example, signs adjacent to nests will not reduce disturbance from drone pilots operating remotely. Signs should be legible to the main groups who might cause disturbance; in areas frequented by tourists, for example, signs may need to be written in multiple languages.

Vandalism: Structures put in place to reduce disturbance may be subject to vandalism, especially if people using the area do not understand or agree with the protection measures. In Patagonia, Argentina, rope fences and signs around plovers nesting on a beach were stolen (Hevia & Bala, 2018). Possible solutions include using heavy, well-secured materials (Hevia & Bala, 2018), combining physical protection with education programmes, and having wardens or rangers present.

4. Implementation

Putting up signs: Signs can be erected to warn and encourage humans to avoid vulnerable shorebirds. Placing signs near to the site of requested behaviour can increase the desired behaviour outcome (Austin *et al.*, 1993). Therefore, it may be more effective to place signs next to exclusion zones rather than at the entrance to a beach, for example directly around breeding colonies of birds (Medeiros *et al.*, 2007) or on buoys around salt marsh islands to prevent disturbance from boats (Burger & Leonard, 2000).

Personalised and humanised messages (e.g. telling the story of an individual bird) can elicit more sympathy (Rare and The Behavioural Insights Team, 2019) as opposed to providing statistics, which can be ineffective for non-environmentalists and lead to 'compassion fade' (Markowitz *et al.*, 2013). Phrasing instructions positively ("You can help by…") rather than negatively ("Do not…") is thought to encourage more pro-environmental behaviours (Schneider *et al.*, 2017). Wording should be clear and unambiguous (e.g. being clear about laws relating to wildlife) and if signs are used across multiple sites, consistent messaging is preferable (Rare and The Behavioural Insights Team, 2019).

An example of a sign used in Ireland that resulted in fewer Northern Gannets *Morus bassanus* being displaced from their nests read: "*These birds are breeding. Under the Wildlife Act (1976) it is illegal to disturb nesting birds. Please do not approach the colony as doing so may result in the abandonment of eggs or the death of chicks. Thank you for your consideration*" (Allbrook & Quinn, 2020). In contrast, there are reports of signs being ignored (e.g. information and interpretation boards around a tern colony in Namibia; Braby *et al*., 2009) or vandalised (e.g. on a beach around a plover colony in Argentina; Hevia & Bala, 2018).

Closing areas: Areas can be closed off by installing fences, e.g. rope fences (Lafferty *et al.*, 2006). Temporary fences can be installed during the breeding season (Wilson & Colwell, 2010). In a study of Hooded Plover *Charadrius cucullatus* nesting sites in Victoria, Australia, a combination of fences and signs achieved a greater compliance rate than signs alone (Maguire, 2008).

Education and awareness-raising: Information about the presence of shorebirds, and the disturbance caused by activities, can be shared through various means – including workshops, videos, newspaper articles, social media posts, information sheets and signage. There is evidence that education programmes, in combination with other interventions, can reduce disturbance of shorebirds (Burger, 2003; Braby *et al.*, 2009). However, be aware that raising awareness doesn't necessarily lead to any behaviour change and may even stimulate undesirable behaviours (Christiano & Niemand, 2007).

Signs can be used as a method of preventing human access or providing information about vulnerable species. The sign pictured here is from a constructed roost site in Moreton Bay, Queensland, one of Australia's most important regions for shorebirds. It illustrates where public access is prohibited, to avoid disturbing shorebirds that use the small area, which is surrounded by human housing during high tide. [Credit: Micha V. Jackson].

Bans/restrictions on activities: Disturbance-causing activities could be banned entirely (e.g. walking dogs on beaches) or restricted (e.g. setting speed limits for boats, setting lower altitude limits for drone flights; Cantu de Leija *et al.,* 2023). Bans/restrictions may only be necessary during the breeding season, or at other times of year when shorebirds are particularly sensitive to disturbance. Bans/restrictions will need to be communicated to the relevant user groups, for example through education programmes, signage or wardens.

Wardens: Professional or volunteer wardens can help to enforce access restrictions and educate people. On a beach in Florida, USA, the number of people entering a protected area (surrounded by symbolic fencing) was around nine times lower when an identifiable "Bird Steward" was present compared to when there was no Steward (Forys, 2011).

Viewing platforms: Viewing platforms can be constructed so that people can view birds from a safe distance (Burger *et al.*, 2004).

Remove/avoid elevated structures: Avian predators may use elevated structures to oversee open areas and this causes increased predation pressure (Ward Hagemeijer, pers. comm.). It is suggested to avoid constructing habitat close to existing points with an overview for predators and avoid erection of new view-points, or even consider removing existing elevated structures (Ward Hagemeijer, pers. comm.).

Catching/culling/restricting access of animals: Animals that may prey upon or disturb shorebirds can be excluded using anti-predator fences (Williams *et al.*, 2013). These can be constructed deep into the ground (to exclude burying animals) and may be electrified (e.g. Dinsmore *et al.*, 2014). Wire mesh with 30-mm-diameter holes should exclude medium- and large-sized mammals (Robley *et al.*, 2007). Fences/cages can be placed on individual nests, but be wary that this may lead birds to abandon their nests (Vaske *et al.*, 1994). Alternatively, with appropriate licences and ethical considerations, animals could be controlled by trapping or culling.

Restricting access of livestock: The presence of livestock can also cause disturbance to shorebirds. This can be prevented by keeping them away from habitats for nesting, roosting and feeding of shorebirds, or by reducing livestock density (Sharps *et al.*, 2017).

Consider stakeholders: The success of disturbance management interventions may be increased by involving stakeholders – individuals or groups that may affect, or be affected by the intervention – in design, planning and/or delivery (Sterling *et al.*, 2017). For example, Burger & Niles (2013) attribute the granting of permission for a beach closure, and subsequent compliance with the closure, to meaningful stakeholder engagement.

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Conservation Evidence

Wetlands INTERNATIONAL

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