Modelling the effects of farmland food webs of herbicide management in the agricultural ecosystem

Final report

A R Eberst[1], J. L. Bown[1], D. Bohan[2], D. Brooks[2], R. Caldow[3], G. Champion[2], J. Cussans[2], S.E.A. Le V. dit Durell[3], L. G. Firbank[3], A. Haughton[2], C. Hawes[4], M. Hill[3], M. Heard[3], M. May[2], J. Perry[2], S. Petit[3], A. Qi[2], P. Rothery[3], R. Scott[3], G. R. Squire[4], R. Stillman[3], I. Woiwood[2] and J. W. Crawford[1].

[1] University of Abertay Dundee
[2] Rothamsted Research
[3] Centre for Ecology & Hydrology
[4] Scottish Crop Research Institute

Objectives:

1 – Review and assess existing modelling approaches, and then to construct a new alternative modelling framework that can be used to predict the effects of herbicide and insecticide management systems on plant and invertebrate food resources and foraging birds in the breeding season and during winter.

2 – Propose a number of crop, field and farm management scenarios that would act as a driver of weed and insect population change and thus have implications for the scaling up processes.

3 – Review existing and new structures for a model that will forecast changes of weed populations in winter and summer with respect to herbicide regime and crop management systems.

4 – Evaluate arable weed and invertebrate species as resources for species higher in trophic levels, with special reference to breeding and wintering birds.

5 – Review existing and new structures for a model that will relate bird populations to food resources within arable fields.

6 – Propose methods of scaling up bird / food models to include other factors and a wider geographic range.

7 – Integration of results and development of recommendations for implementation of systems-based modelling approach for forecasting farmland bird populations using data from the Farm Scale Evaluations.

Executive Summary.

A new approach to modelling the impact of changing farm management on farmland food webs is suggested. Current empirical approaches (often called population-based models) derive relations between resources and population changes from case studies. They are restricted to the study of individual species and specific resources meaning that new data must be collected for each new species, and that simultaneous predictions across a range of species cannot be easily addressed. Furthermore, because the relations describe the test case, population-based models cannot be used to study novel scenarios without incurring inestimable uncertainty. Despite their limitations, these approaches can offer the most cost effective and rapid means of informing conservation measures when time is of the essence. More recently, an alternative approach using behaviour-based models has been developed. These models describe the impact of novel scenarios on behaviour of species and the consequences for survival. Whilst being more accurate and capable of identifying the underlying causes, behaviour-based models are complex, require large amounts of data and take a relatively long time to formulate. They may also be difficult or impossible to formulate for less visible species. Finally, in order to study the impact of change on the relative abundances of several species at once, the existing models must be applied separately to each species and the interactions between them are not explicitly included. The resulting explosion in parameterisation is prohibitive.

The available approaches therefore lie at extreme ends of accuracy, precision and data requirements. A more efficient and effective methodology would be capable of spanning the two extremes, and provide increased accuracy and precision as and when new data becomes available without the need to change the modelling approach.

The new methodology outlined here exploits the advantages of behaviour-based models but aims to provide a more flexible framework in terms of complexity and a reduction in data requirements. Key findings detailed in the report include:

- The apparent complexity in modelling the impact of changes in the farmland bird resource base may be overcome by exploiting patterns in observed feeding preferences. Of the 177 plant and 33 invertebrate test species which are a subset of the potential resources for farmland birds, a description in terms of 6 classes of plant resource and 4 invertebrate classes is possible.
- The apparent complexity in modelling the behaviour of different bird species is overcome through the use of a single generic representation based on key physiological traits.
- Management changes to habitat structure can be directly incorporated by including habitat as a resource and availability of resources as a management-dependent variable.
- Scaling from field to national level is possible with the use of hierarchical scaling laws. An account of changes in spatial patterning in resources is accommodated directly in a function describing feeding rate. Required data exists in the CS2000 database.
- The approach is designed for embedding in an expert system to integrate qualitative expert knowledge and include uncertainties in future management scenarios in predictions.

The approach is illustrated by application to the skylark. Five-year trends following changes to resource levels indicate the bounds in the predicted rate of change in skylark abundances.

The developments leading to and details of this proof of concept are detailed below. The report is structured in term of the objectives above, although to properly reflect the development process objectives are considered out of order. Opportunities for further developments are also highlighted.

Resource Categorisation

- *Objective 4 – Evaluate arable weed and invertebrate species as resources for species higher in trophic levels, with special reference to breeding and wintering birds.*

A fundamental element of the work undertaken was the consideration of the resource base since the manner in which the complex resource substrate is simplified into a smaller number of qualitative categories impacts on the entire modelling approach. This stage of development is key to the progress made with the rest of the project. Without the effective simplification of this extremely complex resource base the development of a truly generic framework is precluded.

For the purposes of developing this model a set of sample data, a classification of the importance of various resources into four ordinal classes was prepared from Cramp (1998). This classification was undertaken for each bird species during the breeding and non-breeding seasons. Multi-dimensional scaling and cluster analyses of the relationship among the 23 farmland bird species in relation to 177 plant taxa and 33 invertebrate taxa allowed the grouping of plant and invertebrate taxa into equivalence classes according to their importance to different bird species during breeding and non-breeding periods. Full details of the resulting categorisation are provided in the Appendix. A subset of the Farm Scale Evaluation (FSE) data relates qualitatively the importance of a large number of plant and insect taxa to farmland bird species, and this may be used to provide a more detailed parameterisation for a full-scale model.

For the plant taxa, six categories emerged from the analysis. At the broadest level, there is no clear distinction between the collective crop and non-crop taxa. However, when considering crop taxa alone, three discrete groups are distinguished. These three groupings may be categorised as main crops, seed crops and non-seed crops. Notably, the main crop taxa, consisting of *Hordeum*, *Avena* and *Triticum*, form a very distinct group lying outwith the rest of the data indicating the importance of these particular taxa. The process of identifying the three crop groupings provided a subsequent demarcation for the non-crop taxa, in that the non-crop occupied regions adjacent to the discrete planes containing the data associated with the crop groupings. This produced three groupings containing the non-crop taxa. Similarly, the invertebrate taxa were categorised into four groupings: major inverts (including bees, wasps, flies and beetle larvae), minor inverts (including millipedes, springtails and mayflies), together with the outlying groupings of earthworms and beetles. (see Appendix).

It should be noted that the current invertebrate categorisation is based on a relatively small number of taxa. However, the approach may be extended to incorporate other invertebrate taxa where data is available. Data from the FSE relates the abundance and distribution of invertebrate groups to particular farm types, allowing broad mappings to be established. In addition, recent work based on Koricheva *et al.* (2000) suggests it may be possible to relate plant taxa abundance directly to invertebrate abundance. In outline, this requires the correlation of plant classes, based on sap, leaves, nectar, etc. production, and the corresponding requirements of herbivorous invertebrates, allowing prediction of the expected effect of altering plant taxa abundance on the abundance of invertebrate taxa. Although this work is provisional at this stage, it is anticipated that such investigations will compensate for the absence of specific invertebrate taxa where information on plant taxa is available in its place.

In addition to the 10 food categories, nesting sites are also considered as a resource. Specifically, tree holes, tree branches, bushes and ground sites are possible nest site types available for different species of bird. The Countryside Survey 2000 (CS2000) provides detailed information regarding the landscape and habitats that exist in the British countryside. The breakdown of this data in relation to farmland and farm types will allow the estimation of the abundance and distribution of environmental factors such as hedgerows and field sizes. This information may be used together with the FSE data to establish abundances and distributions of both food and nesting resources across the UK.

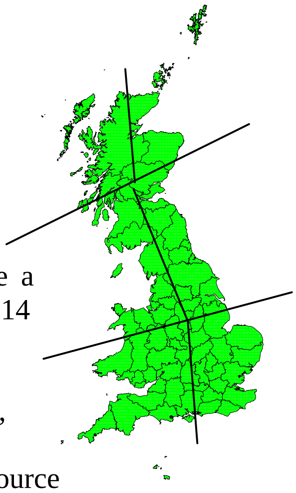
The influence of depletion of resource by the bird population is not included in the model. It is understood that the management policies implemented on farmland are likely to be the major influence on the levels of resources. With regard to resource availability, the interaction of management and extrinsic factors such as weather are likely to be of primary importance, with any direct depletion of resources by birds being a second order factor. This same assumption may be applied to seed resources that are not renewed over winter. In the case of invertebrate foods, the validity of the assumption requires further analysis of the correlation between invertebrate levels and bird populations over this period. (Wilson J.D., Head of Research, RSPB Edinburgh, *pers. comm.*). Importantly, the modelling representation does not preclude the inclusion of depletion if required.

Modelling Requirements

- *Objective 5 – Review existing and new structures for a model that will relate bird populations to food resources within arable fields.*

- *Objective 6 – Propose methods of scaling up bird / food models to include other factors and a wider geographic range.*

A number of existing models have been considered in relation to the problem of linking arable field resources to bird populations. The tendency is for such models to be either highly species specific (*e.g.* Akcakaya 1995, Akcakaya 1997, Freeman 2002 *et al.*), based on a relatively limited spatio-temporal data sets (*e.g.* Wikelski *et al.*, 2003) and /or restricted in the range of resources examined. The tight coupling of such designs to specific aspects of the species and /or resource under study means that it is difficult to extend the results of largely empirical approaches to novel scenarios and to incorporate results from subsequent studies that do not correspond in detail to the model's design. The generic framework outlined here is able to model a variety of different and novel scenarios in terms of species and /or resources on a range of resolutions through the use of physiological traits to describe the functional role of a bird (see below) in the environment and the resource categorisation scheme developed. Importantly, a central strength of the modelling approach is the capacity to incorporate data derived from differing empirical studies in a consistent way, *i.e.* the generic modelling approach may remain constant. Consequently, the approach supports incremental improvements in the modelling framework as a result of the facility to include existing and new information as further (empirical) research becomes available.



In the initial model construction, Great Britain is considered as six distinct regions. The division, albeit somewhat arbitrary given the modelling scheme affords greater or fewer divisions, provides regions with distinct agro-climatic zones. Any particular spatial discretisation may be imposed as required by data available and future modelling requirements. We foresee that in future developments contiguous regions based on the CS2000 will provide a good underlying regional structure. Within a given region, the 14 resources (10 food; 4 nesting) are described in terms of abundance and distribution. The measure of abundance is a qualitative description of the resources available – scarce, limited, average, common and abundant. For resource distribution in a region, a fractal index is used here to describe the underlying spatial variation in resource levels, although more general scaling models can also be used. The modelling scheme accounts for these measures of abundance and distribution on a quarter-month resolution to allow for variation in breeding and non-breeding periods, both in terms of timing and duration, of differing bird species. Thus, the spatio-temporal structuring of resources at the scale of the region is represented in the scheme. As noted, these regions reflect differing agro-climatic zones. Consequently, each region has a qualitative representation of weather, in terms of temperature – cold, cool, average, warm and hot – and precipitation – very wet, wet, average, dry and very dry. As with resources the representation of weather patterns is at the quarter-month scale, again to account for variations in responses among bird species.

Resource is structured in space and time within a particular region. Describing the functional response relating the feeding rate of birds to the food supply is a concept widely used in attempts to understand the interaction between resource and population dynamics of birds. Most of these descriptions fail to acknowledge heterogeneity explicitly (the exception being Ruxton & Gurney, 1994) and so incorporate an implicit assumption about the way that individual foragers average over spatial scale. We have developed a new description which incorporates the parameters of heterogeneity directly in the form of the functional response. The usual Type II or Holling functional response curve is returned, but the parameters depend on time according to a function that contains the parameters of the spatial heterogeneity. The heterogeneity in spatial distribution of resources is driven by farmland management at a local level and is known to be important to feeding rates. Under a few simplifying assumptions an approach has been developed that integrates a number of distinct factors for a given bird species and a given environment: abundance and distribution of resources, significance of resources, bird foraging pattern and accessibility of resource. The resource categorisation is based on the importance of different resource types to different bird species. This importance varies in breeding and non-breeding seasons and is represented in the modelling approach as a set of significance vectors (see model description for more detail). The foraging pattern of birds is characterised by a fractal index in a similar manner to the spatial distribution of resource. Resource accessibility accounts for the effect of weather on acquisition. The functional response of bird populations to resource levels drives the timing of events for individual birds such as migration, nest building etc. as detailed in the model description below.

Approach to resource management

- *Objective 3 – Review existing and new structures for a model that will forecast changes of weed populations in winter and summer with respect to herbicide regime and crop management systems.*
- *Objective 2 – Propose a number of crop, field and farm management scenarios which would act as a driver of weed and insect population change and thus have implications for the scaling up processes.*

The modelling framework described considers a categorised resource base structured in space and time as its input; its output is the response of particular bird species to that input. Clearly any particular resource base is a consequence of imposed management schemes including amounts and types of crops selected for growth, any land set aside, rotations and herbicide and pesticide applications (timing and intensity) across a large number of farms in a particular region. The model allows a wide range of parameter sets to be selected indicative of a similarly wide range of management strategies. The framework allows the embedding of expert knowledge on the relationship between management strategy and resource patterning. This knowledge may be encapsulated within a dedicated computer-based expert system. Additionally, standardised management strategies may be incorporated into the expert knowledge base. Consequently, the influence of any management scheme on the spatio-temporal packing of resource is not considered to be part of the core modelling approach developed here.

Modelling framework

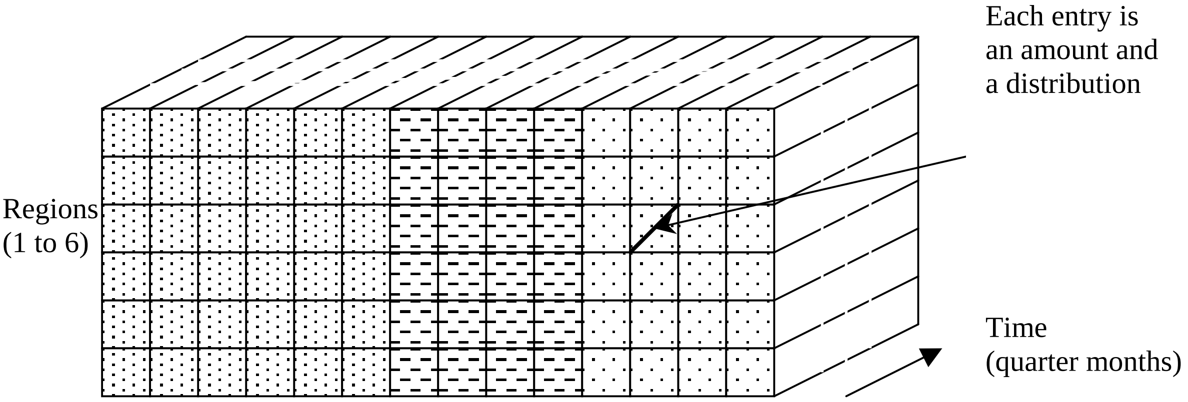
- *Objective 1 – Review and assess existing modelling approaches, and then to construct a new alternative modelling framework that can be used to predict the effects of herbicide and insecticide management systems on plant and invertebrate food resources and foraging birds in the breeding season and during winter.*

Overview:

The modelling framework interrelates a number of key elements established in the conceptual approach. Birds are characterised by a set of physiological traits that define interactions with the environment. This representation subsumes the notion of species given that birds of a particular species may be defined in terms of their functional role in the environment, termed a functional type. Further, a given functional type may incorporate one or more species. The description may be partitioned into (1) breeding details profiling the timing and duration of various breeding season activities; (2) dispersal details governing the migratory patterns of types across six regions in the UK and a migratory region; (3) mortality rates describing the likelihood of death under various resource scenarios during breeding and over-wintering; (4) the sensitivity of behaviour to resource and weather scenarios for varying events over the year. The resource, weather and functional type representation are detailed within the context of the modelling framework. The way in which the traits of a bird type together with the environment govern the timing of events within the model is outlined.

Characterisation of resources:

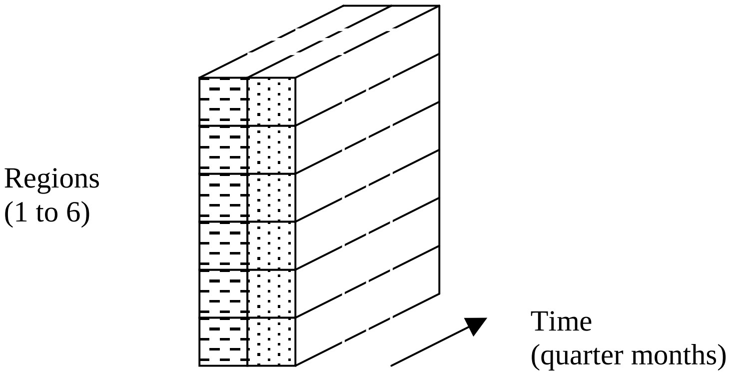
Within the modelling approach 14 categories of resource are defined, as detailed above. There exist profiles of each resource for each quarter month – over multiple years – for each of the six regions defined. These profiles are characterised by a qualitative amount and a description of the heterogeneity in spatial distribution. The representation of resources may be described visually as follows:



Resources (6 plant; 4 invertebrate; 4 nesting)

Characterisation of Weather

Weather is represented in terms of qualitative indicators of temperature and precipitation in each climatic region for each quarter-month. The representation may be described visually, in a similar manner to resources, as follows:



Weather (temperature; precipitation)

Characterisation of functional types:

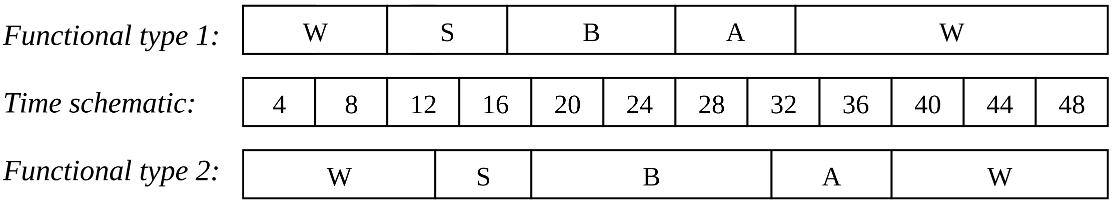
Birds are characterised by a set of physiological traits that define interactions with the environment at various lifecycle stages. Functional types are defined in terms of breeding details, dispersal details and mortality rates. The characterisation of breeding details profiles the timing – start and finish – and duration, measured in quarter-months, of the different breeding season activities. These breeding activities are nest building, incubating up to a maximum number of eggs and chick rearing. Additionally, the opportunity for multiple broods is also represented.

Dispersal details profile the migratory patterns and time intervals – starting and finishing quarter month – of functional types for both over-wintering and spring return. There exist six regions within Great Britain, and, in the case of over-wintering, the dispersal patterns are represented as probabilities of dispersing from the home region, where nesting occurred, to each of the other regions. For types that may leave Great Britain an additional migratory region is implemented to keep account of population levels. In the case of spring return, birds are returned to their home region.

Mortality is assessed at two key periods in the lifecycle: breeding and over-wintering. During the breeding season, mortality is assessed for adult birds during incubation and chick rearing periods within each brooding event and is based on resource availability – a measure of resource amount, patterning and weather (see below). During the winter period mortality is assessed based on the worst contiguous four quarter-month period in terms of resource availability. This longer period reflects the different time-scale associated with winter activity and the shorter brooding period. Within that winter period a further distinction is made between adults and juveniles – those birds entering their first winter. Adults and juveniles have differing mortality rates where, typically, the juvenile mortality rate is higher and the difference in rates is dependent on functional type. Note, the additional region used for overseas migration has a fixed mortality rate since neither resource nor weather characteristics are considered for this region.

Model lifecycle:

The model reflects an annual lifecycle divided into four major phases: breeding season, autumn dispersal, over-wintering and spring return. Of these, the breeding season is further divided into nesting, incubating and chick rearing. The precise intervals of these events in terms of quarter month limits – start and finish – are associated with the traits of a functional type. This affords consideration of bird species of different lifecycles under the same resource regime. The following simple schematic shows two such differing lifecycles referenced against a four quarter-month calendar. Here, W stands for over-wintering, S spring return, B breeding season and A autumn dispersal.



In all cases in the model, the lifecycle fits within the given forty-eight quarter-month year. Here, the internal phases of the breeding are not shown but may be structured with similar variation among types.

Model events and resource significance:

Within the modelling approach, there is a coupling between the lifecycle events of a given functional type and the underlying resource base. Different resources are of different significance to birds over the course of different events. For example, as an extreme case, nest resources are only of significance during the breeding season. Likewise, the group 'mid F2' (see Appendix), constituting many type of berry, is of greater significance in the winter. In detail, each functional type is characterised by a set of significance vectors relating specific events to specific resources. The values in each vector map directly onto the resource levels (above). The events considered are nesting, incubating, rearing, juvenile feeding, adult feeding during the breeding season, autumn dispersal, and over-wintering. Each event has significance vector of 14 values – one per resource type.

Model dynamics and functional response:

The above sub-sections describe the static data structures of resource, weather and traits of functional types, together with the lifecycle of events as prescribed by the trait values. The modelling framework interrelates those static descriptions through a dynamical algorithm that governs the transition from one lifecycle event to another. Governance of the transition from one event to another is by the combination of physiological traits and functional response. The scheme is consistent across all event transitions and an example provides adequate coverage of the approach.

For example, in a given population of a given functional type at a given time (quarter-month) in a given region a specific number of birds will begin the cycle of breeding, having returned from over wintering in the spring return. Prior to the beginning of the breeding period no birds will be in the breeding event; the same is true beyond the end of this breeding period. Within the breeding interval, the number of birds that begin building nests at a given quarter month is determined by the number of birds in the population and that type's functional response to the environment. This response integrates the spatial distribution of resource, the amount and significance (for nest building) of resources, the weather conditions and the foraging pattern of the bird type. Currently, a simplified scheme is in place for assessment of suitability of the approach.

This scheme allows for a spread of bird numbers across different phases. For example, in a period of low resource availability within the breeding interval, as governed by functional response, only a small fraction of the bird population might begin breeding early in this interval; this fraction might increase over time to the point where all birds are breeding but spread out over time. Thus, in a single quarter-month time point, a fraction of the population might be nest building, another fraction incubating, a further fraction chick rearing and some might be beginning a second brood. This capability allows for complex patterning in bird activity under different management regimes.

Results and further developments

- *Objective 7 – Integration of results and development of recommendations for implementation of systems-based modelling approach for forecasting farmland bird populations using data from the Farm Scale Evaluations.*

Parameterisation:

Data relating to the skylark *Alauda arvensis* were used to obtain parameters for the model (Cramp 1998, Chamberlain *et al.* 1999a, Chamberlain *et al.* 1999b, Cracknell 1986, Diaz 1990, Donald *et al.* 2001, Green 1980**,** Kirby 2001 Toepfer & Stubb 2001, Wakeham-Dawson *et al.* 1998, Wilson *et al.* 1996, Wilson *et al.* 1997). Where data specifically relating to skylarks was unavailable, generic values pertinent to other species or taxa were used. Initial results demonstrate the capacity of the model to reflect the general phenology of the skylark and the influence of resource levels on the dynamics of the population.

Results:

The examination of results considered the birds present in region 1 (NW Britain). The population is largely sedentary with little movement to other regions and thus it could be examined in isolation from other areas. In Fig. 1, the graph depicts two breeding seasons. There is an initial burst of nest building followed by the production of eggs, nestlings ("current_chicks") and fledglings ("juven"), with some losses at each stage. A proportion of breeding pairs then commence to have a second, and then third brood, forming a similar, but reduced pattern. In this example, breeding is highly synchronised, *i.e.* all pairs start to breed simultaneously, to assist in interpretation in this report. This can be altered so that a proportion of pairs will start to breed as a response to environmental cues. In this case a broader spread of the peaks would result.

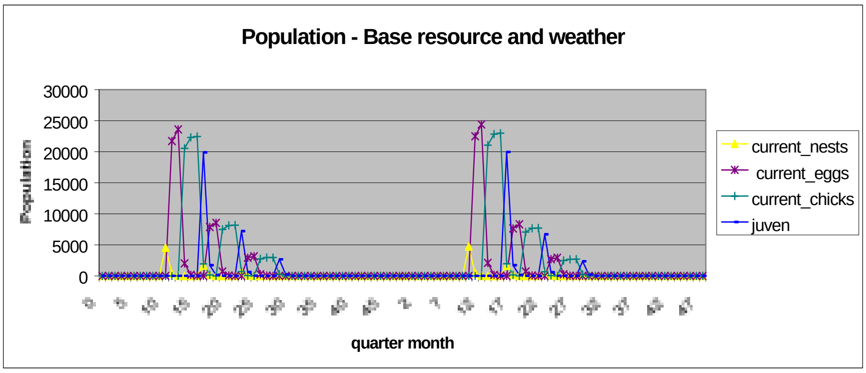


Fig. 1, Simulation of skylark breeding – base data

The fledglings (juven in the legend) produced each season are added to the juvenile population (Pop_juven) (Fig. 2). These juvenile/1st year birds undergo substantial mortality over the breeding and winter periods, and at spring dispersal the remaining birds are added to the adult population. Mortality rates for the adults vary over the year with more substantial numbers being lost during the winter.

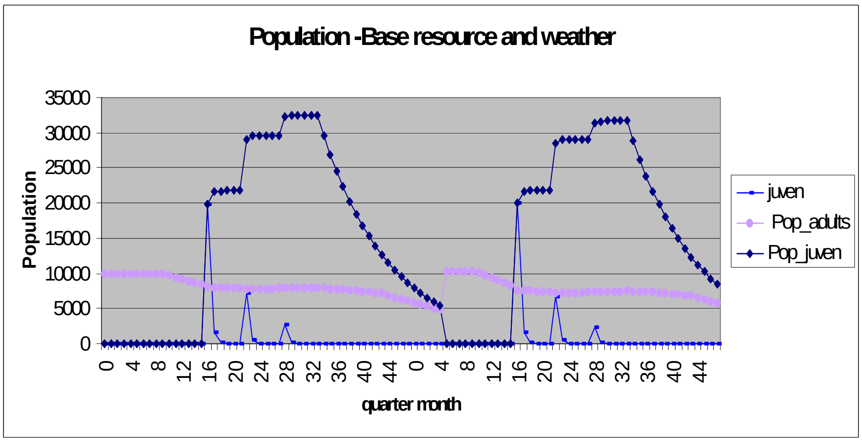


Fig. 2: Simulation of skylark population – base data

The influence of variation in the availability of resources can be seen in Fig.3. In this case five seasons are shown, the divergence in population sizes under different resource regimes is apparent. The difference between the poor and base resource level is not the same as that between the base and good resource level. Therefore the model shows the non-linear response of population to resource, and the differential impact on breeding success and winter survival.

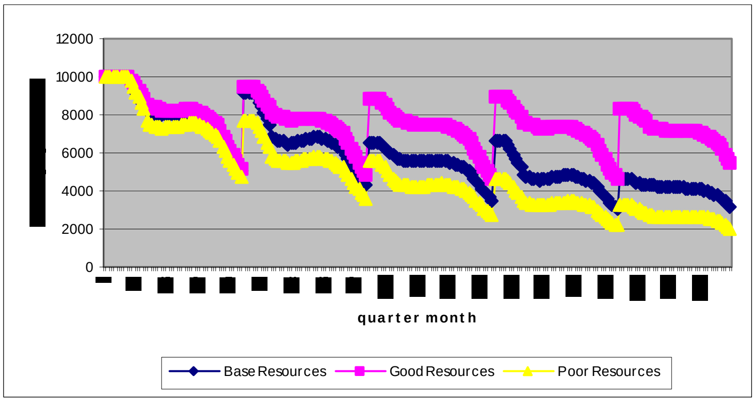


Fig.3: Population divergence under differing resource regimes

Further developments:

The modelling approach developed to date serves as a platform for three broad development potentials. Firstly, whilst the modelling process has allowed the identification of the key features requiring inclusion, a number of simplifying assumptions, largely due to time constraints and a lack of data, are included. However, the approach does not preclude the inclusion of more developed representations of those key features. Indeed, the generic approach described here is complementary to the empirical approaches outlined above. The formulation of the key features present in this generic scheme may firstly be supported by fine-scale details derived from empirical studies and secondly provide a mechanism through which disparate empirical studies may be integrated.

Secondly, a driving factor in design of the conceptual approach is the acknowledgement of uncertainty in the modelling, as a consequence of (1) missing data, (2) a mixture of qualitative and quantitative data and (3) the process of up-scaling and its resultant simplifications. It is possible to incorporate the approach devised into a probabilistic framework for coarse-grained predictions. Proof of concept for this is in our earlier work that derived an expert system for studying the impact of uncertainty in the future climate on the prediction of agricultural production (Gu *et al.* 1996). In that work, a simulation model of similar complexity to the current one was used to train a Bayesian belief network that integrated qualitative knowledge on future weather and its likelihood with quantitative knowledge from the computer model. This allows the prediction of outcomes with associated probabilities for each that depend on the probabilities associated with input knowledge and the dynamics as represented in the computer model.

Finally, a key strength of the modelling approach is its capacity for ‘what if’ scenarios expressed via varying patterns in resource base. Importantly, the framework has the potential to allow questions in two ‘directions’. Of course, the model allows the assessment of the impact of a particular resource base on a particular bird species over a particular length of time. In addition, the model may be coupled to novel artificially intelligent search strategies developed in related projects. This coupling will allow highly sophisticated scenario-based interrogations in the ‘opposite direction’. In particular, the search strategy may seek parameter sets – resource patterns – that give rise to a particular outcome in terms of an abundance of bird species.

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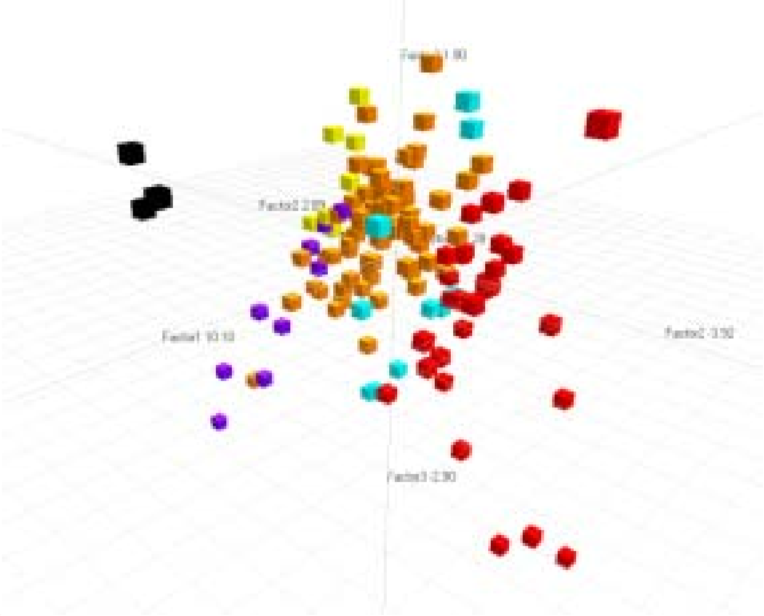
Appendix: Resource base simplification

Data collected on the importance of a variety of resources for 23 species of farmland bird in the breeding and non-breeding seasons were collated. The results were recorded on an ordinal scale from 0 (of no importance) to 3 (of high importance).

In order to simplify the description of resources in the model it was necessary to group together resources with similar patterns of importance across bird species and seasons. The data was analysed using both clustering analysis and multidimensional scaling. The groupings that emerged by both methods were very similar and so only the multidimensional scaling is shown (using the software package Miner3D, Dimension 5).

<u>Multidimensional Scaling Analysis:</u>

a) Vegetation
The six grouping which emerge from MDS are shown:



Crops	Main	(black)	**Non-Crops**	Low Factor2	(red)
	‘Seed’	(purple)		Mid Factor2	(orange)
	‘Non-seed’	(cyan)		High Factor2	(yellow)

The main crops form an isolated cluster that reflects their collective importance to farmland birds. The other crop genera lie in two distinct planes within the mass of other arable plant taxa. The planes lie approximately perpendicular to the Factor2 axis, at values of –1.3 and 1.6. The separation into two planes largely reflect the nature of the crops, the 1.6 plane corresponding to plants which are generally important as seed crops, and the –1.3 plane to other crop types e.g. root, leaf and larger fruit.

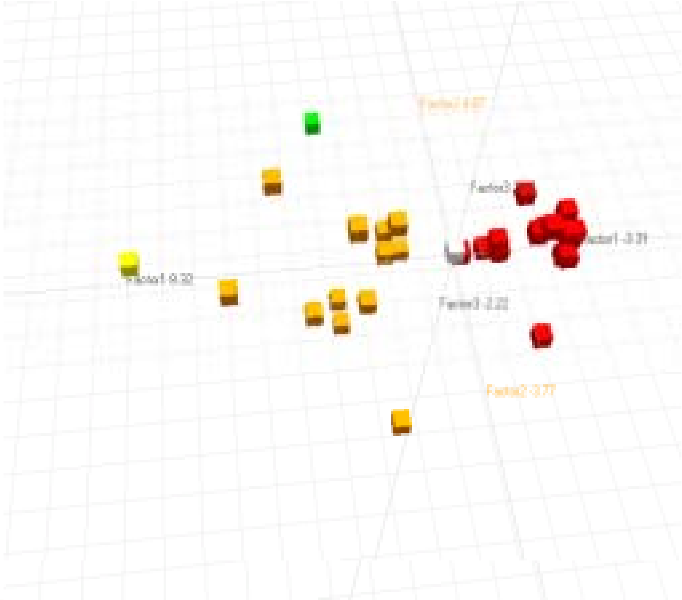
Surrounding these planes lie arable plants with can then be categorised in relation to the planes, two groups lying outwith both planes and one in between them.

Crops			**Non-Crops**		
Main (black)	**Seed (purple)**	**non-seed (cyan)**	**Low F2 (red)**	**Mid F2 (orange)**	**High F2 (yellow)**
Avena	Panicum	Beta	Alnus	Abies	Anemone
Hordeum	Phaseolus	Brassica	Anchusa	Acer	Conopodium
Triticum	Pisum	Cannabis	Arctium	Achillea	Corylus
	Ribes	Lactuca	Artemesia	Aesculus	Hedera
	Rubus	Malus	Atriplex	Agrimonia	Ilex
	Secale	Picea	Betula	Agrostemma	Lathyrus
	Solanum	Prunus	Bidens	Amaranthus	Malva
	Sorghum	Pyrus	Carduus/Cirsium	Amelanchier	Medicago
	Zea	Raphanus	Centaurea	Anagallis	Oxalis
		Trifolium	Cerastium	Anthemis	Potentilla
			Chenopodium	Armeria	Scrophularia
			Cichorium	Aster	Silene
			Crepis	Bellis	
			Dipsacus	Berberis	
			Epilobium	Carex	
			Filipendula	Carpinus	
			Hieracium	Castanea	
			Hypochoeris	Chamaecyparis	
			Knautia/Scabiosa	Chrysanthemum	
			Myosotis	Cicer	
			Oenothera	Convulvulus	
			Papaver	Cornus	
			Petasites	Cotoneaster	
			Pinus	Crataegus	
			Plantago	Cynoglossum	
			Polygonum	Cytisus	
			Populus	Daphne	
			Prunella	Daucus	
			Ranunculus	Dianthus	
			Rumex	Echium	
			Sanguisorba	Empetrum	
			Senecio	Euonymus	
			Solidago	Euphorbia	
			Sonchus	Euphrasia	
			Sorbus	Fagopyrum	
			Stellaria	Fagus	
			Suaeda	Ficus	
			Taraxacum	Fragaria	
			Tragopogon	Fraxinus	
			Tussilago	Fumaria	
			Ulmus	Galium	
				Geranium	
				Helianthus	
				Hippophae	
				Humulus	
				Inula	
				Juglans	
				Juncus	
				Juniperus	

Crops Main (black)	Seed (purple)	non-seed (cyan)	Non-Crops Low F2 (red)	Mid F2 (orange)	High F2 (yellow)
				Larix Leontodon Ligustrum Linum Lonicera Lupinus Lythrum Matricaria Mercurialis Morus Onobrychis Ornithopus Oryza Parthenocissus Phragmites Platanus Polygala Portulaca Primula Pulicaria Pyracantha Quercus Rhamnus Salicornia Salix Sambucus Scorzonera Sequioa Sinapis Sparganium Spergula Spergularia Symphoricarpos Symphytum Syringa Tanacetum Taxus Thymus Tilia Tsuga Typha Urtica Vaccaria Vaccinium Verbascum Veronica Viburnum Vicia Viola Viscum Vitus Xanthium	

b) Invertebrates

The four groups that emerge from MDS are shown:



Invertebrates	Minor	(red)
	Major	(orange)
	Beetles imagos	(yellow)
	Earthworms	(green)

The clustering of invertebrates into four distinct groups is apparent. The invertebrates of generally low importance are relatively tightly clustered, a second grouping of more important taxa form a looser aggregate and the two groups of beetle imagos and earthworms are both important but to different patterns of farmland birds.

Minor Inverts	**Major Inverts**	**Earthworms**	**Beetle imagos**
Thysanura Collembola Ephemeroptera Odonata Plecoptera Chilopoda Dictyoptera Diplopoda Isoptera Psocoptera Amphipoda Thysanoptera Mecoptera Neuroptera Decapoda Isopoda Trichoptera Acari Opiliones	Mollusca Araneae Coleoptera larvae Hymenoptera larvae Hymenoptera Orthoptera Diptera larvae Dermaptera Diptera imagos Lepidoptera larvae Hemiptera Lepidoptera imagos	Lumbricidae	Coleoptera imagos

c) Nest sites

Similar analysis for nest site data gives six clusters of nest site types

Hole/Box	**Coniferous**	**Mixed**	**Scrub/hedge**	**Uniform lowgrowth**	**Arable/Tall herb**
Holes	Woodland/forest	Woodland/forest	Continuous	Short grass	Arable
Boxes	Clumps/copses	Clumps/copses	scattered	Mash/bog	Long grass
	Scattered trees	Scattered trees		saltmarsh	Tall weeds
	Woodland edge	Woodland edge			
		Line or belt			

The model contains arrays for only four of these categories, at the present time, it can however be easily expanded to include all six.