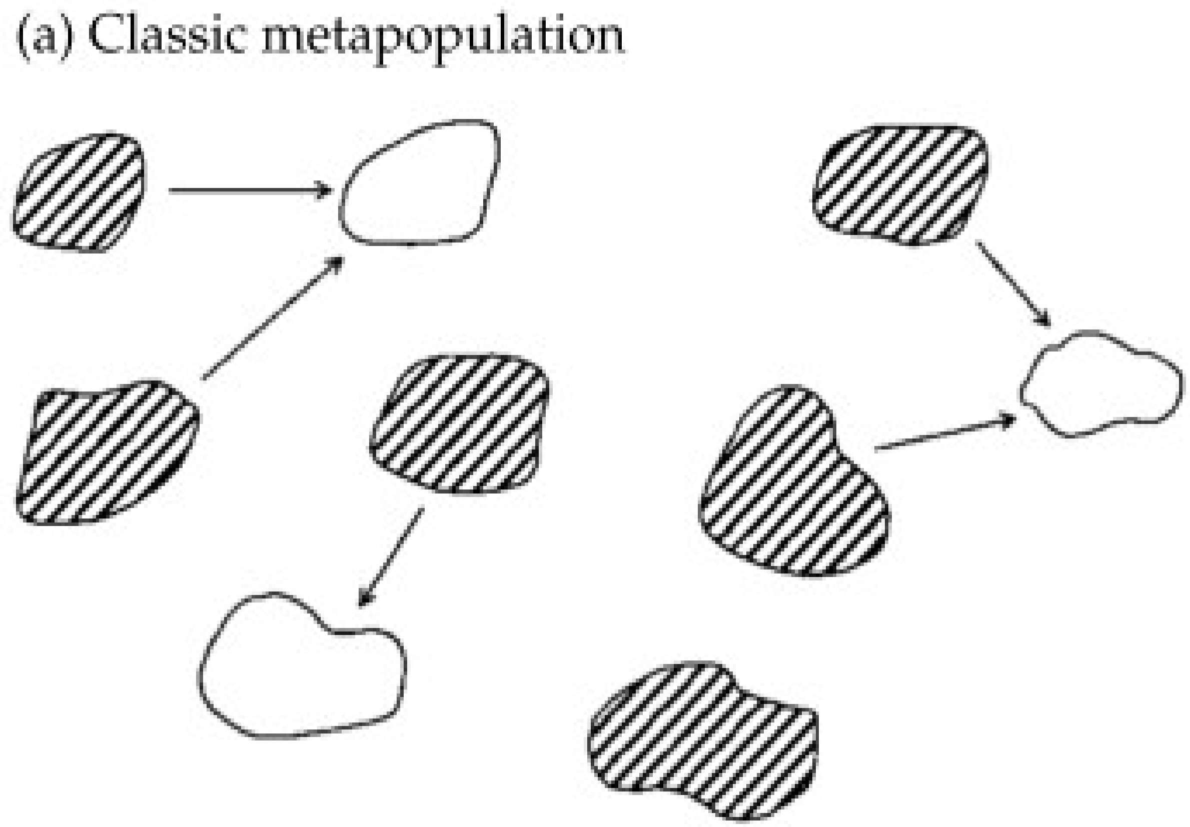
Metapopulations

- Populations are “groups of individuals belonging to the same species that live in a shared region at the same time and interbreed”.
- However .. most species are comprised of more than a single population
- Small populations are intrinsically more vulnerable to extinction than large populations
- If the “shared region” is a habitat patch within a linked network of similar patches the population may form part of a “metapopulation”

Metapopulations

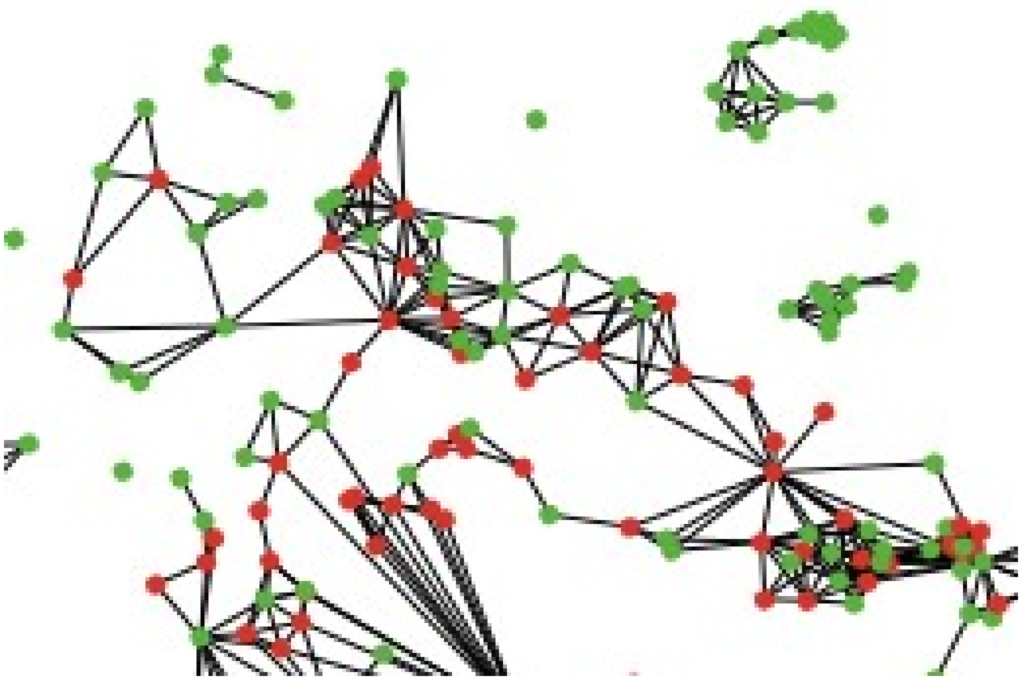
- A metapopulation occurs when a species occupies geographically separated patches within a landscape that are interconnected by occasional movements of individuals and gametes
- First metapopulation models constructed Richard Levins in papers published in 1969 and 1970

A metapopulation



Levin's model

$$\frac{dp}{dt} = cp(1-p) - ep$$



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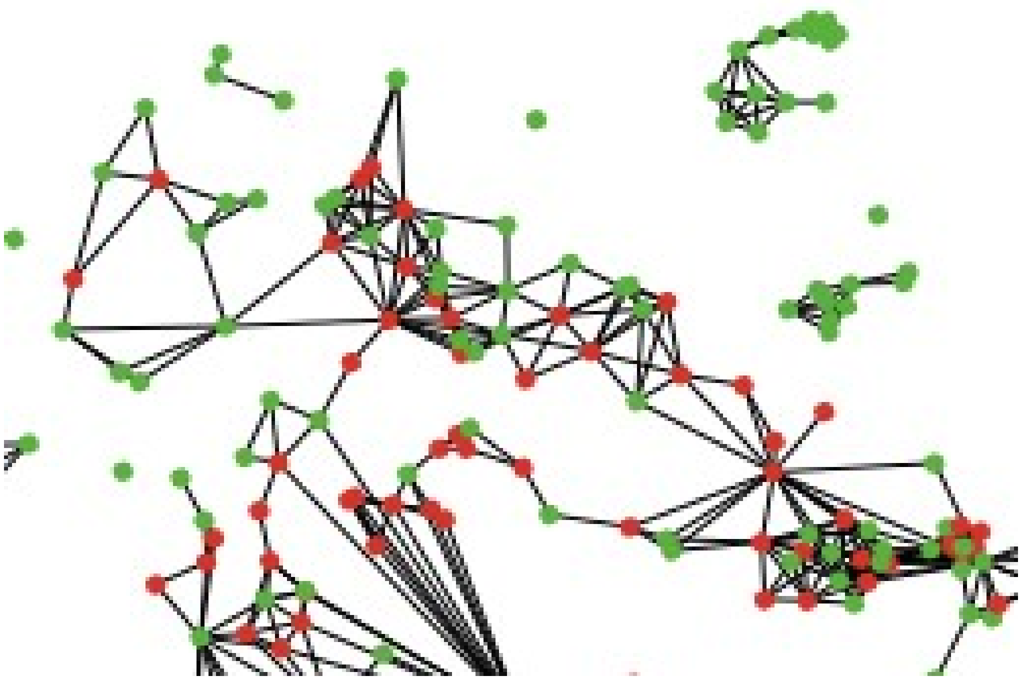
$$\frac{dp}{dt} = cp(1-p) - ep$$



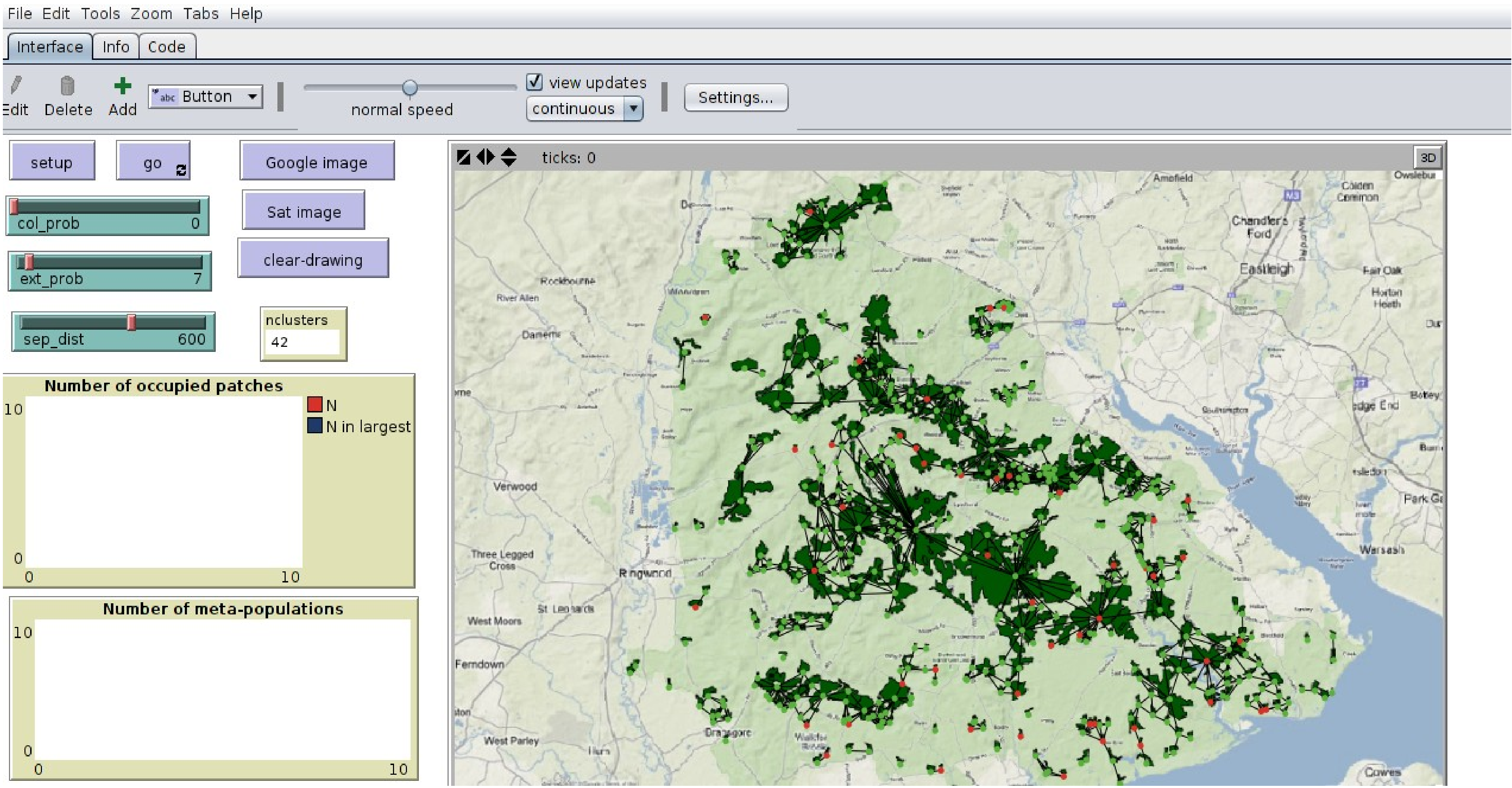
Understanding the underlying model

- p=proportion of occupied patches
- dp/dt is the rate of change in occupancy
- The last part of the equation is very simple
- The proportion of occupied patches declines by the extinction rate (e) multiplied by the proportion of occupied patches

$$\frac{dp}{dt} = ep$$

Understanding the model

- If the only process operating on the landscape were extinction (no colonisation) eventually all the populations would become extinct.
- The Levin's model assumes all populations have the same extinction rate
- So, the time to species level extinction depends on the intrinsic rate of population extinction and the number of populations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3D
Number of occupied patches
N
N in largest
Number of meta-populations
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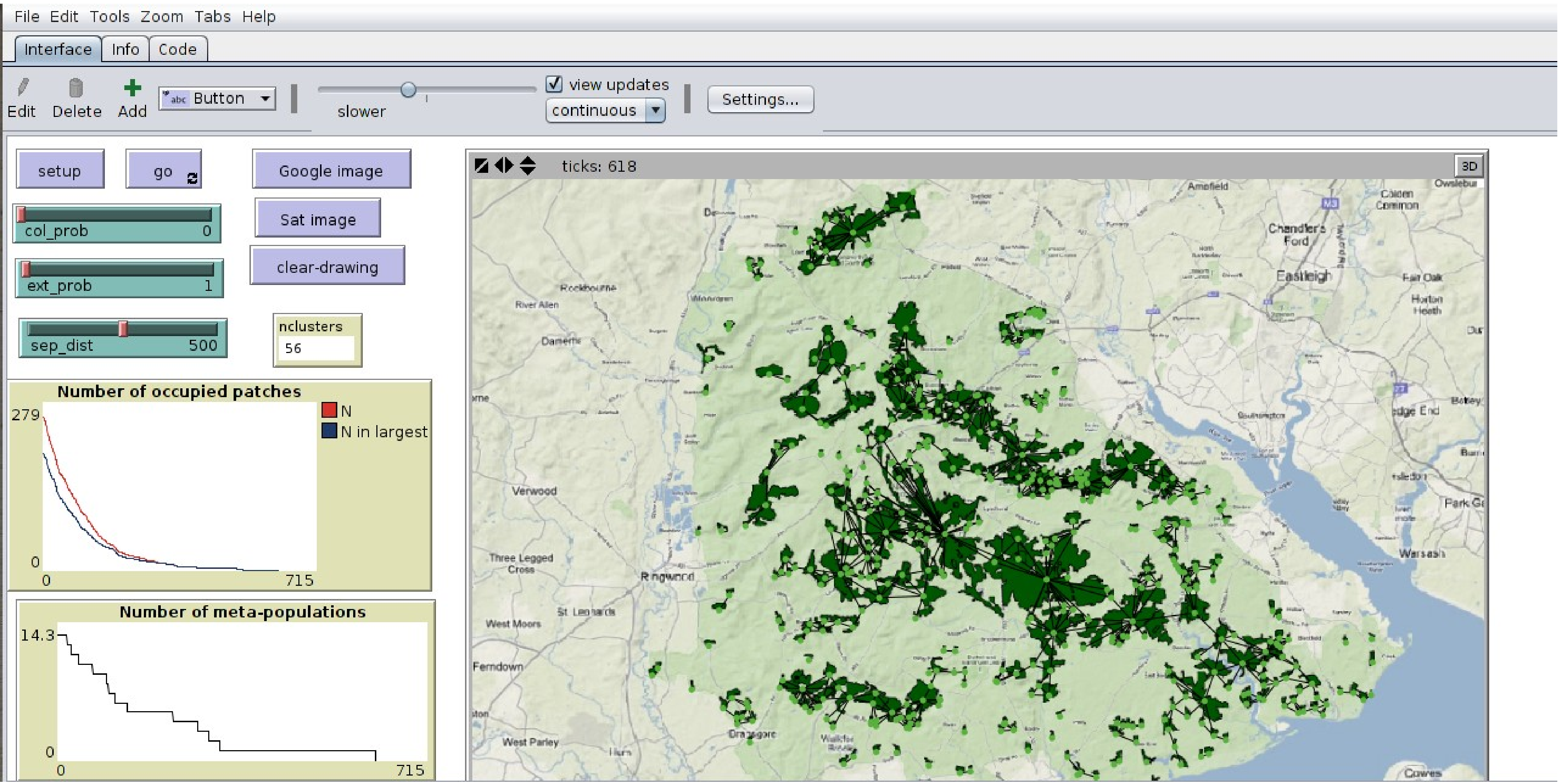
Ringwood
Verwood
Ferndown
West Moors
St Leonards
Three Legged Cross
West Parley
Southampton
Warsash
Cowes



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3D
Number of occupied patches
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715
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N in largest
Number of meta-populations
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Eastleigh
Ringwood
Verwood
Fordingbridge
Ferndown
West Moors
West Parley
Three Legged Cross
St. Leonards
Rockbourne
River Allen
Damerham
Chandler's Ford
Southampton
Warsash
Park Gate
Cowes
Ampfield

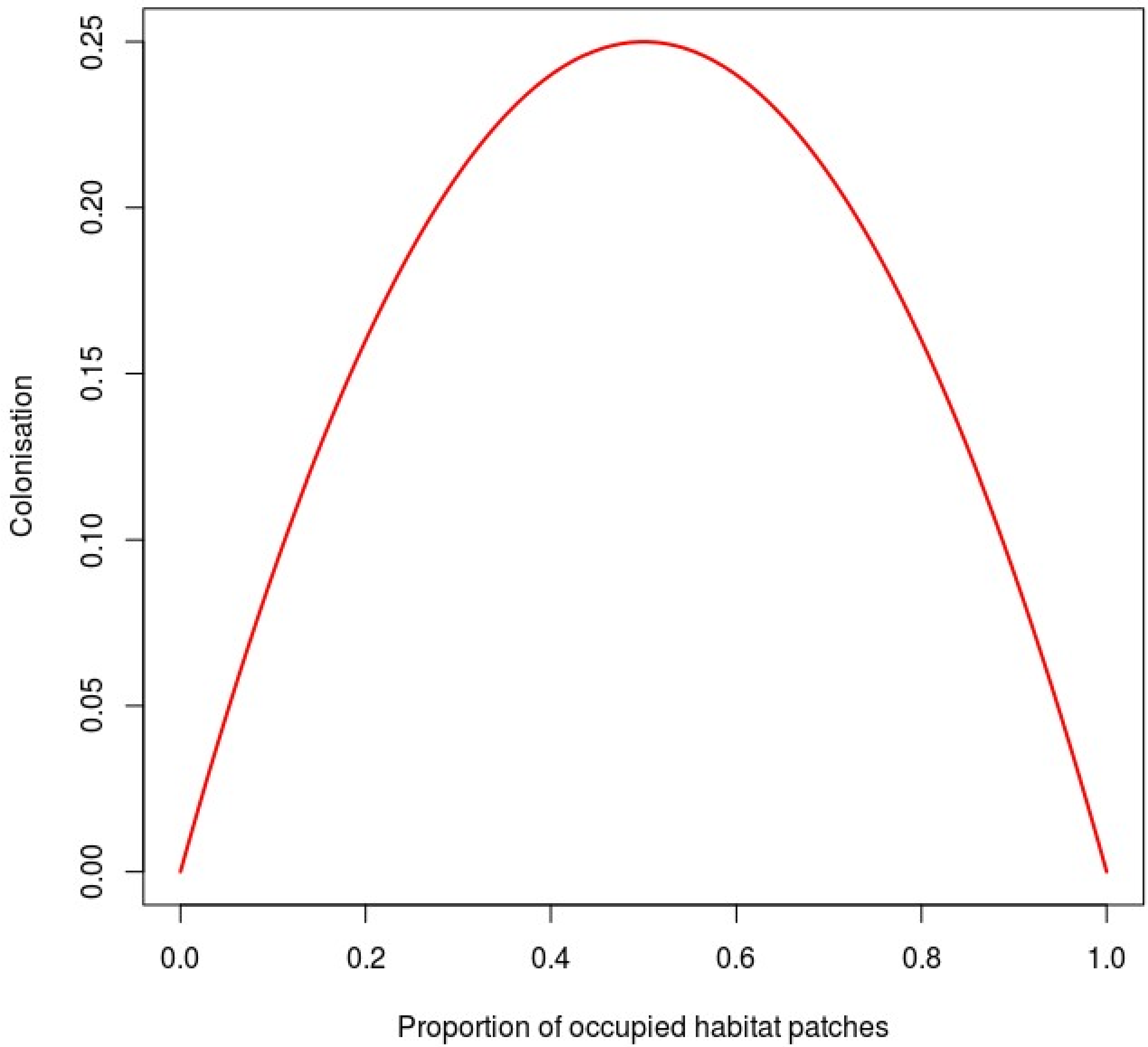
Understanding the model

- Colonisation (i.e. the founding of new populations) can take place within a network of connected patches
- There will be a balance between extinctions colonisations
- This could result in a sustainable metapopulation

Rate of colonisation

- Colonisation requires a source population to provide colonisers
- Colonisation can only take place if there are empty patches of habitat
- Thus colonisation follows a parabolic pattern with a peak occurring when half the patches are occupied

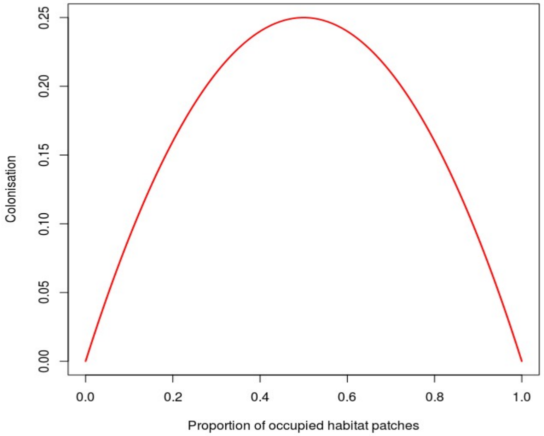
Colonisation



Levin's equation

- The equation represents colonisation as a constant function of the product of empty patches and occupied patches

$$\frac{dp}{dt} = cp\left(1 - p\right)$$



Some simple maths

$$\frac{dp}{dt} = cp\left(1 - p\right) - ep$$

If there is no change in the number of patches occupied, then

$$\frac{dp}{dt} = 0$$

In other words ..

$$0 = cp\left(1 - p\right)$$

Some simple maths

At equilibrium

$$cp(1-p)=ep$$

$$p = 1 - \frac{e}{c}$$

It is difficult to find a solution where
p = 1 (all habitats are occupied) as this implies

$$c=\infty$$

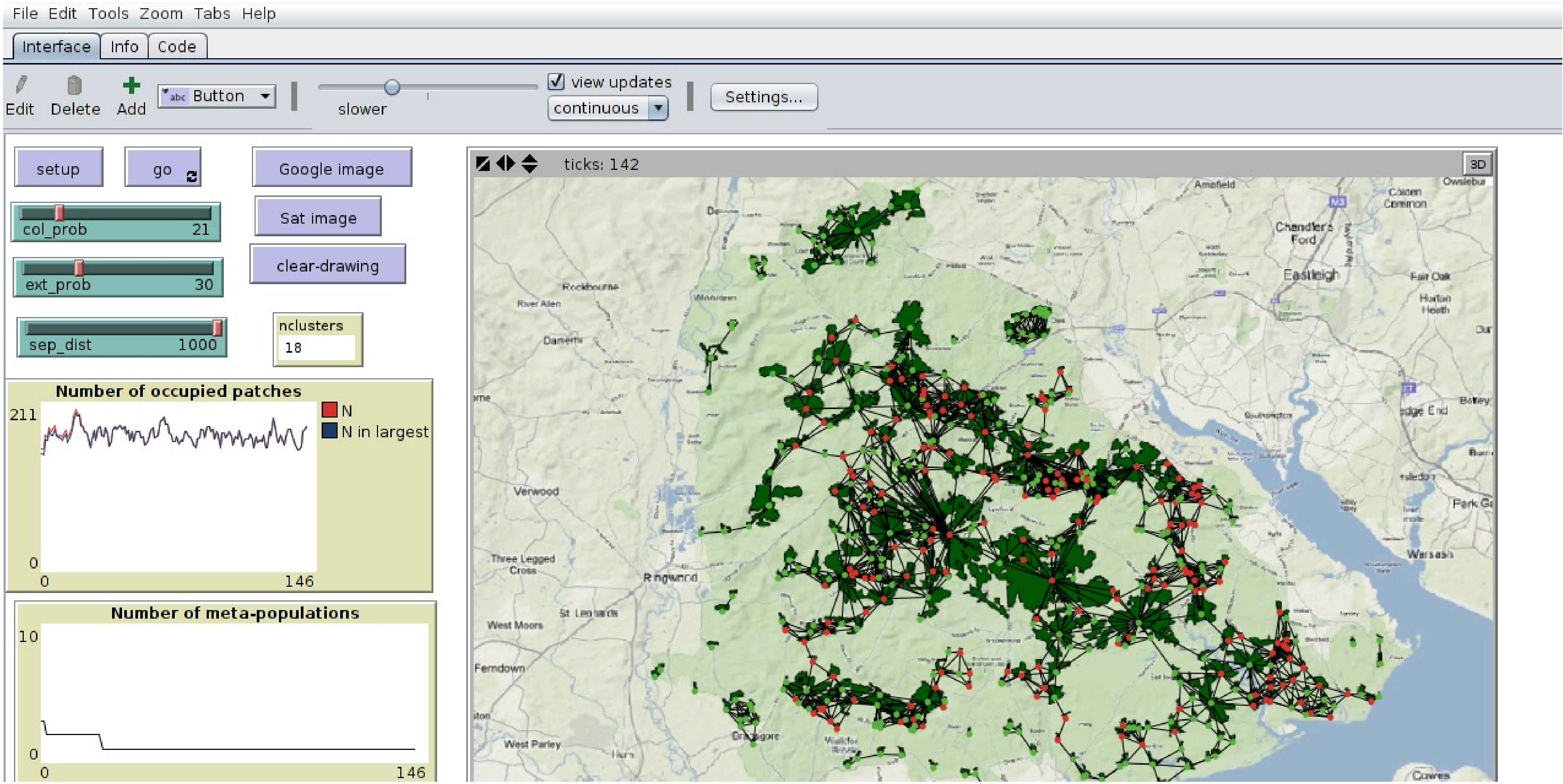
Or

$$e=o$$

What does this imply?

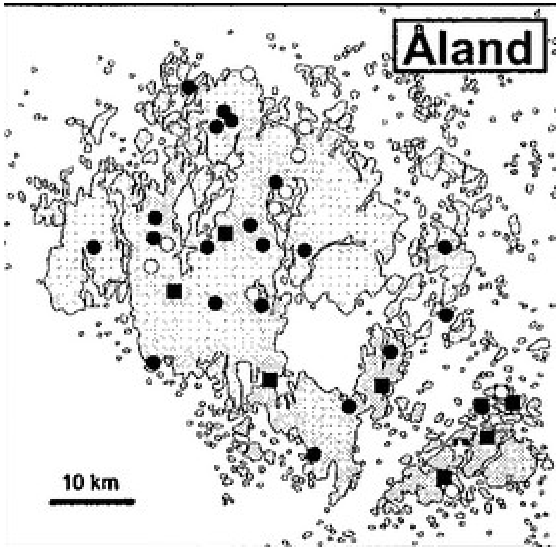
- Although individual population extinctions may be inevitable, connected habitats can be recolonised
- Recolonisations are most rapid if there are equal numbers of occupied habitats and suitable (unoccupied) habitats
- Metapopulations are dynamic. Some suitable habitats will always be unoccupied (unless there is no extinction or instantaneous recolonisation).

Metapopulation model



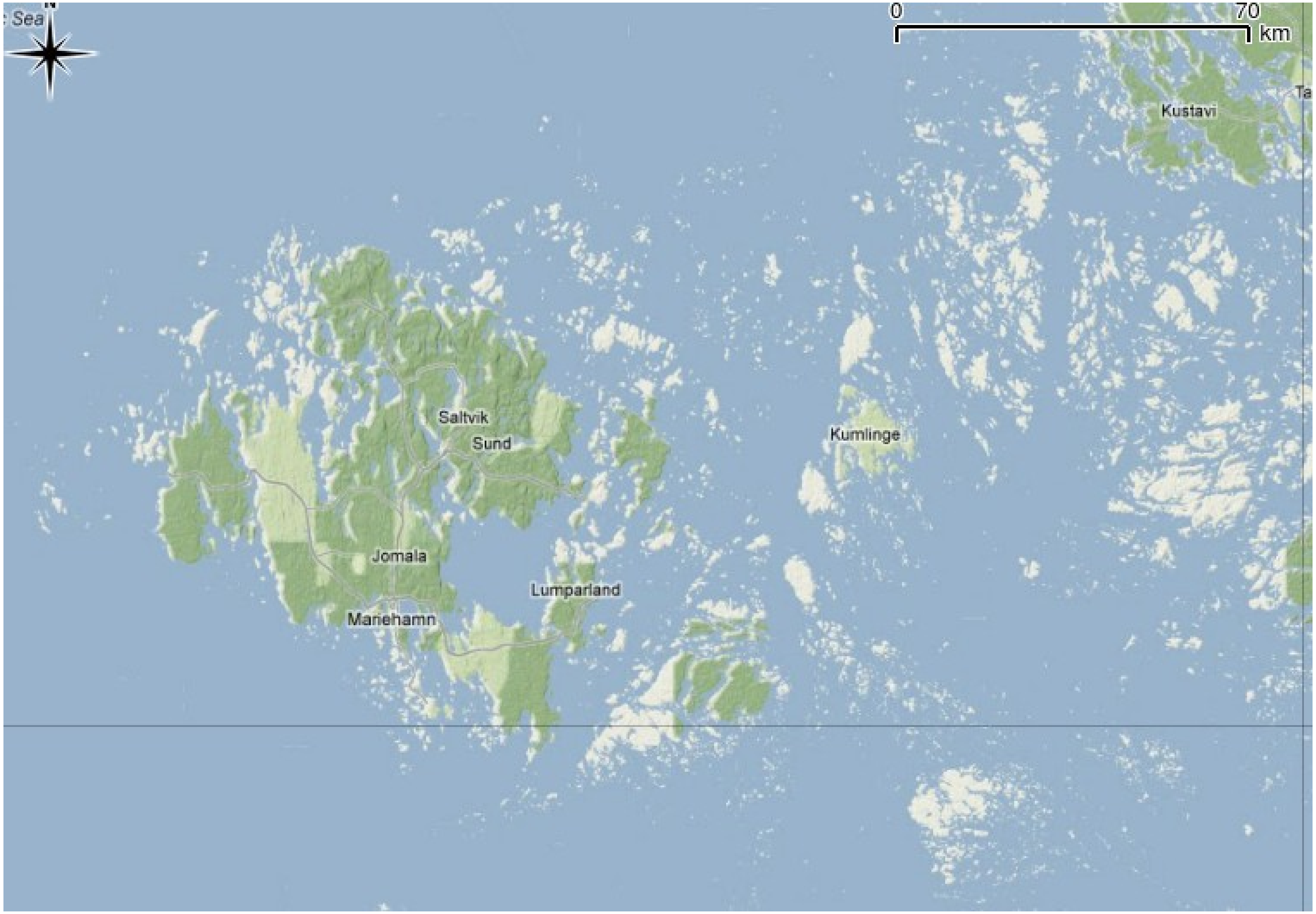
Classic metapopulation

- Hanski and his colleagues have worked on the Glanville fritillary (*Melitaea cinxia*) for over 30 years



Aland islands

Aland islands



Model system

- Over 6000 islands
- Network of small meadows
- Ideal system for testing theory
- Hanski found patterns in the empirical system that partly matched the predictions from models
- Concluded that the system **does** behave as a metapopulation but in a complex manner

Hanski's four conditions for classic meta-population dynamics

1) Habitat patches support local breeding populations,
2) No single population is large enough to ensure long-term survival,
3) Patches are not too isolated to prevent recolonisation, and
4) Local dynamics are sufficiently asynchronous to make simultaneous extinction of all local populations unlikely

Silver studded blue

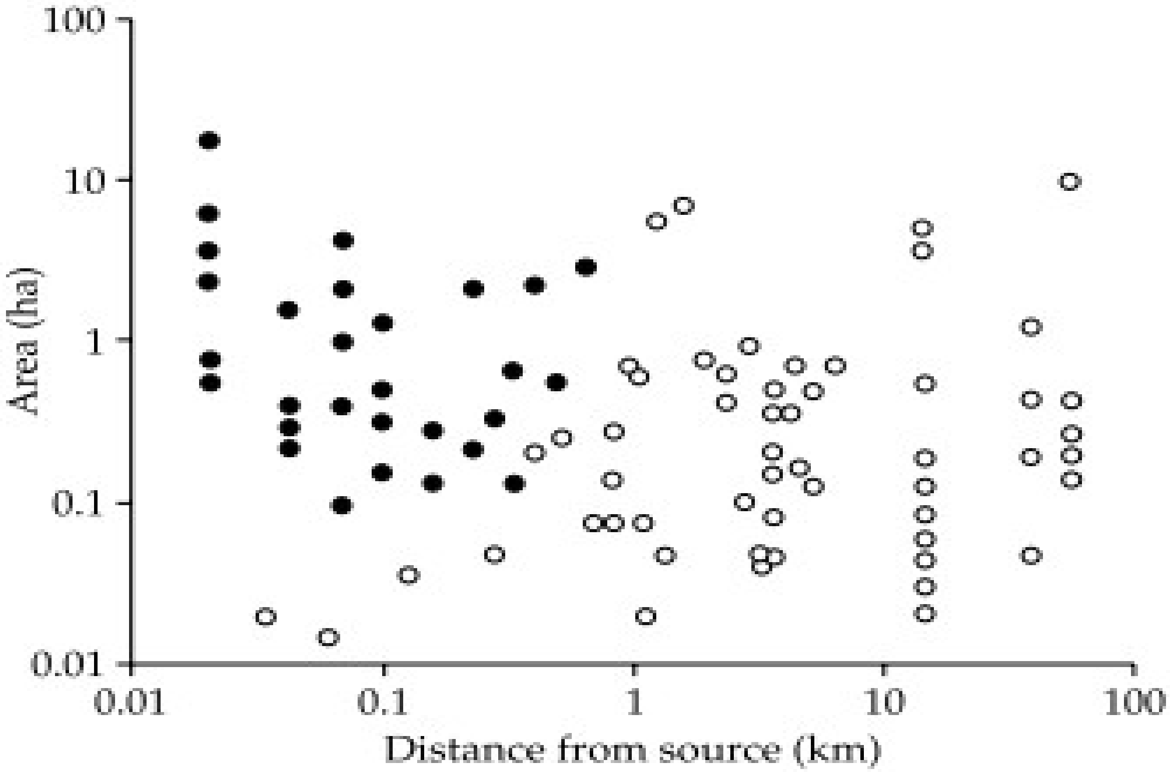


Figure 10.3 Occupancy of suitable habitat by the silver-studded blue butterfly (*Plebejus argus*) in North Wales in 1990. Most patches larger than 0.1 ha were occupied (filled circle), provided that they were within about 600 m of another occupied patch. Beyond this distance, no patches were occupied (open circle), regardless of patch size. (Redrawn from Thomas and Harrison 1992.)

Spatial dynamics
of a patchily distributed
butterfly species
Thomas, CD and
Harrison S (1992)
Journal of Animal Ecology
61:2

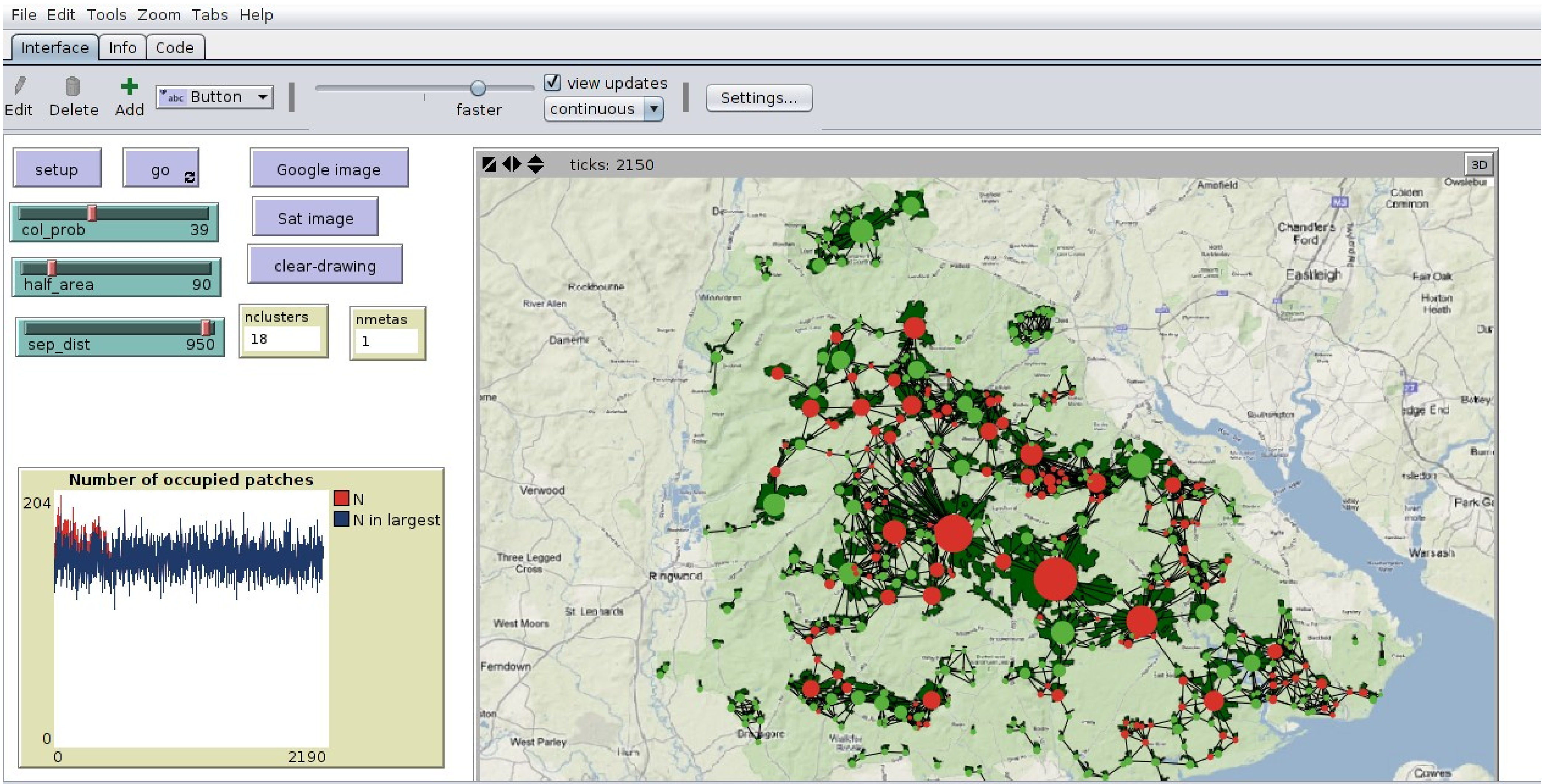
Additions to Levin's model

- Levin's original model treated all populations as identical
- Same size, same probability of extinction
- This is obviously not realistic.
- Extinction probability should be made a function of area (population size)
- This adds a “source sink” element to the model

Additions to Levin's model

- Each subpopulation has its own birth rate, death rate, and probability of going extinct
- Dynamics depend on interpatch distance, dispersal ability, number of patches
- Collapses if number of patches becomes too small

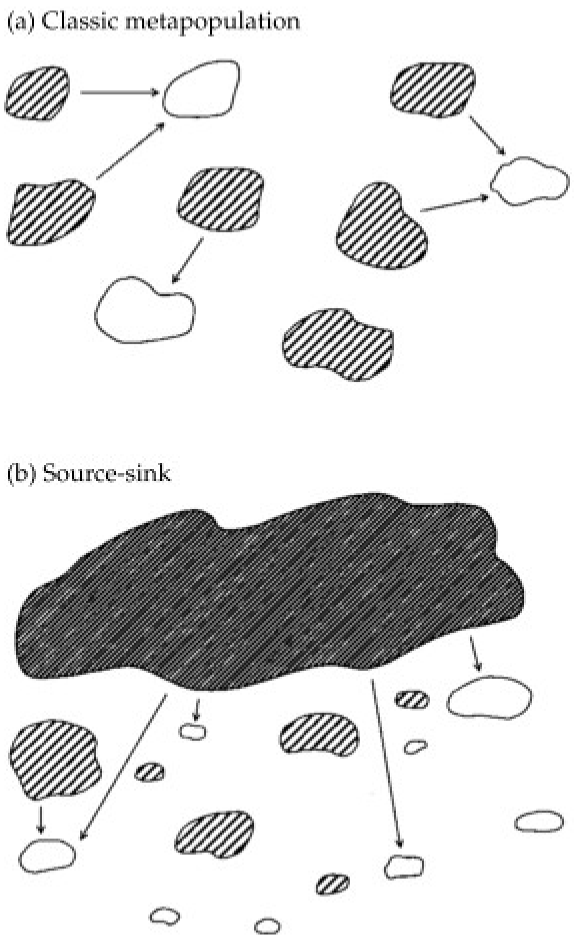
Including area in the model



Source – sink dynamics

- Real metapopulations are always complex
- Large patches tend to act as sources for colonisations
- Small patches tend to act as sinks
- But .. recolonisation of large patches can be the result of the (temporary) survival of populations on small patches

Source sink dynamics



Example

- Shoener and Spiller (1987) demonstrated that small populations of Orb web spiders in the Bahamas were constantly becoming extinct
- These small populations were “rescued” by recolonisation from larger populations

Source sink dynamics

- Complicates analysis of a network
- Small patches of relatively poor habitat may hold populations of the organism if they are close to a source
- In contrast, larger patches of prime habitat may remain unoccupied if distant from a source
- Enhancing connectivity may be especially important.

Population Viability Analysis

Sophisticated PVA takes into account spatial elements (eg. RAMAS GIS software)

Spatial structure of landscapes (fragmentation) often very important

Population structure may be subdivided spatially

Human induced habitat fragmentation may play a major role.

Incorporating metapopulation theory in management

- Interagency Spotted Owl Scientific Committee in US
- Proposed management strategy for spotted owl based on theory
- Metapopulation models have to assume a great deal about owl biology
- US district judge ruled against the plan on the grounds that it carried unacknowledged risks to the owl

Conclusions

- Metapopulation models represent simplified abstractions, allowing ‘what-if’ scenarios to be explored (Harrison 1994).
- It is would be dangerous to assign primacy to any single model in determining conservation policy.
- However, the processes underlying metapopulation dynamics are not controversial and must be recognised
- Connectivity and patch size must influence metapopulation dynamics.
- However precise quantitative predictions based on theory will always be difficult, if not impossible