Ibis (2004), **146** (Suppl.1), 101–110

Managed realignment in the UK – the first 5 years of colonization by birds

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With current losses of saltmarsh running at > 100 ha per year in the UK, creation of new intertidal habitats through managed realignment is likely to be increasingly used. Potentially, this has biodiversity as well as engineering benefits. However, assessing the conservation value of many of the current UK schemes is difficult as the biological monitoring has been generally poor, with a few notable exceptions. At the Tollesbury and Orplands realignment sites, Essex, bird communities were dominated by terrestrial species during the first year of inundation and waterbird communities rapidly developed during the second and third years. Five years after the initial breach in the sea wall, communities were similar to surrounding mudflats but with some notable exceptions. Dunlin *Calidris alpina* and Common Redshank *Tringa totanus* that prey on the early colonizing *Nereis* and *Hydrobia* used the sites in the first 2 years. Eurasian Oystercatcher *Haematopus ostralegus* did not occur on the realignment site as there were no large bivalves, whereas Red Knot *Calidris canutus* used the site after 4–5 years coincidentally with the appearance of *Macoma balthica*. The differences in the bird communities occurred because UK sites are often small, enclosed and poorly drained. If at a suitable height in the tidal frame, UK managed realignment sites are successful in that they have developed saltmarsh and biologically active mudflats but they may lack the full range of biodiversity found in surrounding natural intertidal habitats, even decades after inundation.

The loss of intertidal habitats through industrial development and environmental change is one of the largest waterbird conservation issues in the UK. Loss due to development is likely to be exacerbated by potential future losses to climate change and rises in sea-level (levels are predicted to rise by 23–78 cm by 2050 in East Anglia; e.g. Austin & Rehfisch 2003) if sea-level rise outstrips accretion. This has increasingly become a concern in the UK although it has been argued that few species are currently under threat from sea-level rise (Norris & Atkinson 2000, Norris *et al*. 2004) and that even in the future sea-level rise may not have a major impact on the capacity of estuaries to hold waders if landward estuary rollback is permitted (Austin & Rehfisch 2003) or mudflats can accrete at an equal or greater rate.

Management responses to sea-level rise have included 'holding the line' through soft (e.g. recharge; unpublished report of the Environment Agency) or hard engineering techniques, abandonment or, more recently, managed realignment (Atkinson *et al*. 2001). Managed realignment (allowing the sea to penetrate sea walls and create intertidal habitats behind the sea wall rising up to higher ground or newly constructed sea defences) has been a feature of coastal sea defence policy since the 1990s. It may have ecological as well as engineering benefits

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although in the UK the former have seldom been thoroughly evaluated.

Interest in the creation of new habitats through managed realignment also comes from conservation bodies wishing to respond to loss of intertidal habitat and from developers required by the terms of the EU 'Habitats' and 'Birds' directives to compensate for proposed destruction of Natura 2000 habitats. However, to compensate for the loss of developed areas we need to understand what communities will develop and over what time scales, and yet there has been little evaluation of the nature conservation value of some 17 UK realignment projects that have developed mudflats or saltmarsh (Fig. 1a). Monitoring of sites has concentrated on water flow and sedimentation. The little biological monitoring that has been conducted has largely been restricted to higher plants and invertebrates; relatively few coastal habitat restoration projects in the UK have monitored birds. In terms of creating intertidal habitats, the UK schemes, shown in Figure 1(a), have been very successful. All these sites have developed mudflats or saltmarsh, but little evaluation of these habitats in terms of their nature conservation value has been carried out. In fact, the available data indicate that this may vary between taxonomic groups (Atkinson 2003).

For example, vegetation communities on sites where accidental breaches in the sea wall have occurred are different to those on the surrounding areas, sometimes 100 years after the breach (Burd 1994). Atkinson (1998) showed that Twite *Carduelis flavirostris* occurred on very few of these breach sites and only on those that had specific habitat characteristics suitable for this species. At Tollesbury, Essex, 3 years after breaching, invertebrate communities were more diverse in the realigned area than in the surrounding mudflats, probably reflecting an increase in the variety of sediment types, and the size of *Nereis* and *Hydrobia* was significantly different (Reading *et al.* 1999). At Orplands, Essex, large bivalves had not colonized after 4 years despite substantial populations being present on the adjacent estuary. Biologically active mudflats were created at Seal Sands, Teeside, but it was recommended that a 5-year lead-in time was required (Evans *et al.* 1998, 2001).

Apart from the Twite study, there has been relatively little attention paid to investigating changes in bird usage on UK realignment sites although information is available for other countries, notably the United States (Atkinson 2003). The Tollesbury and Orplands realignment sites are unique in the UK in that standardized bird monitoring has taken place on the sites since intertidal inundation was restored. In this paper we analyse these monitoring data to determine the rate at which bird communities changed and whether, after 4–5 years of intensive monitoring, the bird populations had reached equilibrium.

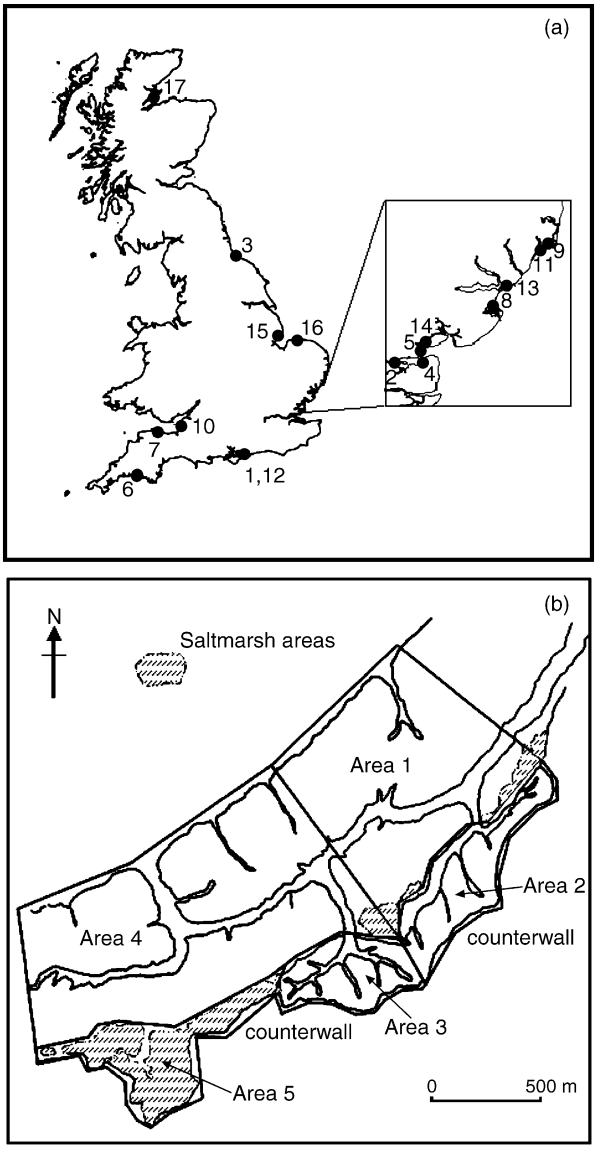

Figure 1. (a) Sites in the UK where intertidal habitat has been created behind sea walls either by breaching or through the installation of sluices and pipes. Numbers 4 and 5 refer to Orplands and Tollesbury, respectively. (b) Map of the Orplands site. Area 1: mudflats seaward of the managed retreat sites; Area 2: Orplands A retreat site; Area 3: Orplands B retreat site; Area 4: mudflat seaward of the control saltmarsh; Area 5: saltmarsh. (Source: unpublished report of the Environment Agency.)

METHODS

Study areas

The Orplands and Tollesbury sites are on the Blackwater Estuary in Essex, UK (Fig. 1a). Mean high water of spring and neap tides at Bradwell Marina, adjacent to the Orplands site, are 2.6 and 1.5 m above UK Ordnance Datum (OD), respectively (Diack 1998).

The Tollesbury managed realignment site covers approximately 20 ha adjacent to Tollesbury Fleet, a side channel of the Blackwater Estuary (51°46′N, 0°50′E). The sea wall was breached in August 1995. At this time, the surface of the site ranged from less than 1.0 m above OD adjacent to the original sea wall to 2.5 m above OD adjacent to the new sea wall constructed prior to realignment (Reading *et al*. 1999). Appreciable accretion of sediment occurred after the site was breached, with average accretion rates in excess of 2 cm/yr during the first 3 years (Reading *et al*. 1999). The lower parts of the site, below the level of high water of neap tides, did not vegetate over, unlike the higher parts that developed at least a partial cover of vegetation dominated by *Salicornia* sp. and *Spartina anglica* (A. Grant pers. obs.).

The Orplands managed realignment site covers about 42 ha adjacent to the main channel of the Blackwater Estuary, to the west of Bradwell Marina (51°43′N, 0°52′E). The site consisted of two fields, one a set-aside field and the other a grassland field. Prior to breaching the wall in two places in April 1995, a series of creeks were excavated where possible following the relic creek topography. At this time, the sediment surface varied from approximately 1.5 m OD, rising to about 4 m OD at the southwest corner. Within 2 years, nearly half of the site was colonized by saltmarsh plants (Diack 1998). By 2001, much of the site was vegetated, but some areas of bare mud remained. *Salicornia* sp., *Halimione portulacoides*, *Puccinellia maritima*, *Sueda maritima* and *Spartina anglica* were all common (A. Grant pers. obs.), and a transition zone from saltmarsh to terrestrial grassland occurred on the highest part of the site.

Bird usage at Tollesbury

Counts of birds in the realignment site were made at low water, neap high tide and spring high tide during each calendar month from October 1995 to September 1999. No attempt was made to establish ‘control’ areas on which bird counts would be made. Only the data up to September 1999 have been analysed as thereafter the methodology changed, making any comparisons difficult. The majority of usage by birds occurred during the winter (October to March inclusive) and data analysis has been restricted to these months only. Northern Lapwing *Vanellus vanellus* and European Golden Plover *Pluvialis apricaria* used the site largely as a roosting area, but feeding and roosting birds were only recorded separately from May 1998, so all bird counts, irrespective of activity, were included in the following analyses.

Factors affecting the winter usage of the site by individual species were determined using generalized linear models (GLMs) with a log link function and Poisson error distribution. Bird count data were modelled as a function of three factors: winter (1995, 1996, 1997 or 1998), month (October through to March) and tidal state (low, neap or high), and one linear variable: disturbance (1 = none, 2 = low, 3 = moderate/high). Likelihood ratio tests were carried out to determine whether significant differences occurred between the numbers of birds in different categories of a specific factor (e.g. differences between years, months or tidal states).

Changes in community composition over time and tidal state were examined using correspondence analysis (CA) in CANOCO (ter Braak & Šmilauer 1998). Total bird usage data were split by winter and tidal state and species that occurred fewer than five times were excluded. A [1 + log(bird usage)] transformation was performed to down-weight very large counts. Axis 1 and axis 2 species and sample scores were plotted and trends in species composition were inferred over time and tidal state. The bi-plot was scaled with a focus on species distances, so that the resulting diagram depicts most accurately the differences between occurrence patterns of species, and the samples in which they occur are scattered around them. Thus, species that are close together in the plot tend to have occurred together and the samples with which they are associated are placed near them.

Bird usage at Orplands

Between November 1994 and March 1999, bird surveys were carried out on two realignment areas (Orplands A & B), two mudflats and an area of saltmarsh adjacent to the realignment sites (Fig. 1b). Counts were made from 30 min after high water for approximately 3 h until the mudflats outside the realignment site were uncovered. Counts were not

carried out during the same months each winter and the number of counts made of each area varied between visits and were carried out at different tidal states. This led to analysis having to be limited to data collected from December through to February. The detailed species-specific analyses carried out on the Tollesbury data were not repeated for Orplands as too few data were available.

To assess changes in the bird assemblage using the site, detrended correspondence analysis (DCA) was carried out on the mean count per winter in each site. DCA, rather than CA, was used to reduce a pronounced arch effect that occurred using CA (ter Braak & Šmilauer 1998). Rare species (recorded on fewer than ten occasions) were excluded.

RESULTS

Bird usage at Tollesbury

Only the 16 species of wader and nine other species of waterbird (Little Grebe *Tachybaptus ruficollis*, Grey Heron *Ardea cinerea*, Brent Goose *Branta bernicla*, Common Shelduck *Tadorna tadorna*, Eurasian Wigeon *Anas penelope*, Eurasian Teal *Anas crecca*, Mallard *Anas platyrhynchos*, Northern Pintail *Anas acuta* and Common Moorhen *Gallinula chloropus*) recorded on more than five occasions on the realignment site during the four years are considered further. European Golden Plover, Common Redshank *Tringa totanus* and Dunlin *Calidris alpina* were the most common species, with over 3000 bird months logged, followed by Grey Plover *Pluvialis squatarola* and Northern Lapwing with 600–700 bird months. Of the remaining species, only Red Knot *Calidris canutus*, Black-tailed Godwit *Limosa limosa* and Eurasian Curlew *Numenius arquata* logged more than 100 bird months (Fig. 2). It was possible to construct models for nine species of waterbird (Table 1).

The state of the tide was important for five species of waterbird (Table 1). European Golden Plover, Northern Lapwing, Dunlin and Eurasian Curlew all showed decreased usage at spring high tide, whereas Brent Goose showed increased usage at neap high tide and the highest usage when the saltmarsh was at least partially covered. Five species of waterbird showed significant changes in usage between winters (Table 1, Fig. 2). Little Grebe colonized the site in the first winter, after which usage declined, whereas Dark-bellied Brent Goose and Common Shelduck

Table 1. Total bird usage (bird months) of the Tollesbury managed realignment site by selected species and groups of species for the winter period (October to March).

	Tide				Winter					Disturbance month		
	P	Low	Neap	Spring	*P*	1995	1996	1997	1998	*P*		
Little Grebe	NS	54	53	75	***	111^{a}	53^{b}	4^{c}	14^{c}	**	+	***
Dark-bellied Brent Goose	***	140^{a}	1391^{b}	381^{ab}	NS	405	834	379	294	*	–	***
Common Shelduck	NS	77	138	219	NS	131	36	110	157	NS		NS
European Golden Plover	***	1809^{a}	868^{a}	0^{b}	***	2^{a}	1494^{b}	295^{c}	886^{bc}	***	–	***
Grey Plover	NS	232	240	149	NS	95	263	132	131	***	+	***
Northern Lapwing	***	533^{a}	73^{b}	38^{b}	***	52^{a}	161^{abc}	349^{b}	82^{ac}	***	–	***
Dunlin	***	514^{a}	587^{a}	435^{b}	**	148^{a}	316^{b}	440^{b}	632^{b}	**	+	***
Eurasian Curlew	***	61^{a}	66^{a}	13^{b}	NS	39	55	14	32	NS		NS
Common Redshank	NS	1243	1441	837	***	182^{a}	955^{b}	1159^{b}	1225^{b}	NS		***
Total waders	***	5448^{a}	4507^{a}	1521^{b}	***	447^{a}	4082^{b}	3202^{b}	3745^{b}	NS		***
Total waders (exc. Golden Plover and Lapwing)	**	3106^{a}	3566^{a}	1483^{b}	***	393^{a}	2427^{b}	2558^{b}	2777^{b}	NS		***
Total wildfowl	***	259^{a}	1869^{b}	902^{c}	NS	1041	970	518	501	**	+	***
Total grebes	NS	54	53	77	***	111^{a}	54^{b}	5^{c}	14^{c}	**	+	***
Total gulls	NS	514	587	435	***	148^{a}	316^{ab}	440^{b}	632^{b}	NS		***
Total granivorous passerines	NS	713	597	736	***	1523^{a}	203^{b}	105^{b}	209^{b}	NS		***
Total insectivorous passerines	NS	74	57	118	***	140^{a}	20^{b}	15^{b}	75^{c}	NS		***

Values relate to the total usage, measured in bird months, for different states of tide and for each winter. The significance level of factor in the GLM model is denoted in the *P* column: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, NS $P > 0.05$. The same superscript letters follow values that are not significantly different to each other. Disturbance was modelled as a linear factor, where + denotes a positive correlation with disturbance (a higher bird usage with disturbance) and – denotes a negative correlation with disturbance.

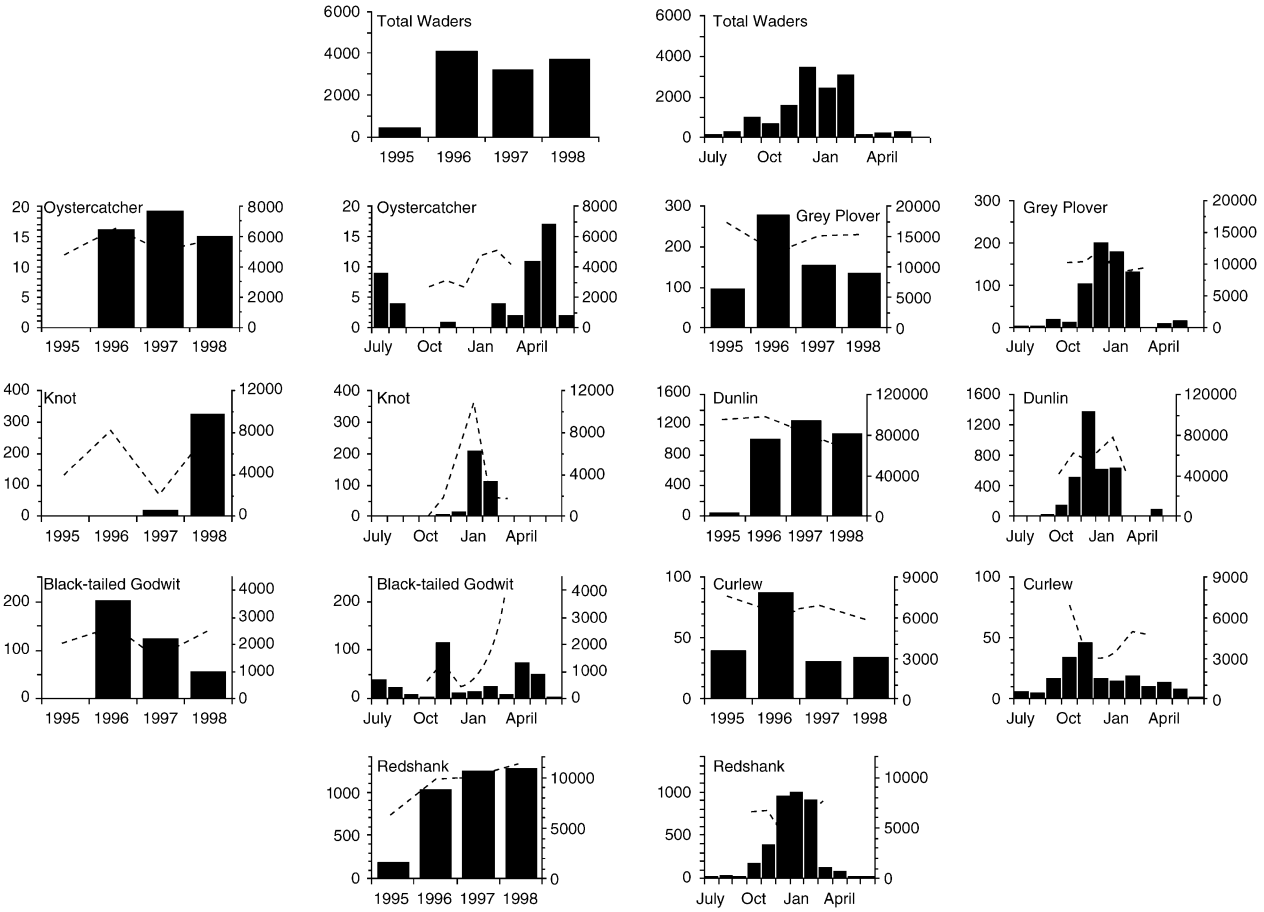

Figure 2. Changes in the total usage of the Tollesbury managed realignment site and the adjacent Blackwater Estuary by waders between 1995 and 1998. The right-hand side axis and the dotted lines relate to Blackwater Estuary bird usage, where usage is measured as the total number of birds seen during all monthly or yearly surveys. 1995 = winter 1995/96, 1996 = winter 1996/97, etc. Data supplied by C.T.

colonized in the first year and numbers did not change significantly between years. Dunlin and Common Redshank colonized the site in the first year but higher numbers were recorded in 1996–98. Following colonization during the first winter, Grey Plover and Eurasian Curlew numbers varied greatly between winters. The numbers of Northern Lapwing and European Golden Plover which predominantly used the Tollesbury site for roosting were lowest during the first winter and increased in the following years.

Thirty-one species of passerine or near passerine were recorded at Tollesbury. Six common species, Sky Lark *Alauda arvensis*, Meadow Pipit *Anthus pratensis*, European Goldfinch *Carduelis carduelis*, Common Linnet *Carduelis cannabina*, Reed Bunting *Emberiza schoeniclus* and Corn Bunting *Miliaria calandra* provided over 87% of the total number of winter records. These species all peaked in the year following the breach, before showing major declines (Table 1) With the exception of Meadow Pipit, the other common species were granivorous and most were observed feeding among the debris washed up on the high tide line. Smaller numbers of other species such as Greenfinch *Carduelis chloris*, Chaffinch *Fringilla coelebs* and Yellowhammer *Emberiza citrinella* also took advantage of the large amount of washed-up debris.

There was a clear change in the bird assemblage between the first two winters and smaller changes during the following years (Fig. 3a). Although the magnitude of the changes was different, the direction of the change was broadly similar across all tidal states. Axis 1 describes a temporal gradient with 1995 data on the right-hand side of the plot that is strongly associated with a community dominated by passerines. As the axis 1 score decreased, waders and gulls

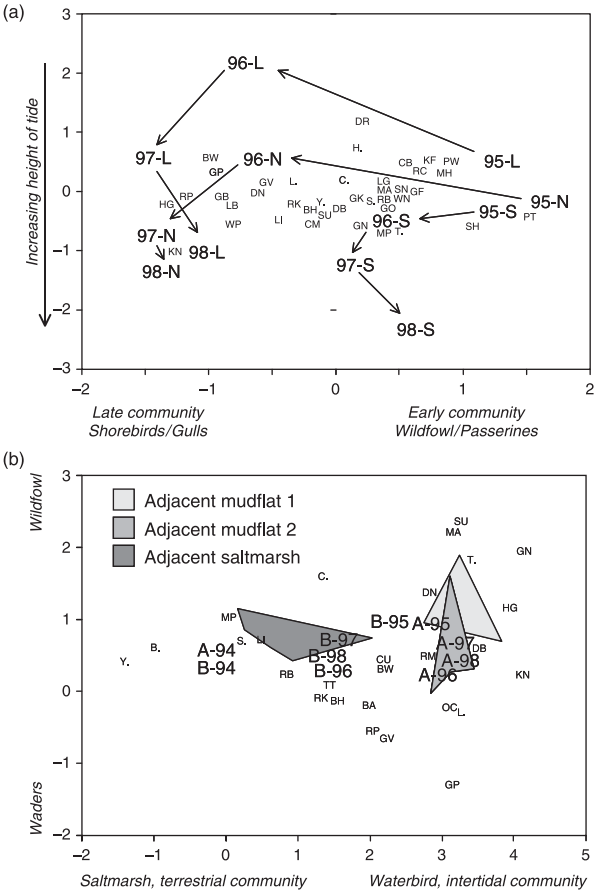

Figure 3. (a) Ordination of Tollesbury bird count data collected from October to March from 1995/96 to 1998/99. 95 = winter of 1995/96, 96 = winter of 1996/97, etc. L = low tide data; N = neap tide; S = spring high tide. (b) Ordination of Orplands bird count data collected from December to February 1994/95 to 1998/99. The shaded areas show the ordination space described by the three adjacent areas. Numbers again refer to years. A = Orplands A, B = Orplands B. B, Blackbird *Turdus merula*; BH, Black-headed Gull *Larus ridibundus*; BW, Black-tailed Godwit; C, Carrion Crow *Corvus corone corone*; CB, Corn Bunting; CG, Canada Goose *Branta canadensis*; DB, Dark-bellied Brent Goose; DN, Dunlin; DR, Spotted Redshank *Tringa erythropus*; GB, Great Black-backed Gull *Larus marinus*; GF, Greenfinch; GH, Grey Heron; GK, Common Greenshank *Tringa nebularia*; GN, Common Goldeneye; GO, Goldfinch; GP, European Golden Plover; GV, Grey Plover; HG, Herring Gull *Larus argentatus*; KF, Kingfisher *Alcedo atthis*; KN, Red Knot; L, Northern Lapwing; LB, Lesser Black-backed Gull *Larus fuscus*; LG, Little Grebe; LI, Linnet; MA, Mallard; MH, Common Moorhen; MP, Meadow Pipit; OC, Eurasian Oystercatcher; PT, Northern Pintail; PW, Pied Wagtail *Motacilla alba*; RB, Reed Bunting; RC, Rock Pipit *Anthus petrosus*; RK, Common Redshank; RP, Ringed Plover; S, Sky Lark; SH, Sparrowhawk *Accipiter nisus*; SN, Common Snipe *Gallinago gallinago*; SU, Common Shelduck; T, Eurasian Teal; WN, Eurasian Wigeon; WP, Wood Pigeon *Columba palumbus*; Y, Yellowhammer.

dominated the bird assemblage in 1996, 1997 and 1998 at low and neap tides, and wildfowl and passerines dominated at spring tides. Axis 2 is more difficult to interpret, but during the first 3 years assemblages could be separated on the basis of height of tide. Higher axis scores were associated with low tide assemblages. This was also a relationship with time, as the difference between neap and low tide counts was reduced by 1998.

Red Knot and Grey Plover tended to show similar temporal trends in usage on both the realignment area and the adjacent Blackwater Estuary but some important differences were observed in the temporal usage made by some other species (Fig. 2). Whereas Eurasian Oystercatcher *Haematopus ostralegus* numbers were high on the surrounding estuary, especially during the passage and winter periods, they only tended to use the realignment area during spring and summer. The usage made of the realignment site by Ringed Plover *Charadrius hiaticula* and Black-tailed Godwit was erratic. Whereas Common Redshank numbers on the Blackwater tended to be high from October to March, they tended to use the realignment site only from December to February, indicating that the area might be used during periods of low food abundance or availability.

In conclusion, there were large changes in the species of birds that used Tollesbury between the first and second years, smaller changes between the second and third years and little change between the last two years, although there was a general trend to a community dominated by waders at low and neap high tides. However, even 4 years after the breach, usage of Tollesbury by species such as Red Knot and Ringed Plover was still increasing (Fig. 2), indicating that the assemblage was likely to continue changing as the site matured.

Bird usage at the Orplands A & B managed realignment sites and surrounding habitats

There were clear habitat and temporal differences in the assemblage of birds occurring at Orplands (Fig. 3b). Axis 1 explained most of the variation in the assemblage and ran from a terrestrial bird community associated with saltmarshes on the left through to a community dominated by waders and wildfowl, typical of intertidal mudflats, on the right. Axis 2 separated the mudflat sites along a wader–wildfowl gradient, wildfowl being associated with higher axis scores. The two adjacent mudflats, Areas

1 and 4 (Fig. 1b), occupied an overlapping area on the bi-plot but Area 1 tended to have larger numbers of wildfowl, particularly Common Shelduck, Mallard, Teal and Goldeneye *Bucephala clangula*.

During the 1994/95 winter preceding the breach the two Orplands realignment sites held similar bird communities that were most similar to the adjacent saltmarsh Area 5. During the winter following the breach, both realignment sites showed an increase in the number of waders using the site and held bird communities that were intermediate between those of the adjacent mudflats and saltmarsh. The first waders to use the sites were Common Redshank, Grey Plover and Dunlin, species that prefer fine mud sediments. In the third winter the realignment sites diverged. Being higher in the tidal frame than Orplands A, Orplands B quickly vegetated over and the bird fauna reverted to one similar to the surrounding saltmarsh, whereas Orplands A showed an increase in axis 1 score. At Orplands A, after a rapid 2-year initial change from a terrestrial- to a waterbird-dominated bird community, relatively little change occurred in the bird community during the subsequent three winters although some species, such as Red Knot, continued to increase to the 1998/99 winter. From two winters after the breach the assemblage on Orplands A closely resembled that using the mudflat in front of the realignment site.

DISCUSSION

Temporal changes in the bird assemblages

The changes in the bird communities during the first 5 years were remarkably similar at both Orplands and Tollesbury, which may not be surprising as both are located on the same estuary. Because the sea defences were breached, both sites developed areas of mudflat and pioneer saltmarsh. Orplands A and Tollesbury are low in the tidal frame and have experienced rapid accretion since the breach (Reading *et al.* 1999, unpublished report of the Environment Agency). This has led to the build up of soft muddy sediments at the seaward edge of the realignment sites, which have been colonized by mobile invertebrates that are mobile or have planktonic larval phases (Reading *et al.* 1999). The increase in invertebrate numbers at these sites has broadly been in line with what would be predicted through knowledge of life history traits. Mobile species, and those that have a planktonic larval phase, such as *Nereis*, other polychaetes and *Hydrobia* have colonized these muddy sediments, whereas bivalves and other species that have no planktonic larval phase, such as oligochaetes, had either not colonized or took several years to appear.

The first benthic invertebrates to colonize Tollesbury in appreciable numbers were *Hydrobia ulvae*, *Macoma balthica*, *Eteone longa*, *Nepthys hombergi*, *Nereis diversicolor*, *Pygospio elegans*, *Spio filicornis* and various unidentified oligochaetes, all known wader prey species. In the following years, species such as *Mya arenaria* and *Abra tenuis* colonized. The spread of *Macoma* across the site and rapid increase in numbers during the fourth winter after the breach may explain the increased usage by Red Knot during the fourth winter. Fewer invertebrate species occurred at Orplands but *Hydrobia* and *Nereis* increased in number following the breach and were consistently the most common and widespread species at both sites. Four winters after the breach, *Nereis* were still significantly smaller in the realignment site than in the surrounding control mudflat, whereas *Hydrobia* were significantly larger (Reading *et al.* 1999).

Invertebrate species diversity in the Tollesbury realignment site increased from 14 species in 1995 to 19 in 1998. This slightly higher species diversity than that found in the surrounding mudflat (11–13 species) was probably as a consequence of the greater diversity of sediment types within the realigned area than the very small adjacent 'control' site. The control site is not ideally suited to make comparisons of bird assemblages with the Tollesbury realignment site as it is too small and does not include a number of independent replicates.

The five common species of waterbird that fed on the two newly created realignment sites are broadly typical of areas with similar sediments and invertebrates. Brent Geese exploited the algal build-up on the sites, whereas Common Shelduck, Dunlin, Grey Plover and Common Redshank probably exploited the *Nereis*, *Hydrobia* and *Macoma* that colonized the sites rapidly and that were among the most widespread intertidal invertebrates by 1998. The large increase in Red Knot on the site coincided with a large increase in *Macoma* in 1998. Fewer species that prey on larger bivalves, such as Eurasian Oystercatcher, used the site. Tollesbury was used by large numbers of roosting European Golden Plover and Northern Lapwing.

There are often high densities of passerines breeding and wintering on UK saltmarshes, although these vary seasonally, between saltmarsh habitats and between

regions (Brown & Atkinson 1996, Kaljeta-Summers 1997). The passerine birds using the Tollesbury site in the first winter were different to those found on the North Norfolk Coast or the Taff/Ely estuary in that Corn Bunting and European Goldfinch were common and other species found on saltmarshes such as Twite, Snow Bunting, Greenfinch, Chaffinch and Common Linnet were either absent or less common (Brown & Atkinson 1996). In the following years, the passerine community diversity was lower and dominated by Meadow Pipits and Sky Larks, more typical of east coast marshes (Brown & Atkinson 1996). No influx of passerines was observed at Orplands during the first winter and it held a passerine assemblage dominated by Sky Larks and Meadow Pipits. Numbers of Meadow Pipits remained similar between winters but Sky Larks increased at both Orplands A and Orplands B as the cover of *Salicornia* spp. increased.

Rates of change in bird species abundance in the realignment sites and implications for subsequent mitigation schemes

Both Tollesbury and Orplands witnessed major changes in their bird communities during the year following the breach and a general shift towards an avifauna dominated by waterbirds. At Tollesbury, large numbers of passerines were recorded during the first winter as seed-rich debris was washed up on the tide line. Following the establishment of a waterbird-dominated assemblage during the second winter, fewer changes occurred but did include the colonization and increase in numbers of Ringed Plover and Red Knot. A similar pattern was seen at Orplands A, with the rapid establishment of a waterbird community followed by smaller annual changes from the second winter onwards as sediments and the number and size of benthic invertebrates changed. As a consequence of the slightly higher position in the tidal frame at Orplands B, the communities that developed there were more typical of surrounding saltmarsh.

After 5 years the waterbird assemblages at Orplands A and Tollesbury appeared similar to those using similar muddy habitats in the surrounding estuary. The low usage made of the areas by Eurasian Oystercatchers and Red Knot is probably due to a combination of little sandy habitat and few large invertebrates in the realignment areas. The delayed usage of Tollesbury by Common Redshank until mid to late winter suggests that habitats outside the realignment areas may be preferred, perhaps as a result of the relatively enclosed nature of the site being associated with a higher perceived predation risk as found at the Tees realignment site (Cresswell 1994, Evans *et al.* 2001). The differences in the bird assemblages in the realignment sites and the whole estuary are probably largely due to the latter having more diverse habitat. The diversity of habitat should be considered when planning mitigation for habitat loss because new sites may otherwise not support all of the species found on the area to be lost.

Saltmarsh and intertidal mud formed at both sites as a result of the realignment. Even though small in area and not typical of more exposed mudflats, the new intertidal mud was colonized by invertebrates and birds. However, even after 4 or 5 years, the waterbird and invertebrate assemblages on these sites were still evolving. This has important implications for the timing, size and quality of area, and extent of post-creation monitoring required for subsequent mitigation projects. If a no-net-loss principle is applied (i.e. habitat lost must be replaced), then there is a strong argument for the provision of new habitats 5 years or more before existing habitat is removed. There is no reason to believe that the general principles from these case studies, typical of muddy estuaries, should not be applied to sandier systems, although their more dynamic nature may affect the time taken for stability to be reached

Future monitoring strategies and how to determine success?

Monitoring should be seen as an essential part of any managed realignment scheme, making it possible to determine whether certain target criteria have been met. For mitigation, monitoring is often used to determine whether a predetermined endpoint has been reached, after which the success of the restoration is measured. Monitoring can also be used to test experimental hypotheses. In the UK, monitoring studies of realignment sites range from those that only allow general observations to be made (e.g. creation of saltmarsh or mudflats) to those that allow detailed statistical analysis (e.g. the detailed bird data from the Tollesbury study).

At mitigation sites, the emphasis is on re-creating areas indistinguishable from natural areas. This is often undesirable or unachievable. Sites should ideally function within the normal variation found in natural sites and retain any key features. These projects can take years to develop and thus allow

much preloss monitoring to take place to estimate this variation. Such information is essential to any well-designed scientific study because it allows estimation of the abundance and annual variation of birds using the area before loss and identification of how the area is used (e.g. for feeding or roosting). However, general studies on feeding birds and their relationship with their food resources are also desirable to improve our ability to (a) identify the effects of habitat change on the birds' usage of the area (e.g. Burton *et al*. 2001) and consequent survival, and (b) provide a benchmark against which the success or failure of the scheme can be judged. Pre-loss monitoring also allows protocols to be developed on the basis of the statistical power required to detect differences. Statistical power is an essential tool for mitigation schemes and allows an optimum sampling strategy to be developed according to available resources, even if the latter often leads to too few replicated treatments for statistical rigour.

The short-term nature of monitoring, typically less than 5 years, does hamper our understanding of how wetlands can be restored effectively for the long term. Easily measurable criteria, such as the density or species composition of plants and animals, can become similar to those of reference marshes after only 3 years but complex ecological interactions do not necessarily follow that time scale (Atkinson *et al*. 2001) and most monitoring schemes are inadequate to identify endpoints of ecosystem or community maturity (e.g. Moy & Levin 1991, Simenstad & Thom 1996).

CONCLUSIONS

The UK experience of creating mudflats through managed realignment is encouraging. Biologically active mudflats have formed at all sites that were sufficiently low in the tidal frame and, on two sites at least, within 5 years invertebrate and bird faunas have developed that were similar, although not identical, to those found on 'natural' mudflats. However, the two sites described here illustrate that some realignment sites may develop habitats that are unsuitable for species, e.g. species that rely on large bivalves such as Eurasian Oystercatcher. Managed realignment also tends to take place at relatively small sites higher in the tidal frame and the large-scale creation of mudflats at lower elevations is untested in the UK. The creation of saltmarsh is more difficult and, even after many decades, vegetation communities may be different from those of surrounding areas (e.g. Burd 1994). Managed realignment is a useful tool to re-create habitats of high biodiversity value, but the likelihood of success will be hampered until we have a better understanding of the restoration processes.

This study relied on data collected by the Environment Agency and the Royal Society for the Protection of Birds (C.T.), the analysis of which was funded by English Nature as part of a larger project on the creation and restoration of intertidal habitats. Paper writing time was funded by BTO. We thank Mark Dixon (Environment Agency) for providing the bird data for Orplands and much other useful information concerning set-back schemes in the UK.

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Received September 2002; revision accepted October 2003.