WaderMORPH – A user-friendly individual-based model to advise shorebird policy and management

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Summary

1. Conservation objectives for non-breeding shorebirds (waders) are determined from their population size. Individual-based models (IBMs) have accurately predicted mortality rate (a determinant of population size) of these species, and are a tool for advising coastal management and policy. However, due to their complexity, the use of these IBMs has been restricted to specialist modellers in the scientific community, whereas, ideally, they should be accessible to non-specialists with a direct interest in coastal issues.

2. We describe how this limitation has been addressed by the development of WaderMORPH, a user-friendly interface to a shorebird IBM, MORPH, that runs within Microsoft Windows. WaderMORPH hides technical and mathematical details of parameterisation from the user, and allows models to be parameterised in a series of simple steps. We provide an overview of WaderMORPH and its range of applications. WaderMORPH, its user guide and an example dataset can be downloaded from http://individualecology.bournemouth.ac.uk.

Key words: Climate change; Coastal conservation; Environmental change; Foraging behaviour; Individual-based model; Shellfishery management

Introduction

Conservation objectives for non-breeding coastal birds (shorebirds and wildfowl) are determined from their population size at coastal sites. To advise coastal managers, models must predict quantitatively the effects of environmental change (e.g. caused by habitat management, industrial development, human activities or climate change) on population size or the demographic rates (e.g. mortality) that determine it. This has not been possible using simple models (Stillman & Goss-Custard 2010).

Individual-based models (IBMs) (Grimm & Railsback 2005), which predict population processes from the behaviour and fates of fitness-maximising individuals of varying competitive ability, have provided a tool for making these predictions. Coastal bird IBMs have predicted accurately overwinter mortality, and the foraging behaviour from which mortality predictions are derived (e.g. Stillman *et al*. 2003). Such IBMs have been parameterised for over 20 European sites over the last decade, and used to predict the effect on survival in coastal birds of sea level rise, habitat loss, wind farm development, shellfishing and human disturbance (e.g. Stillman *et al*. 2003; Durell *et al*. 2006; Caldow *et al*. 2007; West *et al*. 2007). Parameters can be measured and predictions made within the relatively short time scale required to inform conservation management. Stillman & Goss-Custard (2010) provides an overview of these IBMs, including the reason for their development, their range of use and testing. Stillman (2008) describes the latest IBM, MORPH, which is applicable to a wider range of systems than previous models.

Although these IBMs have advised coastal management and policy, they have had the major drawback that their use has been restricted to specialist modellers in the scientific community, whereas, ideally, they should be accessible to non-specialists with a direct interest in coastal management and policy. The reason that these IBMs have not been usable by non-specialists is that parameterising, running and interpreting the results of these models has been a very technical task, requiring specialist modelling and data analysis expertise. For example, the MORPH model takes its settings from large text files containing potentially complex equations and so can only be used by shorebird specialists with technical and mathematical skills.

In this paper we describe how this limitation has been addressed by the development of WaderMORPH, a user-friendly interface to the MORPH model that runs within Microsoft

Windows. We provide an overview of WaderMORPH and its range of applications. WaderMORPH can be downloaded from http://individualecology.bournemouth.ac.uk.

The model

The purpose of WaderMORPH is to provide an interface which allows end-users to create and edit MORPH's simulation files without having to deal with their complexity. It packages all the complexity of MORPH's parameters into a series of modules which can be included in the model simply by selecting options on a series of onscreen forms. Technical and mathematical details of parameterisation are shielded from the user. The end user is then only required to enter details specific to their particular situation, such as the species of bird present and their numbers, the types of prey present and their abundance. WaderMORPH runs the MORPH model using the generated parameter file, and presents the user with a summary of the predictions. In this way, the predictive capability of the MORPH model for shorebird populations can be made available for use by a wider range of organisations. WaderMORPH was developed as a collaborative project between the author's of this paper. WaderMORPH was developed using CodeGear Delphi 2007 (www.codegear.com) taking into account the requirements of and testing by the remaining project partners. WaderMORPH comes with all the data needed to set up a sample model.

WaderMORPH divides the processes of parameterising an IBM into the following steps, during each of which the user is prompted for information through one or more onscreen forms. The first steps are to enter the location of the study site (to determine day length) and the first and last days of the simulation. The next step is to enter the number of bird species to be included in the model. These are selected from a list of species comprising, at the time of writing, Dunlin *Calidris alpina*, Ringed Plover *Charadrius hiaticula*, Knot *Calidris canutus*, Redshank *Tringa totanus*, Grey Plover *Pluvialis squatarola*, Black-tailed Godwit *Limosa*

limosa, Bar-tailed Godwit *Limosa lapponica*, Oystercatcher *Haematopus ostralegus* and Curlew *Numenius arquata*. WaderMORPH builds the parameter file using equations predicting the feeding rate of these species as a function of food (see Goss-Custard *et al*. (2006) Fig. 1 for examples) and competitor density (see Stillman *et al*. (2002) Fig. 4 for examples). It also parameterises the body mass and energy requirements of the bird species (see Stillman *et al.* (2005) Fig. 4 for examples). The user needs to enter the number of individuals of each species, how this varies throughout the course of winter and the diets (prey species and size range) consumed by each species (see Stillman *et al*. (2005) Fig. 5 for examples). WaderMORPH incorporates individual variation in foraging efficiency and dominance, drawn for each individual from a normal and uniform distribution respectively. The next steps define the number of patches in the model, and the number and densities of prey species on each patch. The user needs to enter the size of each patch (e.g. area of a cockle *Cerastoderma edule* or mussel *Mytilus edulis* bed). Prey species are selected from a list comprising major shorebird prey including, at the time of writing, marine worms, earthworms, cockles, mussels, *Hydrobia* sp., *Corophium* sp., *Scrobicularia plana*, and *Macoma balthica*. WaderMORPH builds the parameter file using typical or user-defined masses of these species, and changes in numerical density through the winter. The user needs to enter the initial numerical density of each species on each patch at the start of winter (see Stillman *et al*. (2005) Fig. 3, and Durell *at el.* (2006) Table 4 for examples). The last step is to select details of shellfishing and disturbance from a list of options. Shellfishing removes shellfish at a rate entered by the user, and disturbs birds over a predefined or user-entered distance.

The typical process of simulating the effect of environmental change will be to first parameterise the model for the present-day environment. Simulations will then be run to determine how accurately the model predictions differ from observations from the real system (see Stillman *et al*. (2003) Fig. 3, and Stillman *et al.* (2000) Figs. 2-9 for example tests). These will predict for the overwinter period the percentage survival, body mass, proportion of time feeding and distribution of each bird species. At this stage, a decision will need to be taken as to whether the "un-calibrated" model predicts the observations with sufficient accuracy for confidence to be placed in its predictions for new environmental conditions. If it is decided that predictions are not sufficiently accurate, a process of calibration will be required. Calibration will involve systematically changing the value of one or more "calibrated" parameters over an expected range; for example, adding additional food supplies, changing the amount of food available within patches to account for any uncertainties, changing assumptions on the effect of disturbance on the birds (see Durell *et al.* 2006 and 2007 for examples of calibration). Simulations will then be run for each combination of calibrated parameter values, and the best "calibrated" model taken as that with the combination of parameters with the minimum difference between predictions and observations. After this calibration process another decision needs to be made as to whether the calibrated model describes the real system with sufficient accuracy for confidence to be placed in predictions for new environmental conditions. Assuming that sufficient confidence can be placed in either the un-calibrated or calibrated model, environmental change is simulated by editing the parameter file to incorporate changes; for example, increasing or decreasing the amount of shellfishing (e.g. Stillman *et al.* 2001, 2003; Goss-Custard *et al.* 2004) or disturbance (e.g. West *et al*. 2002), adding or removing habitat (e.g. Durell *et al*. 2005; Stillman *et al*. 2005). Simulations are then re-run and the predictions of interest (usually overwinter mortality rate) compared with those in the absence of environmental change. Replicate simulations based on the same set of parameter values will usually produce slightly different predictions due to random variation variations within the model (e.g. individual variation in the foraging efficiency and dominance of model individuals. It is therefore advised that, throughout the modelling process, at least three, preferably more, replicate simulations are run for each combination of parameters, and predictions averaged.

Full details of the process of parameterising, running and interpreting the predictions of WaderMORPH are given in the model's user guide.

Discussion

WaderMORPH simplifies the process of parameterising and running IBMs, but interpreting the results of such models, and ensuring that they are correctly parameterised can still be a complicated task. Therefore, predictions should be carefully scrutinised and compared with as much observed data as possible to raise confidence that the simulations for the current environment are reliable. Models should also be kept as simple as possible (e.g. restricting patch and prey and bird species numbers) to simplify the interpretation of results. Even with these considerations, some numerical proficiency will be required in the user of WaderMORPH. The key technical tasks will be (i) collating data on the numerical density of prey sizes classes on different patches, (ii) ensuring that mistakes are not made when calculating and entering parameters, (iii) keeping track of various parameter files and associated result files, (iv) transferring data from result files into a suitable computer package for analysis and (v) plotting and / or performing statistical analysis to determine the influence of simulated scenarios on predictions.

The idea behind the development of WaderMORPH was to allow coastal interest groups to have access to the models that have to date been most successful at predicting the consequences of environmental change for coastal shorebirds. The plan is that "opposing" interest groups may one day have copies of the same model on which they can run simulations to understand the impact of alternative site management strategies. For example, conservation and shellfishery organisations may run simulations to predict the consequences of alternative fishery quotas for the survival rates of the birds. This situation has not yet been reached, but announcing the existence of WaderMORPH through this paper is hoped to be the first step. The use of WaderMORPH is of course not restricted to such coastal interest groups, and it is hoped that it may also be used by ecological consultants, or as an educational tool for students.

Although the current version of WaderMORPH is restricted to European coastal shorebirds (as it currently only contains parameters for these species), it has been developed in a flexible way that will allow its parameterisation for other species and locations in the future. Anyone interested in applying WaderMORPH to a non-European system, or to bird or prey species not listed above, is asked to contact the correspondence author with details of the system, bird and prey species. Provided that suitable data (e.g. prey mass and length relationships, and bird foraging behaviour) are available for the system, or can be calculated from the literature (e.g. Goss-Custard *et al*. 2006), the prey and bird species parameters, as well as the system's location will be incorporated into an updated version of the downloadable model. These prey and bird species and the system's location will then be available as options within the model. Through this process the number of shorebird systems to which WaderMORPH is applicable will increase over time. We are also in the early stages of applying MORPH to wildfowl, farmland birds and freshwater fish. If these applications prove to be useful for management and policy, the next step will be to develop a user-friendly interface for these systems.

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