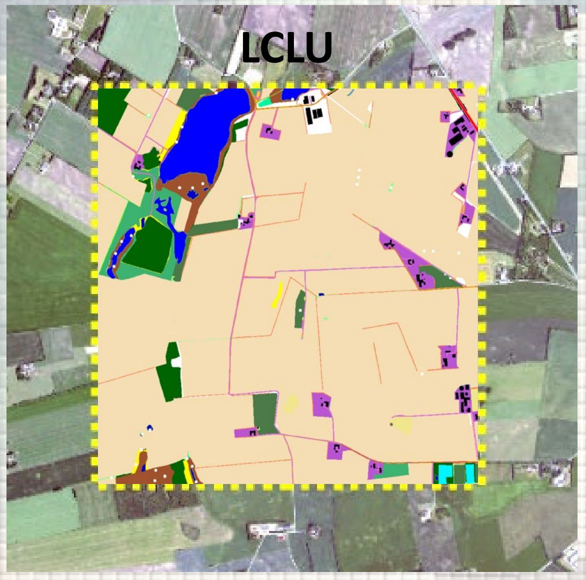
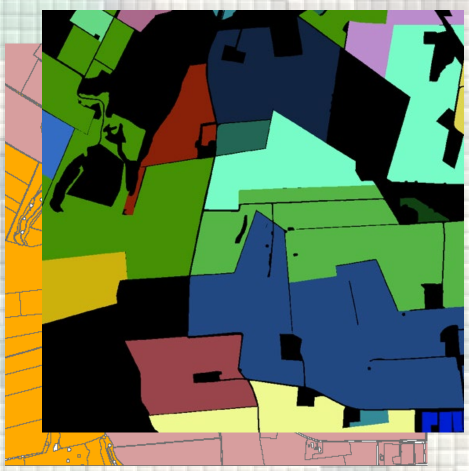
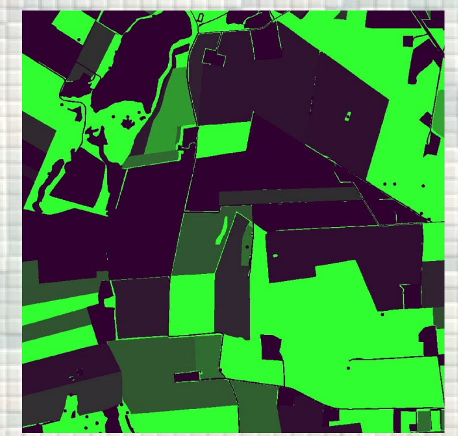
ALMaSS : Animal Landscape and Man Simulation System

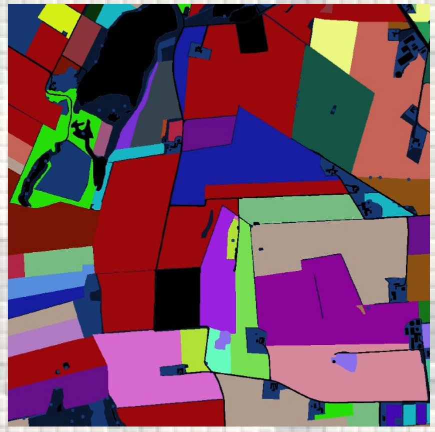


Soil, Farms & Farmtype

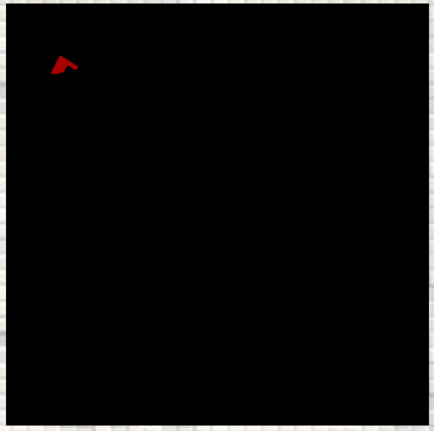


Biomass



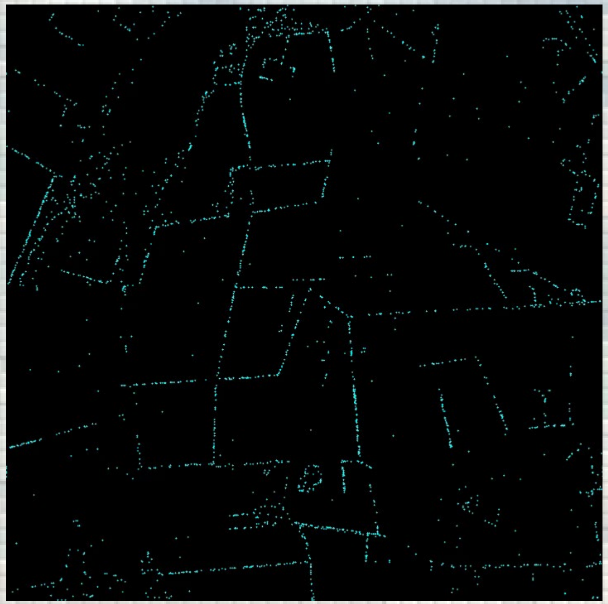


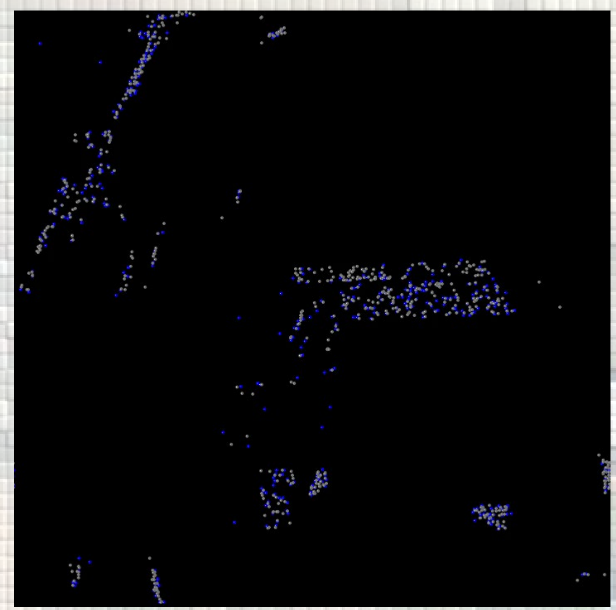
Vegetation Type



Pesticide Application

Beetle





Vole

AU SESS : Socio-Ecological Systems Simulation centre

AARHUS UNIVERSITY
ECOSCIENCE

SESS

SESS, Socio-Ecological Systems Simulation centre

https://projects.au.dk/sess//

formed : 2020 with 8 staff, now, 16+ staff

over 100 articles, including in Nature & Science

Chris Topping : centre leader, ALMaSS programmer since 1998

Jamie & Geoff : static landscape modelling

Jordan : species & environment modelling

Yoko : bee ecology

Xiaodong : modelling, scripting, ML, HPC, parallel programming

Sara : modelling, *SOME*

Astrid : scenarios computing

Trine : environmental modelling

Luna : admin, modelling, computing

James & Natasha : socio-economics

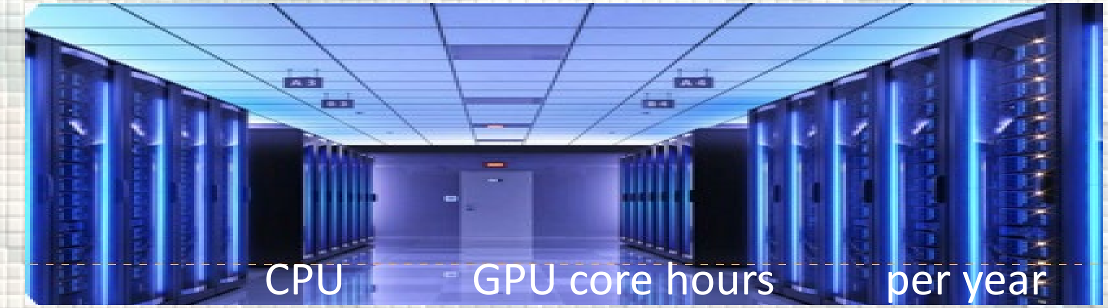
\+ Ela : species and environment modelling
Peet : species modelling
Bjarke : modelling, scripting, HPC
NN : social scientist

\+ Collaborators in :
Poland, Portugal, Italy, Germany, The Netherlands, Belgium, UK, Finland, France, Ireland, Spain

The other "team members" : the scripts …

Static landcape models : python, ESRI / OpenGIS
Landscape dynamics, species models : C++
ca. 120K lines of code : Windows, Linux, OpenSource, Gitlab, GitKraken, VScommunity, MiDox, Cmake, QT, …

The other "team members" : the HPCs …



	CPU	GPU core hours	per year
uCloud :	ca. ½ M	20 K	
Genome :	ca. 1 M		
LUMI :	ca. 1 M	20 K (world's 3rd most powerful HPC)	

WHY ?

ENVIRONMENTAL RISK	Pesticide regulations, non-target organism effects, multiple stressors, multiple exposure, the recovery fallacy, …
BIODIVERSITY LOSS	Pollinator issues Mitigation measures, e.g. organic farming practices
WILDLIFE ECOLOGY	Species management, hare, goose, etc.

the common thread : **population ecology needs reliable predictive models that are alternatives to the fundamentally analytical & reductionist approaches, e.g. density dependence**

HOW ?

ALMaSS : Systems based approach with complex modelling

- emergent & dynamic structures
- responsive to input changes, with high predictive powers

agent-based simulation

FOR WHOM ?

European Commission	Horizon2020, HorizonEurope … 5 projects, 3 as lead
National Agencies and Research Programmes	Danish-EPA, GUDP, ICROFS, LBST, ICØL, Agri Agency, Dutch EPA , German Environmental Agency (UBA)
European Food Safety Authority (EFSA) :	EFSA roadmaps e.g. Partnership for Environmental Risk Assessment (PERA)

7 major projects completed since 2020 each of > 3 M kr
10 current projects each of > 3 M kr

ALMaSS and ”alternatives to fundamentally analytical & reductionist approaches”

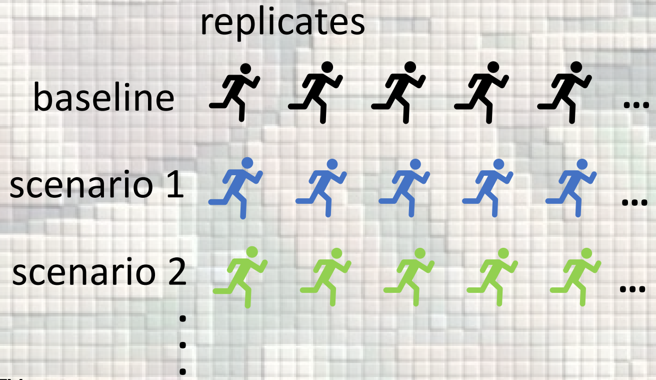
Charles J. Krebs stated “density-dependent relationships occur often but are not repeatable and are an unreliable basis for a predictive ecology”

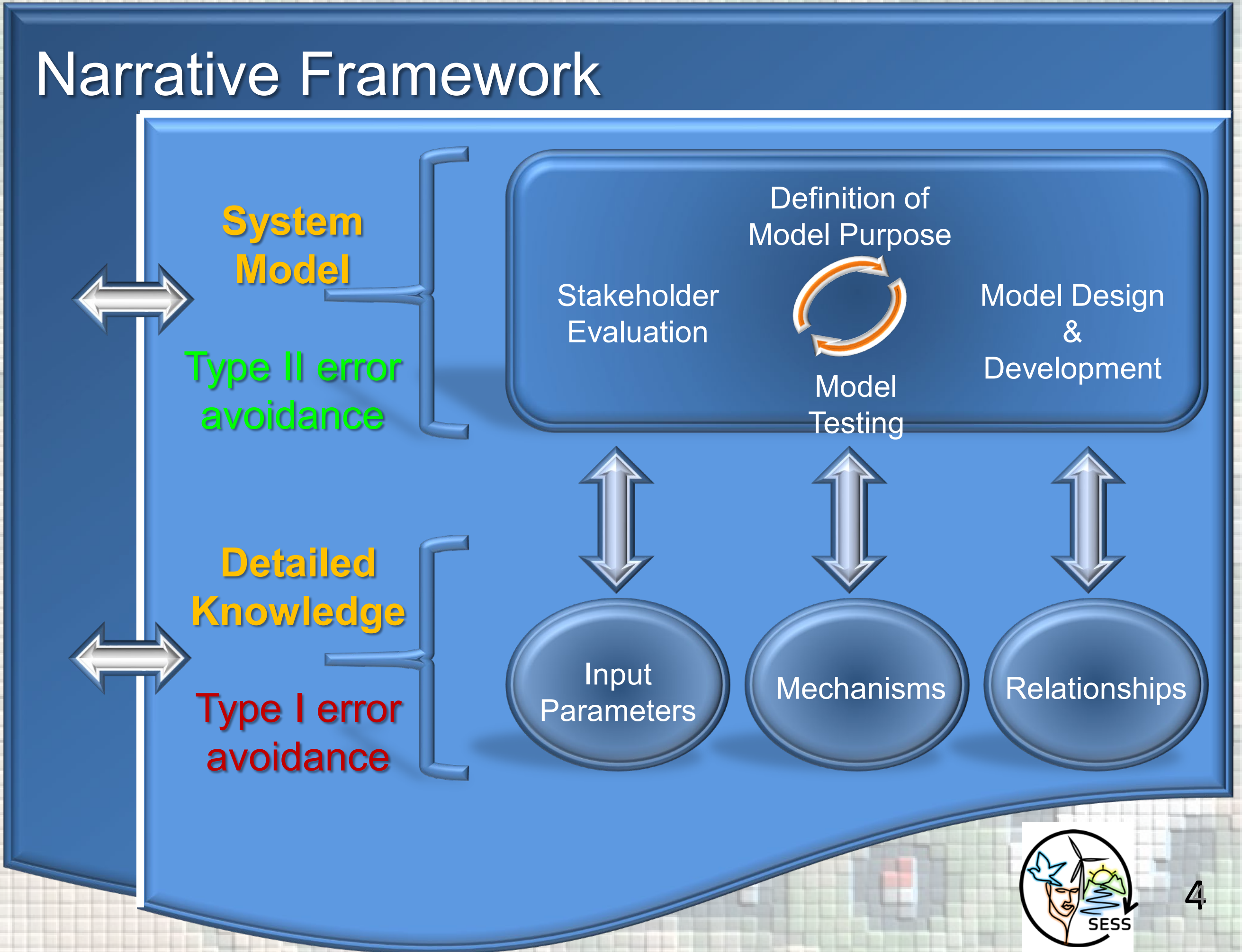
… but expressed fears that complex hypotheses without rigorous (i.e. type I, false-positive error resistant) scientific constraints **could reduce ecologists to storytellers**

ALMaSS :
No!... story-telling **is exactly what is needed**

The **narrative frames** the **model** in terms of its **context** within the **system** it represents:

- what to include + what to exclude
- model results affect the narrative
  changes in the narrative alter the model





The ALMaSS species models

Some of the species modelled in ALMaSS

Each represented as a very highly detailed mechanistic model

also People (the ”M” in ALMaSS), e.g. farmers, hunters … their socio-economics, motivations, aspirations, knowledge, possibilities, networks, etc.

The ALMaSS species models

An example …

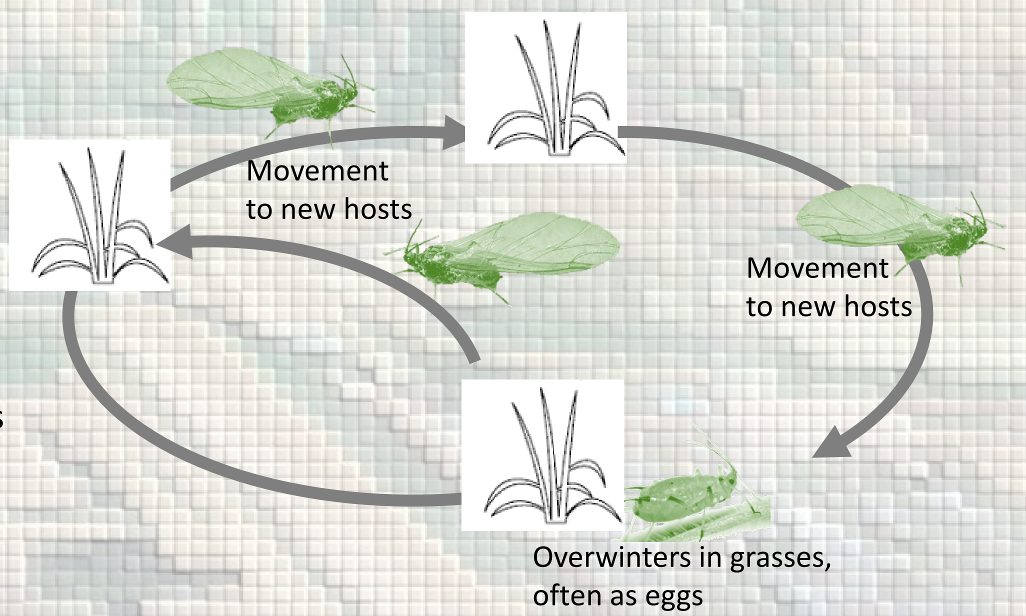
The pea aphid (*Acyrthosiphon pisum*) and grain aphid (*Sitobion arvenae*). Their life-cycles is relatively simple as far as aphids go, but still have very complex spatial dynamics.

Life-stages:

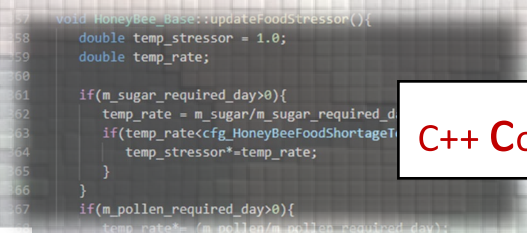
Egg

Nymph, apterae, females, males

Alate asexual, alate females, alate males



The forming of alates depends on weather, time of year crop conditions and local population density



C++ Code

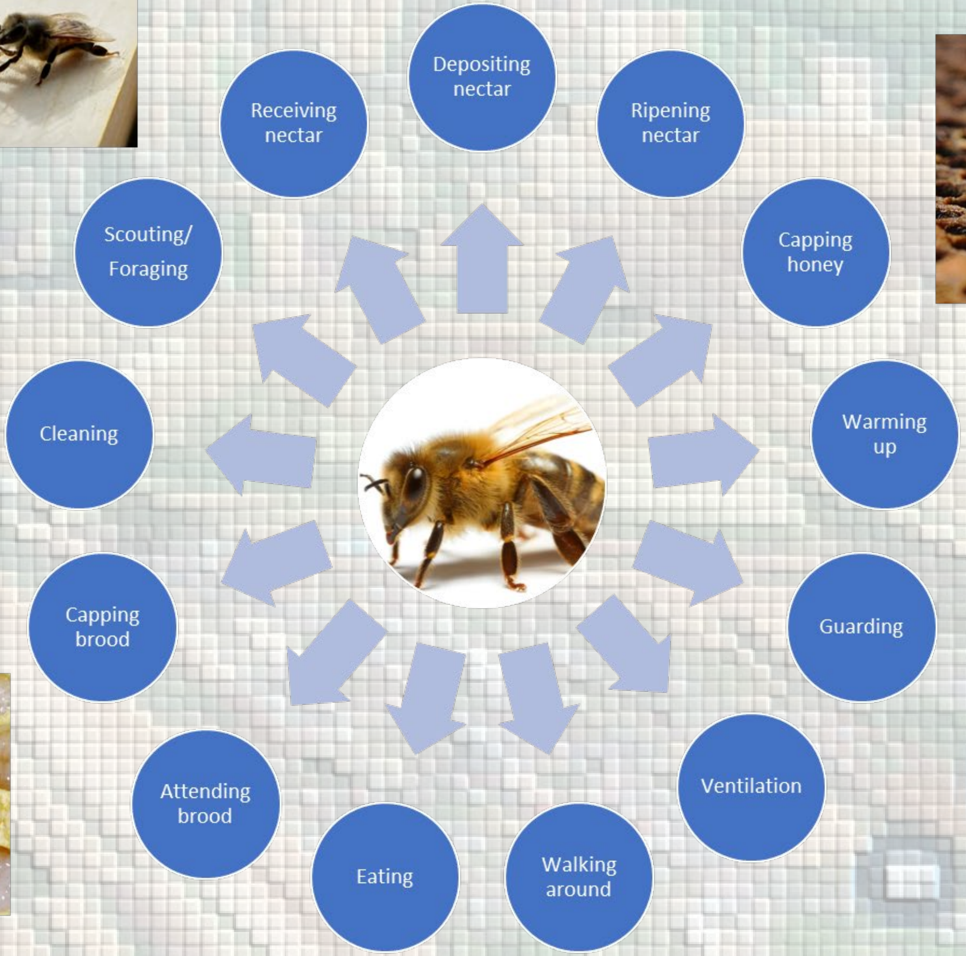
The ALMaSS species models

Another example …

ApisRAM

… the ALMaSS model of the honey bee

- a key pollinator
- with a complex ecology, inside and outside of the colony



```
void HoneyBee_Base::updateFoodStressor(){
    double temp_stressor = 1.0;
    double temp_rate;

    if(m_sugar_required_day>0){
        temp_rate = m_sugar/m_sugar_required_d
        if(temp_rate<cfg_HoneyBeeFoodShortageT
            temp_stressor*=temp_rate;
        }
    }
    if(m_pollen_required_day>0){
```

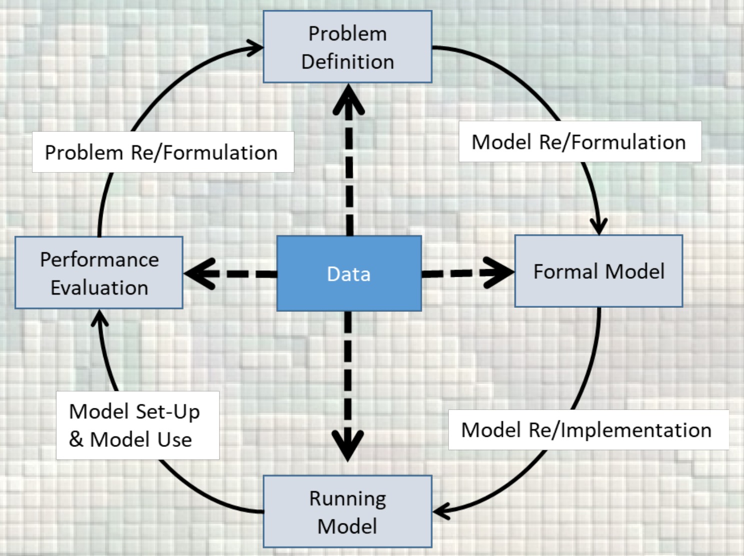
C++ Code

The ALMaSS species models

PRODUCTION OF AN ALMaSS SPECIES MODEL

Each species model involves :

- **production of a formal model**
- **creation the 'agent life story'**
- **how to represent this in code**
- **model testing**
- **sensitivity analysis**
- **uncertainty analysis**

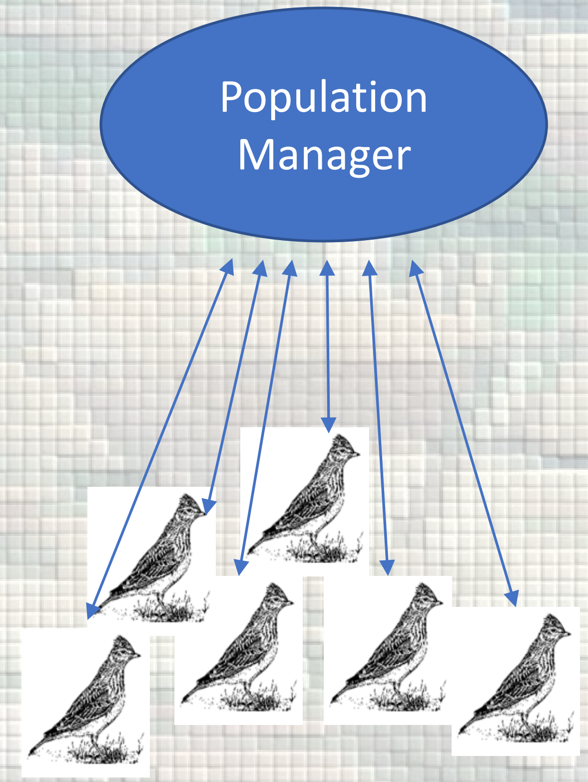


- There are many steps, many of which are iterative
- Requires skills in programming, modelling and the agent ecology and behaviour
- A team approach

The ALMaSS species models

PUTTING AN ALMaSS SPECIES MODEL INTO ALMaSS :

- potentially millions of agents operating at once
  e.g. 48 million concurrent beetle agents have been recorded
- their behaviours, counts etc. are controlled by the **population manager**
- the population manager is an **'instance' of a 'class'** and **exists as an 'object'** in the ALMaSS code
- the population manager is like an administrator for the agent models
- the population manager controls agent activity at each 'timestep'



The ALMaSS species models

PUTTING AN ALMaSS SPECIES MODEL INTO ALMaSS :

Time – one of the big challenges

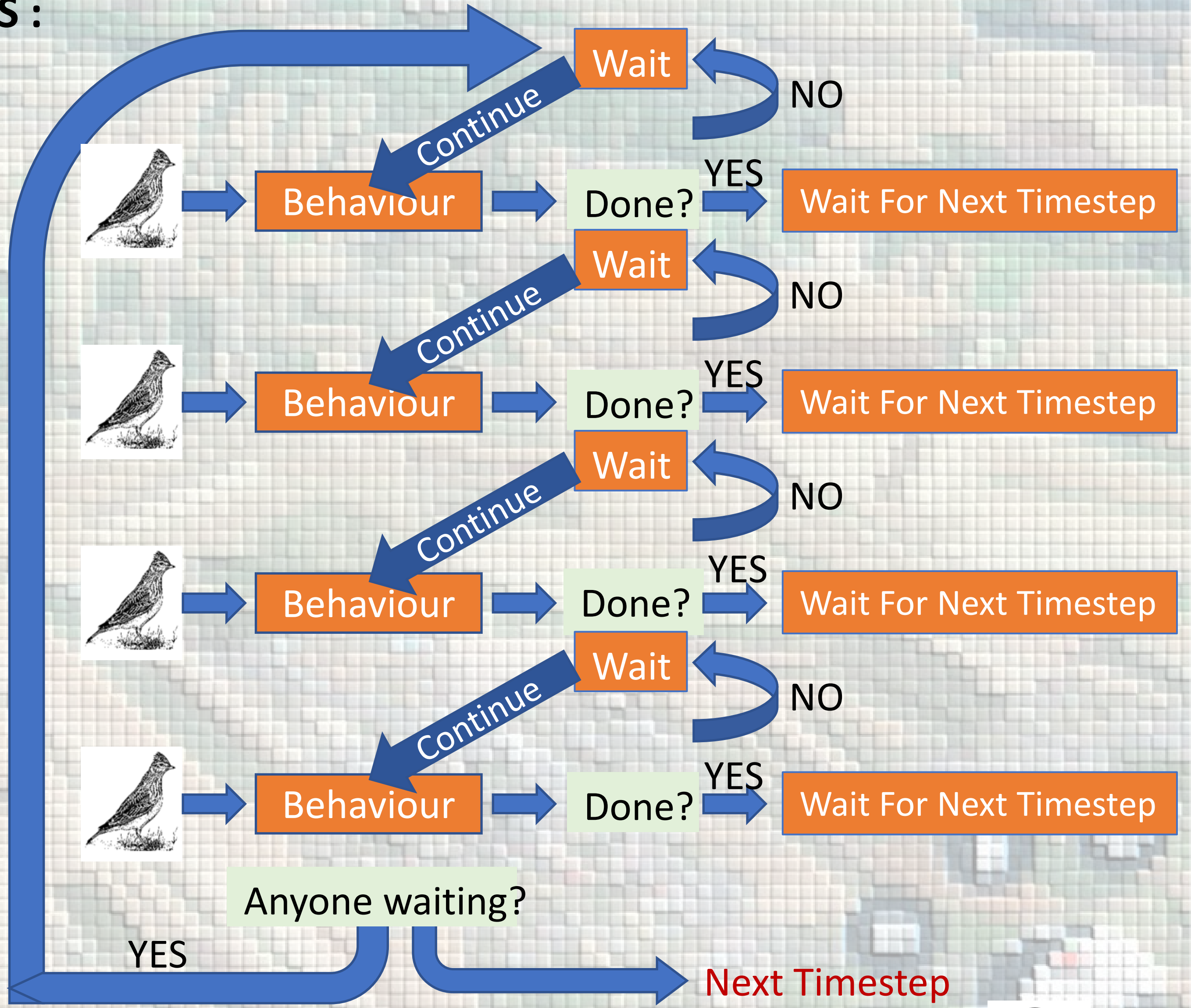
"Timesteps" :

- the landscape model : 1 day timesteps
- for agents, as necessary, e.g. 10 mins for bees

Timestep integration is constrained by serial computing

It is possible for an agent to exhibit many behaviours during a timestep

ALMaSS deals with this using **'step' functions**



The ALMaSS species models

PUTTING AN ALMaSS SPECIES MODEL INTO ALMaSS :

Agent movement in space – the other big challenge

- real organisms **perceive their surroundings** in highly complex ways
- replicating this in the model is impossible
- **so ALMaSS uses proxies**

- E.g. : vole movement design :
  - ❑ represent different types of movement
  - ❑ some more directed than others
  - ❑ but always avoiding unsuitable habitats

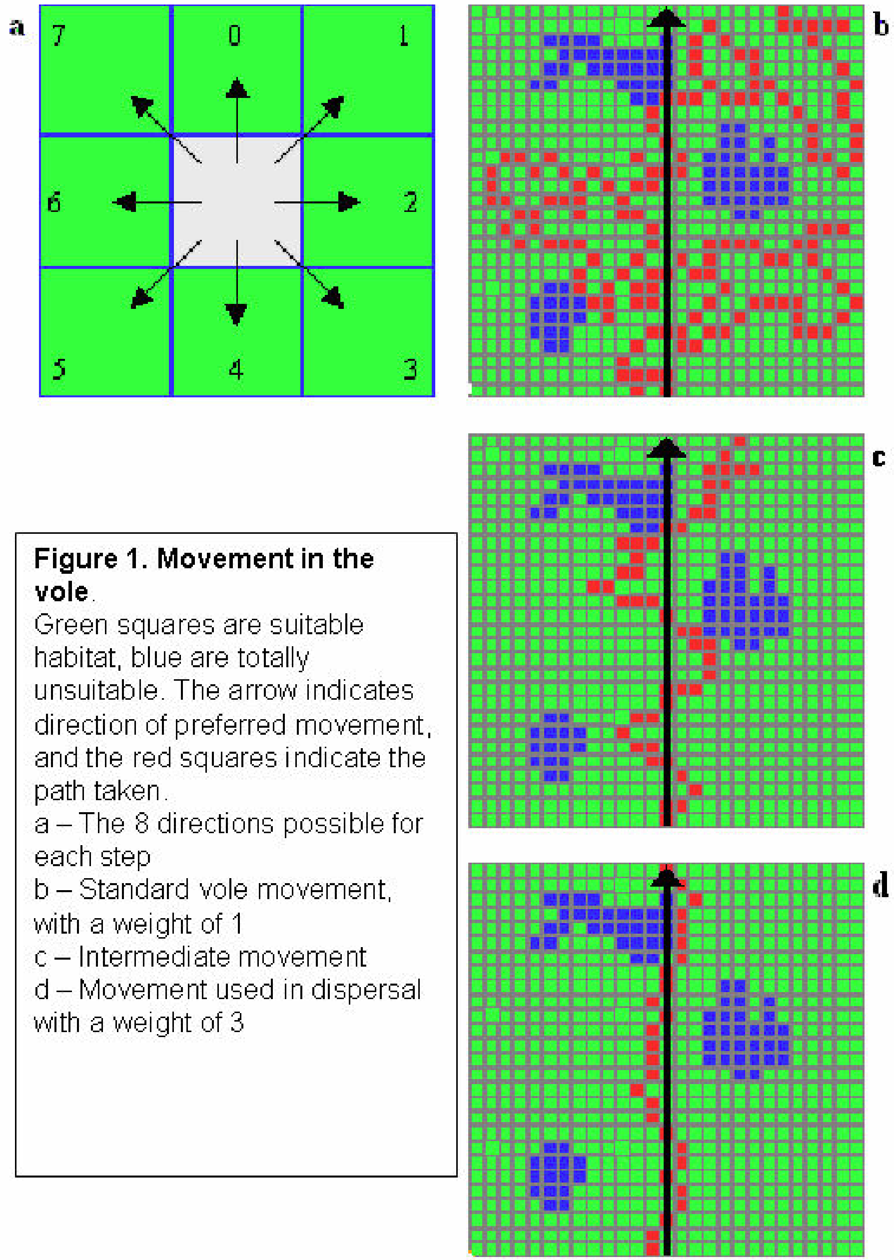
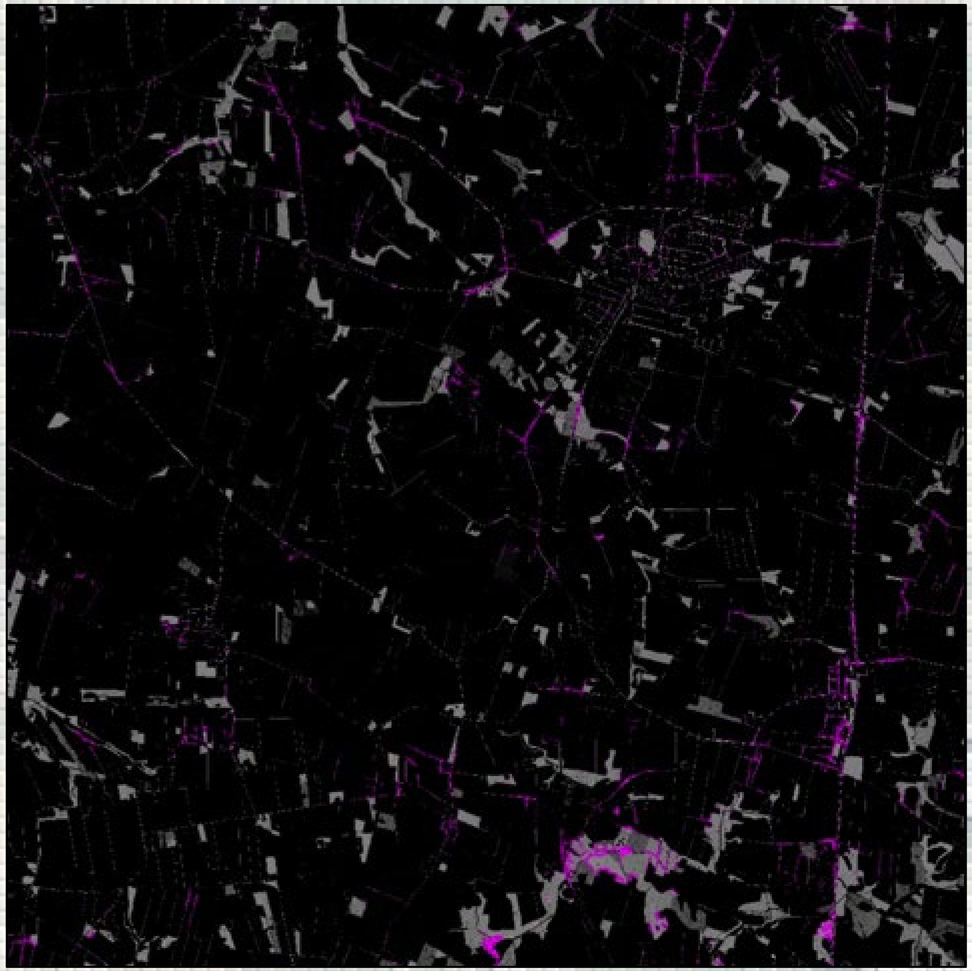


Figure 1. Movement in the vole.
Green squares are suitable habitat, blue are totally unsuitable. The arrow indicates direction of preferred movement, and the red squares indicate the path taken.
a – The 8 directions possible for each step
b – Standard vole movement, with a weight of 1
c – Intermediate movement
d – Movement used in dispersal with a weight of 3

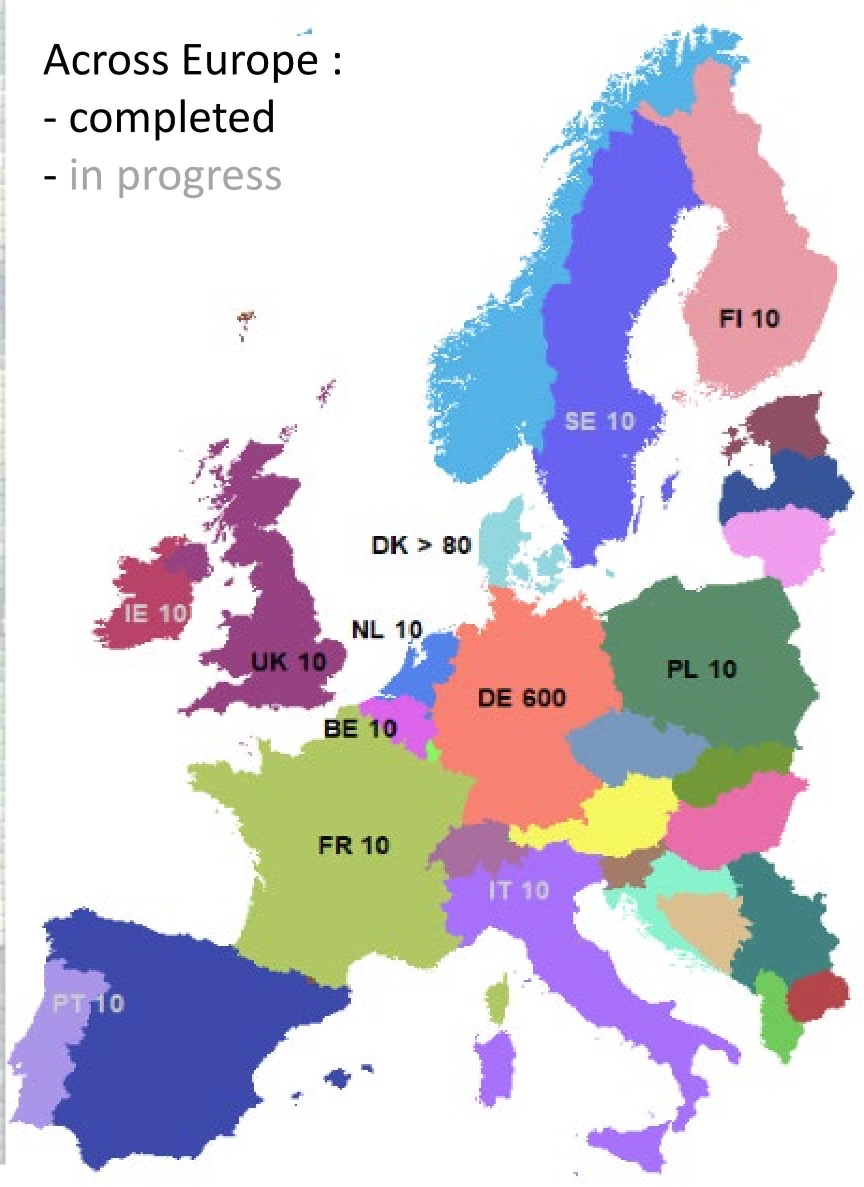
The ALMaSS species models

Species interactions → parallel programming

- ladybird and two species of aphid simulated together
- individuals of each species interact in time and space much as in the real world
- **requires a parallel programming approach to ALMaSS**



The ALMaSS landscape models



A static component :

essentially a landuse / landcover category map model of all relevant landscape components **including individual fields**

- a 1x1 m raster of each contiguous LS part as a ”parcel”
- a 10x10 km landscape typically has 50 K → 100 K parcels

with per parcel information on :

- unique ID, type, parcel size (i.e. number of raster cells)
- field parcel → farm linkage (anonymised farm ”ID”)
- parcel majority soil type (texture categories)
- parcel pollen and nectar production related factors

That drives, in an ALMaSS run, dynamic simulation of :

- arable field parcel crop type
- field parcel crop management
- landscape parcel biomass
- field parcel pesticide application / LS parcel pesticide drift
- parcel pollen and nectar production

all relative to field farm type (8 conventional, 8 organic + other) and driven by hourly / daily ERA5 weather data

And all synced together with the lives of the species organism agents

The ALMaSS landscape models

THE STATIC LANDSCAPE MODEL

polyref.txt … each individual landscape polygon in terms of its element type, polygonRef (= cell value), farmref, soil type,etc.

4712

PolyType	PolyRefNum	Area	FarmRef	UnSprayedMarginRef	SoilType	Openness	CentroidX	CentroidY	PollenNectarCurve
20	0	2035	0	-1	7	0	74	0	0
9	1	52	-1	-1	7	0	142	8	0
13	2	152	-1	-1	7	0	114	35	1
121	3	2215	-1	-1	7	0	156	11	0
.									
.									
13	991	10	-1	-1	-1	0	1065	472	2
20	992	9499	4	-1	7	0	1958	556	1
.									
.									
209	4710	2	-1	-1	-1	0	1085	1998	1
209	4711	76	-1	-1	-1	0	1548	1998	0

This file, this example, tells an ALMaSS run that

- there are 4712 individual polygons in this landscape window
- the polygon that is described by the pixels with pixel value ”0” is :
  - a landscape element type 20 polygon, which is one of the farm field element types
  - comprises 2035 pixels • is a field of the farm with the farm reference 0
  - has soil type 7 as its majority soil type • etc. etc.
- the polygon that is described by the pixels with pixel value ”3” is :
  - a landscape element type 121 polygon, which is ”Large Road”
  - comprises 2215 pixels • etc. etc.
- the polygon that is described by the pixels with pixel value ”992” is :
  - a landscape element type 20 polygon, which is one of the farm field element types
  - comprises 9499 pixels • is a field of the farm with the farm reference 4
  - has soil type 7 as its majority soil type • etc. etc.

Landscape raster, cell value as greyscale

cell value

= 0

= 3

= 992

farmref.txt … that relates the farm field polygons in the landscape window to their farm type code, via the FarmRef (= ID)

17

0	32
1	32
2	34
3	34
4	32
5	33
6	34
7	34
8	34
9	33
10	32
11	38
12	34
13	33
14	33
15	35
16	34

This file tells an ALMaSS run that :

- the fields in this LS window belong to 17 different farms
- the LS polygons with farmref value ”0”, ”1”, ”4”, … are part of farms of ALMaSS farmtype 32
- the LS polygons with farmref value ”2”, ”3”, ”6”, … are part of farms of ALMaSS farmtype 34
- etc.

The ALMaSS landscape models

PRODUCTION OF THE STATIC LANDSCAPE MODELS

- Digital topographical databases (SDFE Geodanmark)
- Data on protected areas / habitats (Arealinformation)
- Additional geodata data e.g. BaseMap
- LBST Internet Field Map (“marker”, “oekologiske arealer”)
- Animal Identification and Registration System (CHR)

Scripted sequence of raster and vector GIS processing steps + table data processing

Same overall sequence for all LS windows, but inner-details vary associated with national source data differences

PART-0 : pre-processing of raw GIS geodata, as needed ; may include use of additional data to determine field farm ID and farm type; analysis of crops per farm type to determine farm type crop rotations; done per LS window or national

---

Good set of geodata layers : typically 20-30

PART-1

- clipping of each of the national data layers to the LS window
- conversion of clip layer to a ”feature / not-feature” 1x1 m cell raster
- combining of rasters into 7 thematic maps (e.g. built-up, roads, nature, water)
- stacking of thematic maps

PART-2

- ”best guess” classification of large ”background” (empty) areas in the LS
- removal of inconsisitencies (e.g. ”slivers”, small holes) : a multi-stage process
- reclassification of codes to ALMaSS type of landcape element values
- regionalisation : each contiguous (same TOLE) set of cells gets a unique raster value
- exports to ”ALMaSS_files” folder

LS xx
- outputs
- xx.gdb

- ALMaSS_files
- project.gdb
- scratch
- scratch.gdb
- xx.gdb

- Raster as ascii
- ATTR_xx.csv
- FIELDS_xx.csv
- SOIL_xx.csv

PART-3

- Raster as ascii
- ATTR_xx.csv
- FIELDS_xx.csv
- SOIL_xx.csv

ascii to LS binary

Python with PANDAS data table manipulations

xx.lsb

xx_polyref.txt

xx_farmref.txt

THE LS INPUTS FOR ALMaSS

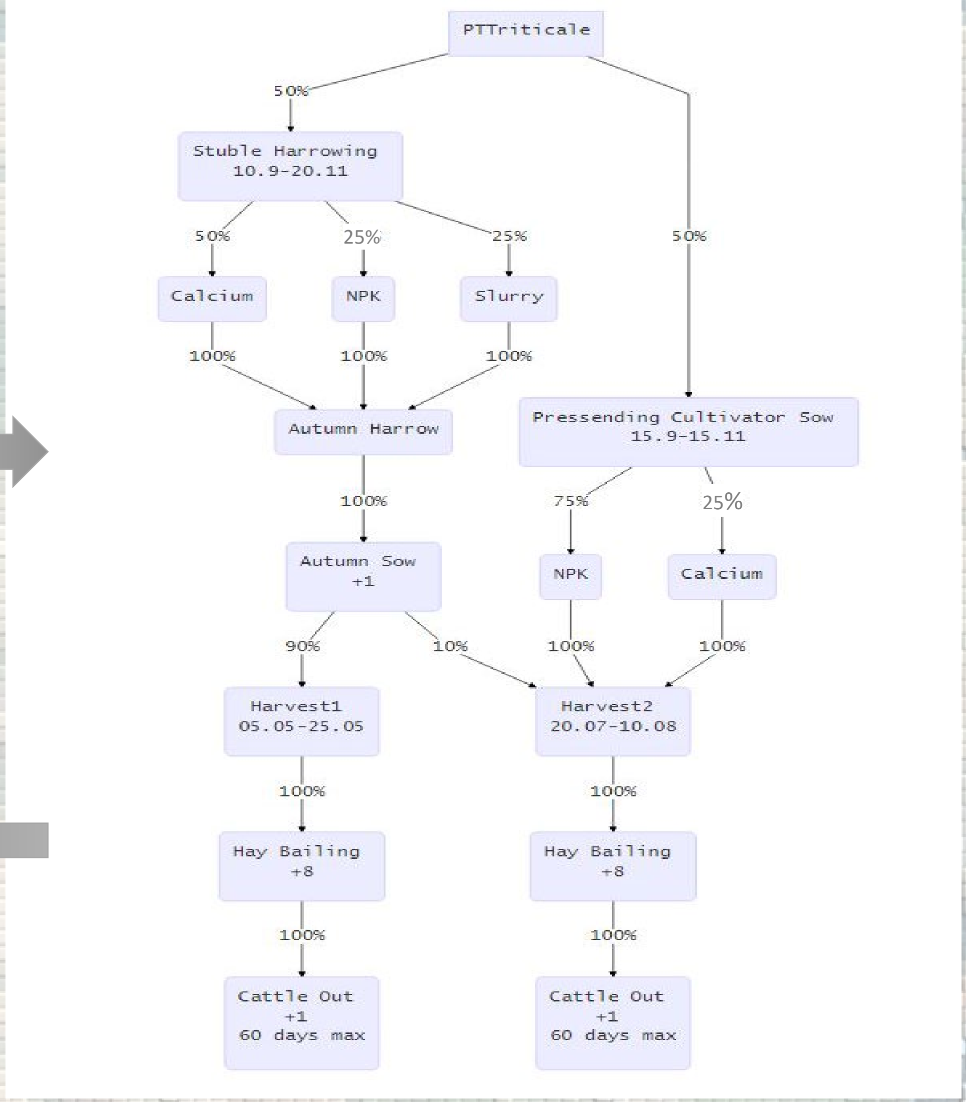
The ALMaSS landscape models

INCLUSION OF LANDSCAPE DYNAMICS : CROP MANAGEMENT

Crop management

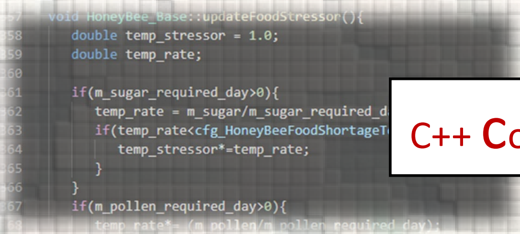
- Farmer´s advisors
- Farmer’s associations
- Farmers (field management records)

Interviews / Enquires



talks to the LS via the lsb, polyref, farmref file triplet

ALMaSS run



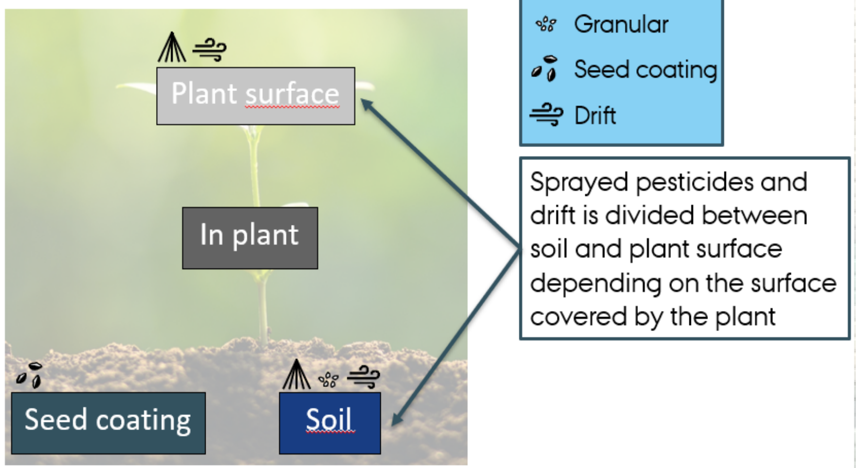
C++ Code

ALMaSS includes Crop Management code for > 300 crops

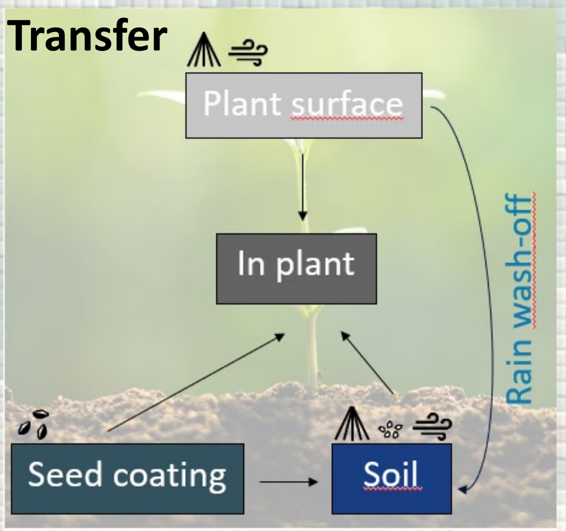
The ALMaSS landscape models

INCLUSION OF LANDSCAPE DYNAMICS : PESTICIDE APPLICATION, COMPARTMENT TRANSFER AND DISPERSION

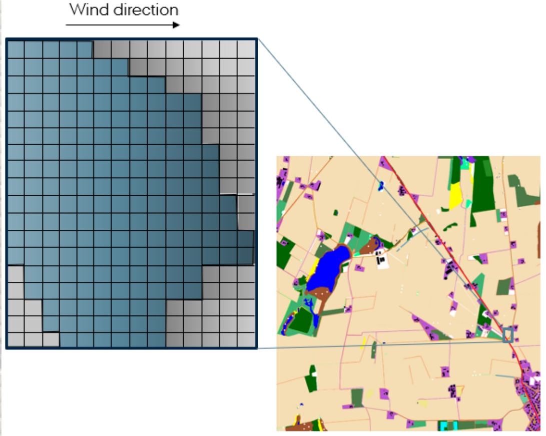
Application

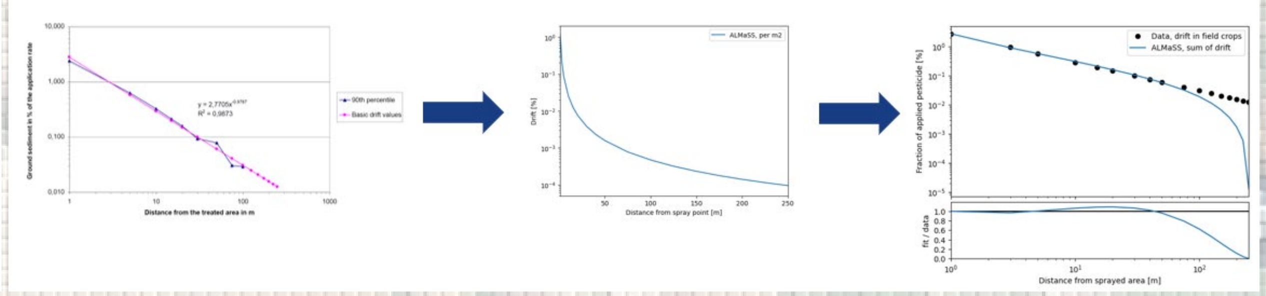


Transfer



Drift dispersion





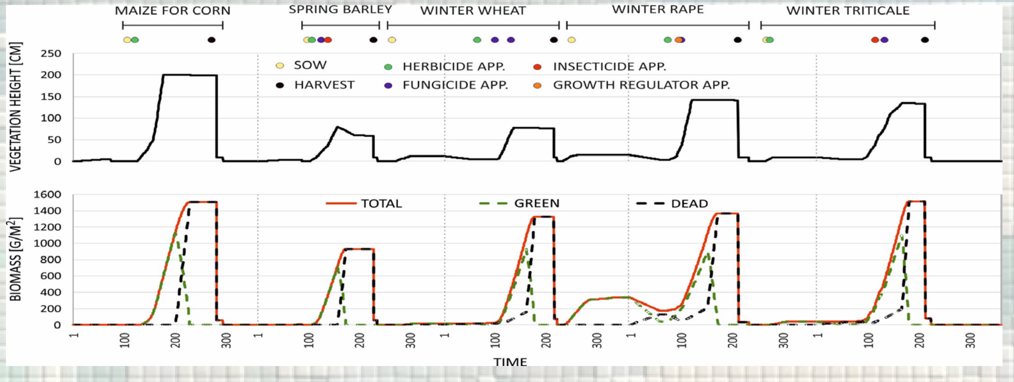
The ALMaSS landscape models

+ DYNAMIC LANDSCAPE MODELLING OF :

Vegetation biomass

Pollen and nectar qualities and quantities

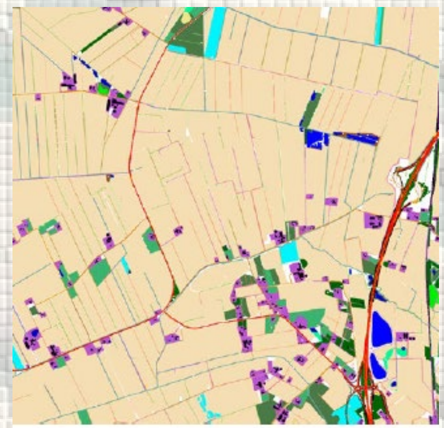
Grazing patterns



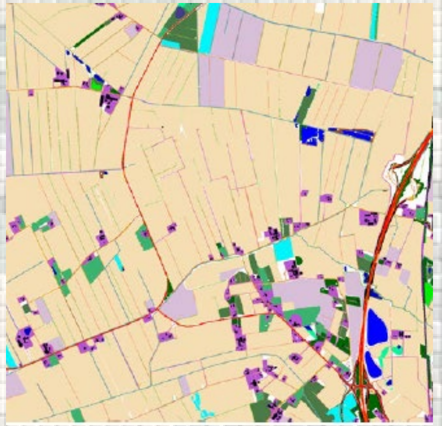
+ INCLUSION OF LANDSCAPE CHANGE SCENARIOS

Farming with addition of uncultivated field boundaries, flower strips, hedge banks, field strips, field patches, set-aside, etc.

- The GUDP ICROFS Organic RDD+ project **Organic+**



Baseline landscape (ALMaSS LS model)



ALMaSS run scenario 1: Set-aside, 10 % by area

ALMaSS run scenario 2: Field strips 6 m, 7% by area

gudp ICROFS Organic RDD

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ECOSCIENCE

SESS

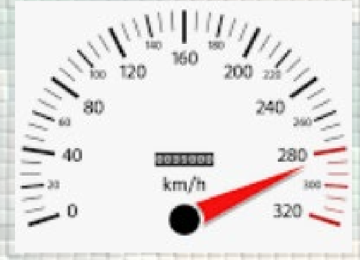
The ALMaSS landscape models

back to … PRODUCTION OF THE STATIC LANDSCAPE MODELS

THE LS INPUTS FOR ALMaSS

- xx.lsb
- xx_polyref.txt
- xx_farmref.txt

WHY NOT USE ESRI FORMAT OR SOME OTHER EXISTING GIS DATA MODEL?



Yes, ALMaSS can run on a PC in Windows

Reality : SCALING-UP

model testing, validations, results runs …
dozens of landscapes, multiple species,
multiple senarios, 30+ year runs, many replications

ALMaSS is coded to make **highly efficient** use of core memory, including bit addressing

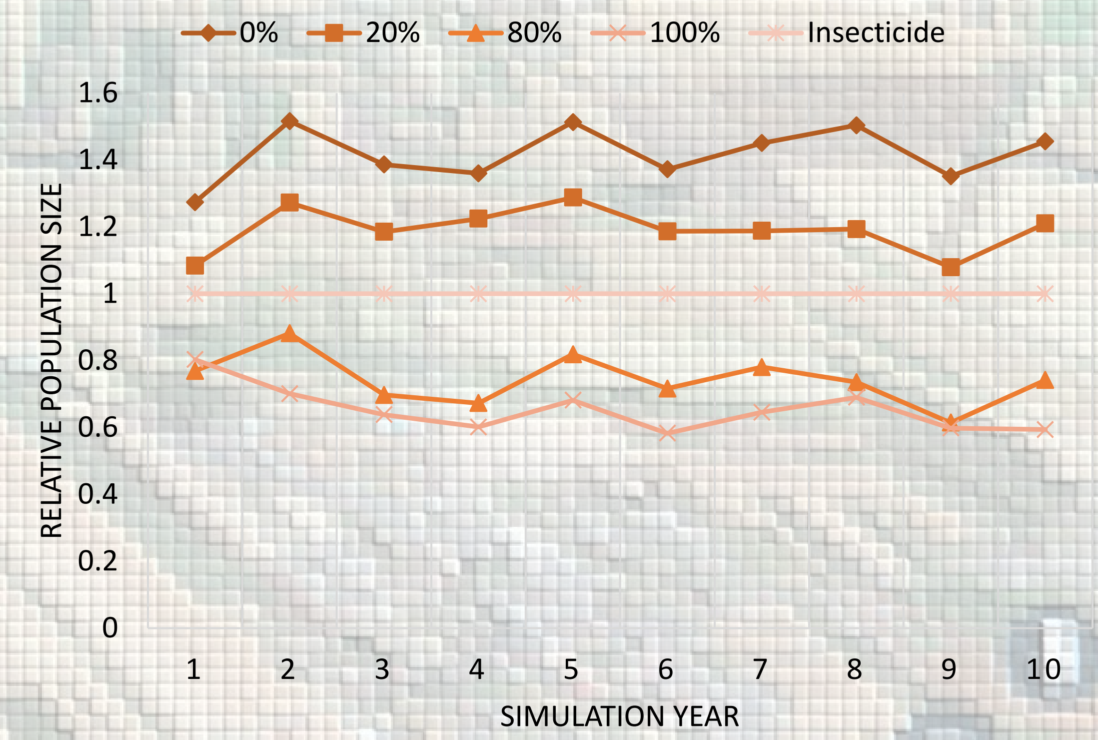
- xx.lsb
- xx_polyref.txt
- xx_farmref.txt

ALMaSS : some results examples

ALMaSS as a virtual ("in silico") laboratory
– to test scenarios for impact

a single species (spider)
+
a single management action (application of biopesticide) with different levels:

***Erigone atra* population size under four assumptions of double application of biopesticide (0-100%) mortality compared to a single insecticide application (80% Mortality) in monoculture**



ALMaSS : some results examples

Stacking and optimising managements

(client : Horizon2020, EcoStack)

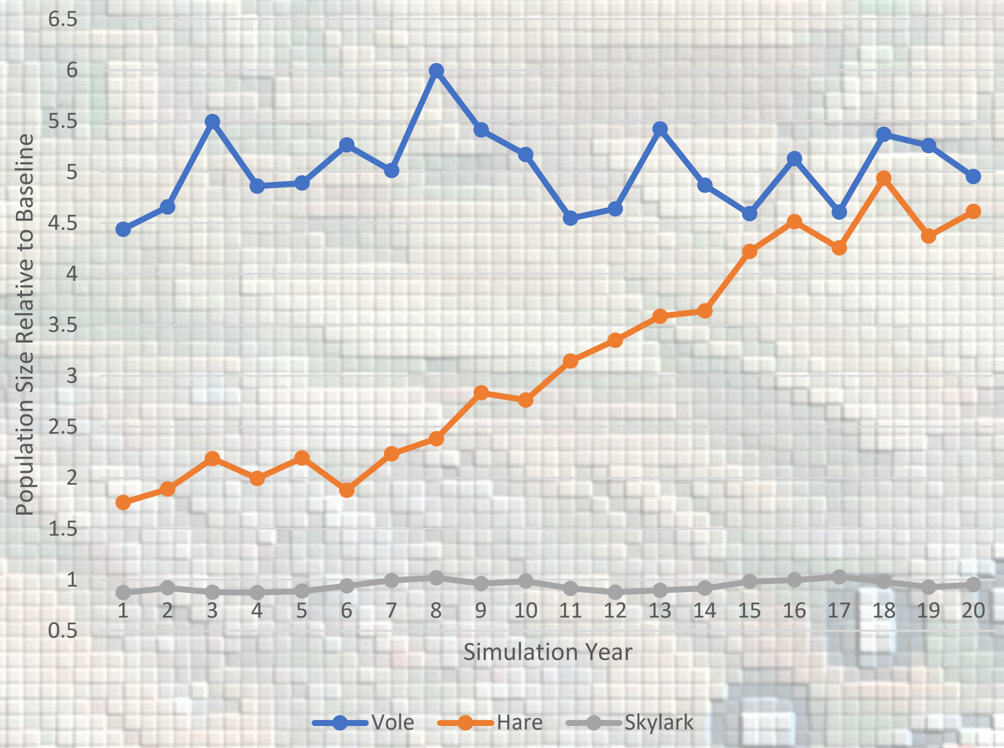
stack managements and test across different species:

e.g. a combined management scenario of :

- **biocide**
- **field margin grass/flowers**
- **diversified rotation**
- **set-aside**

compared to baseline

Relative population size of three vertebrate species after the application of stacked management scenarios



ALMaSS : some results examples

Mapping bat pesticide exposure risk

… coincidence of bat activity and high pesticide application in orchards and bush fruit fields
(client : Danish Environment Protection Agency)

organic field

orchard / bush fruit

Modelled bat activity (BA)
April to September

log (sum of AMJJAS modBA)

0.9265 - 1.090	1.439 - 1.501
1.091 - 1.181	1.502 - 1.565
1.182 - 1.254	1.566 - 1.631
1.255 - 1.322	1.632 - 1.691
1.323 - 1.379	1.692 - 1.747
1.380 - 1.438	1.748 - 1.835

ALMaSS simulated pesticide application (PA)
April to September

log (sum of AMJJAS simF)

- 0.6021 - 0.9109
- 0.9110 - 1.220
- 1.221 - 1.529
- 1.530 - 1.837
- 1.838 - 2.146

0 0.5 1 2 km

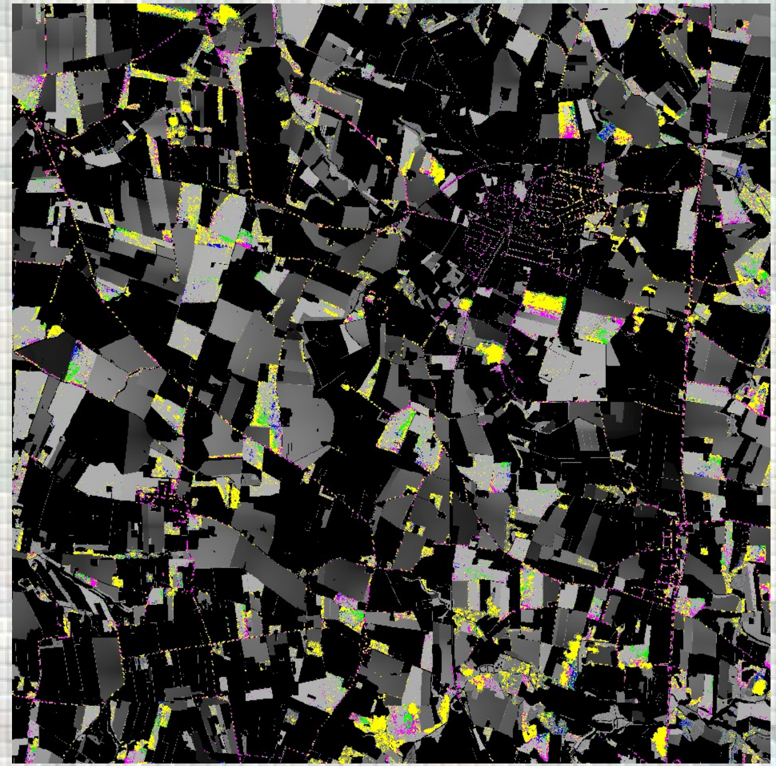
BA : high
PA : low
(organic)

BA : low
PA : medio

BA : high
PA : high
(conventional orchard)

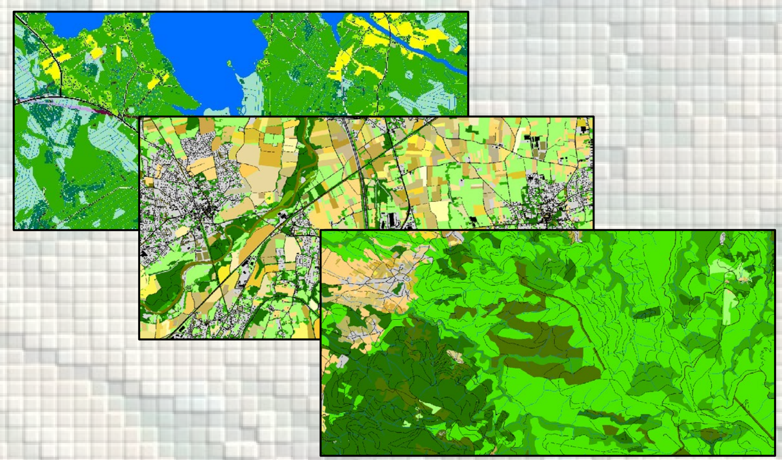
BA : medio
PA : medio

Interested in SESS / ALMaSS – please contact me or the SESS team



ALMaSS is run as a collaborative science project – we are happy to help if you want to use it or develop new models

Thank you for your attention



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- LinkedIn: https://www.linkedin.com/company/the-social-ecological-systems-simulation-sess-centre-aarhus-university
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