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# Predicting impacts and solutions

# Who are we?

**Chris Topping**

Senior Scientist,
Department of Bioscience,
Aarhus University

Modeller working primarily with agent based models of a wide range of systems

**John Stark**

Professor, Ecotoxicology
Washington State University

Modeller working on matrix models, PVA, in context of ecological risk assessment of pesticides

# What we want to cover today

1. Defining the question
2. Types of models for prediction
3. Agent-based modelling examples
4. Complex systems
5. Modelling questions & discussion
6. Applied examples from the USA

# 1. Defining the question

This section covers:

- What we want to predict
- Example systems
- Defining the questions – types of question

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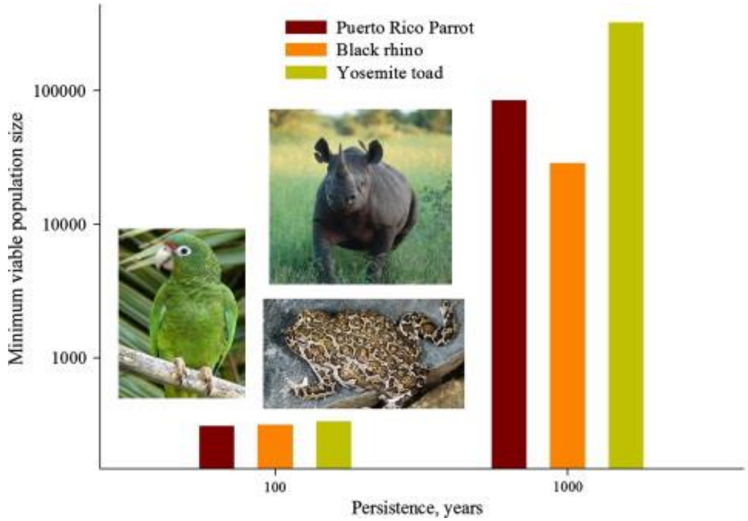
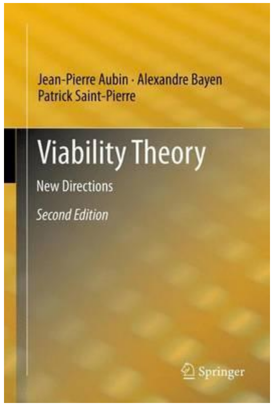
# Prediction in applied systems – what does this mean?

- Nothing specific – what is an applied question to one person is a strategic question to another and a pure question to a third e.g. population viability analysis.




- What we are interested in though is some part of an ecological system that requires some kind of management intervention or is subject to management perturbation.



# Management prediction & Modelling

Biodivers Conserv (2007) 16:2649–2675
DOI 10.1007/s10531-006-9077-y

ORIGINAL PAPER

**Identification of biodiversity conservation priorities using predictive modeling: an application for the equatorial pacific region of South America**

**Manuel Peralvo · Rodrigo Sierra · Kenneth R. Young · Carmen Ulloa-Ulloa**

An example from Ecuador and Peru where research and conservation resources are limited so need to be targeted at the most likely to be important conservation areas.

A modelling approach based on spatial distribution prediction and a simulated annealing algorithm to select a spatially compact set of locations.

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# Other examples

This example evaluates the impact of changing hunting technology on black spider monkeys (*Ateles chamek*).

Simulations suggest that bow hunting is sustainable even at high human population densities, but that the use of shotgun hunting will locally deplete populations of monkey.

*Journal of Applied Ecology* 2009, **46**, 804–814 doi: 10.1111/j.1365-2664.2009.01661.x

**Modelling the long-term sustainability of indigenous hunting in Manu National Park, Peru: landscape-scale management implications for Amazonia**

**Taal Levi[1], Glenn H. Shepard Jr[3], Julia Ohl-Schacherer[3], Carlos A. Peres[3] and Douglas W. Yu[2,3*]**

# Other examples

Prediction of outbreaks of desert locusts is a difficult problem.

This paper uses partial integro-differential equations to model outbreaks by modelling the interplay between locust phase change and spatial dynamics.

Many models exist for this kind or system and other pest problems


OPEN ACCESS Freely available online    PLOS | COMPUTATIONAL BIOLOGY

## Locust Dynamics: Behavioral Phase Change and Swarming

Chad M. Topaz[1]*, Maria R. D'Orsogna[2], Leah Edelstein-Keshet[3], Andrew J. Bernoff[4]

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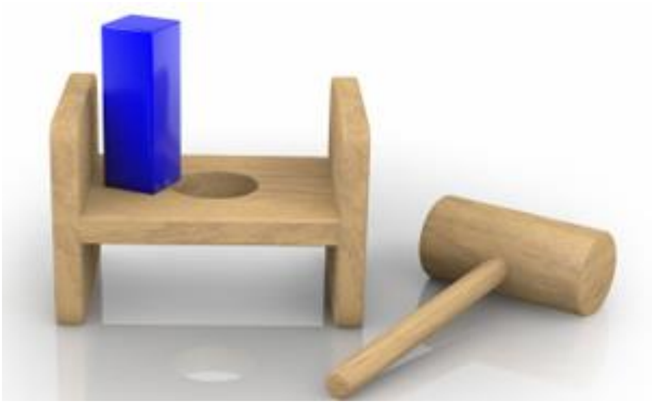
# Types of questions that we might want prediction for

One of the big problems in developing models for an applied science approach to ecological management is failure to understand the questions being asked,
and to fit the tools to the task.



This often means we try to fit
a square peg in a round hole!

It is very important to fit the methods
used to the type of question being asked!

# A rough classification of question types

(no hard and fast boundaries)

- Academic
- Management
- Regulatory/Administrative
- Policy


# Academic questions (& models)

- Most academic questions are aimed at understanding some mechanisms or part of a system's behaviour e.g.
  What regulates populations? How to describe spatio-temporal dynamics? How to describe population viability?
- They are designed for generality and understanding of processes and phenomena.
- The approaches to develop models for these purposes reflect this.
- These are effectively analytical experiments, and models to support this are designed in the same way (reducing dimensionality as much as possible
  – the parsimony rule).

# Academic modelling example

One of a series of papers looking at population modelling from 1973 to1976.

This paper describes single species population growth in terms of differential and difference equations with the aim of understanding variability in cultured lab population trajectories.

Concepts such as density-dependent population control, return rate to carrying capacity, types of population oscillation are all dealt with in this paper.

These concepts form the basis for the majority of population modelling carried out subsequently.

TIME DELAYS, DENSITY-DEPENDENCE AND SINGLE-SPECIES OSCILLATIONS

BY R. M. MAY*, G. R. CONWAY, M. P. HASSELL AND T. R. E. SOUTHWOOD

*Department of Zoology and Applied Entomology, Imperial College, London, S.W.7*

(1) The stability criteria of a single-species population with a maintained food supply depend on the relationship between the characteristic return time ($T_R$) and the time delays of the system. $T_R$ expresses the rate at which the population approaches the equilibrium and the time delays may refer either to generation time or extrinsic delays as may be associated with a resource recovery time.

Here May *et al.* use laboratory cultures of insects as the basis for developing their analysis of the population behaviour.

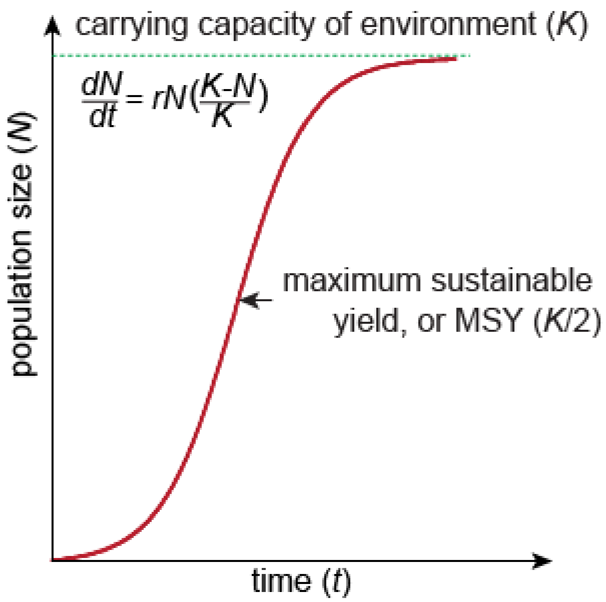
They explicitly assume that the population is under constant environmental conditions and thus forms a stable equilibrium population.

# Management questions

- These questions are specific to a certain system and are somehow related to manipulation of that system by a management intervention.
- The range of systems is huge, as is the range of questions.
- In these cases the specifics of the system need to be considered in order to answer the question. Details are often important and it is important to consider the generality or specificity of the question being posed to determine the approach used.

# Management modelling example

Fisheries management models typically use a model based on maximum sustainable yield (MSY).




These models have however been shown to be too simple and often based on incorrect data and assumptions.

Canadian stocks of Atlantic Cod collapsed despite careful catch control following the MSY because:

- Estimates of abundance did not take into account density-dependence in catchability and increasing catchability with time,
- Overfishing was disproportionately affecting recruitment.

“Details” matter.

# Regulatory/Administration questions

- These questions are linked to an administrative procedure.
- The purpose of the procedure is to implement a decision regarding management of the system in a standardised manner.
- Typically these are Environmental Impact/Risk Assessments (EIA/ERAs)
- The question posed will be constrained by the administrative framework, it is not a 'free' question.


# Regulatory example – pesticide registration in EU

Here the question is whether a pesticide should be allowed in EU or not. One aspect of this is its impact on non-target organisms.

From an ecological perspective the impact will depend on:

- The scale of use
- The toxicity
- The spatial and temporal pattern of mortality
- The recovery potential of the population measured as population growth rate and dispersal
- Population state when exposed
- Interactions with other stressors

Standard EU evaluation models take the following into account:

- The toxicity
- The proportion of the population expected to be exposed
- A safety factor

Why are the rest not included?
Many reasons, but often practical such as for legal reasons or because it cannot be measured or controlled in the real world.

# Policy Questions

Adjustment of policy and the impacts on ecological systems e.g.

- Evaluating changes in CAP reform
- Biodiversity action plans
- Economic controls
- Development of guidance for regulatory questions.

Here the question is how to adapt policy or the implementation of policy to achieve a specific objective.

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# Policy example

Ecological Indicators 14 (2012) 209–221

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Different policy scenarios to promote various targets of biodiversity

L. Mouysset[a,b,*], L. Doyen[a], F. Jiguet[a]

[a] CNRS, CERSP, UMR 7204 CNRS-MNHN-UPMC, 55 rue Buffon, 75005 Paris Cedex, France
[b] INRA, SADAPT, UMR 1048 INRA-AgroParisTech, 16 rue Claude Bernard, 75005 Paris Cedex, France

Here the question was to consider different policy options (taxation/subsidy) for agricultural land-use for promoting bird community biodiversity .

Used micro-economic model with farmers as agents reacting to subsidy, expected gross margin, uncertainty and current land-use to determine predicted land-use.

Predicted land-use under each scenario was then linked to biodiversity by population-dynamics models.

Some findings:

- Scenarios promoting intensive crops lead to small specialized communities. Promoting extensive grasslands increases the population sizes but decreases community specialization.
- Evaluation of agricultural policies should not rely on a single indicator per taxonomic group.
- Non-linear responses between change in policy measures and impacts on bird communities

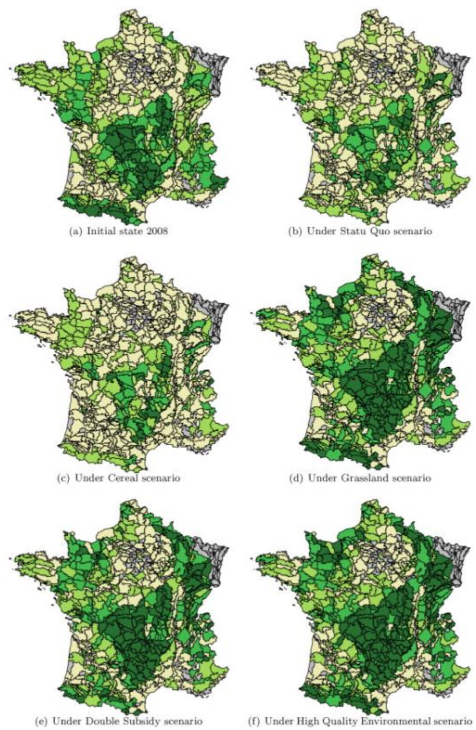
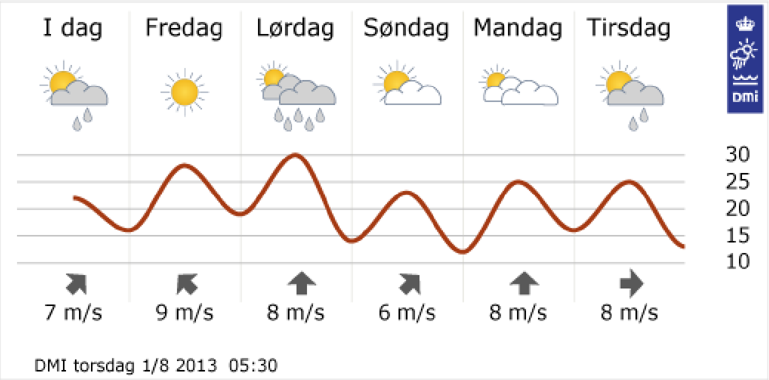



Fig. 5. Proportions of extensive grassland activities at the initial state (2008) and at 2030 under the five scenarios (yellow (resp. yellow–green, green, dark-green) when the ratio is between 0 and 0.1 (resp.0.1 and 0.35, 0.35 and 0.7, 0.7 and 1)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

# Confidence in Models

Ask anyone and they will tell you that a model needs to be 'validated' before it can be trusted – but what does this mean?




Exercise (5mins in pairs if you like):

1. Compose a sentence describing what a predictive model needs to be able to do before you can trust it for management purposes.
2. Think about how you would evaluate if this is achieved?

# 2. Types of models for prediction

## This section covers

- What major types of population models are available
- Properties of different model types
- When to use what model – fitting the model to the question
- Model testing and evaluation

# Modelling/Model definition

**OED definition of modelling**: devise a representation, especially a mathematical one, of (a phenomenon or system): a computer program that can model the behaviour of e.g. smoke

A model is therefore a simplified representation of a process, mechanism or system of these. It can be, but need not be physical, it can be an idea, a diagram, an equation, or a program.

# Model purpose

Our main interest here is prediction, to answer the applied questions from our list. To achieve this we are only interested in knowing:

How well does our model represent the system we are interested in at the level of detail needed for answering our management question?

# Modelling ‘rules’

- Occam’s razor is king – the parsimony rule
- One question - one model
- Complex models lead to poor prediction because uncertainties multiply
- Our goal is to be 95% certain with our predictions

These are all typical modelling rules of thumb

....but how do they stand up to scrutiny in predictive modelling?

We will return to this during the day.

# A model continuum

› Population, individual or agent?

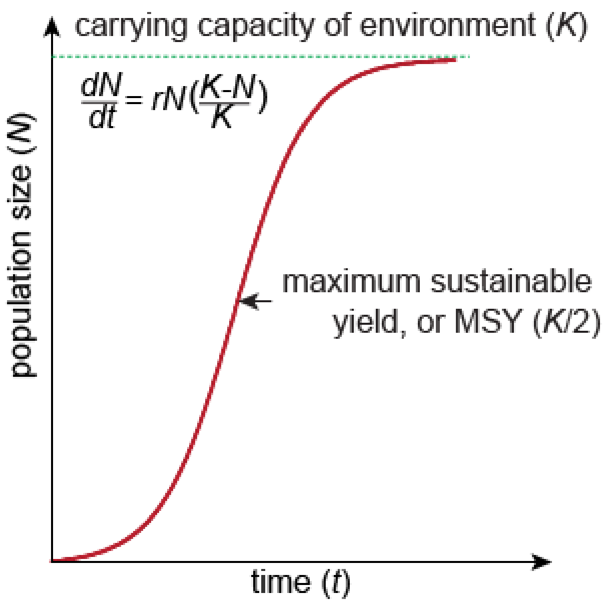
Population

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

Complexity in Space/Time or Both

# Population model

## This is an example basic population model form, the logistic curve from the fish stock example:




What defines these models is the fact that we predict a population size based on intrinsic reproductive and mortality rates.

These can be modified by many factors – here we include density-dependence as a result of the carrying capacity, but other factors can be included up to the limit of mathematical tractability.

There is no space although this can be incorporated to some extent using partial differential equations, but the mathematics becomes rather heavy.

# When to use a population model?

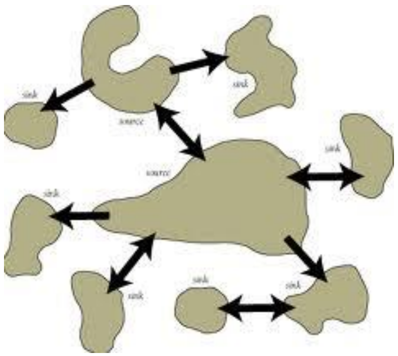
- When it is population size that is the critical output
- When the predictive level required is at a general level (large scale) or when other variables are controlled for (e.g. May's lab cultures).
- When the population size is not thought to be strongly linked to spatio-temporal feedbacks e.g. locally varying resource conditions.
- When the data is not available to construct more detailed/realistic models – unfortunately the typical case.

# A model continuum

› Population, individual or agent?

Population

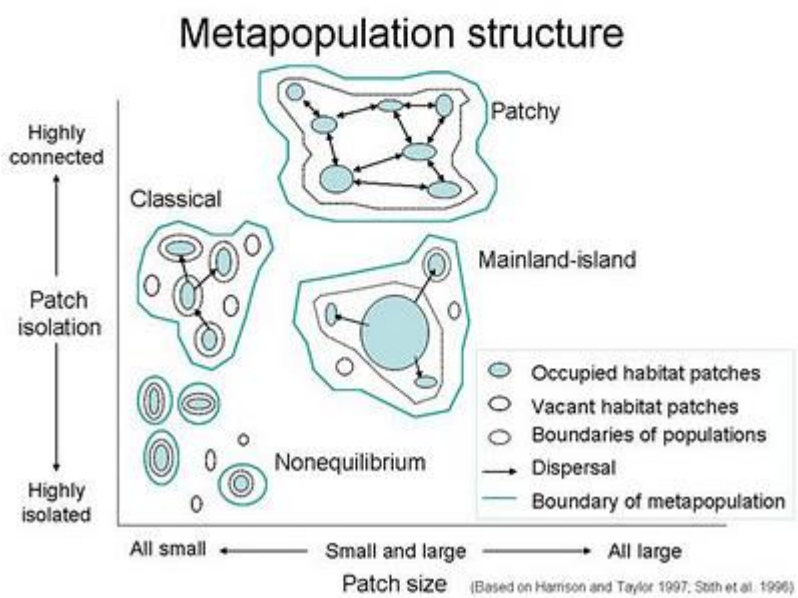
Metapopulation



Complexity in Space/Time or Both

# Metapopulation model

A metapopulation is a population of populations (Levins 1969,1970); in which distinct subpopulations (local populations) occupy spatially separated patches of habitat. The habitat patches exist **within a matrix of unsuitable space**, but organism movement among patches does occur, and interaction among subpopulations maintains the metapopulation.



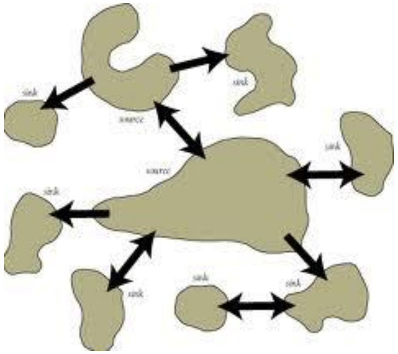

Here we introduce the concept of explicit space. What is important to delimit the metapopulation approach is that it is one of patches.

Within patch dynamics are typically modelled as very simple population processes as previously, but these models can be specified in relatively simple mathematics such as the Levins' model describing the patches occupied:

$\frac{dN}{dt} = cN(1-N) - eN.$ to simulation models where patches and inter-patch distances are realistically modelled.

# When to use a metapopulation model?

- When the population is divided into **distinct** sub-populations which interact by exchanging individuals.
- Habitat in between patches should be unsuitable and is considered matrix.
- When it is possible to estimate the probability of inter-patch exchange
- When individual characteristics do not influence system properties.
- When learning or prediction by individuals does not influence system properties.



# A model continuum

› Population, individual or agent?

Population

Metapopulation

Stage-structured

$$\begin{pmatrix} x_1(t+1) \\ x_2(t+1) \\ x_3(t+1) \\ \vdots \\ x_{10}(t+1) \end{pmatrix} = \begin{pmatrix} R[P(t)] + \frac{s_1(t)}{2} x_1(t) \\ \frac{s_2}{2} x_1(t) + \frac{s_3}{2} x_2(t) \\ \frac{s_4}{2} x_2(t) + \frac{s_5}{2} x_3(t) \\ \vdots \\ \frac{s_{18}}{2} x_9(t) + \frac{s_{19}}{2} x_{10}(t) \end{pmatrix}.$$

Complexity in Space/Time or Both

# Stage-structured population model

## Here we are interested the growth of a population that is composed of multiple, discrete stages or age classes.

$$\begin{pmatrix} x_1(t+1) \\ x_2(t+1) \\ x_3(t+1) \\ \vdots \\ x_{10}(t+1) \end{pmatrix} = \begin{pmatrix} R[P(t)] + \frac{s_1(t)}{2} x_1(t) \\ \frac{s_2}{2} x_1(t) + \frac{s_3}{2} x_2(t) \\ \frac{s_4}{2} x_2(t) + \frac{s_5}{2} x_3(t) \\ \vdots \\ \frac{s_{18}}{2} x_9(t) + \frac{s_{19}}{2} x_{10}(t) \end{pmatrix}.$$

Here again we do not explicitly handle space, but treat different life-stages or age-classes in the population differently.

Survival and reproduction is specified for each stage and typically matrix mathematics is used to describe the model.

Like the population model this approach is a projection approach – it takes a fixed set of rules and applies them iteratively to produce a population trajectory from a given point. These models can be made relatively complex, but mathematics of inclusion of space gets very difficult.

# When to use a stage-structured population model?

Basically the same set of requirements as for a population model, generality, lack of spatio-temporal feedback, individual characteristics don't matter and often data limitations…..

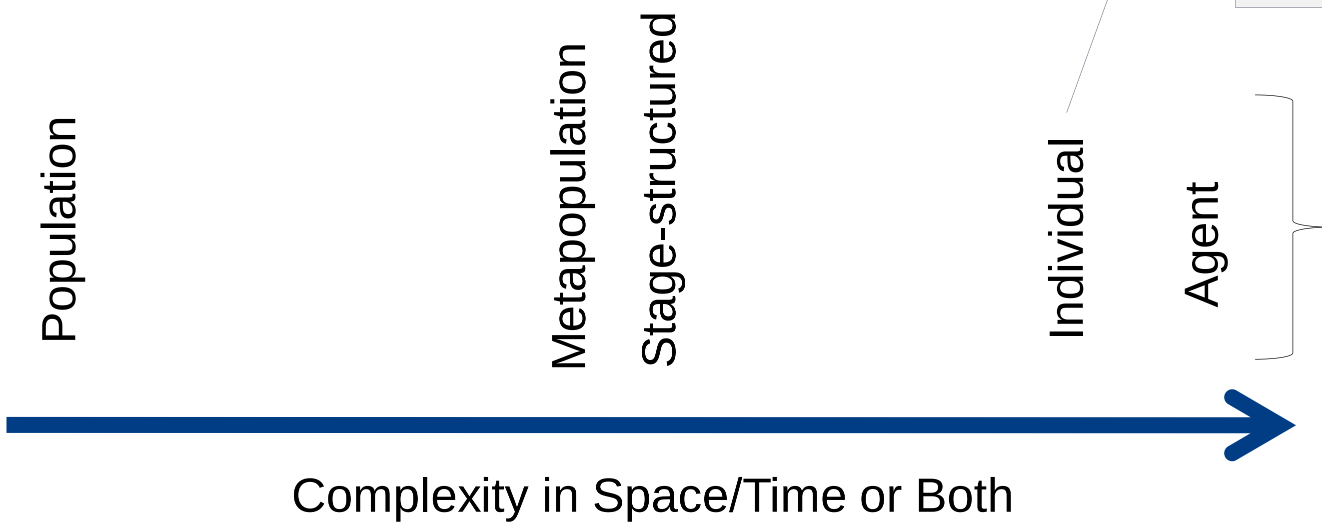
……but these should be used when there is information about differential survival and reproduction of different stages/age classes.

These are very commonly applied e.g. in harvesting models.

# A model continuum

› Population, individual or agent?

More less historical interest now: i-state distribution models, were extensions of the stage-structured model




Agent and individual-based model basically synonyms

# Agents defined

Agent-based models (ABMs) are a class of computational models for simulating the actions and interactions of autonomous agents (individuals or groups) with a view to assessing their effects on the system as a whole

What is important about agent-based models is that the agents (animals, people) obtain their information in the same way as they would in the real world, then act on it to make decisions to further their own agenda

ABMs produce emergent and dynamic structures, responsive to changes in inputs, and with considerable predictive power

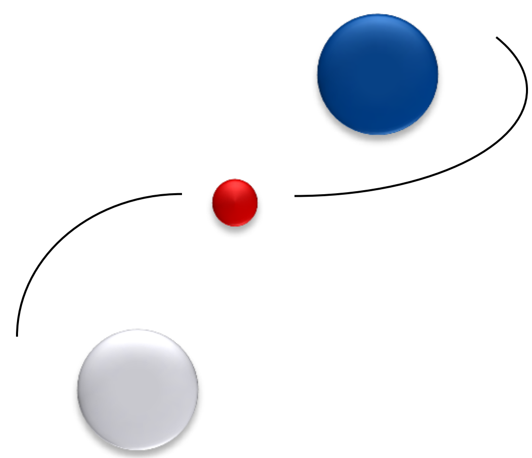
ABMs have three key characteristics that set them apart from the other models:

1. Integration of spatio-temporal factors is natural
2. They can cope with non-linearity and local feedbacks
3. Prediction is possible beyond the scope of the data used to create them.

# ABM's three key characteristics

1. Integration of spatio-temporal factors is natural
2. They can cope with non-linearity and local feedbacks
3. Prediction is possible beyond the scope of the data used to create them.

Integration is natural, and requires only the specification of local interactions e.g. the three-body problem in physics.



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### Original Euler problem

[edit]

In the original Euler problem, the two centers of force acting on the particle are assumed to be fixed in space; let these centers be located along the *x*-axis at $\pm a$. The particle is likewise assumed to be confined to a fixed plane containing the two centers of force. The potential energy of the particle in the field of these centers is given by

$$V(x,y) = \frac{-\mu_1}{\sqrt{(x-a)^2+y^2}} - \frac{\mu_2}{\sqrt{(x+a)^2+y^2}}.$$

where the proportionality constants $\mu_1$ and $\mu_2$ may be positive or negative. The two centers of attraction can be considered as the foci of a set of ellipses. If either center were absent, the particle would move on one of these ellipses, as a solution of the Kepler problem. Therefore, according to Bonnet's theorem, the same ellipses are the solutions for the Euler problem.

Introducing elliptic coordinates,

$$x = a\cosh\xi\cos\eta,$$
$$y = a\sinh\xi\sin\eta,$$

the potential energy can be written as

$$V(\xi,\eta) = \frac{-\mu_1}{a(\cosh\xi-\cos\eta)} - \frac{\mu_2}{a(\cosh\xi+\cos\eta)} = \frac{-\mu_1(\cosh\xi+\cos\eta)-\mu_2(\cosh\xi-\cos\eta)}{a\left(\cosh^2\xi-\cos^2\eta\right)},$$

and the kinetic energy as

$$T = \frac{ma^2}{2}\left(\cosh^2\xi-\cos^2\eta\right)\left(\dot{\xi}^2+\dot{\eta}^2\right).$$

This is a Liouville dynamical system if $\xi$ and $\eta$ are taken as $\varphi_1$ and $\varphi_2$, respectively; thus, the function *Y* equals

$$Y = \cosh^2\xi - \cos^2\eta$$

and the function *W* equals

$$W = -\mu_1(\cosh\xi+\cos\eta) - \mu_2(\cosh\xi-\cos\eta).$$

Using the general solution for a Liouville dynamical system,[16] one obtains

$$\frac{ma^2}{2}\left(\cosh^2\xi-\cos^2\eta\right)^2\dot{\xi}^2 = E\cosh^2\xi + \left(\frac{\mu_1+\mu_2}{a}\right)\cosh\xi - \gamma$$
$$\frac{ma^2}{2}\left(\cosh^2\xi-\cos^2\eta\right)^2\dot{\eta}^2 = -E\cos^2\eta + \left(\frac{\mu_1-\mu_2}{a}\right)\cos\eta + \gamma$$

Introducing a parameter *u* by the formula

$$du = \frac{d\xi}{\sqrt{E\cosh^2\xi+\left(\frac{\mu_1+\mu_2}{a}\right)\cosh\xi-\gamma}} = \frac{d\eta}{\sqrt{-E\cos^2\eta+\left(\frac{\mu_1-\mu_2}{a}\right)\cos\eta+\gamma}},$$

gives the parametric solution

$$u = \int\frac{d\xi}{\sqrt{E\cosh^2\xi+\left(\frac{\mu_1+\mu_2}{a}\right)\cosh\xi-\gamma}} = \int\frac{d\eta}{\sqrt{-E\cos^2\eta+\left(\frac{\mu_1-\mu_2}{a}\right)\cos\eta+\gamma}}.$$

Since these are elliptic integrals, the coordinates $\xi$ and $\eta$ can be expressed as elliptic functions of *u*.

In physics and astronomy, Euler's three-body problem is to solve for the motion of a particle that is acted upon by the gravitational field of two other point masses that are either fixed in space or move in circular coplanar orbits about their center of mass. This problem is significant as an exactly soluble special case of the three-body problem.

## But simulation is <u>easy</u>!

# ABM’s three key characteristics

1. Integration of spatio-temporal factors is natural
2. They can cope with non-linearity and local feedbacks
3. Prediction is possible beyond the scope of the data used to create them.

Models are better than us at integrating factors and the results are often non-linear.

This is one of the simplest ABMs around, yet the resulting behaviour is complex.

http://cmol.nbi.dk/models/boids/boids.html

http://www.flickr.com/photos/mattie_shoes/3106170621

# Real birds - starling flocks

# ABM's three key characteristics

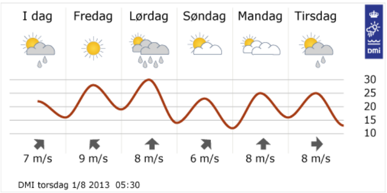
1. Integration of spatio-temporal factors is natural
2. They can cope with non-linearity and local feedbacks
3. Prediction is possible beyond the scope of the data used to create them.

ABMs are created from mechanisms and interactions. If these are specified correctly then new combinations of situations that have not been seen before can be modelled and prediction of system behaviour made. This is what we need for prediction in many situations.

# When to use ABMs?

There are three basic reasons to go to ABMs:

1. If local interactions in space and time are important
2. If differences between individuals matter and can affect system properties
3. If organisms exhibit adaptive behaviour – feedbacks




# Confidence in Models

Ask anyone and they will tell you that a model needs to be ‘validated’ before it can be trusted – but what does this mean?

| | System predictions are field tested | 95% correct predictions | Scientific support for assumptions or mechanisms | Multiple real world pattern tests | Expert Opinion |
|---|---|---|---|---|---|
| Number | | | | | |

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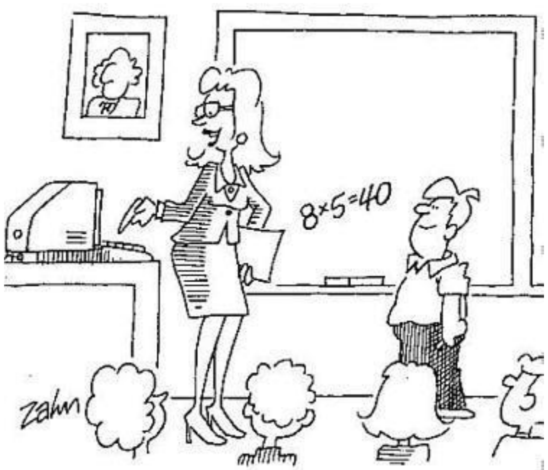
# Validation/Calibration/Testing – some issues to be aware of

- Prediction is difficult to test until after the fact!
- Calibration to a particular data set usually includes calibrating to fit a wide range of invisible factors – these unknowns may have considerable impacts when the model is used.
- Confidence in models is more often a group acceptance than a 'strong' test.
- Validation is a weighted term, it implies a tick mark
  – but a tick mark under what circumstances?




"I think that's right, but let me check."

# 3. Agent-based modelling examples

## This section covers

- ALMaSS and the skylark model – our example
- Simple vs complex model
- Prediction and systems understanding
- Feedbacks in space and time

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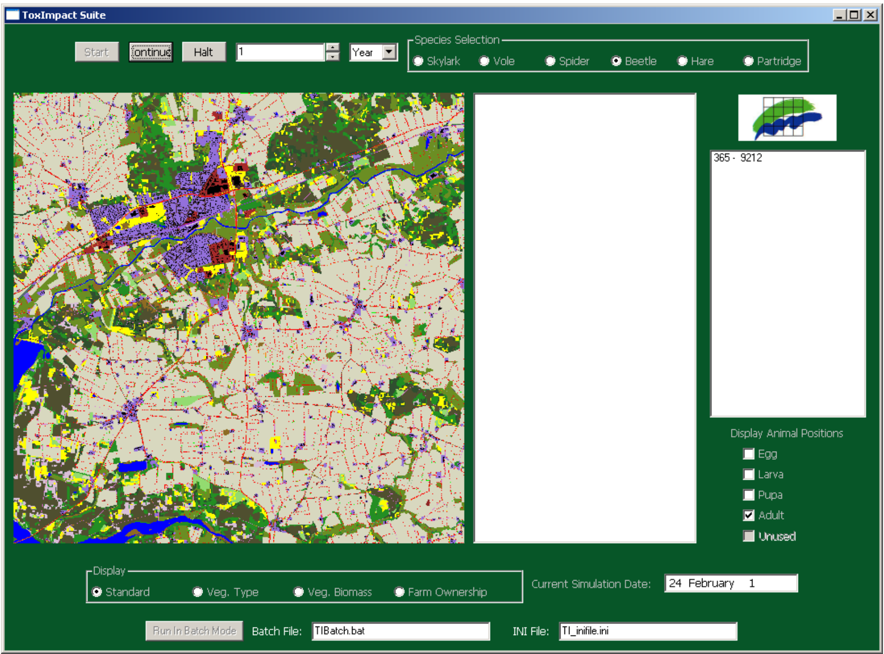
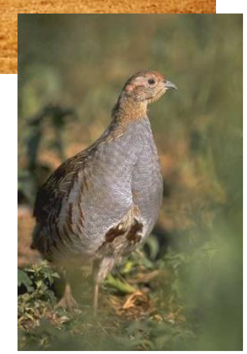
# ALMaSS – Animal, Landscape and Man Simulation System



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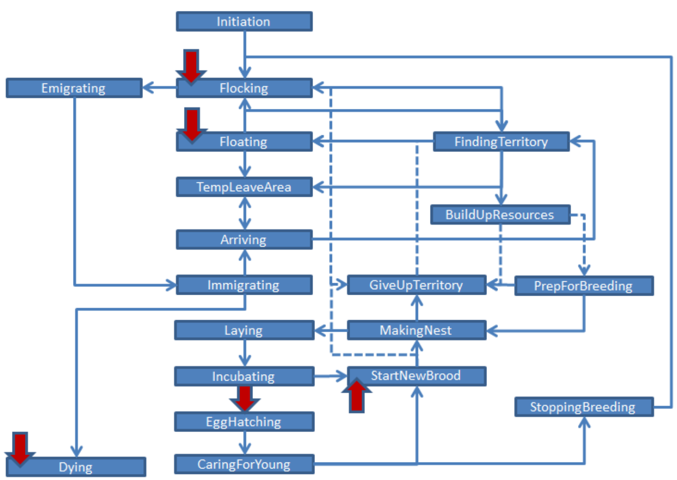
# The ALMaSS skylark model

The skylark model follows each individual skylark in the landscape, simulating dispersal, territoriality, foraging, energetics, growth, reproduction and mortality on a daily basis.




## Find territory

(landscape features, other skylarks, and history)

## Site nest

(vegetation characteristics)

## Lay & incubate eggs

(weather conditions – energetics)

## Feed & brood chicks

(weather conditions, food availability)

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# The skylark model & testing

Testing and developing the model used Pattern Oriented Modelling (POM).

POM is an inverse modelling procedure where the model is manipulated until it fits the real world patterns.

However, multiple patterns must be fitted by the same model – these can/should be at different hierarchical levels, and MUST be emergent properties of the model.

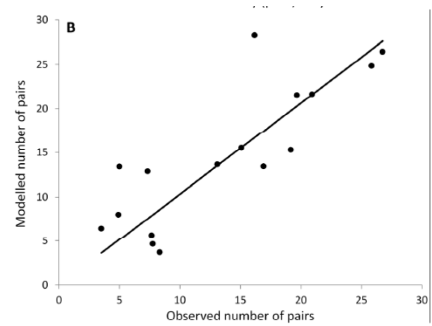
OPEN ACCESS Freely available online PLOS ONE

**Modelling Skylarks (*Alauda arvensis*) to Predict Impacts of Changes in Land Management and Policy: Development and Testing of an Agent-Based Model**

Christopher J. Topping*, Peter Odderskær¤, Johnny Kahlert

Department of Bioscience, University of Aarhus, Rønde, Denmark

Model testing against 4 completely different independent data sets looking at pair density, location, nest and egg fate, and seasonal changes in density – some data and fits from the study:.



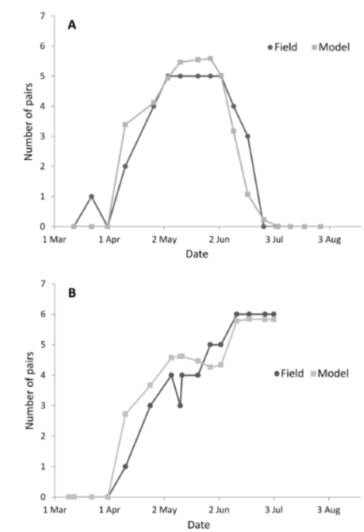
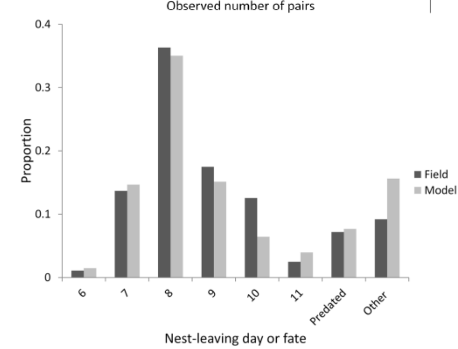




**Figure 5. Comparison of the seasonal distribution of the number of territorial pairs observed in the Kalø study area on fields without (A) and with (B) scrapes, and those predicted by the ALMaSS skylark model.**



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# Discussion question – black box

## Simple Model

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

## ALMaSS Skylark

Skylark_Female | st_StoppingBreeding()

```
    if ( m_toowet > 2 )
    {
      //m_OurPopulationManager->WriteToTest2File( m_OurLandscape->SupplyDayInYear(), 1003 );
      return 3; //TransferToState(StartNewBrood);
    } else
    {
      if ( foodtime > Daylength ) foodtime = Daylength;
      m_NestTime = ( 24 * 60 - foodtime ); //add night time
      return 0; // wait
    }
  }
  //m_OurPopulationManager->WriteToTest2File( m_OurLandscape->SupplyDayInYear(), 1002 );
  return 3; // TransferToState(StartNewBrood);
}
//----------------------------------------------------------------------------

int Skylark_Female::st_EggHatching() {
/**
*  A transition is made to Care for Young.<br>
*/
#ifdef __CJTDebug_5
  if ( IsAlive() != 0x0DEADC0DE ) DEADCODEError();
#endif
  m_toowet = 0;
  return 1; // TransferToState(CareForYoung)
}



//----------------------------------------------------------------------------

int Skylark_Female::st_StoppingBreeding() {
/**
* Called when the female stops breeding for the year. Removes the pair bond and tell the male she is leaving.
* She deregisters her territory ownership and if there has been no breeding success then she forgets the male.
*/
#ifdef __CJTDebug_5
  if ( IsAlive() != 0x0DEADC0DE ) DEADCODEError();
#endif
  if ( MyClutch ) {
    MyClutch->OnMumGone();
    MyClutch = NULL;
#ifdef __SKPOM
    m_OurPopulationManager->WriteSKPOM1( m_OurLandscape->SupplyDayInYear(), 1010 );
```

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Ecotoxicology, 14, 925–936, 2005

DOI: 10.1007/s10646-005-0027-3

# Simple vs complex

ALMaSS compared to a simple population model for evaluating a pesticide impact on skylarks in winter wheat

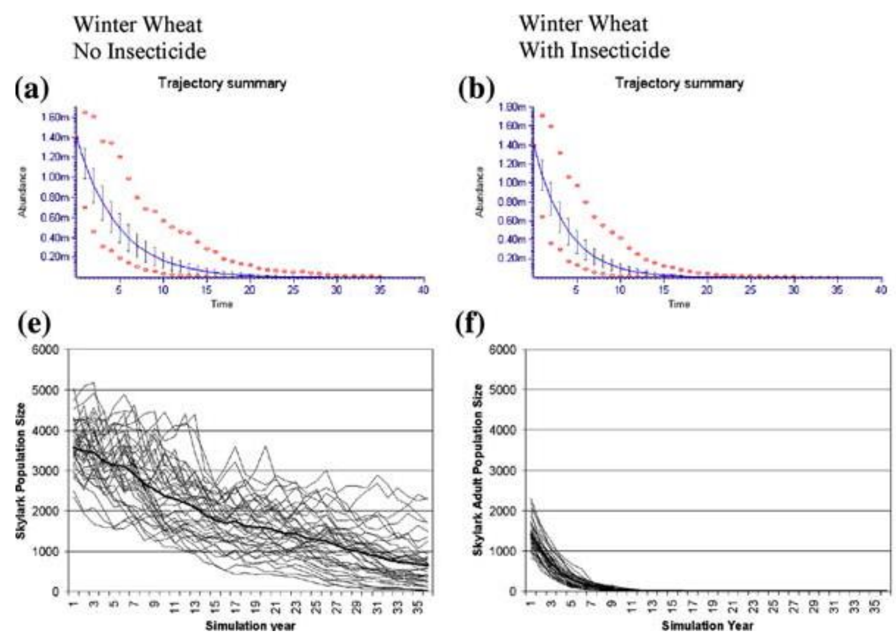
Results the more or less the same – modelling more or less the same thing.

But the simple model took longer to employ because the manual process of integrating to get fecundity and mortality was difficult!

In ALMaSS integrating space, time and management happens naturally so its faster once the model is developed.

**Risk Assessment of UK Skylark Populations Using Life-History and Individual-Based Landscape Models**

C. J. TOPPING,[1,5,*] R. M. SIBLY,[2] H. R. AKÇAKAYA,[3] G. C. SMITH[4] AND D. R. CROCKER[4]
[1]*EcoSol, Fårupvej 54, DK-8410, Rønde, Denmark*
[2]*University of Reading, Reading, Whiteknights, UK*
[3]*Applied Biomathematics, Setauket, New York, USA*
[4]*Central Science Laboratory, York, Sand Hutton, UK*
[5]*NERI, Rønde, Denmark*



# Simple vs complex

*Table 5.* A comparison of model properties between the implementations of the life-history and individual-based landscape models used here

| Property | Life-history model | IBLM |
|---|---|---|
| Ease and speed of construction | Easy and fast (days) | Slow (months or years) requiring specific expertise |
| Simulation run times | Short (seconds) | Long (hours) |
| Analytical tractability | High | Low |
| Specificity and testability of predictions | Low | High |
| Data requirements | Low* | High |
| Explicit modelling of space/landscape/ habitat distribution/weather/pesticide application and fate | No | Yes |
| Method for incorporation and testing of management factors | By inference | Direct mechanistic representation |
| Time-steps | Annual | Daily |

This table show the large differences in approach but also that neither one model or the other is 'better' at all things

# Prediction requires system understanding

- If we have a question and are going to model we need to know what we should model.
- Population, biodiversity, impact – all loose terms unless explicitly defined.
- Physical extent, time frames and accuracy needed for the question in hand.
- What are the main drivers and system behaviours?

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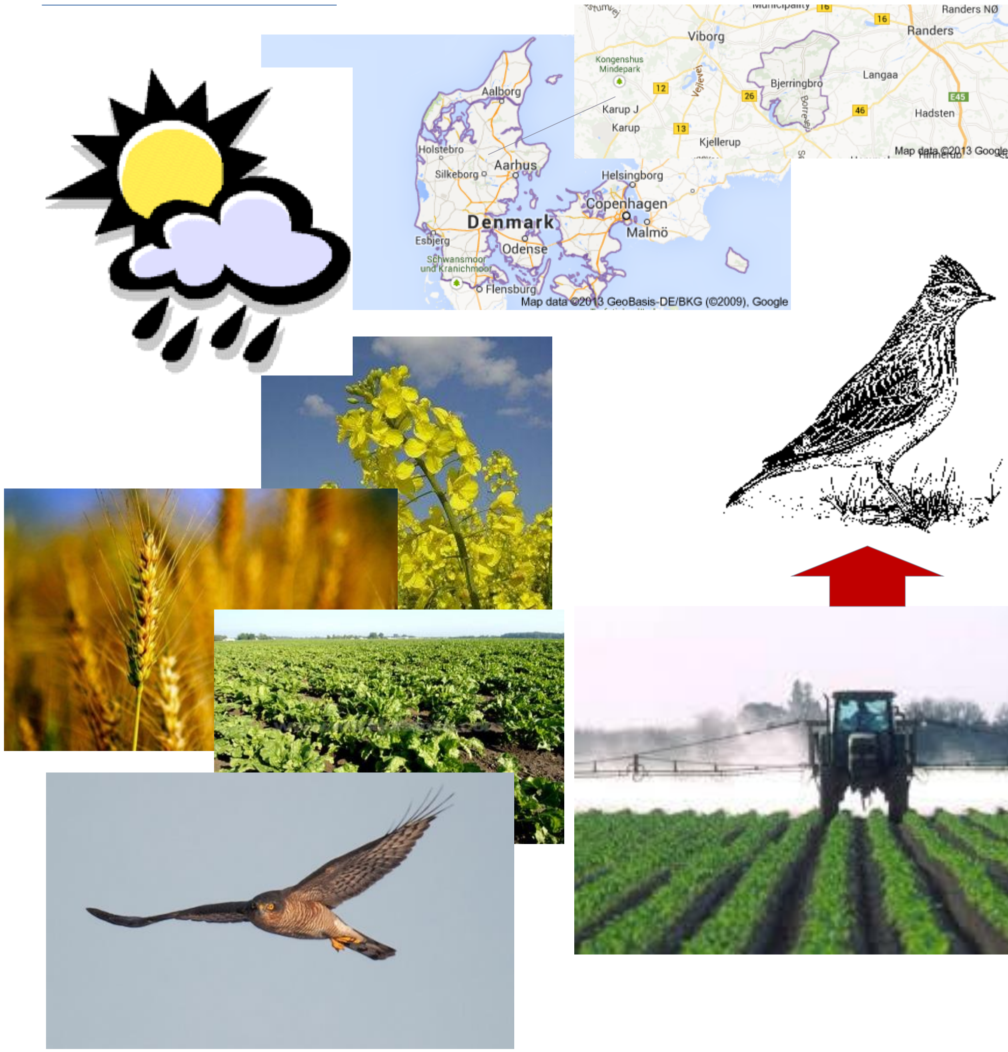
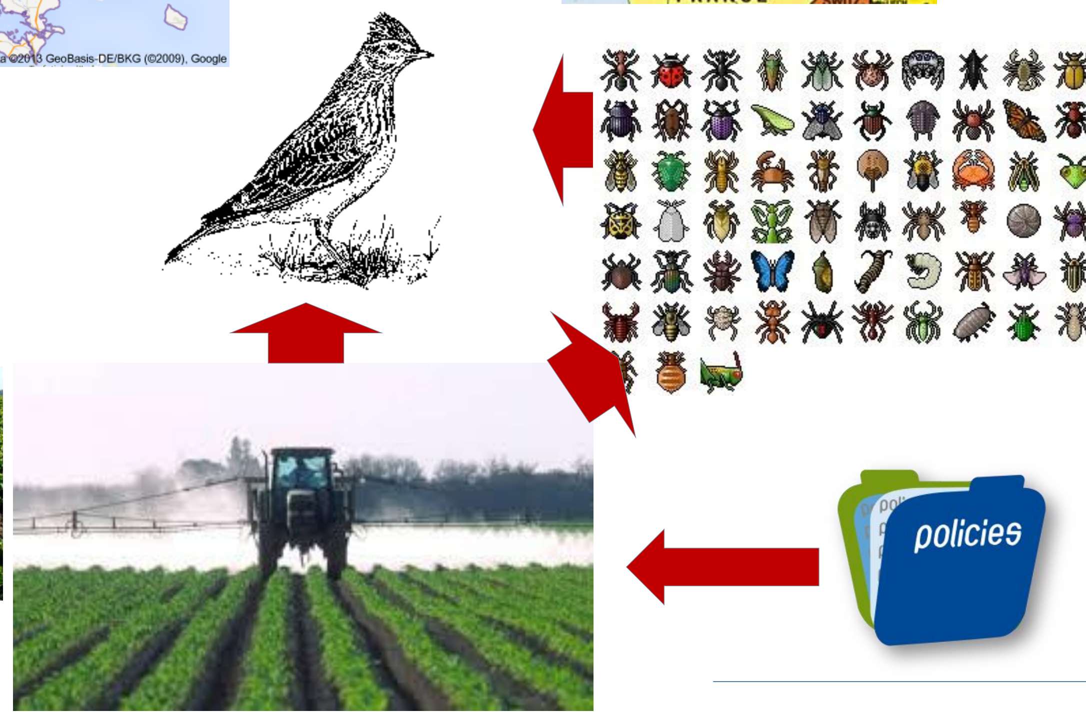
# Modelling skylarks







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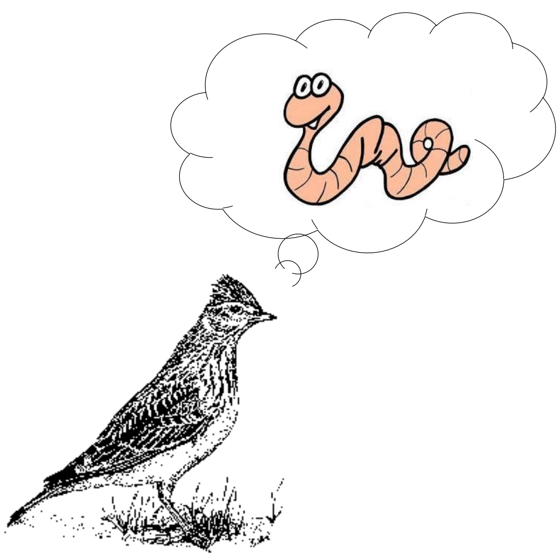
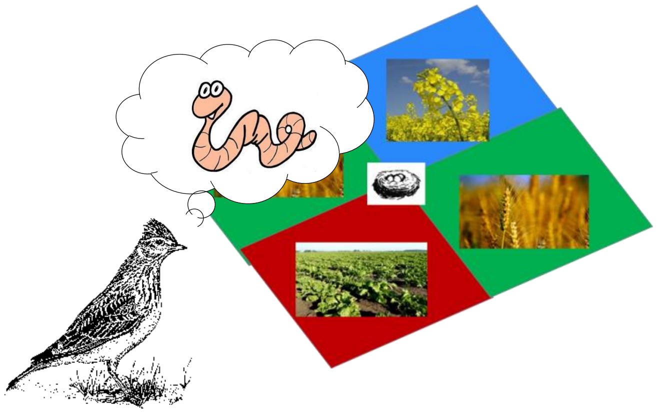
# Feedbacks in space and time

A skylark with a choice of four fields to forage from. How do we determine how much pesticide the bird picks up from its food?



# Feedbacks in space and time

The obvious choice is assuming the rate ingestion is 25% per field and using the rates of pesticide concentration per field:
e.g. 50% WW at 0.2
25% Potatoes at 0.4
25% OSR at 0.1 giving (0.1+0.4+0.2+0.2) = 0.9



But the rate of ingestion of pesticide will depend not only on the pesticide concentration but on the density of prey.
It also depends on accessibility of the prey, which Is primarily a function of height and density of vegetation.

This will alter the time spent in each field, and in fact the birds will not use OSR, and will avoid WW when it is tall – so the equation for some parts of the year will be based entirely on potatoes:
4 x 0.4 = 1.6 nearly double!

# Indirect impacts of pesticides and taxation on skylarks

Indirect effects of pesticides on skylarks was in the region of about 5% in some intermediate weather years.

But not spraying in the real world may mean no tramlines being opened – this results in a negative impact of about 5% too.

Taxation measures to reduce pesticides also have other effects as farmers choose different crops – the result can be much serious than +/- pesticides.

SETAC PRESS

Environmental Toxicology and Chemistry, Vol. 23, No. 2, pp. 509–520, 2004
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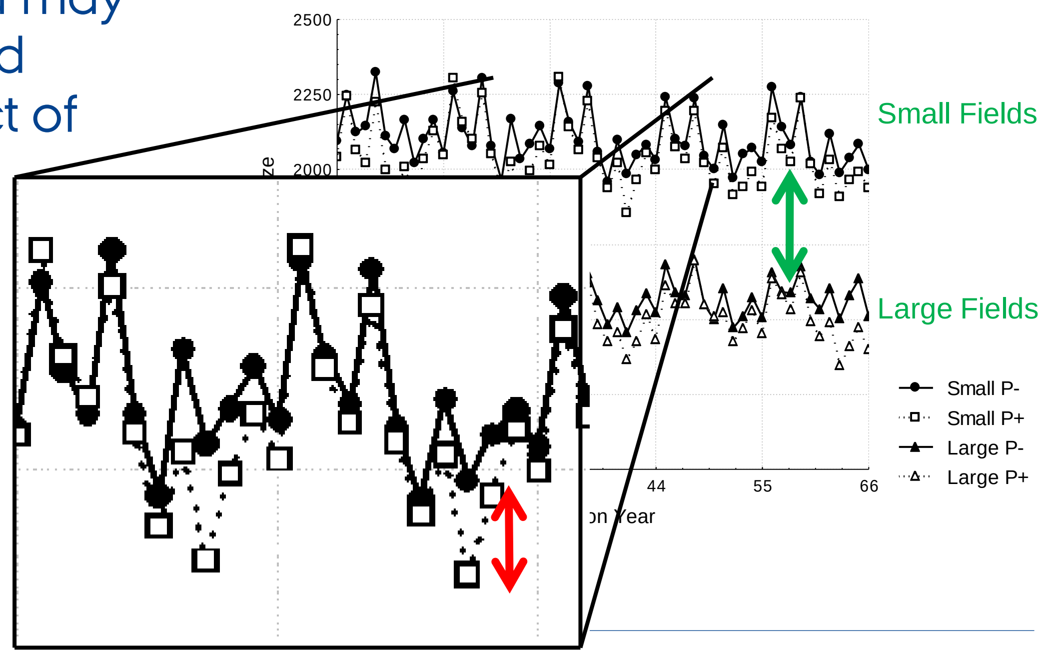
MODELING THE INFLUENCE OF TEMPORAL AND SPATIAL FACTORS ON THE ASSESSMENT OF IMPACTS OF PESTICIDES ON SKYLARKS

CHRISTOPHER JOHN TOPPING* and PETER ODDERSKÆR
Department of Landscape Ecology, National Environmental Research Institute, Grenåvej 14, DK-8410 Rønde, Denmark



# Thought experiment

Climate scenario – what happens to breeding skylarks if there were to be an increase in temperature of + 2˚C per day?

| Population Size | No. Agree | Reasoning |
|---|---|---|
| Bigger | | |
| Smaller | | |

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# Climate scenario

- 1990-1999 daily temperatures + 2˚C

Expected impact on skylark populations:

- Earlier (longer) breeding season
- Higher insect abundance
- Anticipated result: More skylarks

- Model result: 13% reduction in skylark populations

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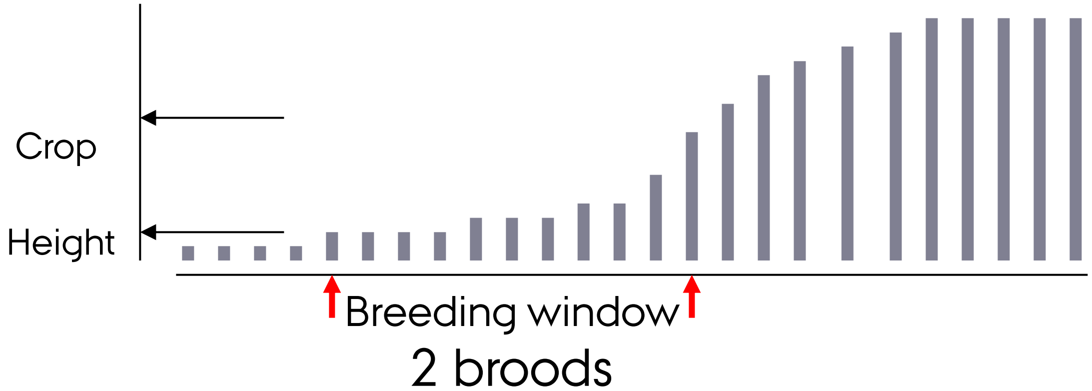
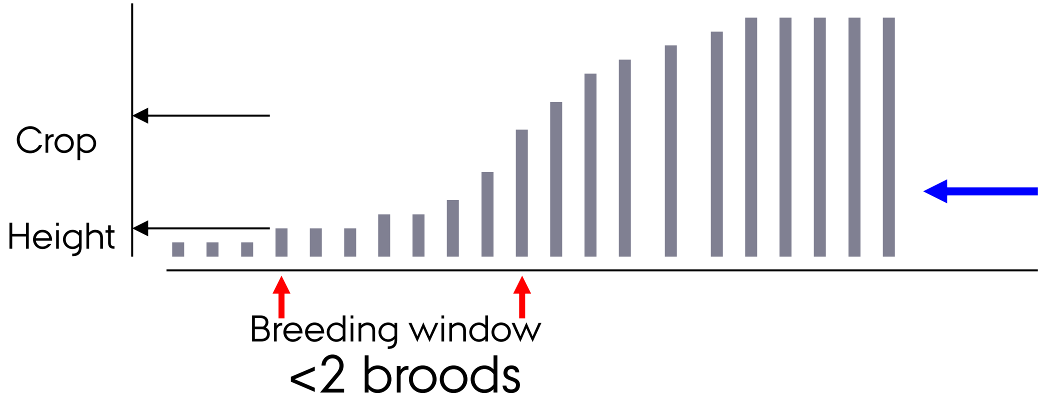
# Why the decrease?




Temperature alters crop growth and shortens the breeding window



# 4. Complex systems

This section covers

- Delimiting the system of interest and complex systems
- Emergent dynamics
- Implications of complexity approaches for modelling
- Including people
- Coupled socio-ecological systems (SES)
- Current state of applied complex system models and SES

# Delimitation of the system is not trivial – they are part of a complex adaptive system

- Complex adaptive systems (CAS) are complex in that they are diverse and made up of multiple interconnected elements and adaptive in that they have the capacity to change and learn from experience.

- Important concepts here are:
  - Complex systems are infinite
  - Feedbacks and multi-level linkages
  - Feedbacks in space and time
  - Emergent system dynamics – tipping points, cascades

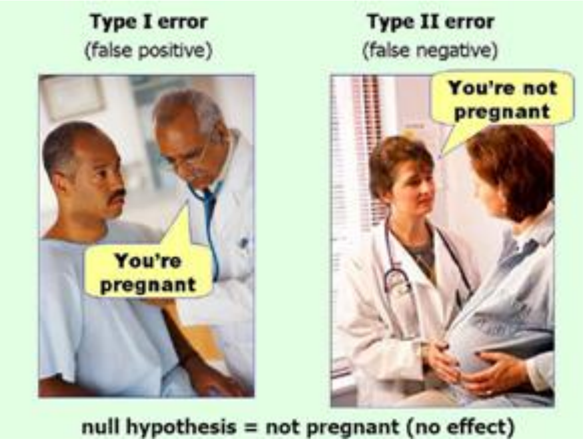
- Accepting that we are dealing with CASs has some profound impacts on the way we think about modelling and prediction.

# Complexity approaches – what this means for modelling

- We want to be right more times than we are wrong.
- Because we want to guard against the unexpected
- Complexity theory – linking systems from biochemistry to human behaviour
- Change focus from elegant parsimony based and precise but inaccurate predictions to big ugly messy models

# Capturing the possible

- Typically the ecologists response to complexity is to simplify and generalise – but this leads us typically to a Type I error avoidance strategy – avoid saying something is true when it is not.




- For prediction in an uncertain world we are probably more interested in the possible not just the probable – ie to warn against the possibility of adverse consequences.

- The consequences of Type II errors may be much more serious than those of a Type I error.

- This is in direct conflict with the traditional natural scientist approach to modelling – which is aimed at the analytical questions, not at being predictive.

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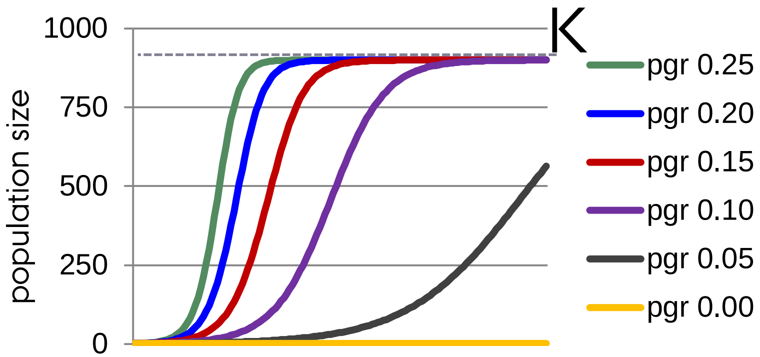
# Emergent system dynamics – tipping points

- Tipping points – the point at which further stress pushes a system into a new, difficult to return from state.

Desertification is the typically cited example. Overgrazing and arid conditions can turn grassland to desert, reversing the procedure is very difficult.

Tipping points are a result of negative feedback loops providing resilience..




In a population growth context as stressors are added (mortality) pgr decreases, but the final population after some time is the same (at K). When pgr <0 there is no growth and the population becomes extinct.

# Emergent system dynamics - cascades

Example – The Indian Vulture crisis, slow breeding long-lived species.

1990 ca 30,000,000 vultures in India & Pakistan but by 2008 the species was functionally extinct.

Cause – dichlofenac used as a painkiller for Hindu sacred cattle. This causes kidney damage in the vultures that feed off dead cattle that are not buried for religious reasons.

Serious knock on ecosystem effects:

- Ground water contamination
- Rabies outbreaks
- Increase in leopard attacks on children
- Serious human disease problems
- Problems with disposal of human remains in Zoroastrian Parsi cultures

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# Including people

## Coupled socio-ecological systems SES

Ecosystems (2004) 7: 161–171
DOI: 10.1007/s10021-003-0215-z

ECOSYSTEMS



**Integrating Social Science into the Long-Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change**

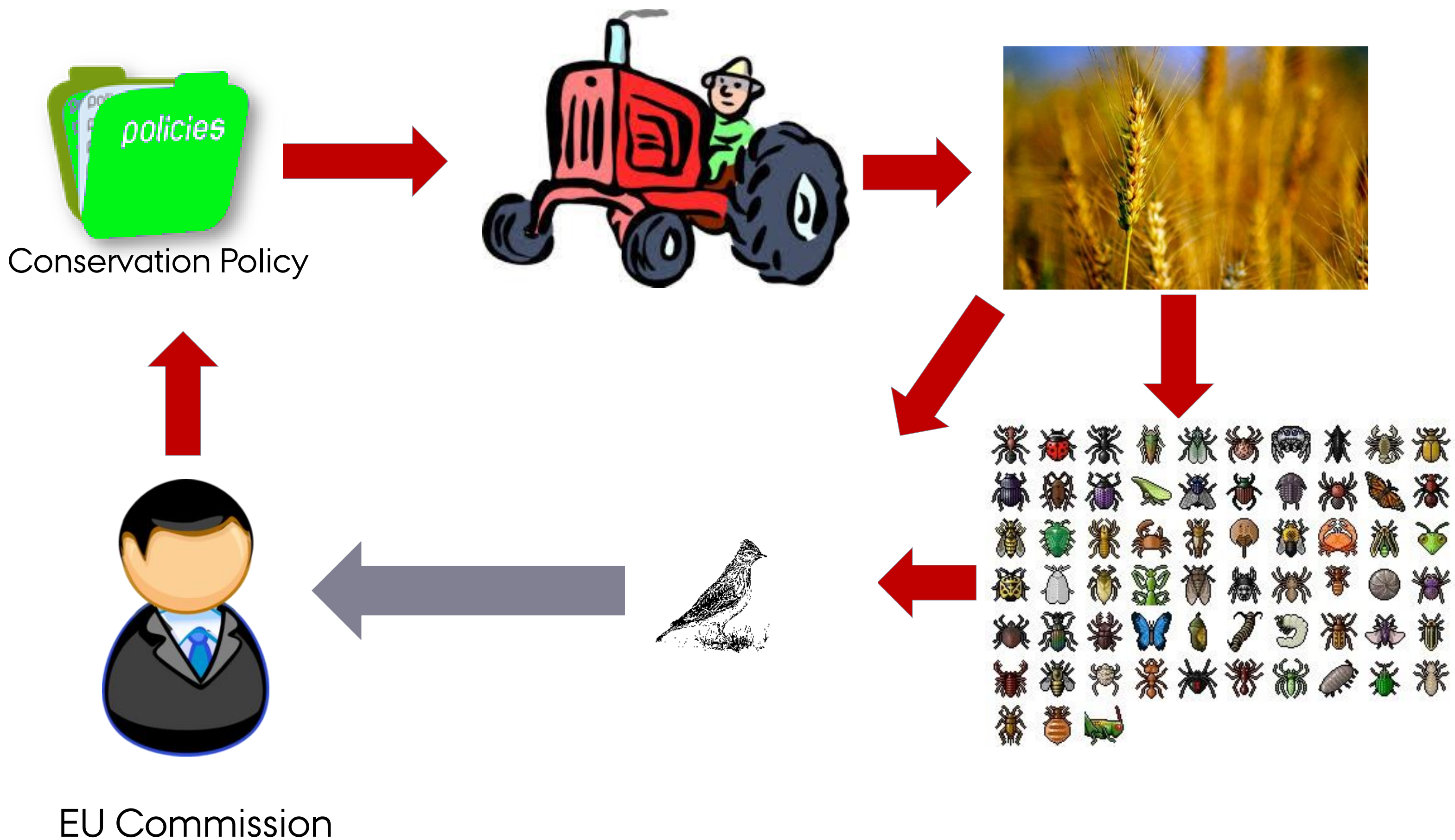
Charles L. Redman,[1*] J. Morgan Grove,[2] and Lauren H. Kuby[1]

Taking the skylark example we can add new models altering farmer behaviour e.g. in response to policy changes
-> SES

## Definitions:

1. a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner;
2. a system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked;
3. a set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and
4. a perpetually dynamic, complex system with continuous adaptation

# Feedbacks and multi-level linkage



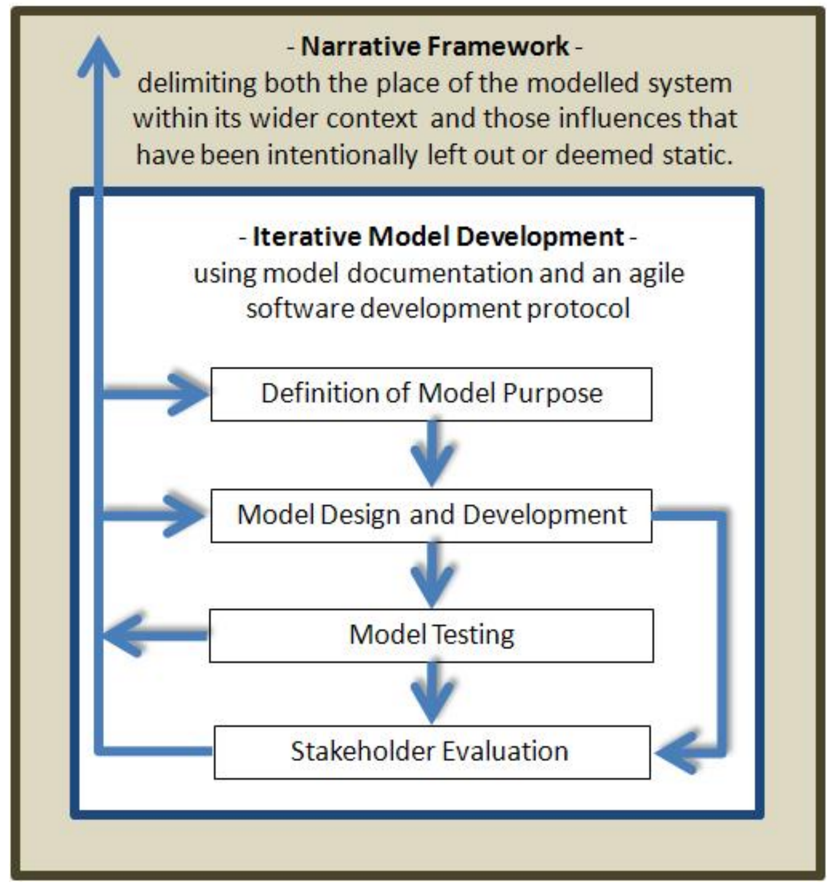
# Techniques for SES

- ABMs and SES – Agents allow the expression of SES dynamics
- Limits to the approach – if we can understand we can replicate – if not !
- Needs data (what)
- Needs heuristics (why)
- Needs well defined processes and mechanisms for interactions (how)

# Thinking about modelling differently

We need to develop models in a new way to cope with the complex system properties and our limited knowledge.

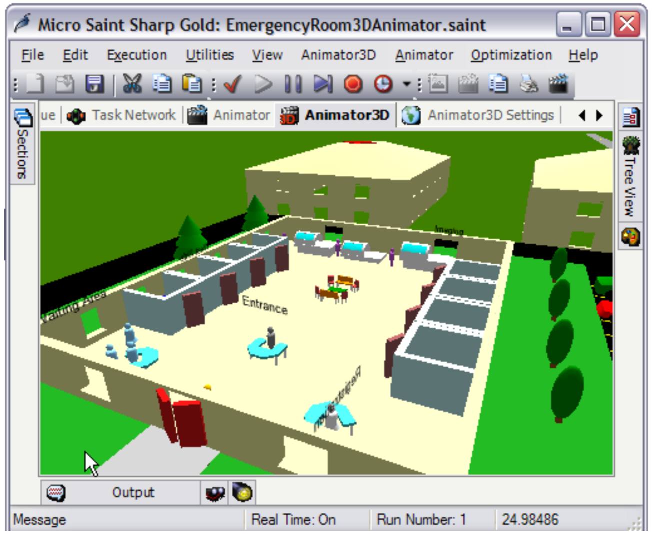
My personal view of how this can be done is to combine traditional approaches from social and natural sciences for developing different parts of the model.



# Current state and future for complex systems models

- Most models being developed are relatively simple

- The result is often the "here we present a simplified system to aid understanding" – but this defeats the object of complex modelling.



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# Simple complex models – why?

**It is not easy to do!**

Many systems developed by scientists are developed in unsuitable software environments

Learning from the professionals here is just:

Similarly, software engi
when software engine

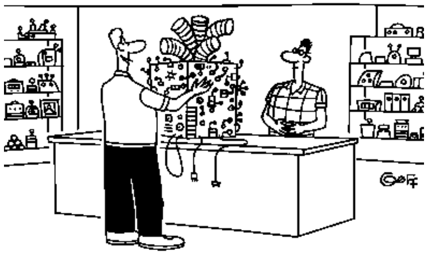
ne scientist modeller – why
!


# Simple complex models – why?

- We still suffer from many misunderstandings (eg mixing analytical and predictive methods), and territorial disputes – simulation is frightening to many ecologists and mathematical modellers.

- Scale of the task – it is hard to get resources for developing these systems e.g. ALMaSS has been under development since 1998.

- Trust – lack of confidence coupled with the above are a poisonous mixture. Not helped by the technical issues mentioned on the last slide.



"Trust me. You don't want that little inexpensive easy-to-use gadget. What you want is this."

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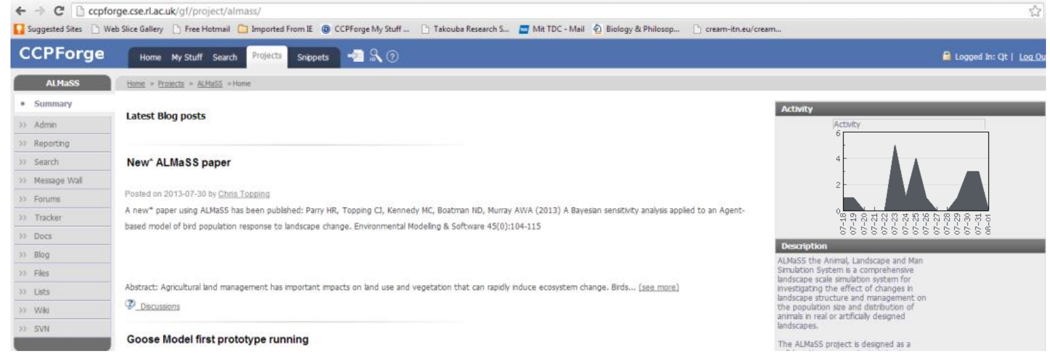
# The future




- Resource problems may be helped by open source and open science projects may provide a focus for long-term system developments e.g. CCPForge projects.
- Software and hardware have improved to the point that we can deal with many of the technical challenges (e.g. 30M beetles in ALMaSS).
- With time training should be more accessible for students leading to a training in computational modelling.
- The future is probably a world where simulation modelling has a much greater role in data frameworks and prediction – forming a linking methodology for multi-disciplinary research projects - this is already happening in other fields:

# 5. Modelling question and discussion

This section covers:

- Determinants of an ecological model
- Discussion – modelling ‘rules’

# How to choose the right model?

Determinants of the choice of model depend on a number of factors – some scientifically justifiable, others not!

- First we have the question – this will indicate the range of model types to consider.
- Next we have the system.
- Finally we have a range of constraints.

# Identifying system drivers and emergent properties

| Driver | Mechanisms | Emergent properties |
|---|---|---|
| Weather | Temperature influence on energetics | Skylark density |
| Farm Management* | Pesticide impact on arthropod food | Skylark reproduction |
| Landscape structure** | Direct pesticide toxicity | Skylark mortality |
| | Availability of nesting habitat | Chick growth rates |
| | Availability of suitable territories | |
| | Stressor dynamics in space and time** | |

* Is this a driver or an emergent property? That depends on the definition of the system to be modelled
** Indicates a spatial model is needed

# Determinants of an ecological model

Deciding what model will be used should be a matter of fitting the model to question but in reality there are many other model determinants.

- Knowledge constraints – what do we know, what can we put into the model - much may be 'known', but not everything is supportable by evidence
- Technical constraints – what is possible to achieve
- Logistical constraints – how long will it take, what resources are needed
- Personal constraints:
  - what do we prefer to do, know about?
  - how far do our technical skills reach?
  - what do my peers do?

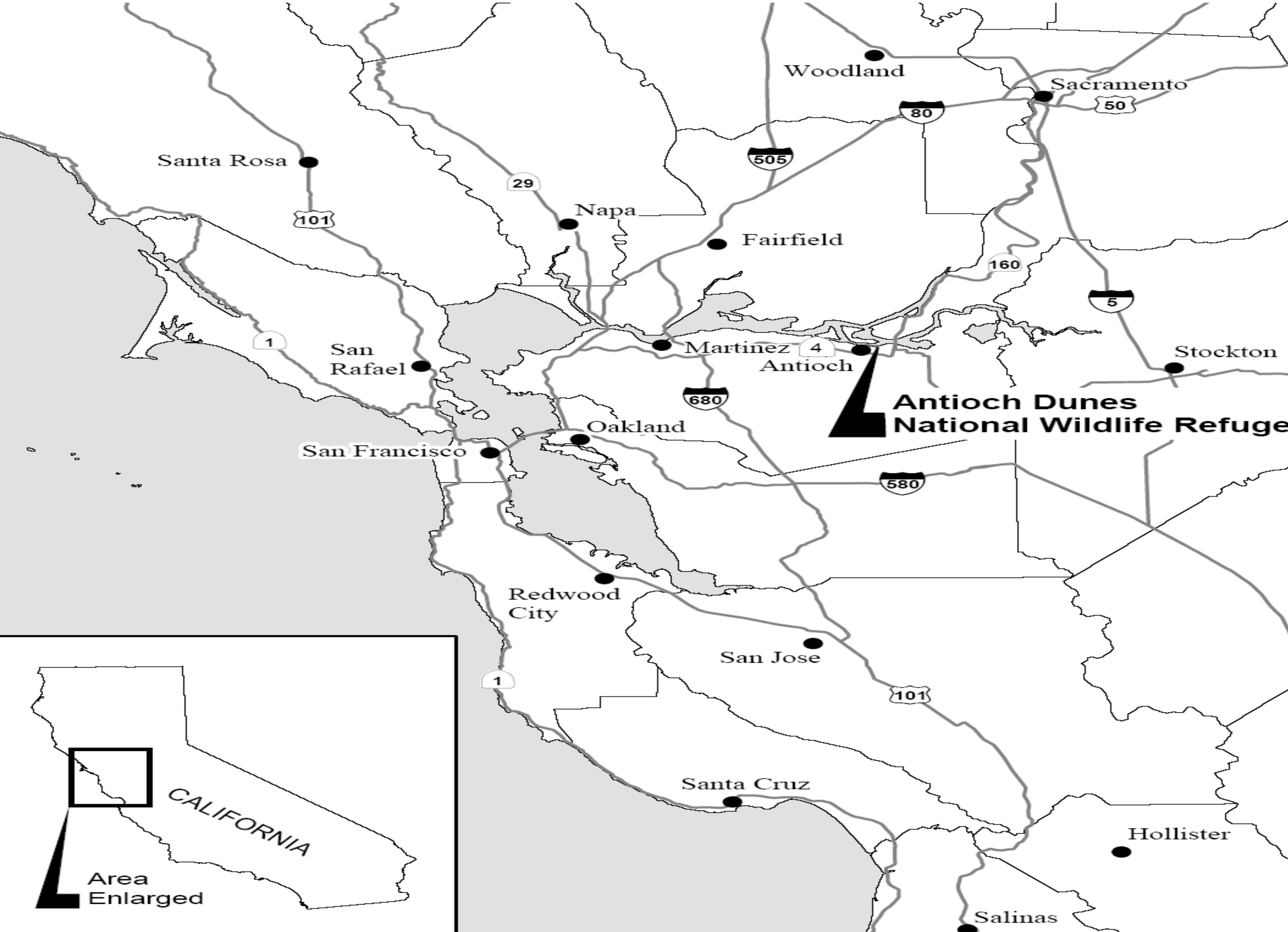
# Discussion: Modelling ‘rules’

- Occam’s razor (the parsimony rule – KISS)
- One question - one model
- Complex models lead to poor prediction because uncertainties multiply
- Our goal is to be 95% certain with our predictions

# Using Population Models to Determine the Impact of Herbicides on Lange's Metalmark Butterflies at the Antioch Dunes National Wildlife Refuge

# Lange's Metalmark Butterfly

- Federally listed as endangered June 1, 1976
- Antioch Dunes NWR - 1978
- 2007 Biological Opinion – Section 7


Woodland
Sacramento
80
50
505
Santa Rosa
29
101
Napa
Fairfield
160
5
1
San Rafael
Martinez
4
Antioch
Stockton
680
Antioch Dunes National Wildlife Refuge
Oakland
San Francisco
580
Redwood City
San Jose
1
101
CALIFORNIA
Area Enlarged
Santa Cruz
Hollister
Salinas


Stamm Unit
Sardis Unit
Image U.S. Geological Survey
1833 ft
38°00'54.41" N
121°47'24.49" W
Jun 2007
Eye alt 6342 ft
Google

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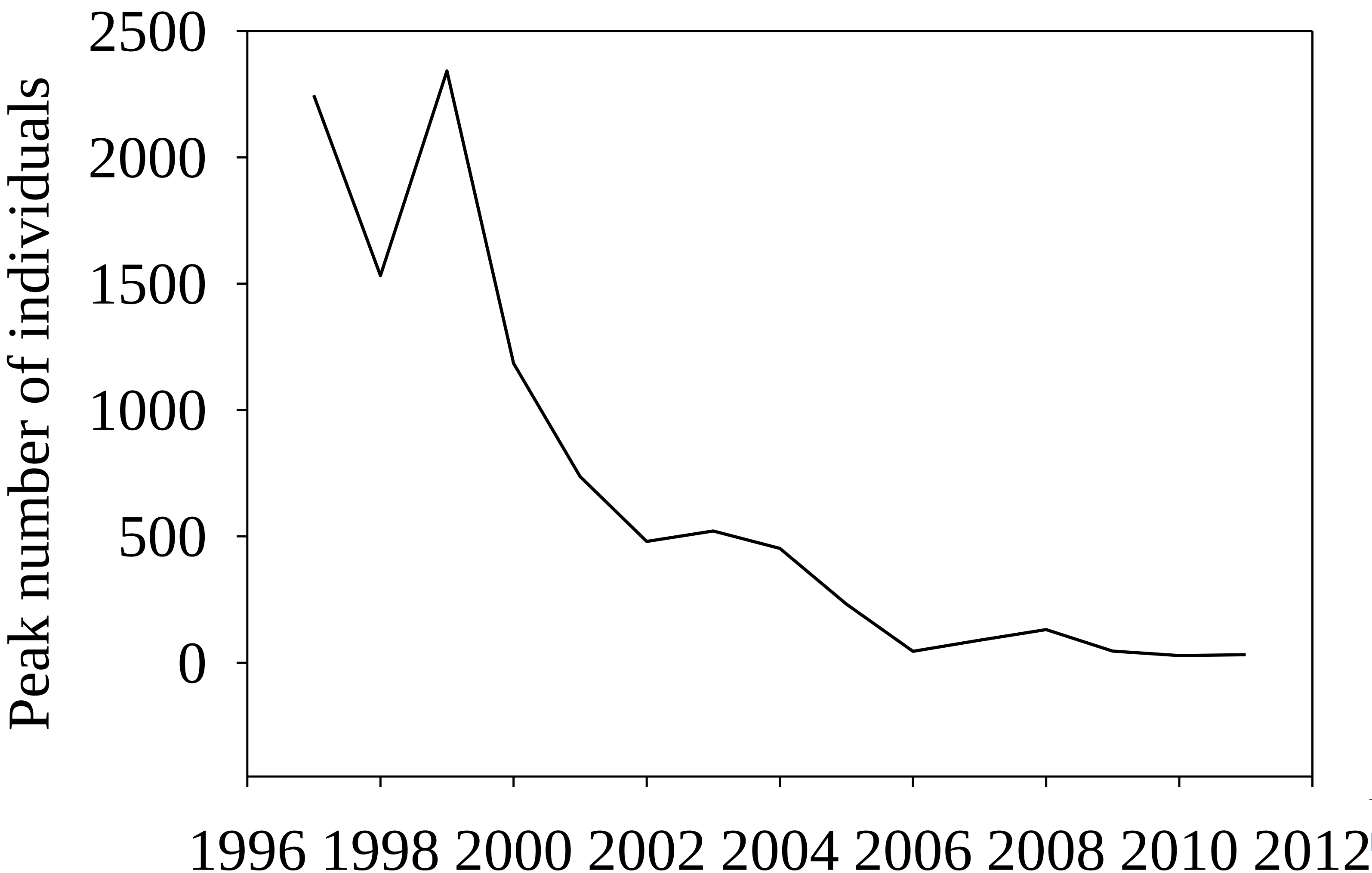
# Stamm and Sardis Unit

# Lange's Metalmark Population Dynamics



# What is Being Done

- Aggressive Restoration at Antioch Dunes NWR
- Propagation of Lange's Host Plant
- Captive Rearing and release of Lange's
- Herbicide Application

# The Problem - Invasive Plant Specifically Vetch (*Vicia villosa)*

- Alters Micro-Climate
- Encompasses the Buckwheat

# Hand Pulling of Vetch Can Damage Buckwheat and Disturb Eggs and Larvae

# Therefore, herbicides are being applied to remove invasive weeds

- However, after several years of herbicide applications, populations started to decline even further

# Herbicides Used at Antioch Dunes NWR

- Garlon 4 ® - Triclopyr
- Poast ® - Sethoxydim
- Stalker ® - Imazapyr
- Transline ® - Clorpyralid
- Roundup ® - Glyphosate

# Herbicide Applications

Could the herbicides being applied to remove invasive weeds be having a negative effect on LMB?

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# Objectives

- Determine lethal and sub-lethal effects of three commonly used herbicides at Antioch Dunes NWR on Lange's metalmark.

- Develop and apply a population life-cycle model to (1) integrate field and laboratory data into population-level projections of the impact of the herbicides on Lange's metalmark butterfly over developmental time-scales, and (2) provide a comparative assessment of the impact of herbicides relative to other stressors.

We are using a surrogate species in the lab; Behr's metalmark (*Apodemia virgulti virgulti)*.

# Methods

- First instar (larvae) and surrogate buckwheat (Siskiyou wild buckwheat) were exposed at labelled field rate with a Potter Tower

- Endpoints evaluated

Daily survival, time to pupation, pupal weight, time to adult emergence, number of emerged adults, adult weight, number of eggs laid per female and a series of other measurements were recorded.

# No Effect Results for all three herbicides

- Development Time In Days
- Pupal Weight
- Adult Weight
- Number of Eggs Laid

# Only found an effect on adult emergence

| Treatment | % reduction in adult emergence compared to control |
|---|---|
| Triclopyr | 24 |
| Sethoxydim | 27 |
| imazapyr | 36 |

# So what do these reductions in adult numbers mean to butterfly health?

# Population modeling may help to answer this question

# Population model

Developed stage-structured deterministic and stochastic matrix models based on laboratory demographic data

The vital rates were reduced 20% to account for field conditions

Starting population was 100 individuals

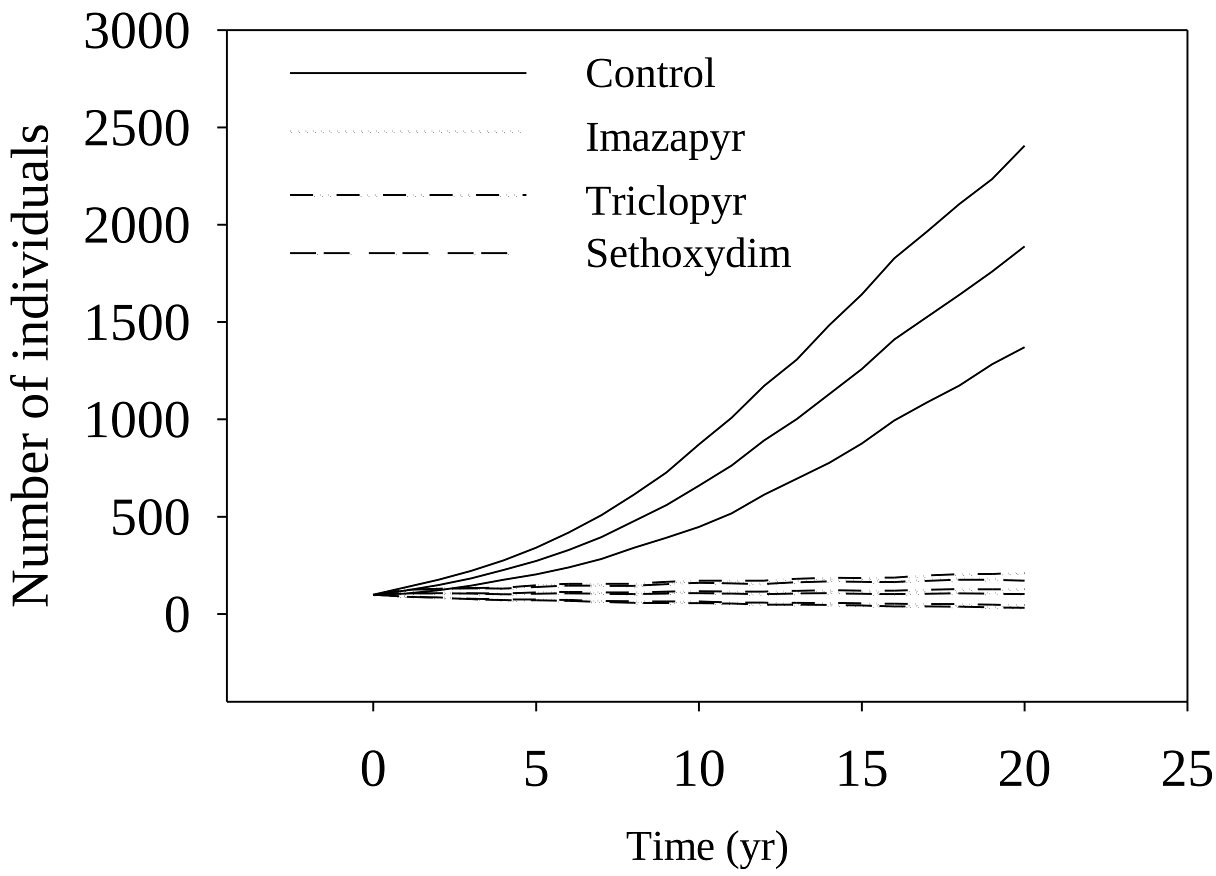
Carrying capacity was set at 2,500

Density dependence = scramble

Time step = 1 year

Model run for 10 years

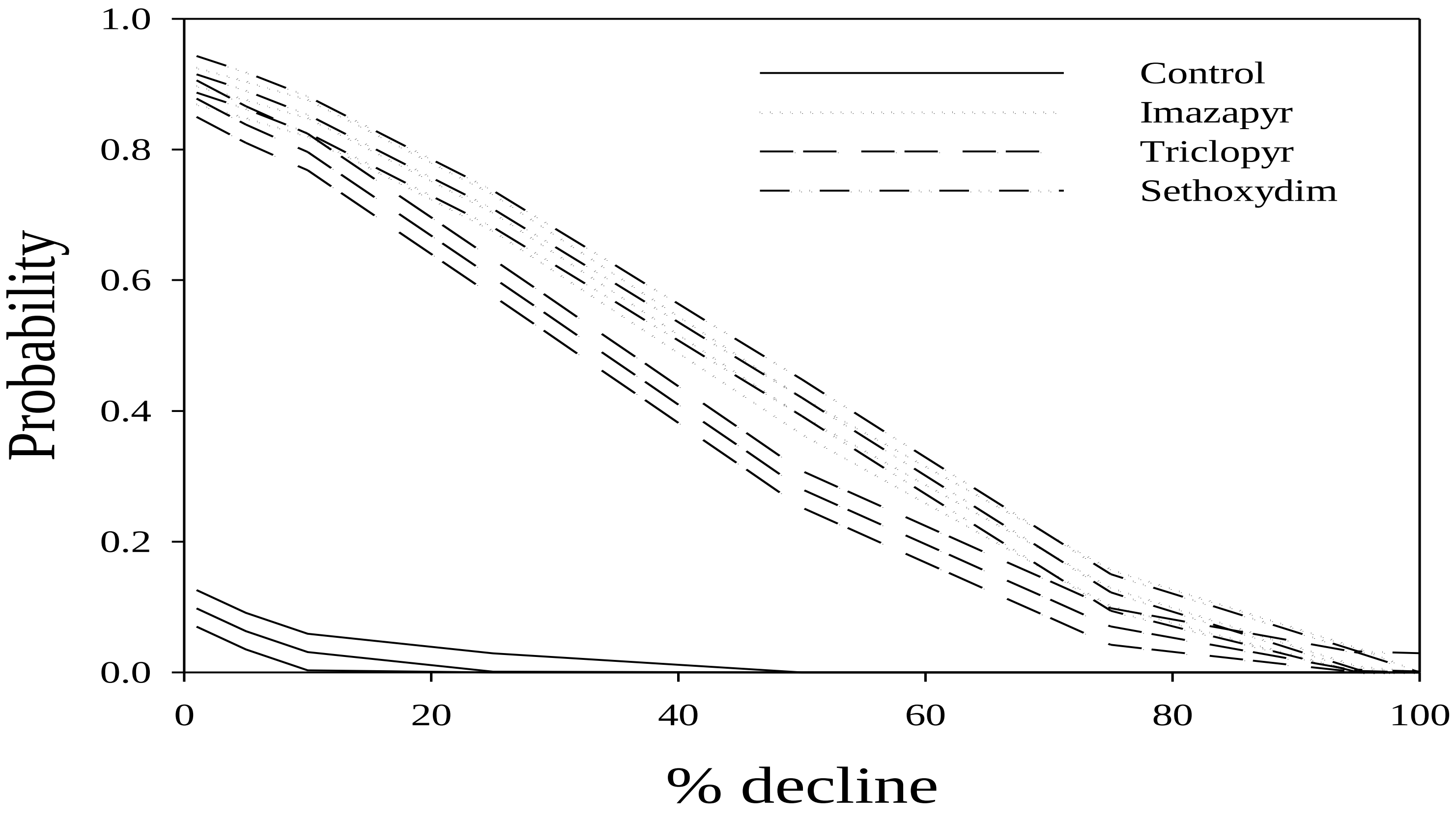
# Population dynamics



# Herbicide effect on population numbers after 20 years

| | % of Control<br>X (SD) |
|---|---|
| Imazapyr | 5 (2-7) |
| Triclopyr | 7 (3-9) |
| Sethoxydim | 5 (2-7) |

# Probability of extinction



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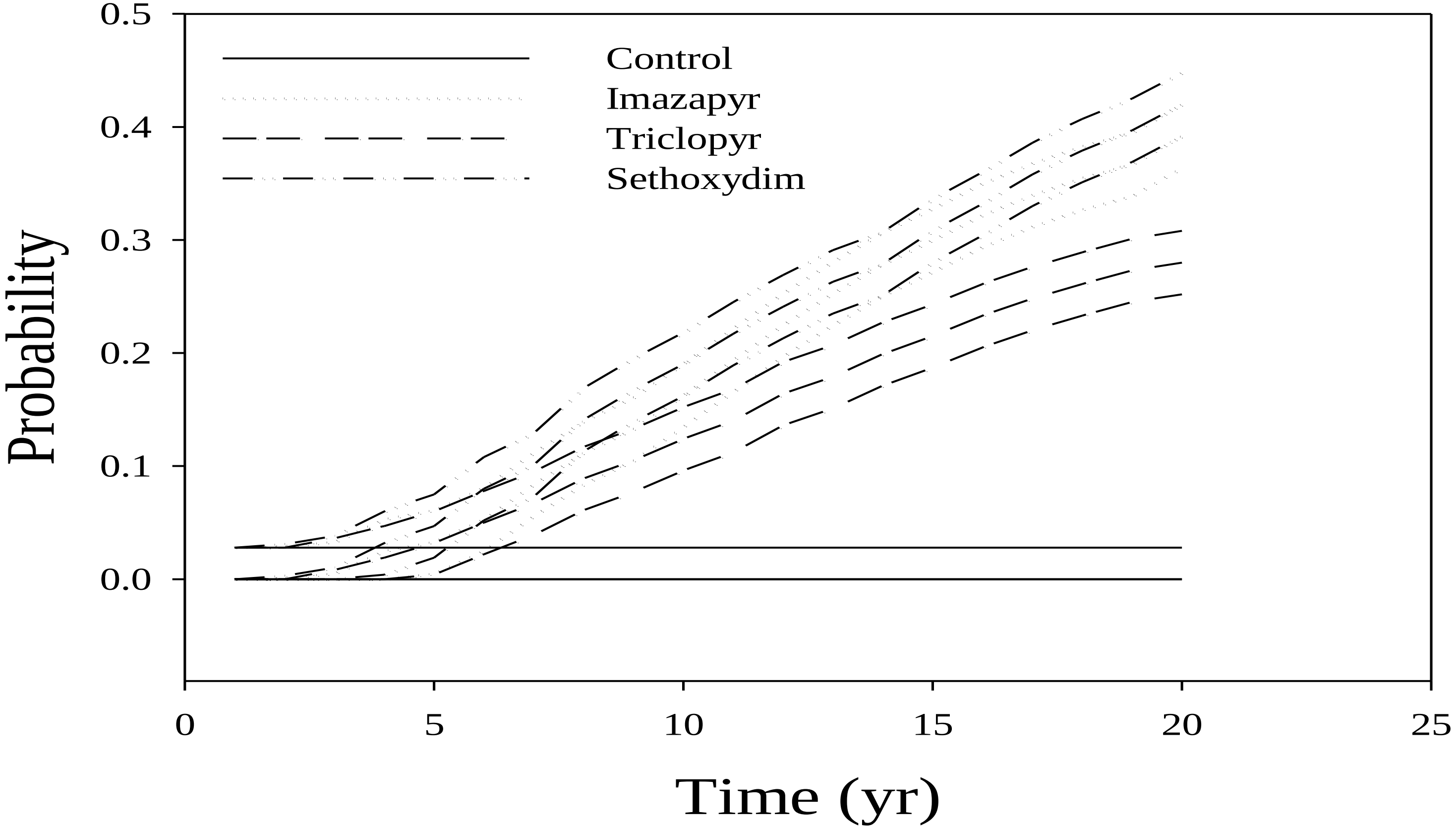
# Time to Quasi-Extinction



# Herbicide effect on time to extinction

Probability of extinction after 20 years

| | |
|---|---|
| Control | 0 (0-0.28) |
| Imazapyr | 0.39 (0.36-0.42) |
| Triclopyr | 0.28 (0.25-0.31) |
| Sethoxydim | 0.42 (0.39-0.45) |

# Conclusions

1. Exposure of Behr's Metalmark to the 3 herbicides evaluated caused reductions in adult emergence.  This in turn resulted in reductions in population growth rate.
2. Results of stochastic matrix models showed that exposure to each of these herbicides would greatly increase the probability of extinction and speed the time to extinction.
3. Use of these herbicides is detrimental to Lange's Metalmark assuming that Lange's Metalmark exhibits similar susceptibility to Behr's Metalmark.

# Pacific Salmon

A comprehensive systems approach is needed for these species

# Salmon species in the Pacific Northwest United States

1. Chinook
2. Coho
3. Pink
4. Chum
5. Sockeye

Others?

Steelhead

Cutthroat trout

Bull trout

# Most wild populations are in decline and listed as threatened or endangered

Declines are due to:

1. Habitat damage/destruction
2. Hydropower
3. Hatchery fish
4. Harvest

5. Pollution

# Stakeholders

1. Tribes
2. Commercial fisherman
3. Sport fisherman
4. Governments – Federal, State, City, County, etc.
5. Environmental groups
6. Agricultural producers and their allies

# These different groups may have very different interests and concerns regarding salmon

# On the Use of Surrogate Species for Ecological Risk Assessment

# Lack of Toxicity Data

## Number of Species Tested

- Of the more than 1.3 million animal species known in the world, EPA generally has acute toxicity data on perhaps 15 species for new chemicals and perhaps 50 species for older chemicals. For herbicides, EPA may only have 15 tested species of plants.

- This limited amount of data is used to predict toxicity levels (mortality generally) to a much larger number of potentially exposed species in a pesticide use site.

# Some General Assumptions

- 15 species of plants are used to indicate sensitivity of entire plant kingdom
- 3 or 4 species of invertebrates are used to indicate sensitivity of 1 million species
- 1 insect species to represent over 800,000
- 2 – 3 species of fish represent 22,000 fish and 4000 species of amphibians
- 2 species of bird represent 9000 species of birds and 6500 species of reptiles

Mallards and bobwhite quail are used as surrogates for all birds and reptiles

A few fish species - fat head minnow, blue gill, rainbow trout are used as surrogates for all fish and amphibians

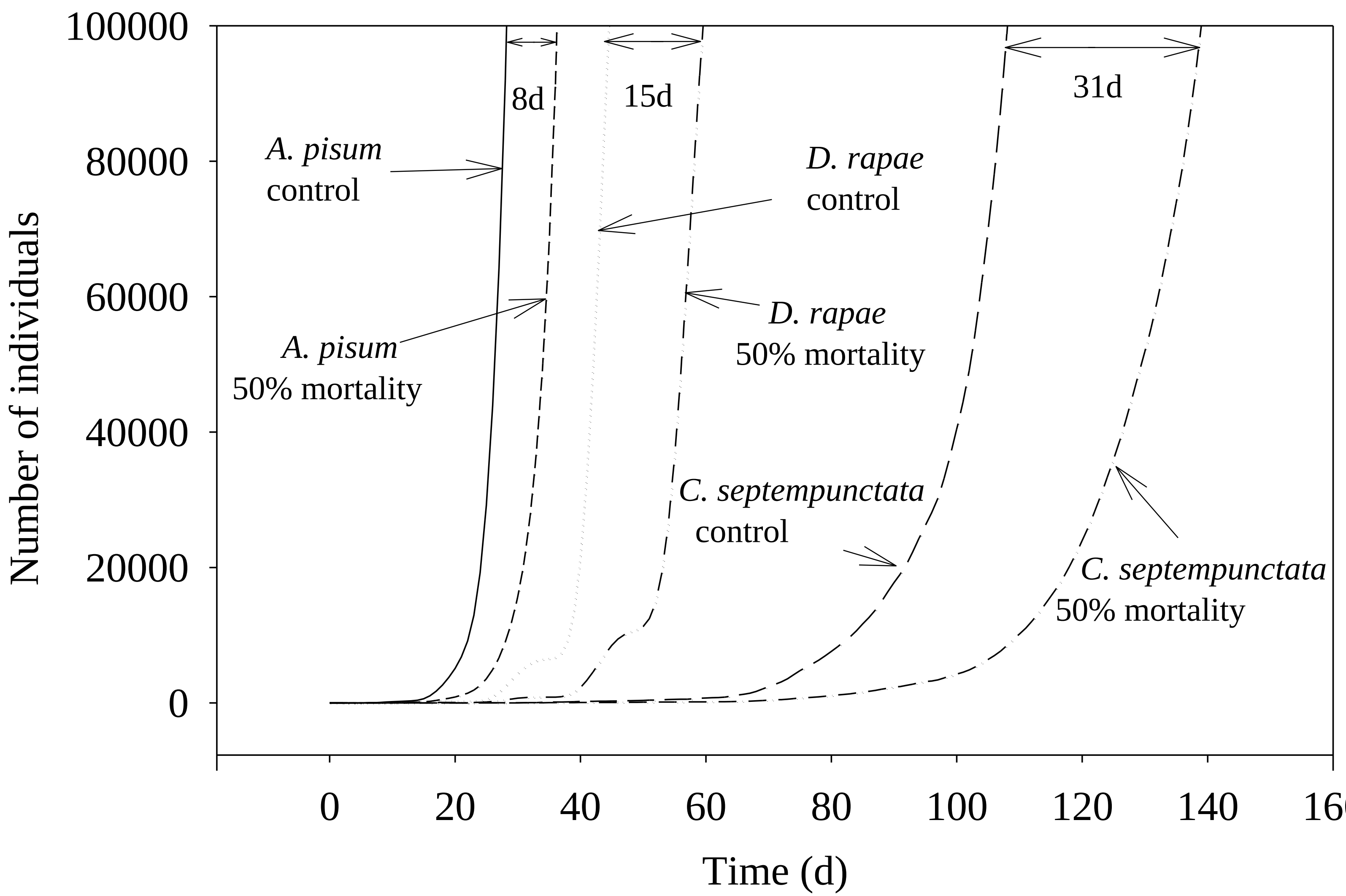
Honey bees represents all insects

# Species used to develop toxicity data are not chosen because they are representative of other species, but because they are easy to rear in the laboratory

# Rat-Elephant Phenomenon

Stark JD, Banks JE, Vargas RI. 2004. How risky is risk assessment? The Role that Life History Strategies Play in Susceptibility of Species to Stress. 2004. Proceedings of the National Academy of Sciences 101: 732-736.

Comparison of population numbers in controls and chronic LC50 (This is it!)



# More holistic approach:

- Include life history data into models
- Incorporate age/stage-structure
- Predict population effects of toxicants

# Leslie matrix model: plug in life history parameters (mean values)

$$\begin{bmatrix} n_{0,t+1} \\ n_{1,t+1} \\ \vdots \\ n_{\omega-1,t+1} \end{bmatrix} = \begin{bmatrix} F_0 & F_1 & F_2 & \cdots & F_{\omega-1} \\ G_0 & 0 & \cdots & \cdots & \cdots \\ 0 & G_1 & 0 & \cdots & \cdots \\ \cdots & \cdots & \ddots & \ddots & \cdots \\ 0 & 0 & 0 & G_{\omega-2} & 0 \end{bmatrix} \begin{bmatrix} n_{0,t} \\ n_{1,t} \\ \vdots \\ n_{\omega-1,t} \end{bmatrix}$$

$$\lambda X = AX$$

# Choice of surrogates

- Physiology
- Phylogenetics
- Life history similarities

Testing plus “safety factor” (1/10th, 1/100th)

- Better predict reliability by explicitly incorporating life history traits?

# Stage-structured model (four stages) population grows for λ > 1

$$X(t+1) = \begin{bmatrix} x_1(t+1) \\ x_2(t+1) \\ x_3(t+1) \\ x_4(t+1) \end{bmatrix} = \begin{bmatrix} 0 & 0 & f_3 & f_4 \\ a_1 & 0 & 0 & 0 \\ 0 & a_2 & 0 & 0 \\ 0 & 0 & a_3 & a_4 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} = AX(t) \qquad (1)$$

$a_i$ are survival from class *i* to class *i+1*; $f_3$ and $f_4$ are fecundity rates (young and older reproductive classes, respectively)

(Banks, Ackleh, & Stark. 2010 *Risk Analysis)*

$$F = \begin{bmatrix} 0 & 0 & f_3 & f_4 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \text{ and } T = \begin{bmatrix} 0 & 0 & 0 & 0 \\ a_1 & 0 & 0 & 0 \\ 0 & a_2 & 0 & 0 \\ 0 & 0 & a_3 & a_4 \end{bmatrix}$$

$$A = F + T$$

# Population rate of increase - $R_0$ = great eigenvalue of matrix $F(I-T)^{-1}$

$$F(I-T)^{-1} = \begin{bmatrix} f_3 a_1 a_2 + \dfrac{f_4 a_1 a_2 a_3}{1-a_4} & f_3 a_2 + \dfrac{f_4 a_2 a_3}{1-a_4} & f_3 + \dfrac{f_4 a_3}{1-a_4} & \dfrac{f_4}{1-a_4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad (2)$$

$$R_0 = f_3 a_1 a_2 + \frac{f_4 a_1 a_2 a_3}{1-a_4} = f_3 a_1 a_2 + f_4 a_1 a_2 a_3 (1 + a_4 + a_4^2 + a_4^3 + \ldots) \qquad \text{(iii)}$$

$$R_0{}^S = 1 + \varepsilon^s > 1$$

(surrogate species rate of increase without toxicant)

$$R_0{}^L = 1 + \varepsilon^L > 1$$

(listed (endangered/threatened) species rate of increase without toxicant)

**Worst case scenario:** ***surrogate survives, whereas listed species dies out!***

"Type II error" (false negative)

# Conditions for misleading assessment:

## $R^{S,T}_0 > 1$ while $R^{L,T}_0 < 1$

Stipulate reduction in fecundity for surrogate and listed species:

$$f_3^{S,T} = f_3^{S}(1-\delta_1),\ f_4^{S,T} = f_4^{S}(1-\delta_2),\ f_3^{L,T} = f_3^{L}(1-\delta_1) \text{ and } f_4^{L,T} = f_4^{L}(1-\delta_2)$$

# Population growth for surrogate and listed species

$$R_0{}^{S,T} = a_1{}^S a_2{}^S f_3{}^{S,T} + \frac{a_1{}^S a_2{}^S a_3{}^S f_4{}^{S,T}}{1-a_4{}^S} = a_1{}^S a_2{}^S f_3{}^S (1-\delta_1) + \frac{a_1{}^S a_2{}^S a_3{}^S f_4{}^S (1-\delta_2)}{1-a_4{}^S}$$

$$R_0{}^{L,T} = a_1{}^L a_2{}^L f_3{}^{L,T} + \frac{a_1{}^L a_2{}^L a_3{}^L f_4{}^{L,T}}{1-a_4{}^L} = a_1{}^L a_2{}^L f_3{}^L (1-\delta_1) + \frac{a_1{}^L a_2{}^L a_3{}^L f_4{}^L (1-\delta_2)}{1-a_4{}^L}$$

Recall: $R_0{}^S = 1 + \varepsilon^s > 1$ $\quad R_0{}^L = 1 + \varepsilon^L > 1$

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# Conditions for survival of surrogate (vi) and listed (vii) species:

$$a_1^S a_2^S f_3^S \delta_1 + \frac{a_1^S a_2^S a_3^S f_4^S \delta_2}{1 - a_4^S} < \varepsilon^S \qquad \text{(vi)}$$

$$a_1^L a_2^L f_3^L \delta_1 + \frac{a_1^L a_2^L a_3^L f_4^L \delta_2}{1 - a_4^L} < \varepsilon^L \qquad \text{(vii)}$$

Problem: (vi) holds while (vii) does not!

(Banks, Ackleh, & Stark. 2010 *Risk Analysis)*

# Case Study I: salmonid surrogate life history data

- Spromberg & Birge (2005) published data (four-stage matrix)

- Chinook and Coho salmon represented by four species of surrogates:

- Round goby (*Neogobius melanostomus*)
- Smallmouth bass (*Micropterus dolomieu*)
- Fathead minnow (*Pimephales promelas*)
- Cutthroat trout (*Oncorhynchus clarki lewisi*)

# Plug values into limiting similarity criteria:

| Life History Parameters | Round goby (*Neogobius melanostomus*) | Smallmouth bass (*Micropterus dolomieu*) | Fathead minnow (*Pimephales promelas*) | Cutthroat trout (*Oncorhynchus clarki lewisi*) | Chinook & Coho Salmon (*O. tschawytscha* & *O. kisutch*) |
|---|---|---|---|---|---|
| $a_1$ | 0.03 | 0.04 | 0.5 | 0.05 | 0.05 |
| $a_2$ | 0.1 | 0.3 | 0.18 | 0.25 | 0.05 |
| $a_3$ | 0.2 | 0.4 | 0.12 | 0.25 | 0.5 |
| $a_4$ | 0.05 | 0.15 | 0 | 0.15 | 0 |
| $f_1$ | 187.5 | 25 | 6 | 22.5 | 0.3 |
| $f_2$ | 1050 | 187.5 | 62.5 | 300 | 920 |
| $\varepsilon$ | 0.225657895 | 0.358823529 | 0.215 | 0.384191176 | N/A |
| $\delta_1$ | 187.2 | 24.7 | 5.7 | 22.2 | N/A |
| $\delta_2$ | 130 | -732.5 | -857.5 | -620 | N/A |

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# Comparison of fish species undergoing different levels of reductions in fecundity

| Species | 10% redt | 15% redt | 20% redt | 25% redt | 30% redt |
|---|---|---|---|---|---|
| Chinook/Coho | Persists | Extinct | Extinct | Extinct | Extinct |
| Round goby | Persists | Persists | Extinct | Extinct | Extinct |
| Smallmouth bass | Persists | Persists | Persists | Persists | Extinct |
| Fathead minnow | Persists | Persists | Extinct | Extinct | Extinct |
| Cutthroat trout | Persists | Persists | Persists | Persists | Extinct |

Banks, Ackleh, Stark 2010. The use of surrogate species in risk assessment:
using life history data to safeguard against false negatives
Risk Analysis 30:175-182

# Results:

- All is well for 10% and 30% reductions to fecundity…
- …but not so much for reductions in between the low an high end!
- The Round Goby and Fathead minnow were the best surrogates for salmon (counter intuitive)
- Potentially misleading to rely on surrogates!

# Case Study II : Biological Control
# ( w/ R. Vargas, USDA-ARS)

parasitoid wasps:

- *Diachasmimopha longicaudata*
- *Psyttalia fletcheri*
- *Fopius arisanus*
- *Diaeretiella rapae*

# Life history parameters for parasitoid model

| | *Diachasmimopha longicaudata* | *Psyttalia fletcheri* | *Fopius arisanus* | *Diaeretiella rapae* |
|---|---|---|---|---|
| a1 | 0.91 | 0.91 | 0.93 | 1 |
| a2 | 0.912088 | 0.912088 | 0.914 | 1 |
| a3 | 0.771084 | 0.783133 | 0.765 | 1 |
| a4 | 0.015625 | 0.015385 | 0.015 | 0.1 |
| f3 | 0 | 0 | 0 | 0 |
| f4 | 2.711538 | 1.714685 | 2.55 | 2.545 |
| epsilon | 0.76293 | 0.131961 | 0.683428 | 1.827778 |

# Parasitoid population outcomes

| Species | 10%reduction | 20% reduction | 30% reduction | 40% reduction | 50% reduction | 60% reduction | 70%reduction |
|---|---|---|---|---|---|---|---|
| *F. arisanus* | Persist (0.168 < 0.683428) | Persists (0.336 < 0.683428) | Persists (0.505 < 0.683428) | Persists (0.6731< 0.683428) | Extinct (0.8417 > 0.683428) | Extinct (1.010 > 0.683428) | Extinct (1.1784 > 0.683428) |
| *D. rapae* | Persists (0.2827 < 1.82777) | Persists (0.5655 < 1.82777) | Persists (0.8483 < 1.82777) | Persists (1.1311< 1.82777) | Persists (1.4138 < 1.82777) | Persists (1.696 < 1.82777) | Extinct (1.9794 > 1.82777) |
| *D. longicauda* | Persists (0.1762< 0.7629) | Persists (0.3525 < 0.7629) | Persists (0.52887< 0.7629) | Persists (0.70517 < 0.7629) | Extinct (0.881 > 0.7629) | Extinct (1.0577 > 0.7629) | Extinct (1.23405 > 0.7629) |
| *P. fletcheri* | Persists (0.1131 < 0.13196) | Extinct (0.2263 > 0.13196) | Extinct (0.3395 > 0.13196) | Extinct (0.4527 > 0.13196) | Extinct (0.5659 > 0.13196) | Extinct (0.6791 > 0.13196) | Extinct (0.7923 > 0.13196) |

# Conclusions

- Parasitoid species not interchangeable – e.g. *D. rapae* not a reliable surrogate for protecting *F. arisanus*
- Matrix model approach can reveal unexpected differences in population outcomes
- Derived equations useful for wide range of species, taxa (aquatics, fish, etc.)
- Add stage-dependent survival rates to model; fecundity vs. survivorship effects

# Some issues that need to be address in the context of ecological risk assessment of pollutants

# Issues that need to be addressed

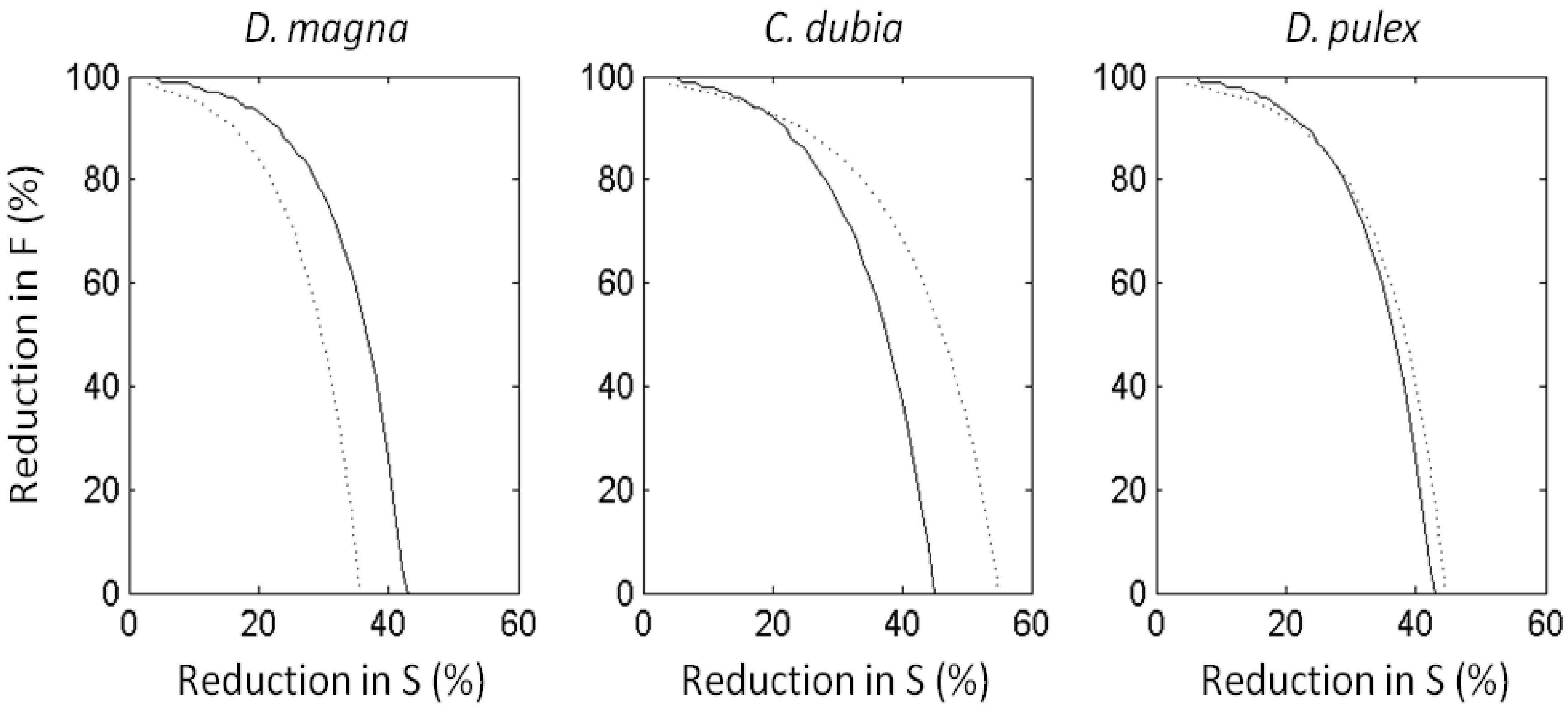
1. Can simplified models be used in place of more complex models and give similar results
2. Influence of population structure and differential susceptibility on population viability
3. The use of surrogate species
4. Deterministic versus stochastic matrix models. Can we get the same information from simpler models?
5. Generic models: can they be developed and do they work

# Study 1 with Nik Hanson

# Compared 2-stage matrix models (juvenile and adult stages) with matrix models containing the complete life tables for 3 species of Daphniids

Hanson, N., Stark, J.D. 2011. A comparison of simple and complex population models to reduce uncertainty in ecological risk assessments of chemicals: Example with three species of *Daphnia*. Ecotoxicology 20:1268–127

# The combination of reductions in survival (S) and fertility (F) that renders $\lambda=1$ according to the matrix model ($\lambda_{MM}$, solid line) and the 2-stage model ($\lambda_{2s}$, dotted line).



# Conclusions

2 stage and full matrix models – very similar for *D. pulex*, but less so for the other two species. Strong correlation found between the two approaches

However, species differences are important and there may be no generalities

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# Issues that need to be addressed for use of models in ERA

1. Can simplified models be used in place of more complex models and give similar results
2. Influence of population structure and differential susceptibility on population viability
3. The use of surrogate species
4. Deterministic versus stochastic matrix models. Can we get the same information from simpler models (deterministic)?
5. Generic models: can they be developed and do they work

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# Generic models for ecological risk assessment: Are they possible to develop?

Hanson, N., Stark, J.D. Developing simple generic models for ecological risk assessments of fish populations.

Environmental Toxicology and Chemistry. Submitted April 2011.

# Working with five fish species with different life history strategies

1. Round Goby – a generalist
2. Small mouth bass - high adult survival
3. Fathead minnow – high young of the year
4. Cutthroat trout – no parental care
5. Anadromous salmon species

Developed an average model and a protective model as well as models for each species based on their demographic traits

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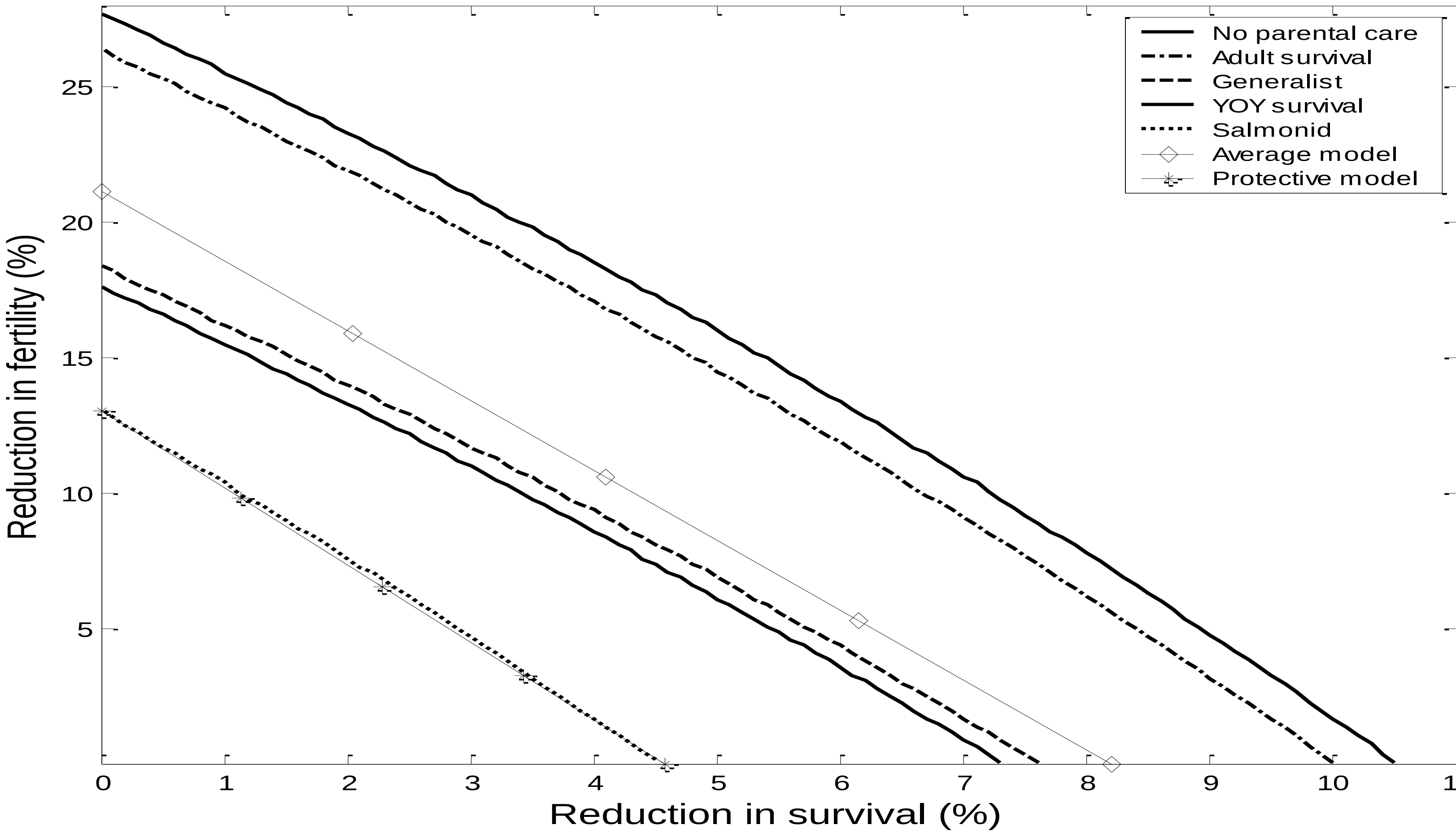
# Combination of reductions in survival and fertility that renders a stable population size ($\lambda=1$) for the five life-histories generalist, high adult survival, high young-of-the-year (YOY) survival, no parental care and salmonid




ions

# Results

- Average models protects some species but not others
- Protective model protects all species

# Overall Conclusions

Population models have value to risk assessors because they are simple to construct and understand and provide much better information than the presently used approach (RQ)

These models may help bridge the current gap between FIFRA and the ESA

# The ecological risk assessment process

Similar in U.S and E.U.

# Risk Quotients

**The USEPA uses a Risk Quotient (RQ) where the Expected Environmental Concentration (EEC) is divided by a toxicity endpoint**

**EU uses same systems but the RQ is reversed**

# Safety Factors

**For the RQ in the US, ratios are compared to Levels of Concern (LOC) based on the type of pesticide being evaluated and whether the toxicity data is acute LC50 or NOEC**

# Risk Presumption for Direct Effects to Aquatic Animals

| Pesticide category | Risk quotient | LOC |
|---|---|---|
| Acute High Risk | EEC/LC50 or EC50 | 0.5 |
| Acute Restricted Use | EEC/LC50 or EC50 | 0.1 |
| Acute Endangered Species | EEC/LC50 or EC50 | 0.05 |
| Chronic data | EEC/NOEC | 1 |

# Potential problems with the RQ approach

**It doesn't take into account:**

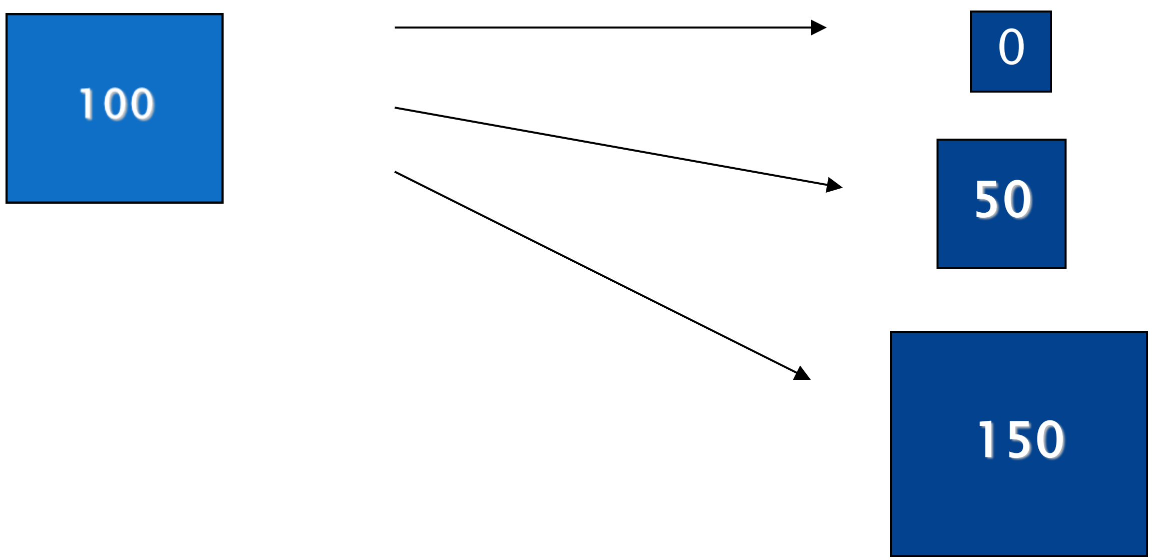
- Multiple effects (lethal and multiple sublethal)
- Population-level processes
- Differential susceptibility among life stages
- Differences in life history strategies

# What happens to individuals over the short-term (acute mortality) doesn't necessarily translate to the population level

Starting population

Some possible outcomes

Exposure to LC50




Timeframe

(long enough for reproduction to occur)

# Does the current ecological risk assessment process work?

# Does the RQ-LOC method work?

# We have found that the RQ-LOC approach may be over protective as well as under protective

Hanson, N., Stark, J.D. Utility of population models to reduce uncertainty and increase value relevance in ecological risk assessment: An example with Daphnia exposed to the pesticide spinosad. Integrated Environmental Assessment and Management (in press)

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# Example with three Daphniid species exposed to spinosad

| Species | LC50 (µg/l) | RQ |
|---|---|---|
| *C. dubia* | 1.8 | 1.3 |
| *D. magna* | 4.8 | 0.48 |
| *D. pulex* | 129.0 | 0.018 |

*C. dubia* is 72 times more susceptible than *D. pulex*

EEC=2.3 µg/l



Deardorff, A., Stark, J.D. 2009. Acute Toxicity and Hazard Assessment of Spinosad and R-11 to Three Cladoceran Species and Coho

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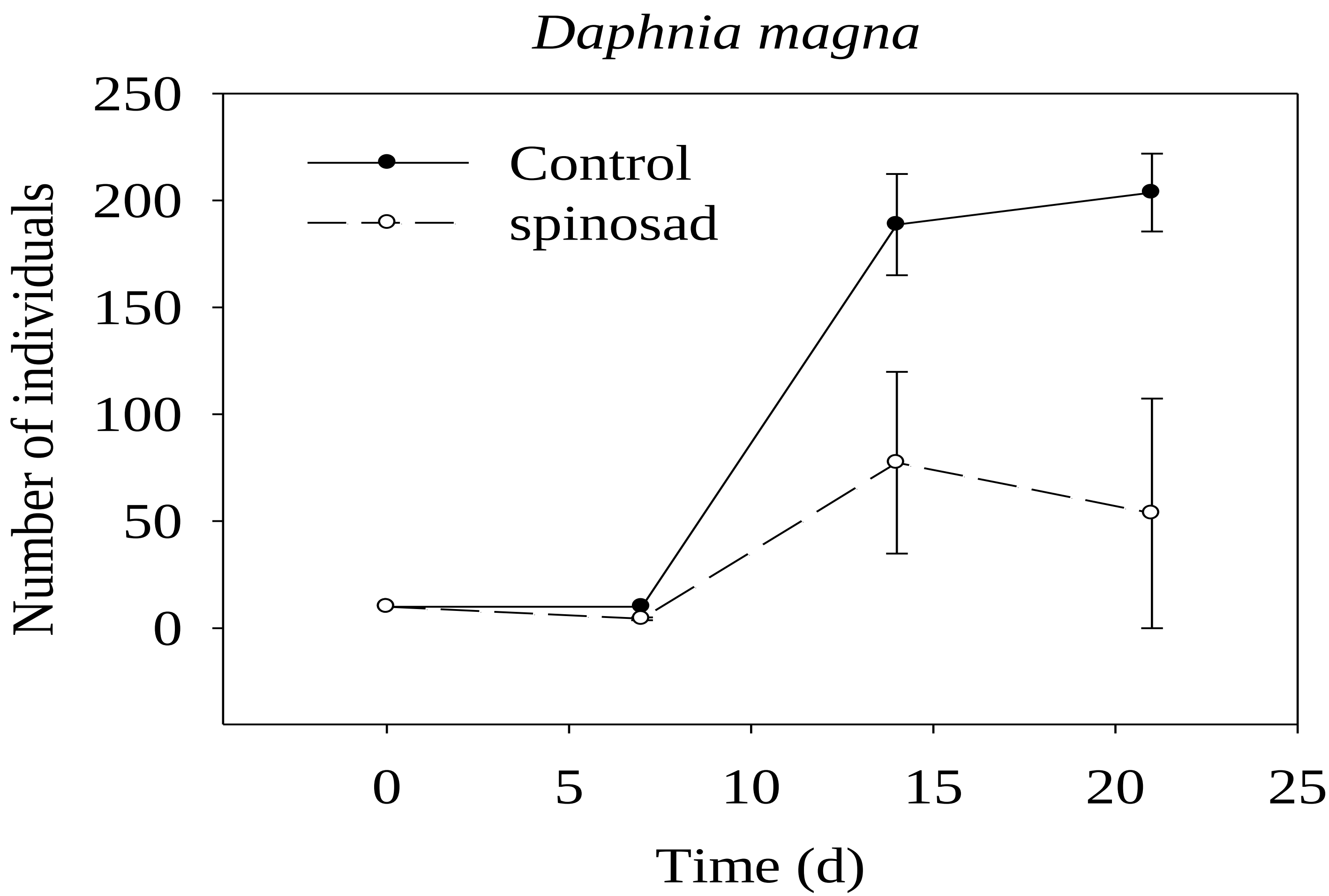
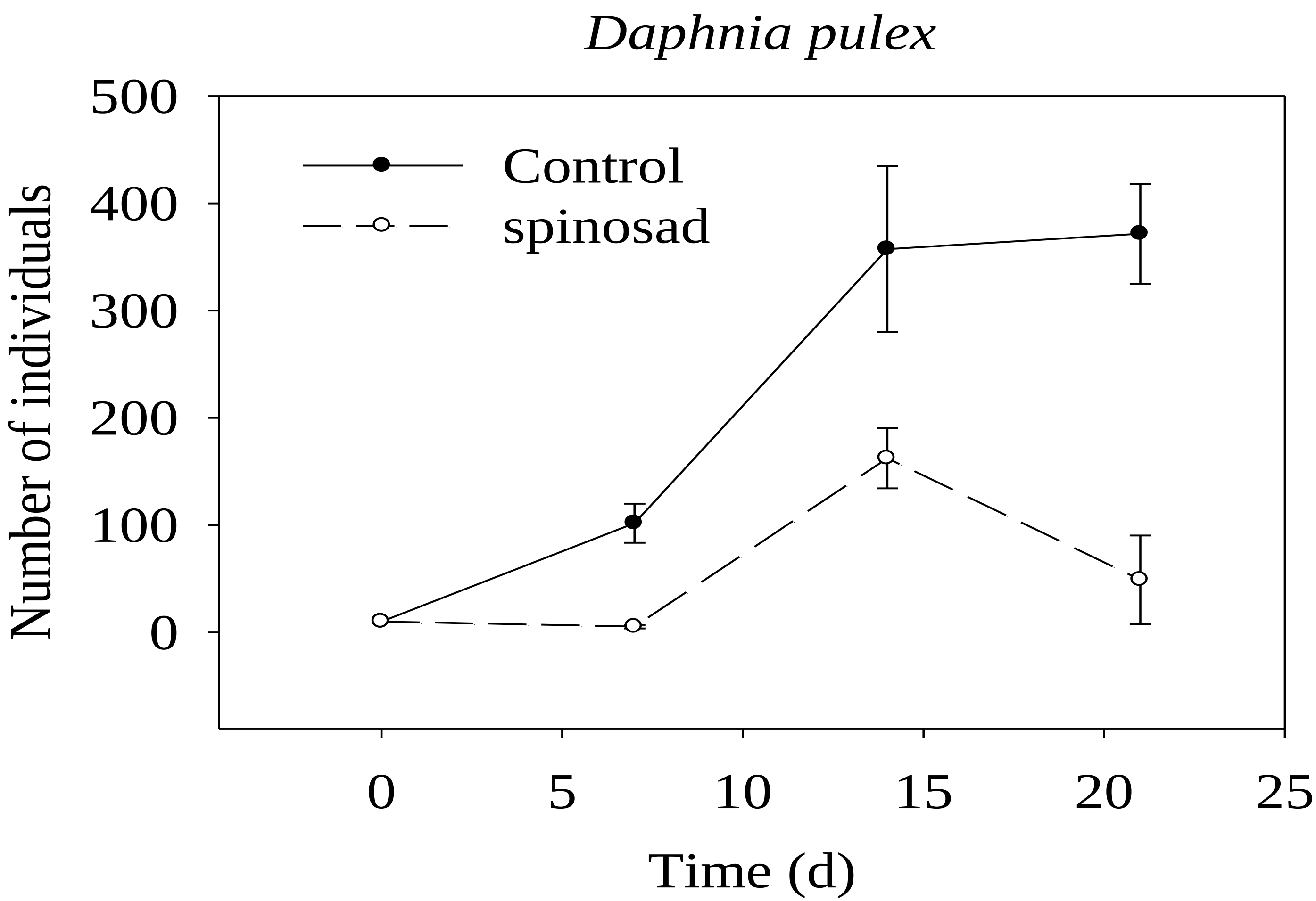
# Exposure to the EEC (2 µg/l)




**Spinosad caused a 74% decline in population size**

# Exposure to the EEC (2 μg/l)




**Exposure to spinosad caused an 87% decline**

# How do we improve the risk assessment process?

**Population modeling?**