Can we recreate or restore intertidal habitats for shorebirds?

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Loss of intertidal habitat to development continues apace. Coupled with the long-term effects of climate change there will be an increasing need to create new areas of intertidal habitats if shorebird populations and flyways are to be effectively conserved. Habitat restoration and creation efforts in the US, Europe and Japan have shown that creating salt marsh is often a hit or miss affair as new sites tend to support different communities and a different range of ecological functions to surrounding areas. Creating mudflats often meets with a higher degree of success if sediment supply is sufficient as benthic invertebrates and shorebirds colonise relatively quickly. Sites in higher energy environments tend to reach equilibrium quicker than lower energy environments. Many restoration sites tend to be small and thus factors, such as enclosure, tend to impact on the birds that use the sites. Not only do the factors controlling the restoration need to be better understood so that high quality habitats can be produced but also the impacts of creating new habitats on shorebirds at the population level. This will require a much better understanding of flyways, migration strategies and other factors controlling populations at a large scale.

INTRODUCTION

One of the greatest threats facing shorebirds has been the loss or degradation of breeding, staging and wintering habitats. This has been global in extent and there is probably not a flyway that has not been affected by large-scale loss and deterioration of wetland habitat. Total wetland loss worldwide has been estimated at 50% of those that have been in existence since 1900 (Dugan 1993, OECD 1996). In northern countries much of this loss took place during the first half of the twentieth century but during the latter part, tropical and sub-tropical wetlands were increasingly being degraded or lost, predominantly through conversion to agricultural use, which is the major cause of wetland loss worldwide. By 1985, it was estimated that 56–65% of wetlands had been drained for intensive agriculture in Europe and North America, 27% in Asia, 6% in South America and 2% in Africa, a total of 26% loss to agriculture worldwide (OECD 1996). These figures mostly refer to freshwater habitats and the global coastal wetland resource is generally poorly known. However, changes within these habitats (including tidal flats, salt marshes, sea grass beds, mangroves, saline lagoons, shingle banks and transitional brackish-water habitats) have been every bit as large as freshwater habitats. In the United Kingdom, 23% of estuaries and 50% of salt marshes have been drained since Roman times (Davidson *et al.* 1991, Moser *et al.* 1996).

Added to this continuing anthropogenic loss will be the creeping effects of changing environmental conditions through climate change and rising sea levels. As a result, managers of estuarine and open shore habitats, which support important populations of waterbirds (defined here as any species dependent on wetland habitats at any time during its lifecycle), will face new challenges to mitigate the effects of both direct habitat loss and these changing environmental conditions. The response to these changes will differ, but in many countries where this has been an issue, there has been an acceptance that loss of habitats will need to be compensated for by the restoration or creation of new habitats.

Many countries now have a policy of compensating for lost wetland habitats. The compensation will vary in response to each particular situation, e.g. compensation for a the loss of an area through development will be very different to the strategy used to mitigate the widespread effects of changing climatic conditions and accelerating sea-level rise. Compensation for loss of a particular site usually involves the creation of a new site elsewhere. Solutions to sea-level rise will necessarily include a larger scale approach which will include a mix of maintaining current sea defences through soft or hard engineering techniques, abandonment or managed realignment, i.e. taking back sea walls and creating intertidal habitats (Dixon *et al.* 1998). There is huge potential to replace lost areas and create valuable habitat for waterbirds.

The science behind the restoration and creation of many terrestrial habitats is well advanced. However, intertidal habitats pose special problems for restoration because they are topographically and ecologically complex and they support many species of animals, some of which require specific habitats and linkages to other terrestrial or marine habitats. Moreover they exist and evolve within dynamic coastal settings, subject to changing tidal levels, salinities and long term mechanical processes that are associated with sea-level rise and climate change (Atkinson *et al.* 2001). Often these complexities are ignored and there is a tendency for created coastal habitats to lack the diversity seen in natural areas and support only generalist species. Also, created sites rarely follow expected paths and the stable states that are reached often differ from what was expected, despite multi-million dollar investments (Zedler & Callaway 1999), leading to the conclusion that the current state of restoration theory applied to coastal habitats does not necessarily lead to predictability.

To effectively mitigate this loss, there is a great deal to learn, not only about the processes underlying coastal habitat restoration or creation, but also those that control the shorebird populations that many of these areas will be created for. The purpose of this paper is to assess the state of knowledge about creating or restoring salt marshes and tidal flats for shorebirds, and to ask what we need to know to be better equipped to predict the outcomes of creation and restoration efforts on shorebird populations. As most research has been carried out on these two habitats, this paper concentrates on them. However, it must be acknowledged that much needs to be done to address the issues of creating and restoring other intertidal habitats such as mangroves and sea grass beds which are also important for waterbirds (e.g. Field 1968).

CURRENT STATE OF COASTAL WETLAND RESTORATION SCIENCE

The science of restoring coastal habitats has been developed in the United States for three decades and there is now a substantial and growing body of literature covering the expertise that has been acquired there on the creation and restoration of wetlands. Of most relevance to this review, are those studies that have focussed on efforts to create and restore tidal wetlands (e.g. Broome *et al.* (1988), Zedler *et al.* (1988) & Zedler (1996)), despite the fact that many of them have concentrated on physical features with only limited monitoring of plants, fish and invertebrates. This has culminated in the production of practical handbooks for the restoration of tidal wetlands (e.g. Zedler 2001). A recent special issue of *Wetlands Ecology and Management* focused upon the beneficial use of dredge material for the restoration of US salt marshes and mudflats (Streever 2000). Unvegetated mudflats are not classed as wetlands under S.404 of the US Clean Water Act and thus intertidal habitat creation work in the US has focussed on the creation of salt marshes. As a consequence, mudflat creation schemes in the US have usually been motivated by a desire to dispose of dredged material rather than by nature conservation concerns.

In NW Europe the experience of creating new habitat, especially mudflats, is fairly limited and the use of dredge material or managed realignment to create or restore areas has often been haphazard with little or no monitoring. Again, few studies have monitored the impact on shorebirds though there have been some. In particular, a created mudflat on the Tees estuary, NE England, has been monitored intensively and this has provided valuable information on benthic invertebrates and shorebird usage (Evans *et al.* 1997, 2001). In addition, managed realignment sites at Tollesbury and Orplands on the Blackwater estuary, SE England, have been monitored for plants, invertebrates and birds (Reading *et al.* 2000, Atkinson *et al.* in press b).

The majority of papers about managed realignment in the UK have concerned non-biological processes such as geochemical changes, tidal exchange, persistence of salt marsh in unmanaged retreat sites and policy related to managed realignment (see Atkinson *et al.* 2001 for list). It is perhaps not surprising that little has been published in the peer-reviewed literature on the biological aspects, as sites at which habitat creation or restoration has been practised in the UK are generally less than five years old.

Large areas of man-made marshes and mud flats are found in the Wadden Sea. Although only a fraction of the area present about 2,000 years ago, these intertidal habitats are still the largest contiguous area of salt marsh in Europe, and the Wadden Sea is Europe's largest intertidal wetland covering some 8,000 km^2. However, in the 50 years to 1987, 33% of the area was lost to embankments (Dugan 1993) and new marshes formed in front of the new sea walls. Within The Netherlands, there are over 17,000 ha of man-made salt marshes, created specifically for flood defence purposes rather than for any other environmental benefit (Esselink 1998). This policy is changing and salt marshes on the North Sea coasts of Germany, Belgium, The Netherlands and Denmark, which are of high conservation importance because of the large concentrations of wintering, passage and breeding waterfowl that they support, are now increasingly being managed for nature conservation purposes (Esselink 2000). Again little has been published in the peer-reviewed literature although the created marshes at Sieperda in The Netherlands are a notable exception (Castelijns *et al.* 1997, Eertmann *et al.* 2002).

Elsewhere in the world, Japan has led the way in creating tidal mudflats and, according to the Environment Agency of Japan, 37 covering approximately 900 ha were created between 1973 and 1998 (WAVE 2001a,b). This is small compared to the loss of nearly 4,000 ha (42% to reclamation) over the same time period (WAVE 2001a,b). The total area of tidal flats in Japan is 51,443 ha (Environment Agency of Japan 1997). Six of the newly created mudflats were directed towards creating areas for birds, but there are few accessible data with which to assess success.

Research has therefore been geographically rather limited and focussed on particular habitats or ecosystems. One of the largest issues, rarely tackled in most studies, has been a detailed assessment of the physical, temporal and biological factors that determine the resulting habitats and communities and how these relate to the range of variation found in natural areas. Most studies have simply described the biological communities and the changes within them. Restoration schemes are also generally small (both in extent and number) compared with surrounding "natural" areas. Where comparisons are made, the high variability exhibited by natural areas often hides differences in the sampled attributes between created and restored sites and surrounding natural areas. This means that results from many studies may not be applicable at a larger (i.e. regional rather than site) scale.

This makes the definition of a "successful" restoration quite difficult, given that natural habitats are very varied and restoration sites tend to be small. It may be that we can only create a subset of natural habitats and thus any wetland habitat created could be thought of as a success. Therefore to be able to restore or create habitats for shorebirds successfully, they should exhibit the functions and processes within the variation found in surrounding natural habitats at a range of spatial scales. In many cases, this will mean allowing dynamic change to take place, e.g. allowing habitats to shift upshore in relation to sea level rise. In estuaries, it means taking a strategic approach at the flood plain level, using the whole estuary as a functional unit rather than concentrating on particular vulnerable areas within the estuary. This type of approach has the advantage of allow ephemeral habitats such as saline lagoons and fresh/brackish water transitional habitats, which are important for shorebirds, to remain.

WHAT DO STUDIES TELL US SPECIFICALLY ABOUT SHOREBIRDS?

Are created/restored salt marshes equivalent to natural marshes? Despite waterbirds, and shorebirds in particular, being an important component of coastal ecosystems, few intertidal habitat restoration schemes have specifically targeted this group, unless specialist or endangered species are involved (e.g. Light-footed Clapper Rail *Rallus longirostris* in the United States). The results of the few studies in the US that have assessed bird usage on restored or created *Spartina* dominated marshes are mixed. Both natural and restored marshes provide habitats for birds, but not necessarily for the same communities. For example in Galveston Bay, Texas, shorebird usage and diversity was higher on natural marshes due to a greater diversity of habitats in natural areas (Melvin & Webb 1998). However, Havens *et al.* (1995) found that, although waterbird abundance was higher in restored areas, they did not hold populations of Willet *Catoptrophorus semipalmatus,* a marsh specialist, whereas Brawley *et al.* (1998) found that restoration of tidal flow to an impoundment led to reinstatement of breeding Willet. In a study of ditched and unditched marshes, Reinert *et al.* (1981) found that more open water led to a greater diversity of shorebirds.

Overall, the few US studies have concluded that, in terms of bird usage, functional equivalence of man-made marshes with natural marshes may or may not occur and much of this is due to differences in habitat between the two types of site. In most cases, macrofauna (including birds) colonise quickly and the assemblage reaches maturity in a short space of time, often less than three years, e.g. at the Gog-le-hi-te wetland (Simenstad & Thom 1996). At this site, the taxa richness of epibenthic organisms, fishes and density of fishes all approached asymptotic trajectories (i.e. stability) within three to five years of restoration, but the numbers of birds using the site continued to increase over the seven year duration of the study. Despite these rapid responses by fish, invertebrates and birds, the restoration, creation and enhancement of the estuarine marshes appears to have been problematic (Zedler 1988, Moy & Levin 1991), as measurements of other ecological functions indicated that this particular wetland was in an early stage of maturity. Few predictable trajectories of community development were evident and few indicated system maturity. For example, the organic content, chlorophyll/phaeophytin pigments and the infauna taxa richness and density increased slowly or remained relatively depressed over the same three to five years of monitoring, but *Carex* production showed a gradual progression towards reference marsh levels. Simenstad & Thom (1996) also point out that many "functional trajectories" are unpredictable and, due to the short-term nature of monitoring projects, it is impossible to understand why trajectories either converge, diverge, fluctuate or achieve an alternative stable state to reference areas.

Differences in habitat are often cited as reasons why bird assemblages are not the same in restored and reference marshes. Havens *et al.* (1995) showed that a constructed marsh in Sarah's Creek in Virginia supported far fewer Marsh Wrens *Cistothorus palustris* than natural marshes because the band of *Spartina* on the restored marsh was too thin. The stem density and height of *Spartina* on some restored marshes in southern California was unsuitable for Light-footed Clapper Rails (Zedler 1993). Also, Havens *et al.* (1995) showed that the higher length of open water/marsh interface in restored sites caused a higher usage by shorebirds whereas the lack of a mature salt bush community (*Iva frutescens* and *Baccharis halmifolia*) led to a lower usage of the restored marsh by passerines.

In Galveston, Texas, species richness and diversity was higher in the natural marshes due to the presence of migratory waterfowl, wintering shorebirds and salt marsh specialists such as rails and marsh sparrows (Melvin & Webb 1998). The assemblage on constructed sites was dominated by gulls and terns, which nested on the surrounding unvegetated berms. The main conclusion from this study was that created salt marshes provided bird habitat, but not necessarily for the same species assemblage as natural salt marshes. The reasons for the differences were thought to be due to the nature of the sites. All of the created marshes were on smooth, gently sloping shorelines exposed to wave action and contained flat monocultures of *Spartina* with few openings. Ponds and tidal flats were rare. Natural marshes tended to have more marsh edge and open water. Melvin and Webb postulated that created marshes supported fewer shorebirds and rails because they were at overall higher elevation, had less edge habitat, deep and steep-sided channels and taller and denser *Spartina*. Peaks and troughs in bird abundance on natural salt marshes were strongly related to seasonal migration chronology, whereas those in restored areas did not. This indicated that natural marshes provided habitat that was not available in nearby created salt marshes.

Salt marshes in the UK and US show very different soil characteristics, ones in the US tending to be peat rather then sediment based. One frequent difference between restored and natural marshes in both the UK and US, is the consolidated nature of the sediments in restored and created salt marshes (due to re-wetting with salt water), as well as their lack of natural creek systems, smooth topography and poor drainage. Re-wetted sediments in the UK tend to be extremely hard and tabular in form and thus, if sediment does not come in from the surrounding area and settle, these hard mud habitats are inhospitable environments for invertebrates and plants. This has lead to reduced structural diversity and differences in vegetation communities on some of the naturally-regenerated marshes in SE England.

Although not a shorebird, the English population of Twite *Carduelis flavirostris* winters exclusively on salt marshes and feeds on some restored salt marshes. Atkinson (1998) compared usage of naturally restored salt marshes by Twite with surrounding areas. Twite feed on the seeds of *Salicornia* spp. and the pioneer communities dominated by this species were absent from many of the restored marshes. The sites tended to be flat, highly dissected and poorly drained, except around creek edges. Consequently, the vegetation communities were dominated by a rank mix of salt marsh grass *Puccinellia maritima* and Sea Purslane *Halimione portulacoides* and lacked the diversity found on surrounding "natural" areas even though some of the restored sites were more than 100 years old. It is therefore unlikely that they will ever reach a state where they will be colonised by Twite. This study indicates that, because created marshes in SE England tend to be different from natural marshes, other species such as Redshank *Tringa totanus*, which breed extensively on salt marshes in NW Europe, may well use created areas in different ways to natural areas.

DO CREATED MUDFLATS FUNCTION IN A SIMILAR MANNER TO "NATURAL" ONES?

Although mudflat creation is most highly developed in Japan (WAVE 2001), there are few accessible reports of bird usage from there and success has to be inferred from studies of benthic invertebrates. The best examples of how birds use areas of created or restored mudflats are from UK studies.

At two of the most intensively studied managed realignment sites in the UK (Tollesbury and Orplands on the Blackwater estuary in SE England), the sediments typically became consolidated as re-wetting with saltwater occurred. However, accretion of soft sediments was quite rapid and benthic invertebrates colonized relatively quickly and shorebirds and wildfowl soon began to use the site. Shelduck *Tadorna tadorna*, Dunlin *Calidris alpina*, Grey Plover *Pluvialis squatarola* and Redshank probably exploited the polychaetes and *Hydrobia* that initially colonised the sites (Atkinson *et al.* in press b, Reading *et al.* 2000). In three to four years *Macoma balthica* colonised and particularly at Tollesbury this coincided with increasing usage by Red Knot *Calidris canutus*. Other species such as Eurasian Oystercatcher *Haematopus ostralegus*, which feed mainly on larger bivalves, tended to show very low usage of the site.

At the created mudflat at Teesmouth, both shorebirds and their invertebrate prey colonised in the first winter (Evans *et al.* 1998, 2001) and man-made wetlands surrounding the almost completely reclaimed estuary provided extra feeding time for shorebirds, especially during severe and windy weather (Davidson & Evans 1986). It was found, however, that successful recolonisation by three of the main invertebrate prey species, *Corophium*, *Nereis* and *Hydrobia*, required a lead in time of about three years (Evans 1998). Even after abundant prey populations had become established, some wader species, such as Grey Plover, Bar-tailed Godwit *Limosa lapponica*, Dunlin, Red Knot and Ringed Plover *Charadrius hiaticula*, were still rare or absent. The degree of enclosure of the site was thought to be responsible, highlighting the importance that perceived predation risk can play in determining where birds feed. This has important implications for the siting and design of future mitigation sites as birds may only use such unsafe sites when food resources are low elsewhere or during severe weather. Creating "poor quality" sites to replace "high quality" ones is likely to lead to population declines or at least a reduction in the capacity of the habitats to support birds.

Many more studies look at changes in invertebrate numbers. The speed with which invertebrates colonise these sites tends to be in line with what can be predicted through knowledge of life history traits. Mobile species, and those that have a planktonic larval phase, such as *Nereis* and other polychaetes, and *Hydrobia* colonise in the first year or two. Bivalves and other species that have no planktonic larval phase or take time to grow to a suitable size, such as oligochaetes and larger bivalves, either fail to colonise or take several years to appear (Atkinson *et al.* 2002). This has implications for the rates of colonisation by birds, so that species that feed on small polychaetes are likely to colonise before those that feed on large bivalves, a feature observed at various UK realignment sites (Atkinson *et al.* in press b).

The Waterfront Vitalization and Environment Research Center (WAVE) handbook (WAVE 2001a,b) details the mechanisms by which mudflats can be created and highlights the importance of creating small-scale habitat diversity for waterbirds. For example, Dunlin *Calidris alpina* gather near the water's edge, Red-necked Stints *Calidris ruficollis* are found "where the water has drained to a thin film" and species such as Grey-tailed Tattler *Heteroscelus brevipes* and Greenshank *Tringa nebularia* are found where there are small pools. Kentish Plover *Charadrius alexandrinus* and Lesser Sand Plover *C. mongolus* are found in drier areas. This highlights the fact that a diversity of habitats, even within what might seem homogeneous mudflats, is important for shorebirds. Restored sites often lack this range of microhabitats and tend not to show such habitat diversity at a fine-scale.

HOW CAN NEW HABITAT CREATION SCHEMES MAXIMISE BENEFITS TO SHOREBIRDS?

Coastal habitats can be created or restored. The majority of studies reviewed by Atkinson *et al.* (2002) involved coastal sites that were created for reasons other than supporting wildlife and success, however it was measured, was often a very hit or miss affair. Most sites supported populations of waterbirds, but often failed to capture the diversity observed on natural areas.

Most studies looking at the processes underlying restoration/creation have been carried out at small scales in comparison with surrounding areas and often fail to capture the range of natural variation found at the larger scales (Neckles *et al.* 2002) at which migratory shore birds usually operate. Successful restoration/creation may take time but, once the general roles of hydrodynamics, sediment dynamics and other forcing factors are understood, then wetland habitats can be created. The current results are often unpredictable and it is unclear whether the salt marsh creation process is essentially chaotic (i.e. small differences in starting states or management leading to very different stable states) or whether it is just a case of "getting the recipe right". Whatever the case, to maximise the likelihood of creating a fully functioning wetland encompassing that range of variation found in natural areas, it is likely that larger-scale projects are more likely to be successful. At present, our knowledge is limited and it is essential that new projects adopt an experimental approach and ensure that adequate monitoring is carried out at appropriate timescales.

Generally, once habitats are created, benthic fauna and birds respond fairly quickly if conditions are suitable. This is because coastal wetlands are often high-energy environments, at low elevations, and with high soil-water tables. As such, they are likely to resemble the surrounding natural environment in a relatively short time-frame, i.e. years rather than centuries (Warren *et al.* 2002). For example, created marshes in the high energy sandy environments of the Severn Estuary are virtually indistinguishable from surrounding marshes. However, marshes in the muddy, lower-energy environments of some estuaries in SE England are often of a very different structure and support different vegetation types than surrounding natural marshes (Atkinson 1998, Atkinson *et al.* 2001).

HOW WILL SHOREBIRDS RESPOND?

As recognition of the need for mitigating industrial development increases, one of the greatest challenges may not be the creation of suitable sites with sufficient food and shelter, but a good knowledge of shorebird ecology. Given the interdependence of sites, changes in one site may have knock on effects on populations in others. Therefore it is necessary to maintain a complete network of sites in each flyway in order to preserve viable shorebird populations. These must include wintering, staging and breeding areas as well as other key sites such as cold-weather refuges and or "drop out" zones for migrants during adverse weather conditions. In most years, such additional sites may not be important for maintaining survival rates, but in a few, they might be crucial.

Very few studies have evaluated the impact of creating new habitats on birds. However, the general principles found in the large literature on habitat loss can be applied, as this is the converse situation. Migratory shorebirds rely on whole networks of sites so, to understand the impacts of habitat creation on these populations, research needs to be carried out at large scales encompassing whole migratory ranges (Haig *et al.* 1998). It is fine to create habitats that birds use but a more relevant question to ask is what are the consequences for the population as a whole? Sites vary in quality and if, for example, a site created for wintering shorebirds runs out of food, it may have led to an increase in mortality rates and not have improved the capacity of the network to support the species. Similarly, if the food supply is insufficient at a staging site, birds may fail to refuel with sufficient speed and thus fail to reach the breeding grounds in time to breed successfully.

For the vast majority of species, we do not know the consequences of habitat creation or loss on the population as a whole. Given the interdependence of sites, changes in one area will affect the populations in other areas. The choice of wintering or staging areas can have important implications for survival and possibly the production of young in shorebirds (Clark & Butler 1999, Gill *et al.* 2001). The effects of climate change may alter the quality of currently used sites and thus impact on shorebird populations sometime in the future. At present, however, it can be argued that few clear impacts of climate change at a population level have been seen in shorebirds (Norris & Atkinson 2001, Piersma & Lindstrom in press) and that changes in populations have been due to impacts by man (e.g. Evans 1997, Piersma *et al.* 2001, Atkinson *et al.* in press).

HOW DO WE PROCEED IN THE FUTURE?

To understand the impact of habitat creation we need a better understanding of the consequences of wintering, staging and breeding in particular sites. The available evidence is that the "quality" of a site is important, but for the majority of species this concept is not fully understood. We are beginning to achieve an appreciation of this through detailed large-scale studies of birds and their food supplies (e.g. Gill *et al.* 2001), through investigating the role of density-dependence in breeding and wintering areas (Sutherland 1996) and through the use of process-based models that predict mortality under different scenarios (e.g. Stillman *et al.* 2000, Stillman *et al.* in press, Stillman, this volume). However, we still need more detailed studies that relate environmental factors to demographic rates.

With an increasingly developed world, the capacity of the network of sites upon which shorebirds depend will become reduced and more and more shorebird species will effectively become "managed populations" through a network of protected sites. There will come a time when there will be a need, not only to create high quality habitats, but also to know where to target them in the best way that will maintain and shore up the inevitable gaps that will appear along the flyways.

To answer the question in the title of this paper: yes, we can create intertidal habitats, but if the question is "can we created habitats to order", the answer is probably no. The track record in creating good quality habitats has been poor and, especially where salt marsh is involved, restoration has tended to be a very hit or miss affair. This is because we know far too little about what constrains the restoration process. In the long term, a partnership is needed between ecologists, conservation bodies, governments and engineers. Only in this way will it be possible to set up the kind of large capital projects required to take the science forward and reach an understanding, not only of how to create coastal habitats, but also the impact they will have on shorebird populations.

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