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S08-5 A methodology for predicting the impact of sea level rise on shorebirds (Charadrii) in estuaries

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Abstract Mean sea level has been rising around Britain and the North Sea region over the past century and is predicted to rise more over the next century as a result of global climate change. Britain is internationally important for the large numbers of shorebirds (Charadriiformes) that winter on its estuaries, a habitat that will be directly affected by rising sea levels. The BTO has developed models for estimating estuarine shorebird densities from measurements of estuarine geomorphology predisposed to predict how sea level rise may affect shorebirds. A methodology integrating these models with digital elevation models, coastline management plans and predictions of sea level rise was explored using two case study estuaries. The studies suggest that the densities of shorebird species favoring muddy sediments will decrease as sediments become increasingly sandy under management scenarios that allow land behind existing sea defenses to be reclaimed by the sea. However, where changes in estuary shape become great enough to bring about this shift, the associated increase in area more than compensates for the assumed degradation of habitat and such that numbers of shorebirds may be accommodated overall.

Key words Climate change, Waders, Habitat change, Modeling

1 Introduction

Mean sea level has been rising by approximately 1 mm yr-1 around Britain and in the North Sea region over the past century (Shennan and Woodworth, 1992; Nydick et al., 1995), and is predicted to rise further over the next century as a result of global climate change. Britain is internationally important for the shorebirds (Charadriiformes) that winter on its estuaries (Cayford and Waters, 1996; Rehfisch et al., 2003), a habitat that will be directly affected by rising sea levels.

Within estuaries, sediment particle size and salinity influence invertebrate abundance and availability to foraging shorebirds (Goss-Custard et al., 1977; Quammen, 1982) and, therefore, shorebird distribution (Goss-Custard et al., 1991; Yates et al., 1993; Rehfisch, 1994). Consequently, such environmental variables can be reliable descriptors of shorebird densities within an estuary (Goss-Custard and Yates, 1992; Yates et al., 1993). The nature of intertidal sediments is largely a consequence of wave action, currents and tide (Yates et al., 1996); and consequently, both the quality and quantity of estuarine habitat available to shorebirds is in part a function of estuary shape.

In Britain, the majority of estuaries (88%) have been modified by the construction of sea defenses which claim former intertidal habitat for agriculture (Davidson and Evans, 1986). These are all being affected by changing sea level. Given an adequate supply of suspended material in the water column, it is expected that natural processes leading to the deposition of intertidal sediments will continue to track changes in sea level and realignments of sea defenses.

The British Trust for Ornithology (BTO) and Center for Ecology and Hydrology (CEH) have developed generalized linear models (GLMs — McCullagh and Nelder, 1989) that predict estuarine shorebird densities on British estuaries from measurements of estuary morphology and location (Austin et al., 1996; Austin and Rehfisch, 2003). These geomorphological variables are based on readily obtained parameters such as mean estuary width, length of channel, mouth width and intertidal area, full details of which can be found in Austin and Rehfisch (2003). The models are predisposed to predict how shorebird numbers may be affected by changes in the shape of estuaries due to managed or unmanaged responses to sea level rise. The models make it possible to compare and contrast how various scenarios of estuary realignment are likely to maintain the present populations of wintering shorebirds, in compliance with international agreements encompassed by the Birds Directive (79/409/EEC).

2 Aims

In this paper we describe and apply a method that makes it possible to assess how rising sea levels may affect populations of shorebirds wintering on the estuaries of Britain and elsewhere.

3 Methods

The methodology described was developed using data from two British case study estuaries, the Deben

(52°03'N, 1°21'E) and Duddon (54°10'N, 3°16'W), chosen to represent extremes of historical land claim, proposed future management of sea defenses, habitat characteristics, and shorebird population. Estimates of relative sea level rise under various scenarios by the United Kingdom Climatic Change Program (UKCIP98; Hulme and Jenkins, 1998) were derived from estimates of sea level rise for Britain and Ireland (Austin et al., 2001) using the ESCAPE model of Hulme et al. (1995) which calculates sea level rise for a given level of warming after allowing for vertical land movements in the North Sea region and Great Britain (Shennan and Woodworth, 1992).

Determining how the shape of an estuary may change with sea level rise requires high resolution, accuracy and precision elevation data for land above the current high water mark. Data collected by the airborne Light Detection and Ranging system (LIDAR) that records elevation to 10 cm precision at a 2 m × 2 m spatial resolution were obtained from the Environment Agency, National Center for Environmental Data and Surveillance, and processed within the ArcView Geographical Information System (GIS; ESRI, 1999) to derive digital elevation models (DEMs) for land up to 2 m a.s.l. surrounding each estuary.

Potential sea defense management plans for the case study estuaries were also obtained from the Environment Agency (Environment Agency, 1998, 1999). These plans detail how various compartments (areas of land which can be managed as a unit) would be managed. The management strategies were then incorporated into the GIS, and, in combination with the DEMs, used to assess how the shape of the chosen estuaries might be expected to develop both with and without intervention. This procedure was carried out for each of ten, 20 cm incremental increases in mean high water spring (MHWS) tidemark, from a baseline set of current values taken from the Admiralty Tide Tables (UKHO 1999). Values for the geomorphological variables required by the bird models were extracted for each incremental rise of sea level for each management scenario.

Models that explained a substantial proportion of the variation in bird density (Austin et al., 1996; Austin and Rehfisch, 2003) were available for five species (*Haematopus ostralegus*, *Calidris canutus*, *Calidris alpina*, *Numenius arquata*, *Tringa totanus*) that together account for over 90% of the shorebirds overwintering on British estuaries (Cayford and Waters, 1996). These models were then used to predict the densities of these species in each estuary for each incremental rise in sea level under each management scenario. Density predictions for the present were compared to contemporary data obtained from the Wetland Bird Survey (WeBS), in order to assess the applicability of the models for each site.

4 Results

The predictions of baseline shorebird numbers at present were similar to recent WeBS counts for both estuaries, suggesting that the models were performing reliably in each case. Under the UKCIP98 high scenario, the ESCAPE model predicted a maximum increase in relative mean sea level of 78.4 cm for the Deben and 67 cm for the Duddon by around 2050. The management plans for both estuaries equate to a "hold the line" policy for all land compartments vulnerable to sea level rise exceeding these predictions by a factor of three or more. Consequently, if these management proposals are followed, the parameters in the bird density models will not change. If sea-level rise remains within current predicted values by 2050, then this would also be true under a policy of no intervention (a management option not currently envisaged).

Without managed intervention, current sea defenses and local topography on the Duddon would still prevent substantial change in estuary shape unless sea levels exceed the predicted values by a factor of three or more, notwithstanding a slight upward trend predicted in both the densities and numbers of both *Haematopus ostralegus* and *Calidris canutus* beyond a rise of 100 cm. A policy of non-intervention on the Deben, however, would result in sufficient change to estuary shape to affect shorebird densities if relative sea level were to increase beyond 90 cm, when existing sea defenses would be unable to prevent inundation of large areas of the lower reaches. Beyond this level, the models predict decreasing densities of *Tringa totanus* and *Calidris alpina*, increasing densities of *Haematopus ostralegus*, and stable densities of *Numenius arquata*. However, the numbers of *T. totanus*, *C. alpina* and *H. ostralegus* that the estuary could support would all increase, due to the associated gain in area that would more than compensate for reduction in habitat quality. For example, given a rise of up to 150 cm, estuary carrying capacity for the three species could increase by up to 100%. *H. ostralegus*, *T. totanus*, *C. alpina* and *N. arquata* account for about 70% of shorebirds that currently overwinter on the Deben.

5 Discussion

Assuming that mean high water spring mark will rise in line with mean sea level rise, substantial changes in the shape of both case study estuaries are unlikely, even under the UKCIP98 High scenario for climate change. For the Low, Medium-Low and Medium-High scenarios, the rise predicted for both estuaries is such that existing sea defenses are unlikely to be compromised in the next 50 years. However, extreme tidal events such as those that result from low barometric pressure, seiches, onshore winds and storm surges (UKHO, 1999) may well overrun those defenses with increasing frequency as sea level rises. Low barometric pressure and seiches may raise tide heights by up to 30 and 100 cm respectively above normal. Storm surges, particularly those caused by strong and sustained northerly or north westerly winds, may, in extreme cases, raise sea level temporarily by as much as 2 m in the North Sea. Smaller maxima, currently in the region of 60 to 90 cm, occur several times per year; and when these events coincide with high water equinoctial spring tides, extremely high tide levels can result.

The UKCIP98 scenarios predict that mean wind speed will increase and extreme wind events become more frequent. This should increase the strength and frequency of storm surges. An increased frequency of flooding may affect the viability of current land use, which, in turn, could affect future management proposals.

As sea level rises, a general pattern of change to estuarine habitats, and thus shorebird populations, might be expected. Where management scenarios seek to retain current intertidal habitat, the parameters used by the shorebird density models, and thus the resulting predictions, will remain unchanged. Where there is scope for realignment of sea defenses, changes in shorebird densities would be predicted with change of estuary shape. In Britain and much of Europe, estuary realignment will, in practice, often equate to abandoning land formerly claimed for agriculture from the intertidal zone. This will generally result in estuaries becoming wider and more exposed to wave action, producing sandier sediments (Yates et al., 1996). Consequently, they would support lower densities of such mud-preferring species as *Tringa totanus* and *Calidris alpina* than at present, and higher densities of such species as *Haematopus ostralegus* which favor sandier sediments (Austin et al., 1996).

The change in the nature of sediments brought about by increased estuary width will be driven principally by increased fetch, that is, the distance over which wave energy builds before breaking on the shore. Increased wave action would serve to keep finer particles suspended in the water column before being flushed from the estuary, leaving behind an increasingly sandy substrate (Yates et al., 1996). Offshore sea defenses designed to reduce wave action and to protect an estuary from tidal surges would counter this effect. As a result, estuaries might increase in area yet remain muddier than expected. In such circumstances, the densities of shorebirds favoring muddy sediments would be expected to be higher than predicted by the models, while increases in those preferring sandy substrates would be less.

The case studies suggest that while habitat quality will fall for the majority of shorebirds, estuary enlargement may well offset it. On estuaries historically subject to land reclamation, shorebirds may gain a windfall increase in habitable area wherever current sea defenses are breached or intertidal management realigned. Where reclaimed areas have been urbanized or industrialized or is at a premium for agriculture, however, there is probably little scope for managed realignment. Moreover, where estuaries are confined by hard natural features, changes in estuary shape or area are likely to be negligible. The impact of sea level rise on shorebirds can, therefore, be expected to differ between regions, depending on geology, isostatic realignment and historical land claim.

A methodology for predicting the effects of sea level rise on estuarine shorebirds has been demonstrated here for two estuaries. In Britain, many estuaries are surrounded by low lying land vulnerable to sea level rise, much of it previously reclaimed for development. The ultimate fate of such land will depend largely on socio-economic factors that will either retain its integrity or manage it by realigning existing sea defenses. This must be balanced against Britain's obligations as signatory to international agreements that require maintenance of areas designated for bird and habitat conservation (Stroud et al., 2001). The methodology described here offers an empirical approach for the assessing and comparing the impact of sea defense management on governmental obligations to conserve internationally important bird populations sustainably. Such a methodology has potential for application to other sites globally, wherever predictions of the effects of managed realignment are needed. Its outcomes may offer conservation opportunities for mitigating loss of habitat in situations where options for managed realignment are limited.

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