

Towards an integrated coastal simulator  
of the impact of sea level rise in East Anglia:

Part B3- Coastal simulator and biodiversity:  
Modelling the change in wintering  
Twite *Carduelis flavirostris* populations  
in relation to changing saltmarsh area

Phil Atkinson

May 2006

# **Research Project IT1.37: Final Report**

## **Towards an integrated coastal simulator of the impact of sea level rise in East Anglia**

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### **Part B**

#### **Coastal simulator and biodiversity**

##### **Technical Report 3**

#### **Modelling the change in wintering Twite *Carduelis flavirostris* populations in relation to changing saltmarsh area**

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#### **Introduction**

Seed-eating passerines are one of the groups of birds that are most likely to be impacted by large changes in saltmarsh area. Within the UK, saltmarshes hold distinctive communities of seed-eating passerines (Brown & Atkinson 1996, Kaljeta-Summers 1997) including key species such as Skylark *Alauda arvensis*, Snow Bunting *Plectrophenax nivalis*, Shorelark *Eremophila alpestris* and Twite *Carduelis flavirostris*. In England, all but one of these species occupy habitats other than saltmarsh, but the Twite almost exclusively occurs on this habitat in winter. The large decline in the extent of saltmarsh in south-eastern England since the early 1970s (Burd 1992) is cause for concern for Twite and the number of birds wintering on the coast has declined over this period. As a result, Twite is a species of conservation concern and is Red-listed within the UK (Batten *et al.* 1990).

Twite occur in three geographically-separate populations in the UK, breeding in Scotland, the Pennines in northern England and a very small population in Wales. They breed in heather-dominated moorland and undergo an altitudinal migration and spend the winter in lower areas. The majority of the English population (between 500 and 800 pairs in 1999, Langston *et al.* in press) spends the winter on saltmarshes in south-eastern England, some moving further to winter on the marshes in the Wadden Sea (Atkinson 1998).

Between 1975 and 1995, the numbers of Twite wintering in southern-eastern England underwent a massive decline. To understand whether associated changes in saltmarsh habitat could account for the decline, a theoretical model based on a modification of ideal free distribution theory was constructed to make predictions about the effects of past and future changes in saltmarsh habitat on wintering Twite populations. Specifically, it was set up to investigate the potential effects of habitat loss, changing climatic conditions and creation of new saltmarsh areas on bird numbers using sites.

The model is based on an extensive survey of Twite, saltmarsh plants and seed densities carried out across eastern England in the winter of 1994/1995 (Atkinson 1998). Although Twite eat the seeds of several species of saltmarsh plant, including *Aster tripolium*, *Limonium vulgare* and *Suaeda maritima*, the seeds of Glasswort *Salicornia europea* are a favoured food. In the survey, Twite distribution in late winter was strongly determined by the density of *Salicornia* seeds left on the plants. The number of Twite in the surveyed sites declined over the course of a winter and, by the end of the winter, the only sites which held birds were those with significant numbers of *Salicornia* seeds left on the plant, i.e. the Twite population became more localised in its distribution

During the course of the 1994/1995 winter, the number of Twite declined or stayed the same in all but one site, strongly suggesting that there were no large scale movements of birds from one area into another over the course of the winter. Coupled with the strong relationship between Twite numbers and *Salicornia* densities in late winter, this suggests that winter habitat is, in fact, an important factor in regulating the population.

As Twites' winter range covers a large area, it is probable that individuals are not able to accurately track the distribution and change in *Salicornia* seed populations, especially as the rate of natural depletion in *Salicornia* (seeds falling into the mud where they become unavailable) will be strongly influenced by random events such as storms (Smith 1985). A travel cost, which can be expressed as a mortality associated with moving between sites, was therefore introduced into the model.

### **The Model**

The model consists of 500 different sized *Salicornia* patches arranged in a linear fashion with varying seed densities amongst which birds forage (the model framework is outlined in Figure 1). Seed densities are set at the beginning of each winter based on the distribution of densities found in the field and are depleted in two ways: (1) predation by birds and (2) seeds falling into the mud where they become unavailable to Twite. The latter is termed *natural depletion* and is expressed as a constant proportional loss per day. Birds are allowed to forage for 100 days over the patches and move between patches if seed density in the patch they are exploiting falls below a threshold level. This threshold level is determined by the birds' intake rate, which is assumed to follow the Type II functional response as described by the disc equation (Holling 1959). Winter mortality is determined by a travel cost which is introduced into the model as a mortality rate associated with moving a given distance from a patch.

At the end of the 'winter' the birds breed and their reproductive output is density-dependent. They return to the winter sites at the start of the next 'winter', or cycle of the model, where they are spread evenly over sites and the process repeats. Each site has the same initial seed density as at the start of the previous 'winter'. Birds are initially spread evenly (i.e. the same number of birds in each site) at the beginning of the winter and do not return to sites they wintered in previously. This is for two reasons: (1) from their body size it is likely that Twite are short-lived and (2) it is unlikely that there is a tradition of adult birds wintering in the same areas as juveniles.

Modelling was carried out using the computer package *CodeWarrior*. An initial value of the number of Twite is entered in the model and the model is run (using the same initial parameters) until an equilibrium number of birds, or a stable cycle, is reached. The model is then run for a further 150 cycles and the mean number of birds at the end of a winter over these cycles is calculated along with the total number of ‘bird days’ on the site. This last measure is an indicator of the total usage of the site made by the birds.

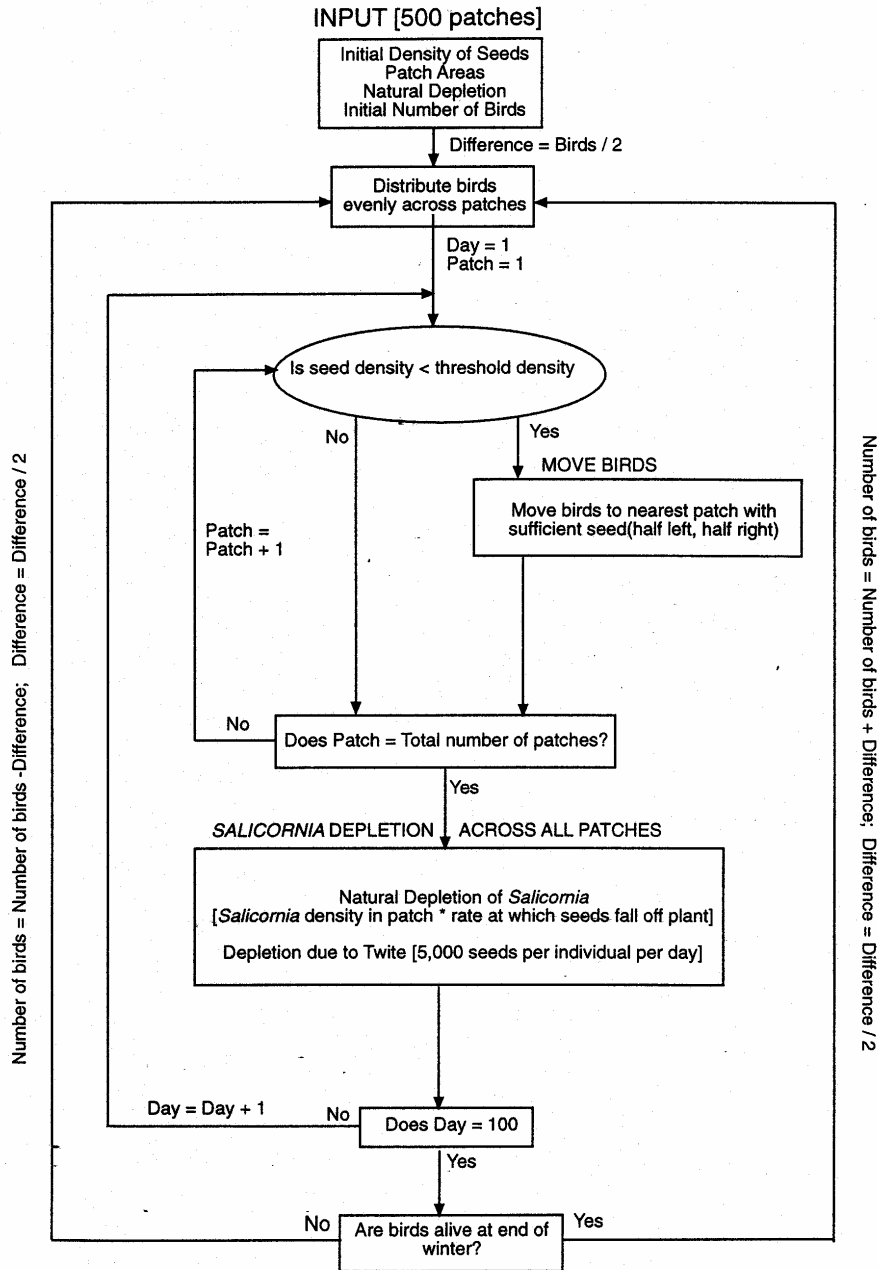


Figure 1. Framework of an iterative model to determine the number of Twite a series of patches of *Salicornia* can support.

### Model parameters

### *Seed density*

Seed densities from a survey of 22 saltmarsh sites during the 1995/1996 winter were used as a basis for the model. Methods describing how these densities were obtained appear in Atkinson (1998). The seed density data from 22 *Salicornia* beds were normalised using a log transformation and the mean and standard deviation calculated (Figure 2a). Within the model framework, the seed density in each patch was allocated by randomly selecting values from this normal distribution.

### *Rate of natural seed depletion*

Rates of natural depletion were approximated from the 1995/96 extensive survey. The number of *Salicornia* seeds on plants, and the number of Twite, were measured at the start and end of the winter. It was assumed that the number of Twite changed at a linear rate between the beginning and end of the winter. As birds depleted the *Salicornia* seeds within the site it was not possible to calculate the rate of natural depletion directly. Instead the rate of natural depletion was calculated using an iterative process, which combines the depletion attributable to Twite with the natural rate of depletion. A range of values of  $r$  (the proportional rate at which seeds fall off the plant) was entered into the model along with the bird numbers, and seed densities were calculated on a daily basis until the end of the winter. The values of  $r$  were then systematically altered until the seed density at the end of winter equalled that recorded from the field data. Using field data, there was no relationship between the initial seed density and the value of  $r$ , and so in the model, values of  $r$  were picked from a uniform random distribution between varying between 0 and 0.07 and hence a mean of 0.35 (Figure 2b).

### *Functional response, threshold intake rate and daily intake*

The threshold intake rate in the model is the resource density below which animals are unable to maintain a sufficient intake rate and so move out of a patch in search of another suitable area. This is difficult to measure in the field but has been estimated by directly observing the birds feeding in the field. During the winter of 1995/6, intake rates of birds feeding on *Salicornia* was measured by observing the birds

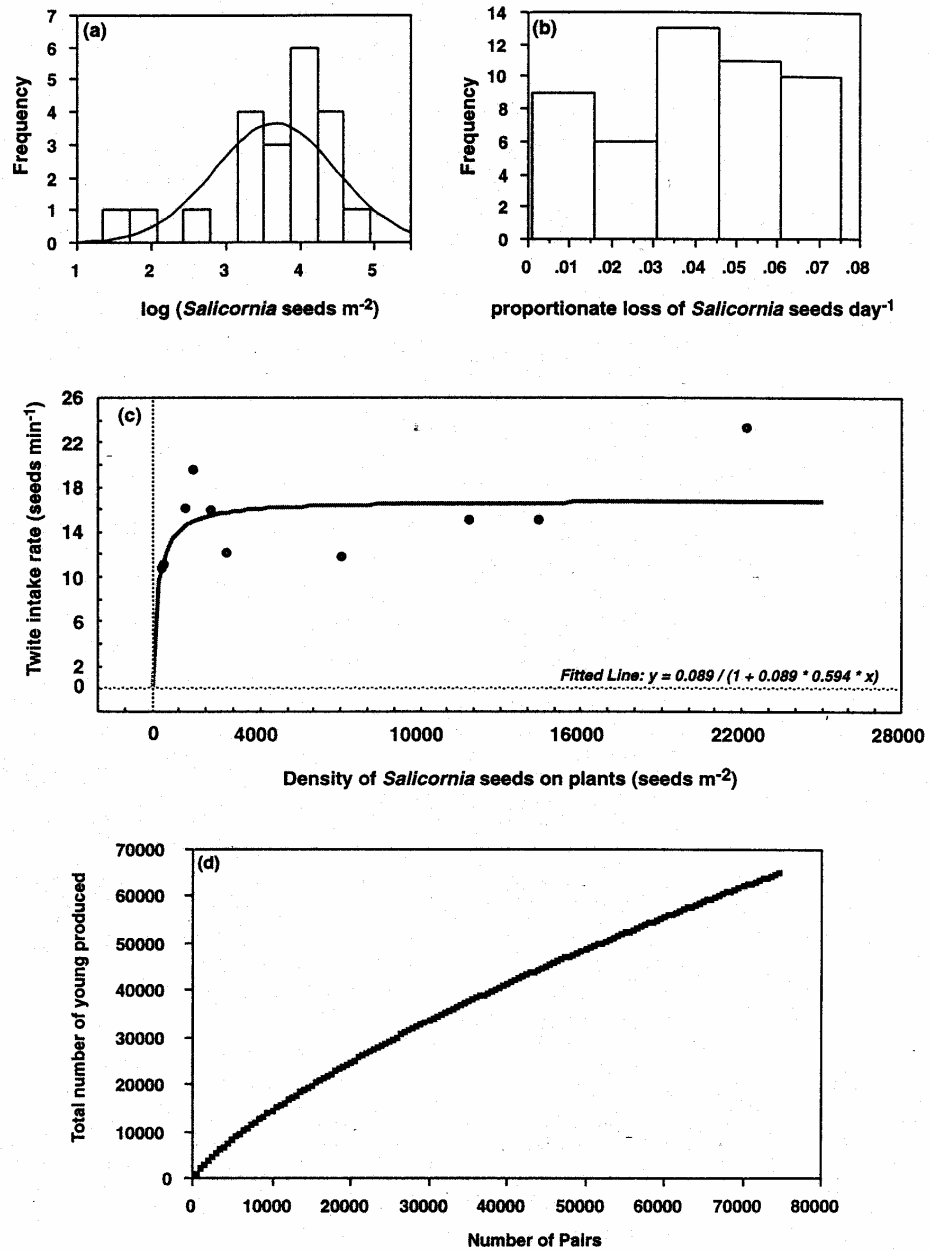


Figure 2. Schematic diagram of the parameters used in the Twite-*Salicornia* model; (a) *Salicornia* seed densities in autumn 1996 and fitted log-normal distribution; (b) proportionate loss of *Salicornia* seeds from plants per day excluding Twite predation; (c) the functional response and (d) the description of breeding density dependence used in this model.

through a 30x telescope and measuring peck rates on the *Salicornia* plants. It was possible to distinguish between successful and unsuccessful pecks as birds could be seen manipulating and in some cases swallowing the seeds. It is possible that more

than one seed per peck was consumed but for the purposes of this model it was assumed that one seed only was consumed per successful peck. At each site, 30 observations of at least 30 seconds were obtained and the mean intake rate was determined. After 30 intake rates were collected from the same area, the density of *Salicornia* seed on the plants was estimated.

The relationship between prey density and intake rate is termed the functional response, the shape of which has important implications for the manner in which birds distribute themselves across patches. Interference for this flocking species was assumed to be zero as there was no apparent depression of feeding rates at high flock densities. Most vertebrate foragers show a Type II functional response (Sutherland 1996), which is described by the disc equation (Holling 1959):

$$\text{Intake Rate} = a' N / (1 + a' h N) \quad (\text{Equation 1})$$

where  $a'$  is the attack constant,  $h$  is the handling time and  $N$  is the resource density.

The disc equation was fitted to the intake data collected in the field and the parameters,  $a$  and  $h$ , were estimated (Figure 2c). The asymptote of the fitted disc equation is approximately 16 seeds per minute and the lowest mean intake rate is approximately 15 seeds per minute. The number of seeds eaten per day was determined by approximating the number of hours Twite spend feeding. Twite spend approximately 40 minutes per hour feeding (Atkinson 1998) and in mid-winter may feed for 8 hours per day. Hence, the total daily intake rate for 15 seeds per minute is 4,800 and, for 16 seeds per minute, 5,120 seeds per day. For the purposes of the model, I therefore assume that each Twite consumes on average 5,000 seeds per day. Through rearrangement of the disc equation, an intake of 15 seeds per minute would require a seed density to be greater than a threshold density of 1,546 seeds  $\text{m}^{-2}$ .

### *Cost of Moving*

In the model, birds move out of a site once the seed density has reached the threshold level. Half the birds move one direction and half the other, until they find a suitable site (i.e. one with a seed density higher than the threshold). If they reach the end of the line of sites, they then change direction and move back until they find a suitable

site. Mortality is introduced into the model as a mortality cost associated with moving between sites and can be seen as the ability of Twite to find food. Patches of *Salicornia* may be small, especially in relation to total coastal area with large areas containing no suitable habitat, resulting in considerable costs associated with moving. The cost is expressed as percentage mortality according to the logistic equation:

$$\% \text{ mortality} = a / (a + e^{-(b * \text{proportion of sites moved})}) \quad (\text{Equation 2})$$

This produces a family of ‘S’ shaped curves and the parameters  $a$  (which describes the initial cost of moving from a site) and  $b$  (the rate at which the cost increases with moving further) can be varied to change the shape of the curve. An ‘S’ shaped function was used, as the relationship between distance moved and mortality is unlikely to be linear. Based on observations of individually-marked Twite in the field, parameters were chosen that allowed birds to move the equivalent of 20 km per day without significant mortality, after which mortality increased rapidly.

#### *Habitat change*

For the purposes of this project, various scenarios of habitat change (habitat area, initial starting density of *Salicornia* seeds and the rate of natural depletion) were considered by running 999 model simulations to estimate the magnitude and variance in relation to bird usage associated with the area, rate of natural depletion and the initial starting density of *Salicornia* seeds. Mean bird usage was calculated in relation to the initial starting density (0 to 80,000 seeds m<sup>-2</sup>), the degree of exposure determined by the rate of natural depletion (sites with a rate of 0.98-0.99 were deemed ‘sheltered’, 0.96-97 ‘intermediate’ and 0.94-0.95 ‘exposed’). The areas considered ranged from 0 to 30 ha. The model was run for each scenario until the total bird usage of each site was determined.

#### *Breeding output*

Twite are loosely colonial in the Pennine breeding area and show no obvious signs of competing for breeding territories, or for feeding sites at current breeding densities, suggesting that density-dependence in the breeding areas is low (McGhie *et al.* 1994). Breeding output has therefore been included in the model with weak density dependence using the function from Hassell (1975):

$$\text{Total number of young produced} = N(1 + sN)^{-m} \quad (\text{Equation 4})$$

where  $N$  is the population of adult birds,  $s$  a scaling factor and  $m$  the strength of density dependence. In the model, density dependence in the breeding areas is weak and a value of  $m = 0.3$  and  $a = 0.0001$  has been used for the model (Figure 2d).

## Results

Figure 3 shows an example of output from the Twite-*Salicornia* model. In these scenarios, the model was run and a measure of Twite usage (in terms of the cumulative numbers of Twite predicted to use an area) was calculated and averaged across the different simulations. As expected the degree of exposure was an important determinant of the magnitude of bird usage, with more exposed sites losing their seeds at a faster rate than sheltered sites. As a result, the seed densities at the more exposed sites reached the point at which it was not profitable for birds to feed quicker and so the birds moved on to other sites with higher seed densities. Usage was therefore lower at more exposed sites.

The area of a site was also important. As might be expected, larger areas tended to be used more by birds but a levelling-off in usage is clearly observable in the graphs. This is for two reasons. In the model, birds distribute themselves in a uniform manner across the model as, at the start of the winter, food is in abundance and most sites hold food above the critical density that Twite can profitably feed on. However as sites are depleted, birds will move on and incur a mortality cost, thus imposing a maximum distance that birds can fly to find food. Hence, there are only a limited number of birds that can find any particular site. It is also likely that under the current model scenarios, the number of high quality site is such that most birds will find a site to settle on and would not have to move further.

The quality of a site is not only determined by the rate at which seeds are depleted, but also the starting density of seeds. Sites with an initial seed density of 0 – 10,000 seeds were used very little by birds and seed densities of > 30,000 were needed to

ensure that there was a high likelihood that the site remained suitable for birds throughout the winter.

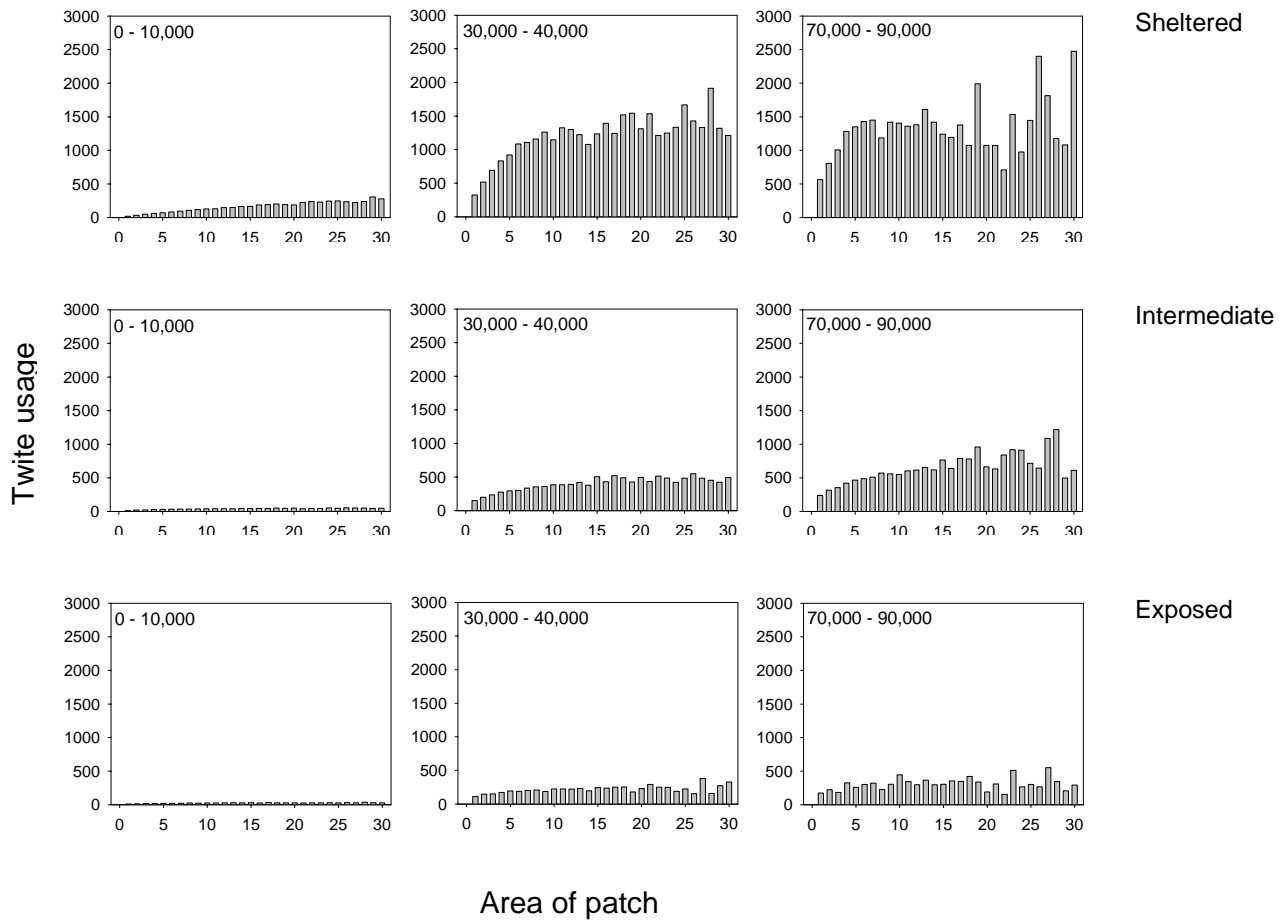


Figure 3. Example output from the Twite model showing the expected Twite usage (on the y-axis) in relation to the size of the patch (ha) on the x-axis. Figures in the top left hand corner of the graph indicate the starting density of *Salicornia* seeds in the patch (0-10,000 seeds, 30,000-40,000 and 70-90,000) across three different types of saltmarsh area (sheltered, intermediate and exposed)

### Implications for site design

For Twite, there are some clear guidelines that can be derived from the model in order to create new areas of saltmarsh for this species. At the start of the winter, birds do not distribute themselves according to the sites that have food at the end of the winter. They therefore do not have perfect knowledge of which sites will be suitable. Therefore, any newly created site should ideally be close to other suitable sites to

increase the probability of Twite locating the new sites. Twite can fly at least 20 km per day in search of food and, ideally, sites should therefore be less than this distance apart. The site should also be of good quality. This is determined by a combination of the degree of exposure to wind and wave energy, and the initial density of seeds in the area. Even relatively small sites with a high density of seeds and a low exposure rate can support large numbers of birds. Third, the area of a new site is less important than the amount of *Salicornia* available to the birds within the site. As the size of the site increased, the Twite usage on the sheltered sites rapidly increased reaching an asymptote at approximately 6 ha for sites with seed densities in the 30,000-40,000 category and less for sites with higher initial seed densities. After this, Twite usage did not increase as rapidly with additional habitat.

The loss of saltmarsh habitat in south-eastern England has been most pronounced for pioneer saltmarsh, where the largest areas of *Salicornia* occur. However these pioneer communities, low down on the shore, are also the most exposed, and it is areas such as embayments or sheltered borrowpits under sea walls that tend to have low exposure rates, which will provide suitable habitats for Twite at the end of the winter.

### **Links to the coastal simulator**

The Twite model has been fully incorporated within the coastal simulator to allow estimates of the impact of changes in saltmarsh habitat at any given location for seed-eating passerine populations. Thus, both the loss of saltmarsh through processes such as coastal squeeze and continued erosion of intertidal habitats, and potential gains in saltmarsh through managed realignment of sea defences, are likely to influence populations of species of conservation concern, such as Twite. The East Anglian saltmarshes are of key importance for Twite and several other similar species. The ability to predict the impact of changes in saltmarshes for these key species will allow policy-makers to explore a range of coastal management strategies in great detail.

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