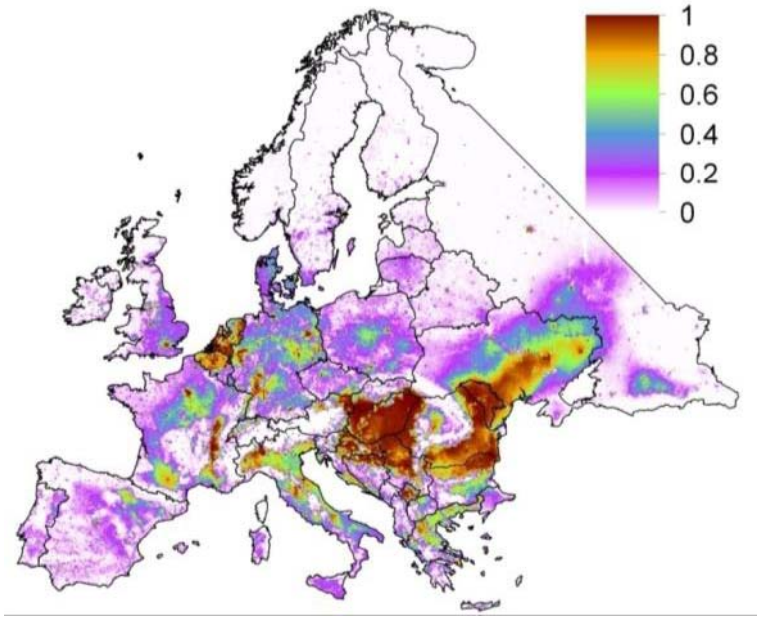
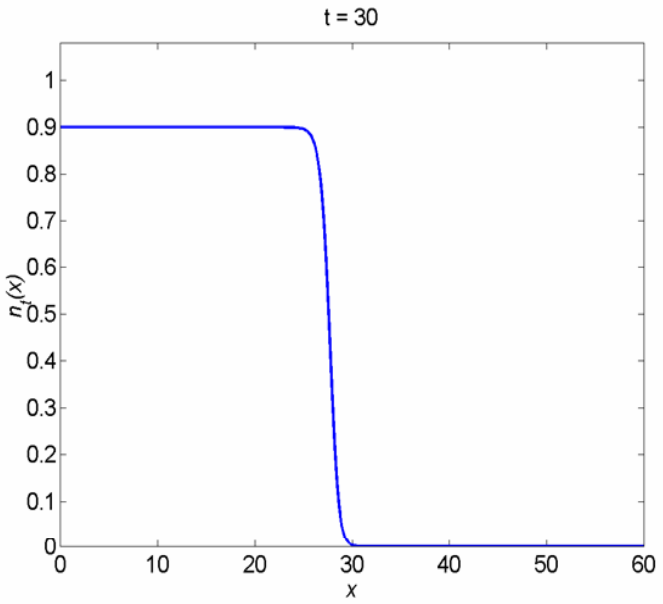
Using analytical models in applied ecology: when is it good to simplify?





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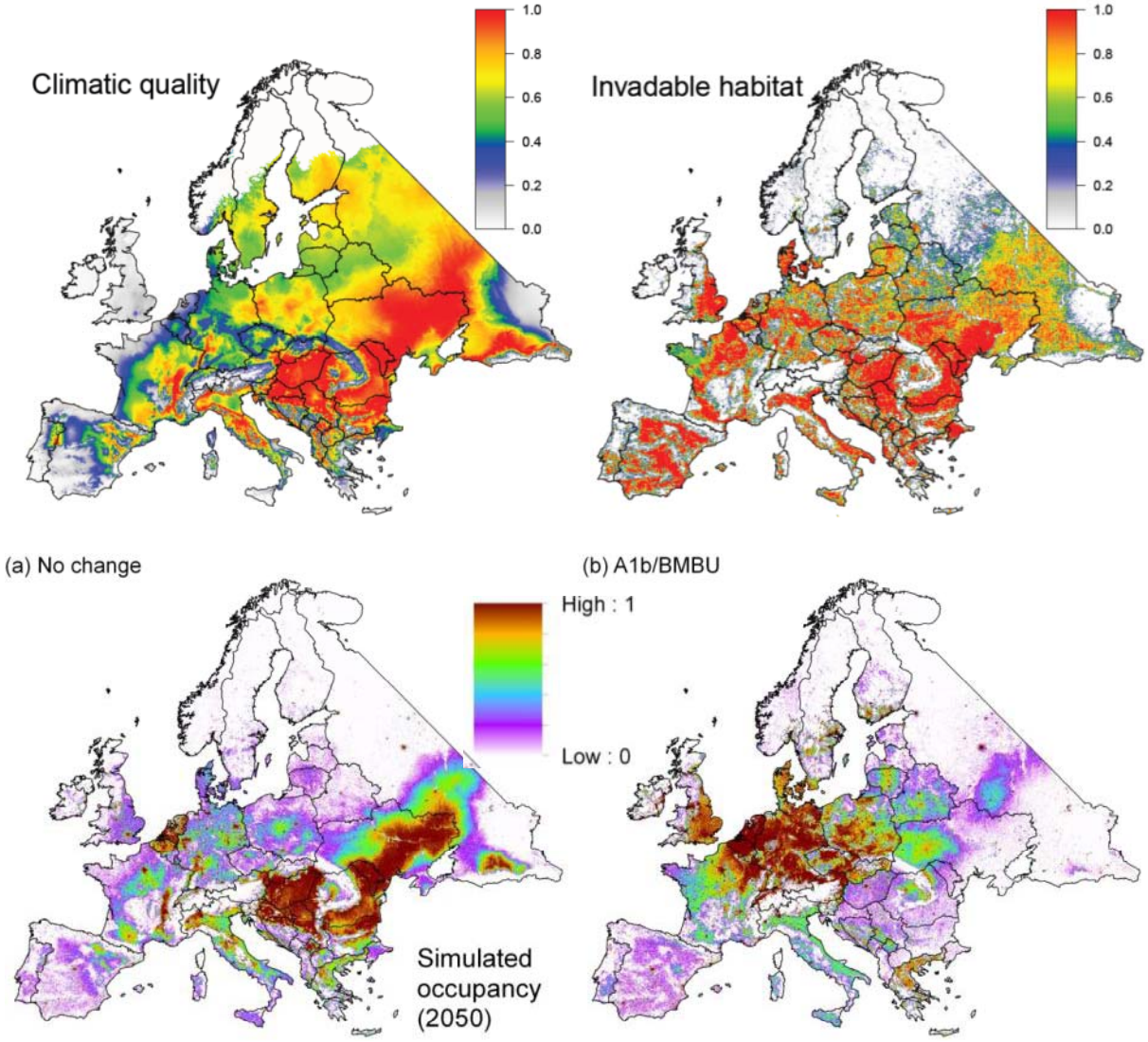
Modelling for a specific applied question

The spread and impacts of a harmful US invasive in Europe

Modelling for a specific applied question



Projecting future ragweed distribution (& impacts & control outcomes) requires spatially-explicit modelling of:

-Climatic tolerances
-Introduction hotspots
-Population dynamics
-Multiple dispersal processes
-Future climate & habitat

Data hungry and computer intensive, but do-able

Modelling for a specific applied question

The spread and impacts of a harmful US invasive in Europe

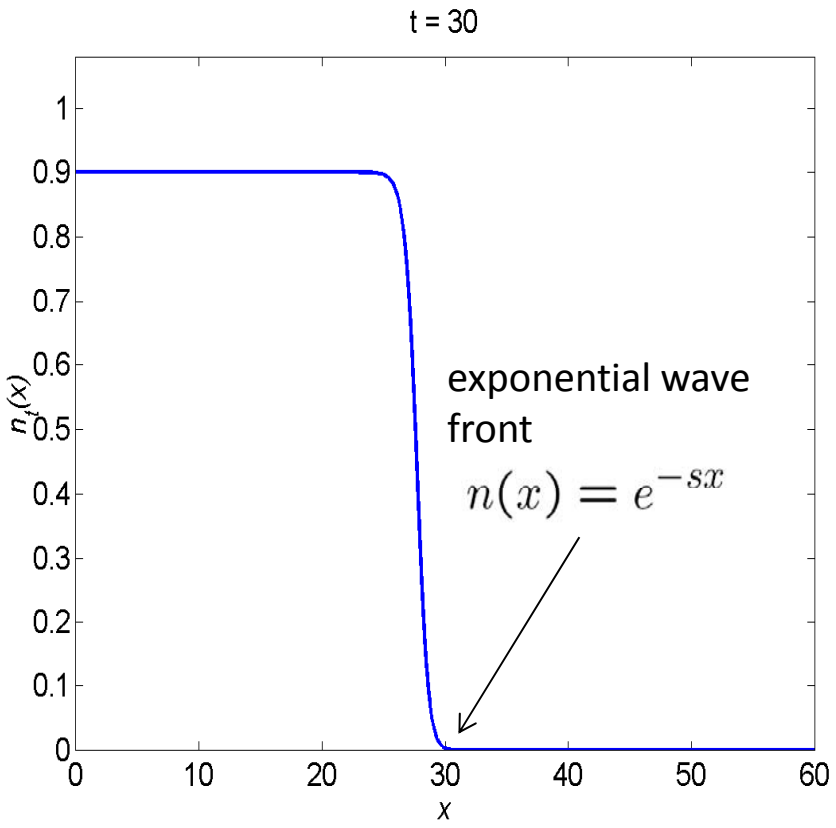
Why use simple models in applied ecology?

e.g. IDE models of population spread (wavespeed)

Dispersal

$$\mathbf{n}(x, t+1) = \int_{-\infty}^{\infty} [\mathbf{K}(x-y) \circ \mathbf{B}_{\mathbf{n}}] \mathbf{n}(y, t)\, dy.$$

Population growth



Solved for asymptotic wavespeed *c

$$c^* = \min\left[\frac{1}{s}\ln[\rho_1(s)]\right]$$

ρ_1 = dominant eigenvalue of **H**(s) (= **M**(s)∘$\mathbf{B}_0$
M(s)= matrix of dispersal MGF).

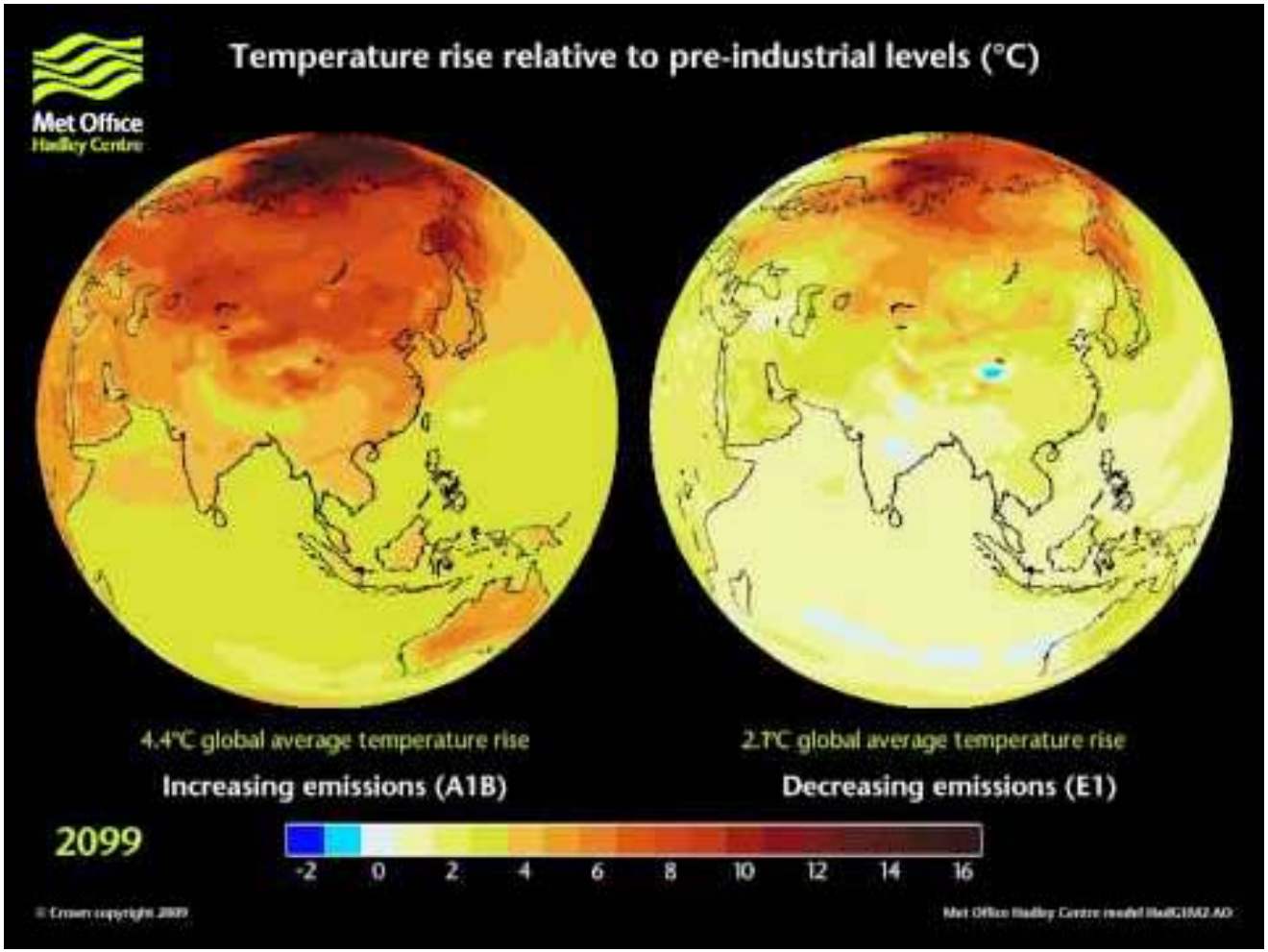
Space is infinite, homogeneous & 1D

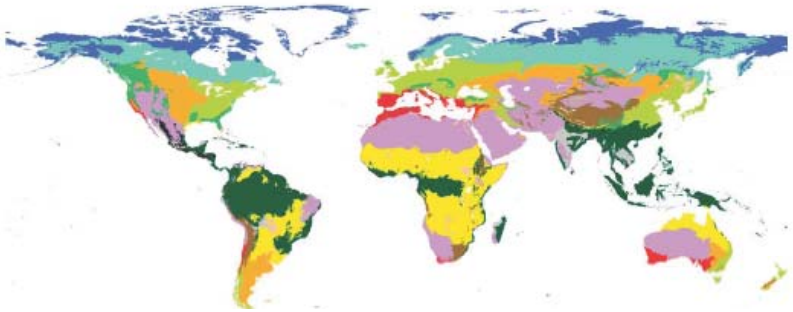
Neubert & Caswell (2000) Ecology

Using wavespeed models to explore possible futures:

will plants keep up with climate change?

how will climate change alter plant dispersal & spread?





The velocity of climate change

(Loarie et al 2009 Nature)

Global mean = 0.42 km/yr

Range = 0.11-1.46 km/yr

Will plants keep up?

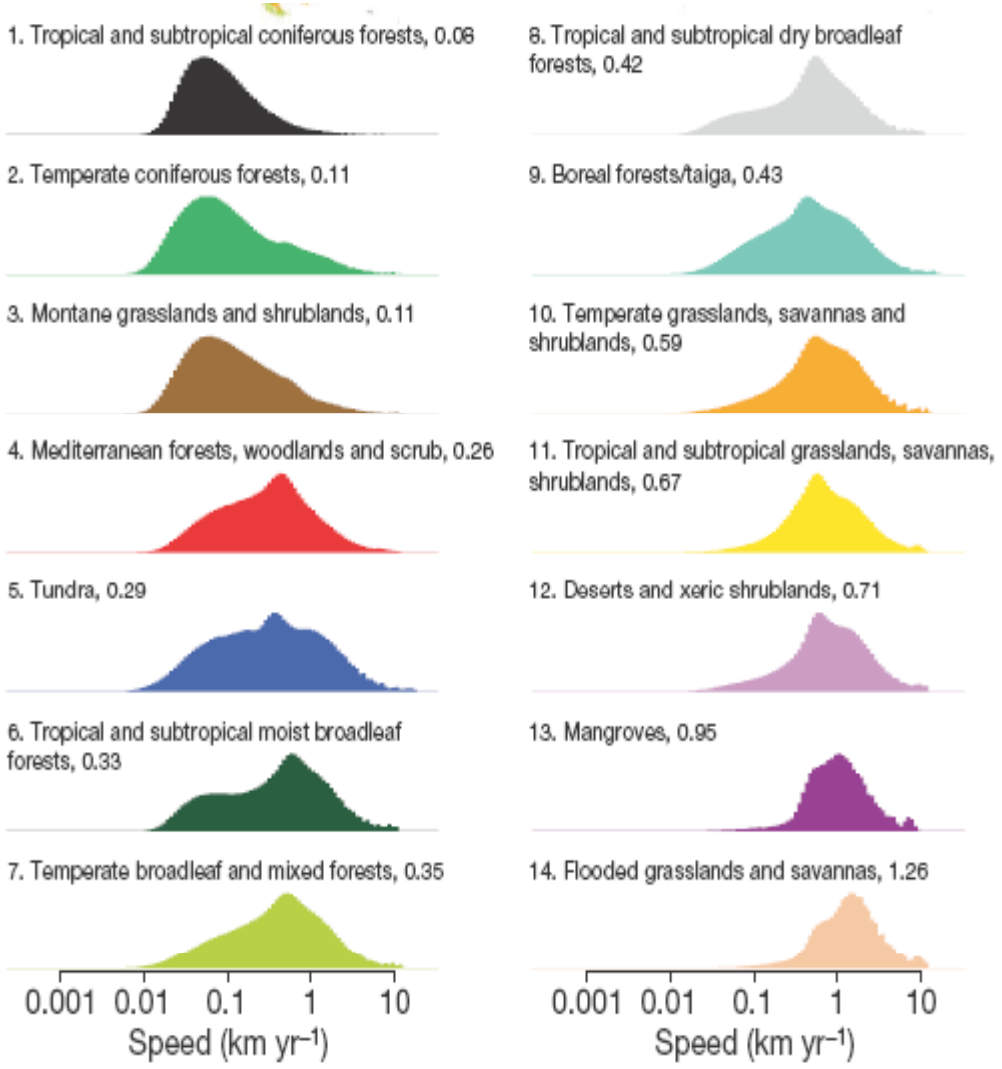
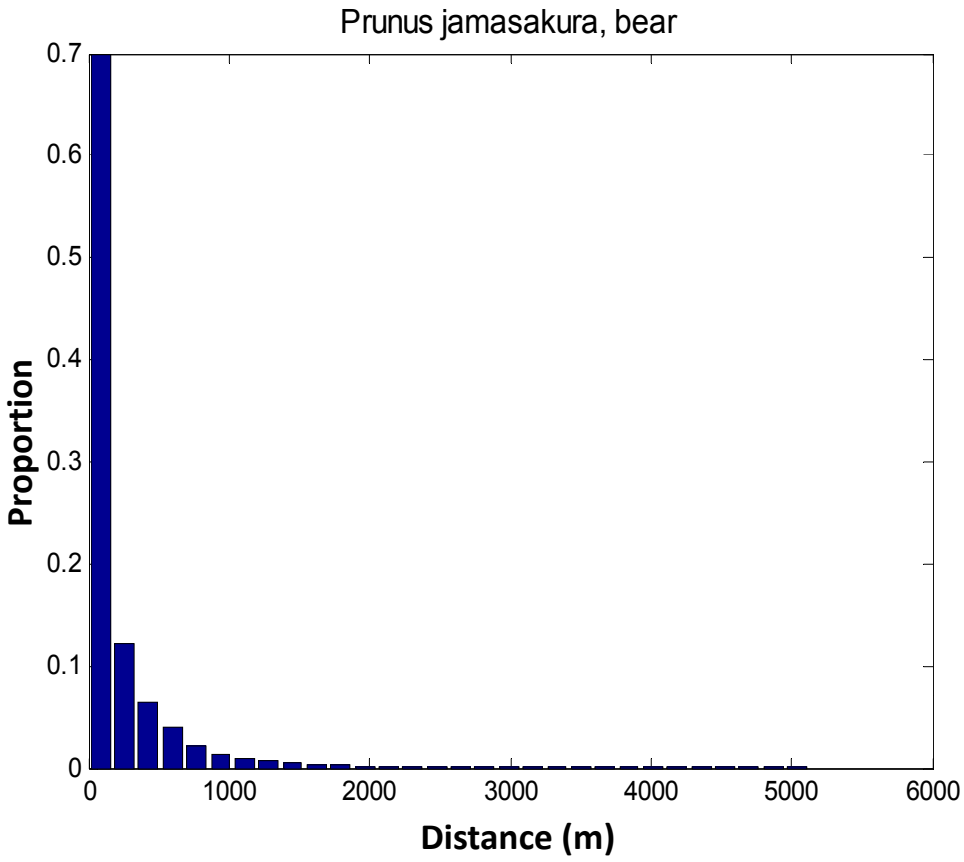


Figure 3 | The velocity of temperature change by biome. A map of biomes and histograms of the speed of temperature change within each biome.

Use wavespeed models to explore best-case scenarios using knowledge of plant dispersal distances

A few good studies of plant dispersal over long distances



e.g. *Prunus jamasakura* by Asiatic black bear. Japan

(Koike et al. 2011)

Bullock (2012). In *Dispersal ecology and evolution.* OUP

Amass good dispersal data & explore using scalar wavespeed models

$$c^* = \min\left[\frac{1}{s}\ln\left[\lambda M(s)\right]\right]$$

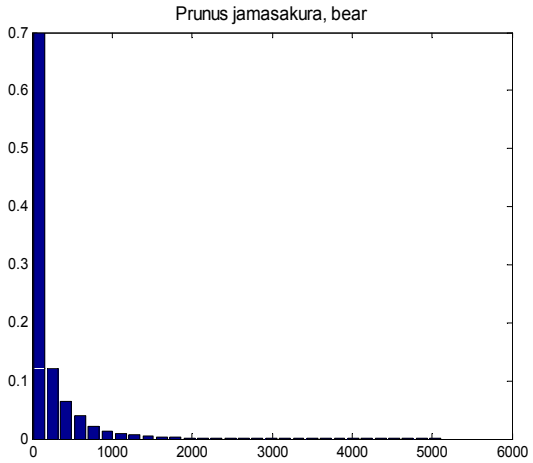
(e.g. Lewis et al. 2006)

λ = population growth rate, assumed (optimistically) to be 2 here

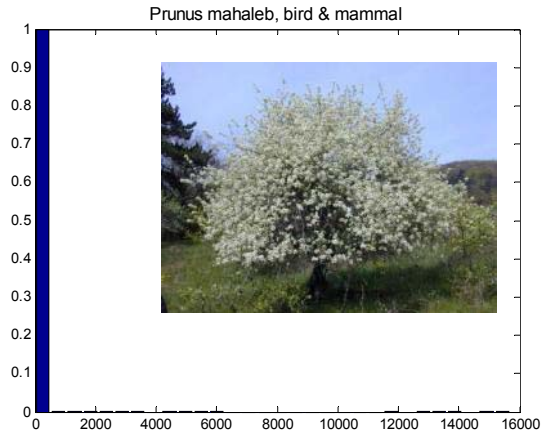
M(s) **= 1d MGF of the dispersal kernel (empirically estimated)**

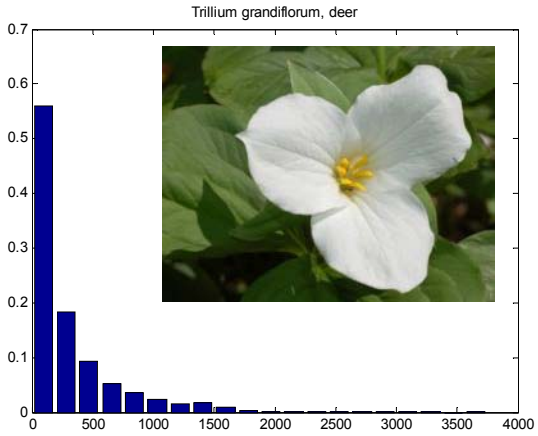
Prunus jamasakura **by Asiatic black bear**

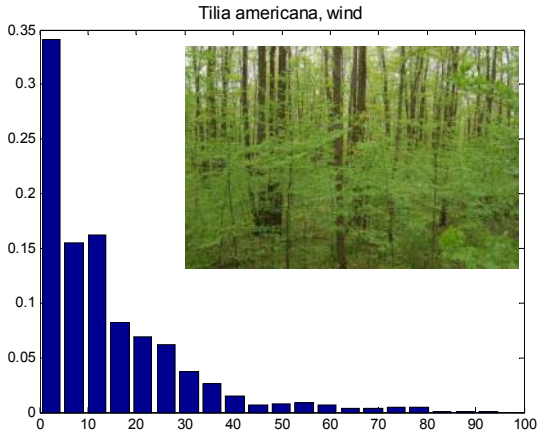
– wavespeed = 0.79 km/yr

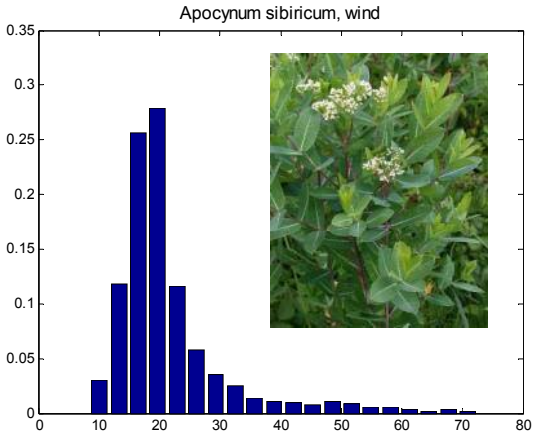


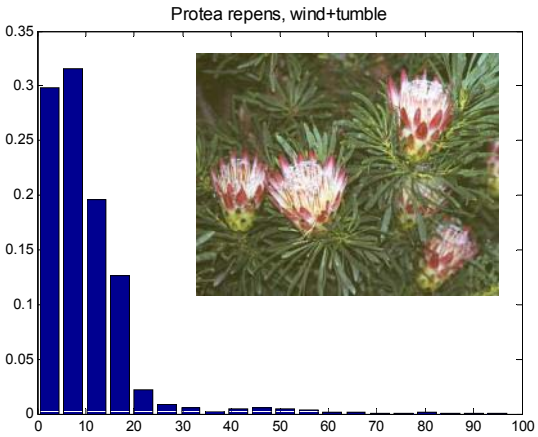
Bullock (2012). In *Dispersal ecology and evolution.* OUP

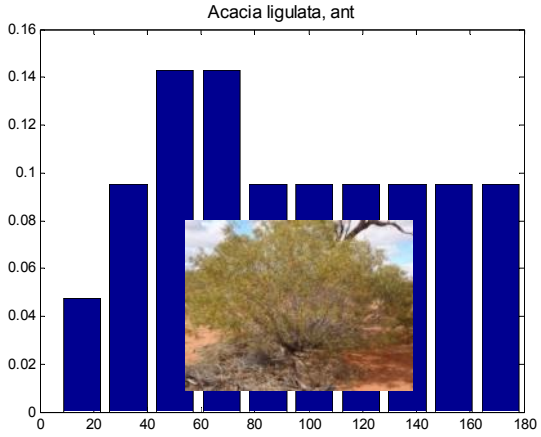


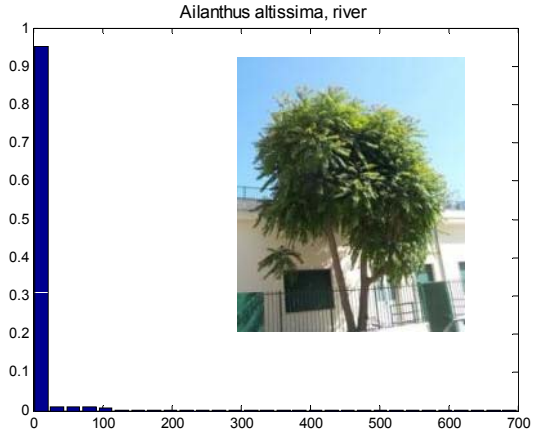






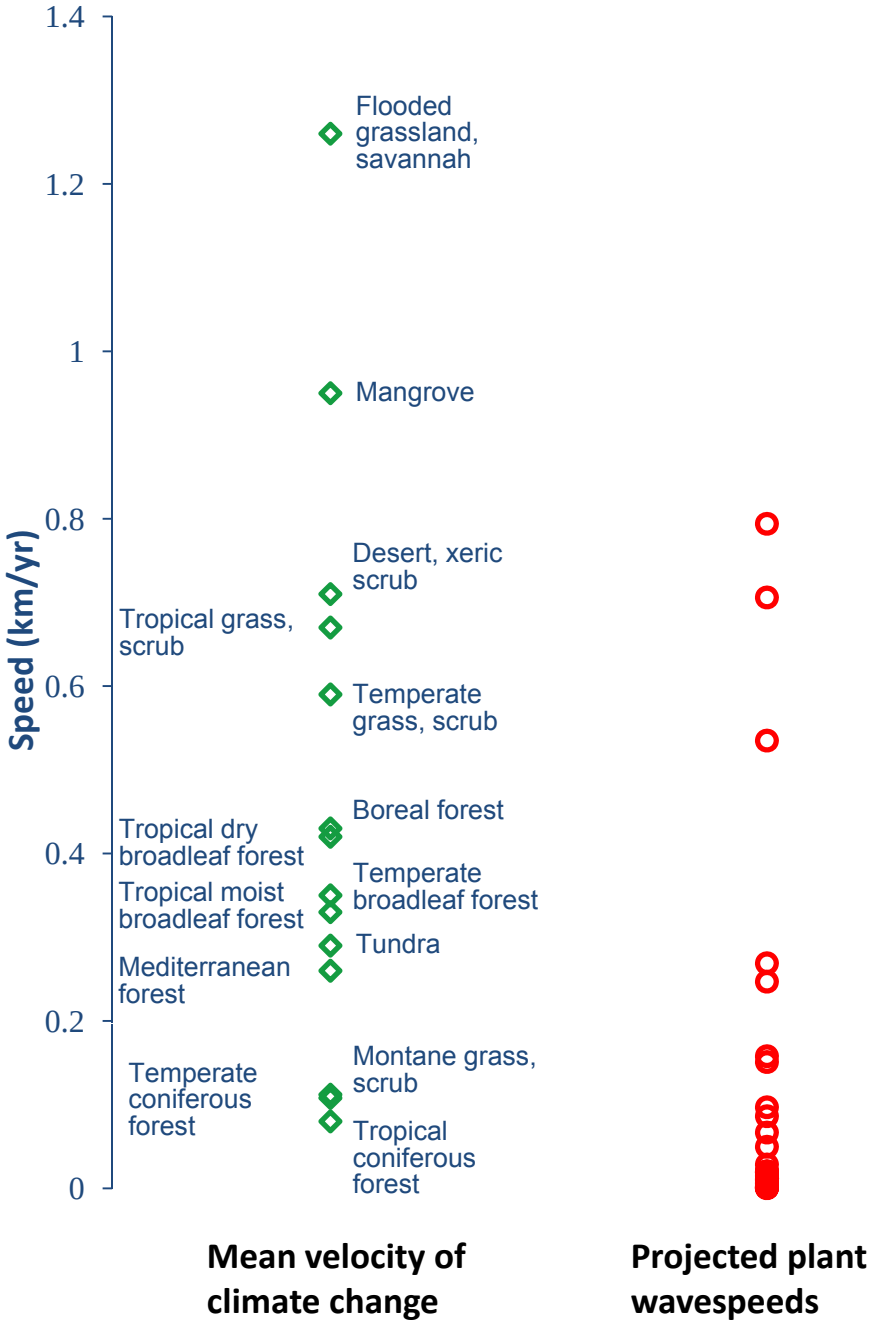


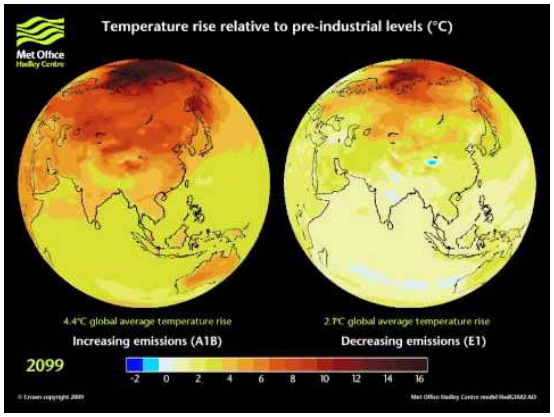




- ***Prunus mahaleb*** **(shrub, vertebrates): 0.71 km/yr**
- ***Trillium grandiflorum*** **(herb, deer): 0.53 km/yr**
- ***Tilia americana*** **(tree, wind): 0.02 km/yr**
- ***Apocynum sibiricum*** **(herb, wind): 0.02 km/yr**
- ***Protea repens*** **(shrub, wind): 0.02 km/yr**
- ***Acacia ligulata*** **(shrub, ant): 0.09 km/yr**
- ***Ailanthus altissima*** **(tree, river): 0.10 km/yr**

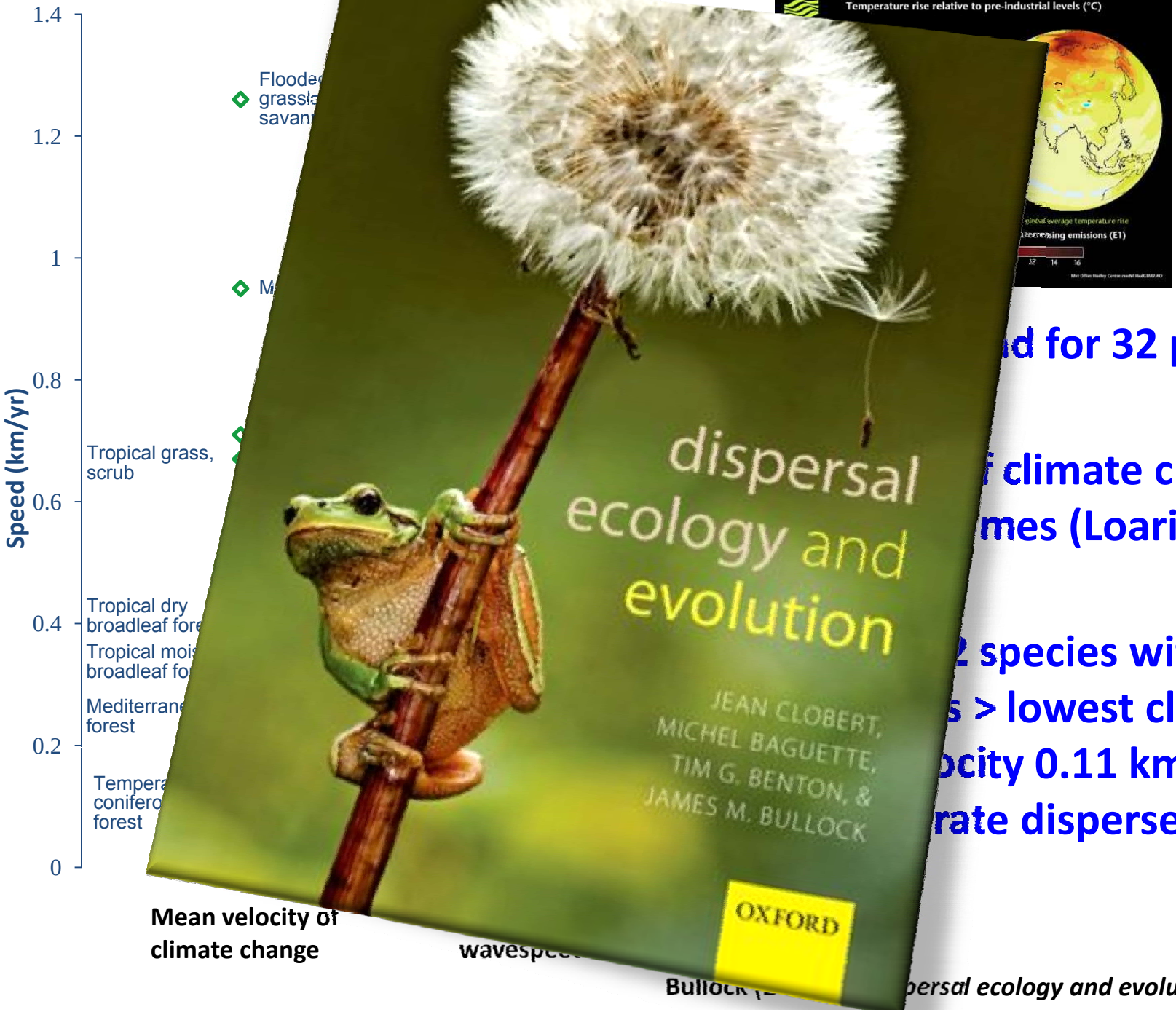
Bullock (2012). In *Dispersal ecology and evolution.* OUP





- **Rates of spread for 32 plants (λ = 2)**
- ***vs* Velocity of climate change for major biomes (Loarie et al. 2009)**
- **Only 7 of 32 species with wavespeeds > lowest climate change velocity 0.11 km yr^{-1} - all vertebrate dispersed**

Bullock (2012). In *Dispersal ecology and evolution.* OUP



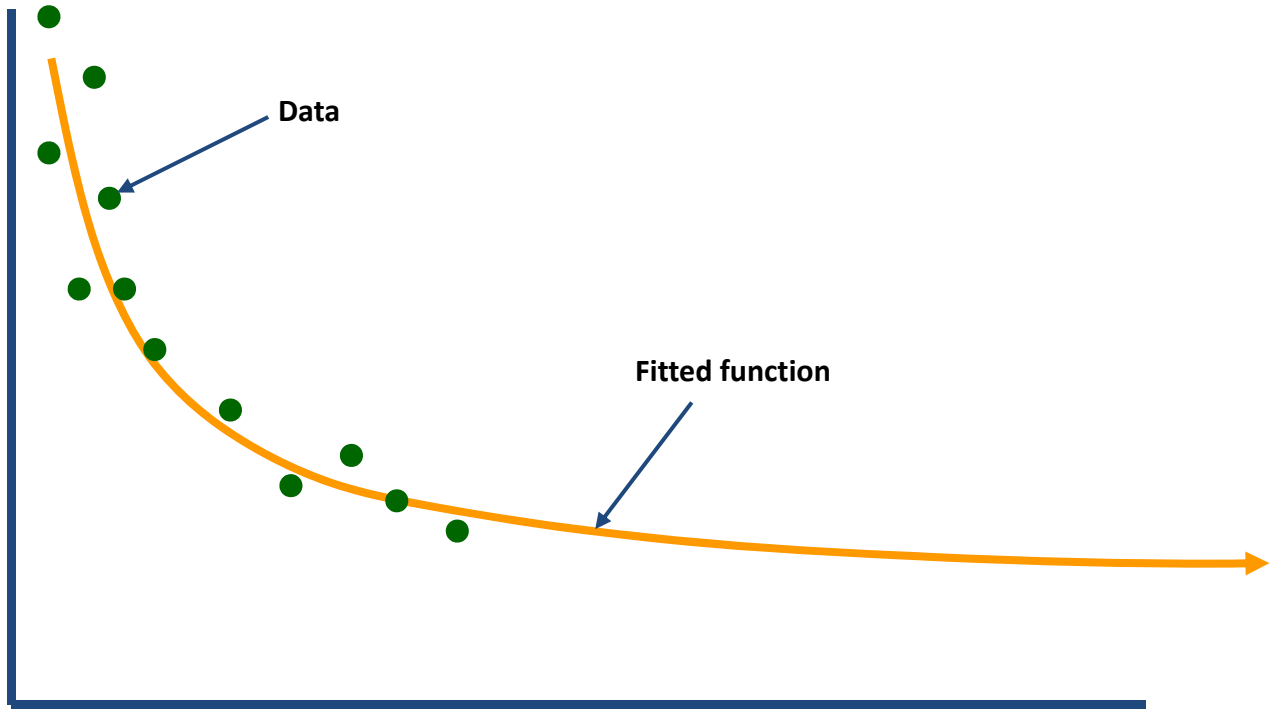
d for 32 plants

f climate change
mes (Loarie et

2 species with
s > lowest climate
ocity 0.11 km yr^{-1}
rate dispersed

Bullock [2… *persal ecology and evolution.* **OUP**

Good dispersal representation is critical: danger of extrapolation using fitted functions

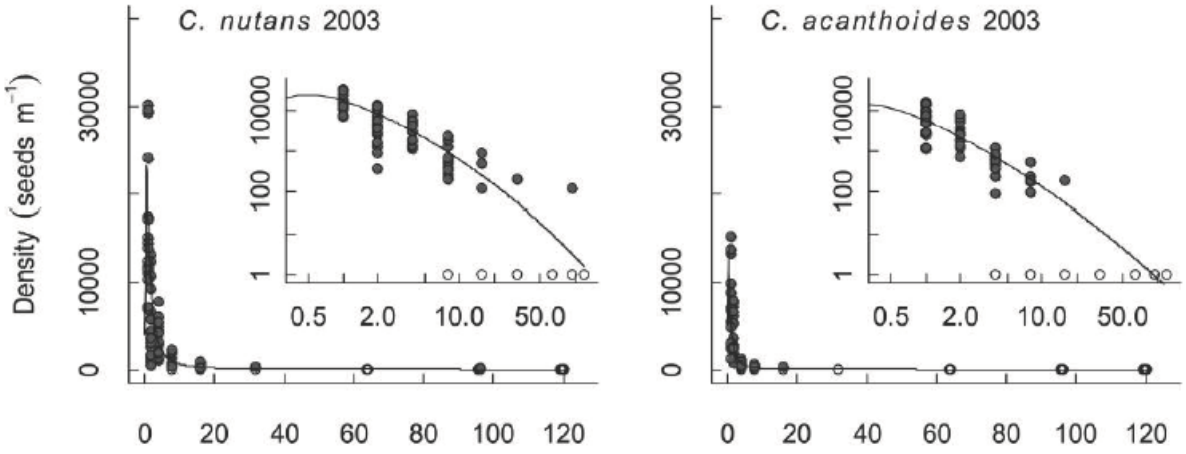


Good dispersal representation is critical: one approach = mechanistic models

e.g. WALD mechanistic model for dispersal by wind (Katul et al. 2005)

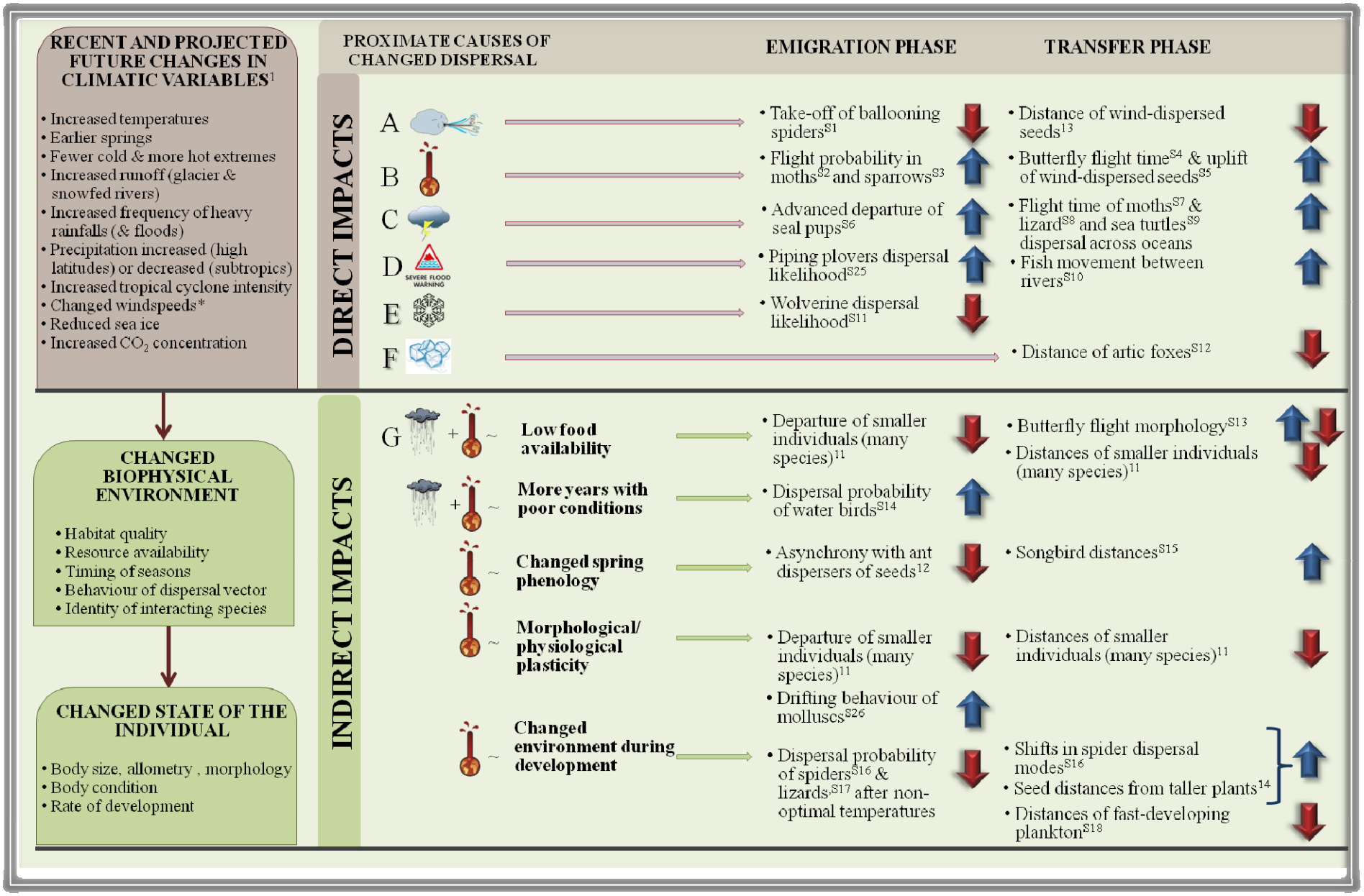
$$p(r) = \left(\frac{\lambda'}{2\pi r^3}\right)^{1/2} exp\left[\frac{-\lambda'(r-\mu')^2}{2\mu'^2}\right]$$

r = distance, μ' = location parameter and λ' = scale parameter.
μ' and λ' can be calculated from seed release height & falling velocity, and wind speed & turbulence



Shown to match wind dispersal data – e.g. Shea & Skarpaas 2007

Dispersal of many species may be affected by climate change



Travis et al. In review

Use WALD to project dispersal of climate-limited, wind-dispersed plants: using measured demography

UK invasives

Canadian fleabane
Conyza canadensis

Tree of Heaven
Ailanthus altissima

Prickly lettuce
Lactuca serriola

UK scarce natives

Dorset heather
Erica ciliaris

Stemless thistle
Cisium acaule

Lizard orchid
Himantoglossum hircinum

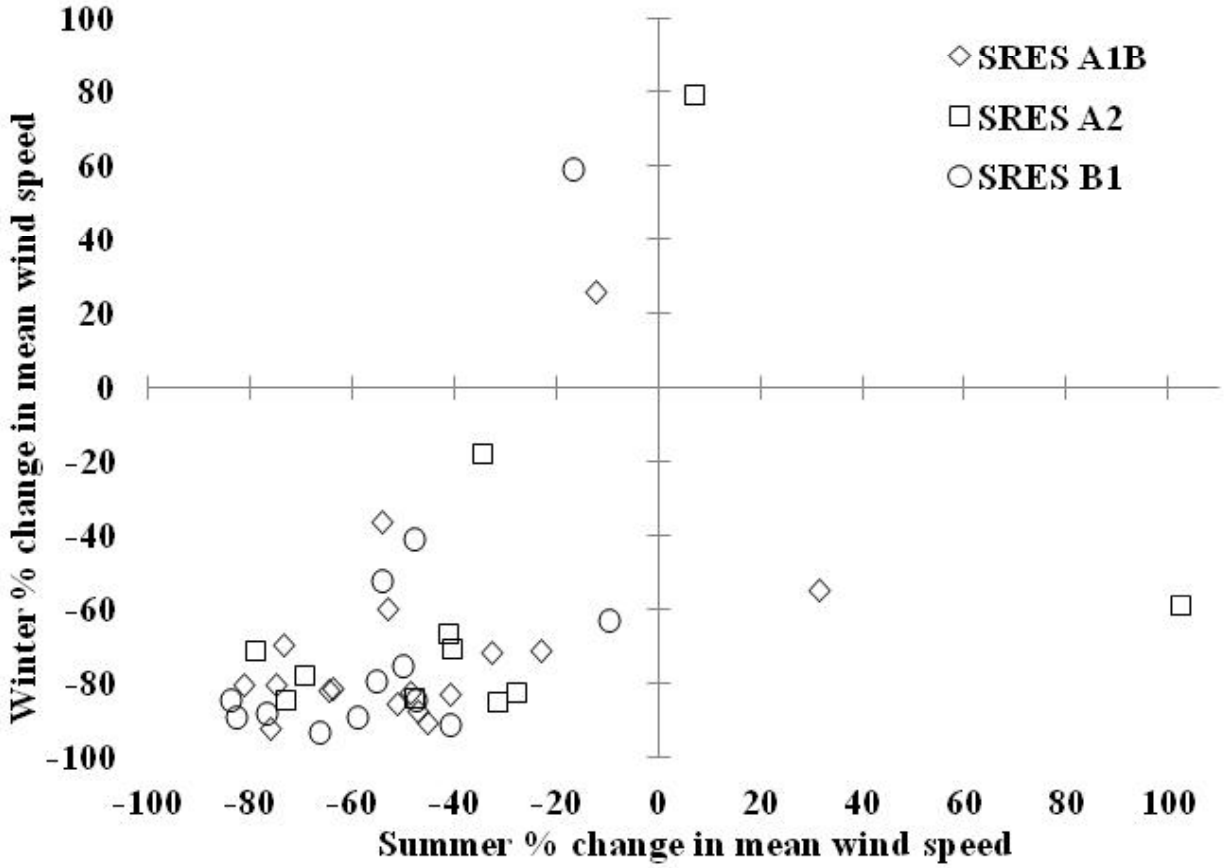
Mean windspeed is predicted to change under climate change

% change in mean windspeeds

for winter & summer periods

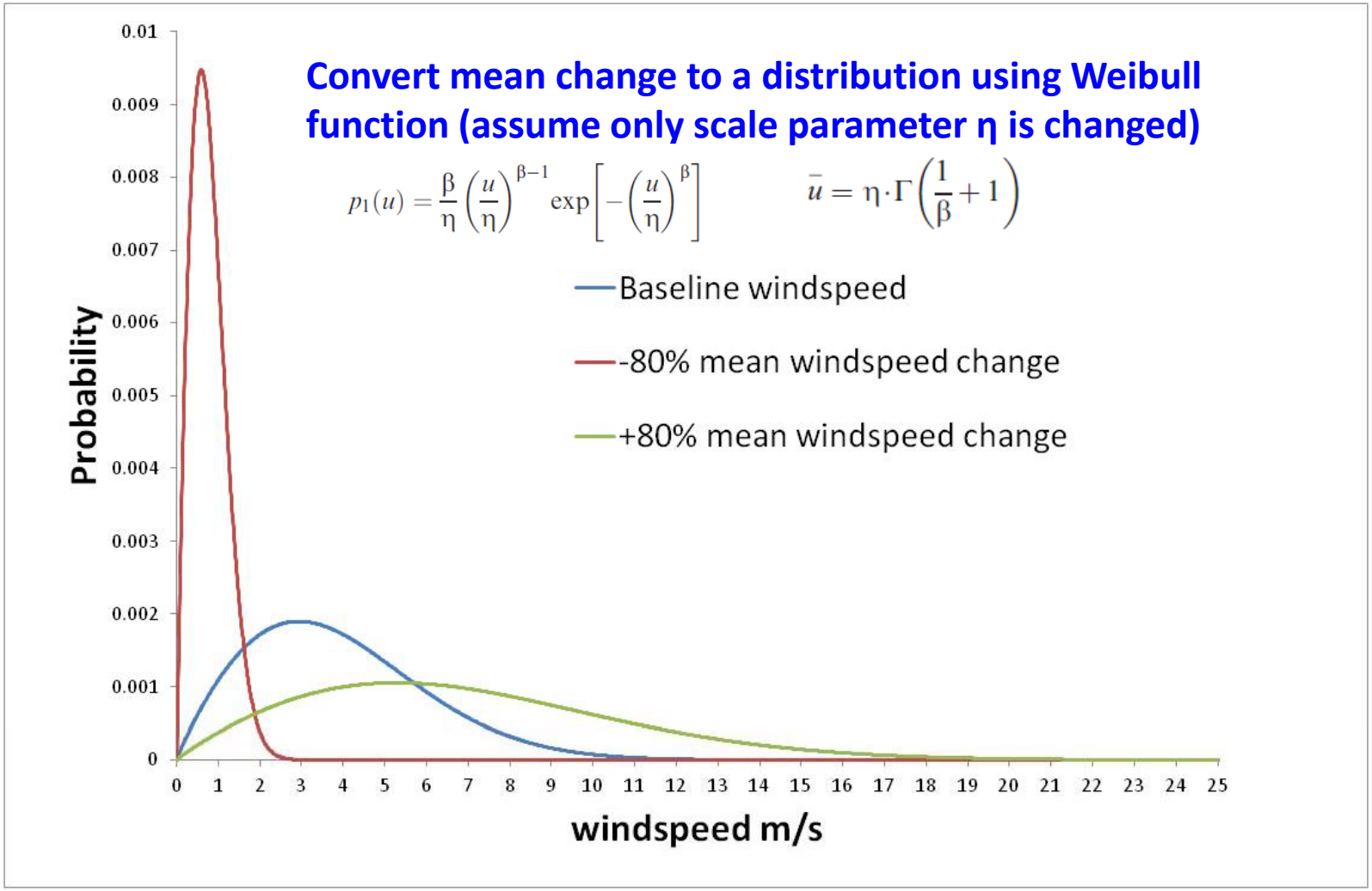
projected by 18 GCMs for 3 emissions scenarios 2070-2099

Differences among GCMs more than among scenarios



Bullock et al. (2012). J. Ecol

Current & projected future windspeeds in S. England



Bullock et al. (2012). J. Ecol

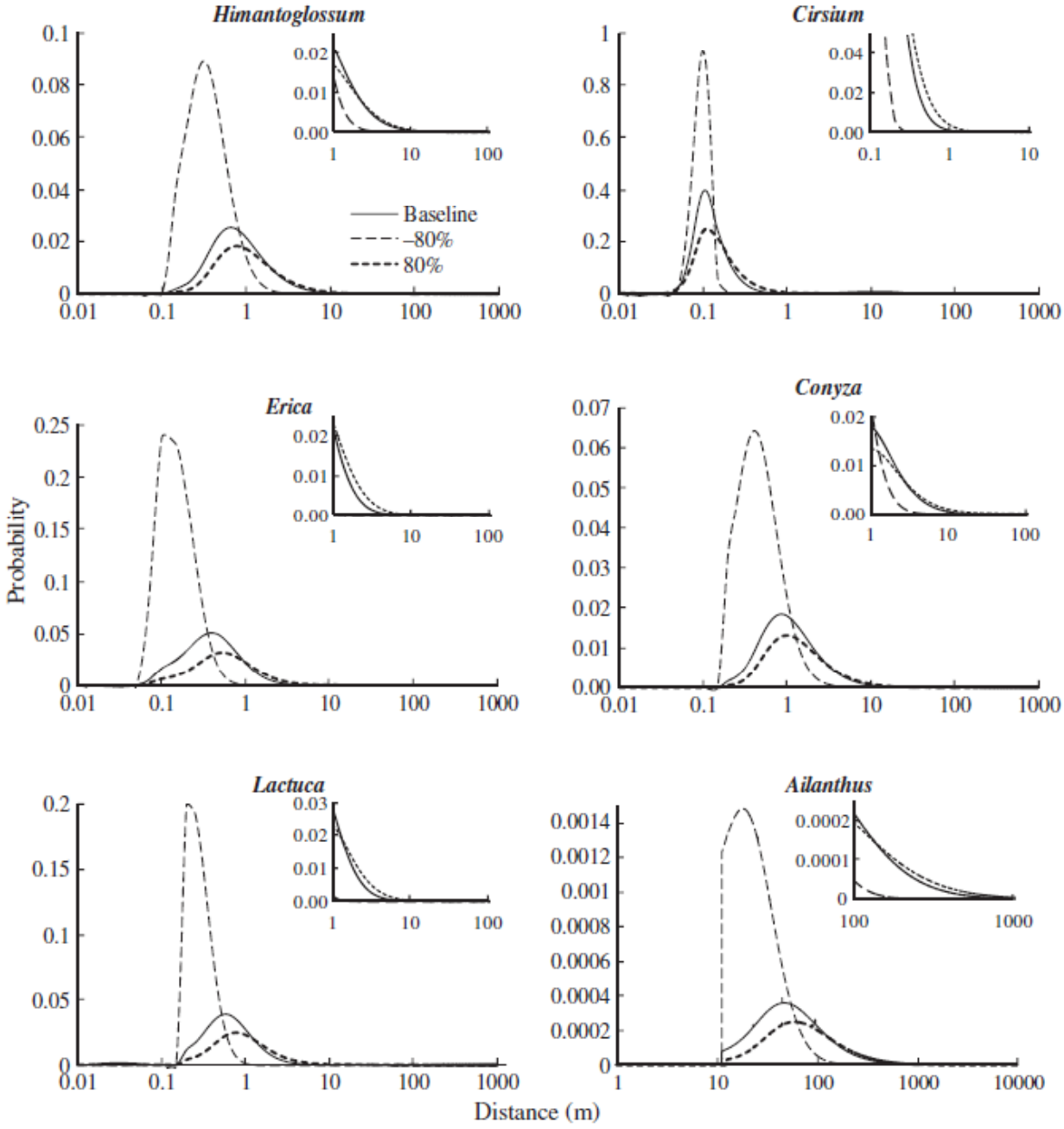
Dispersal dramatically changed by windspeed

Seasonal dispersal kernel *p(r)* derived by integrating WALD over the windspeed distribution (hourly measures over 3 months & 20 yrs)

$$p(r) = \frac{1}{C}\int_0^{25} p_1(u)p_2(r,u)\mathrm{d}u,$$

$p_1(u)$ is the Weibull PDF
$p_2(r,u)$ is the PDF of the WALD

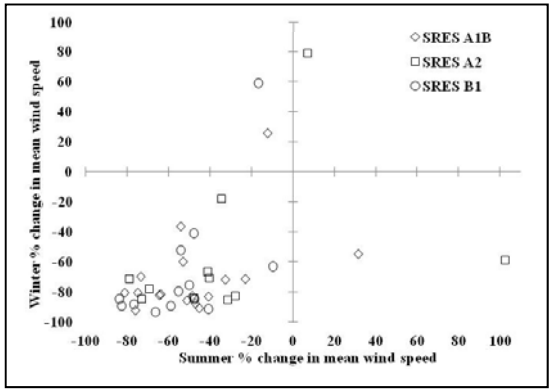
$$C = \int_0^{\infty}\int_0^{25} p_1(u)p_2(r,u)\mathrm{d}u\mathrm{d}r$$

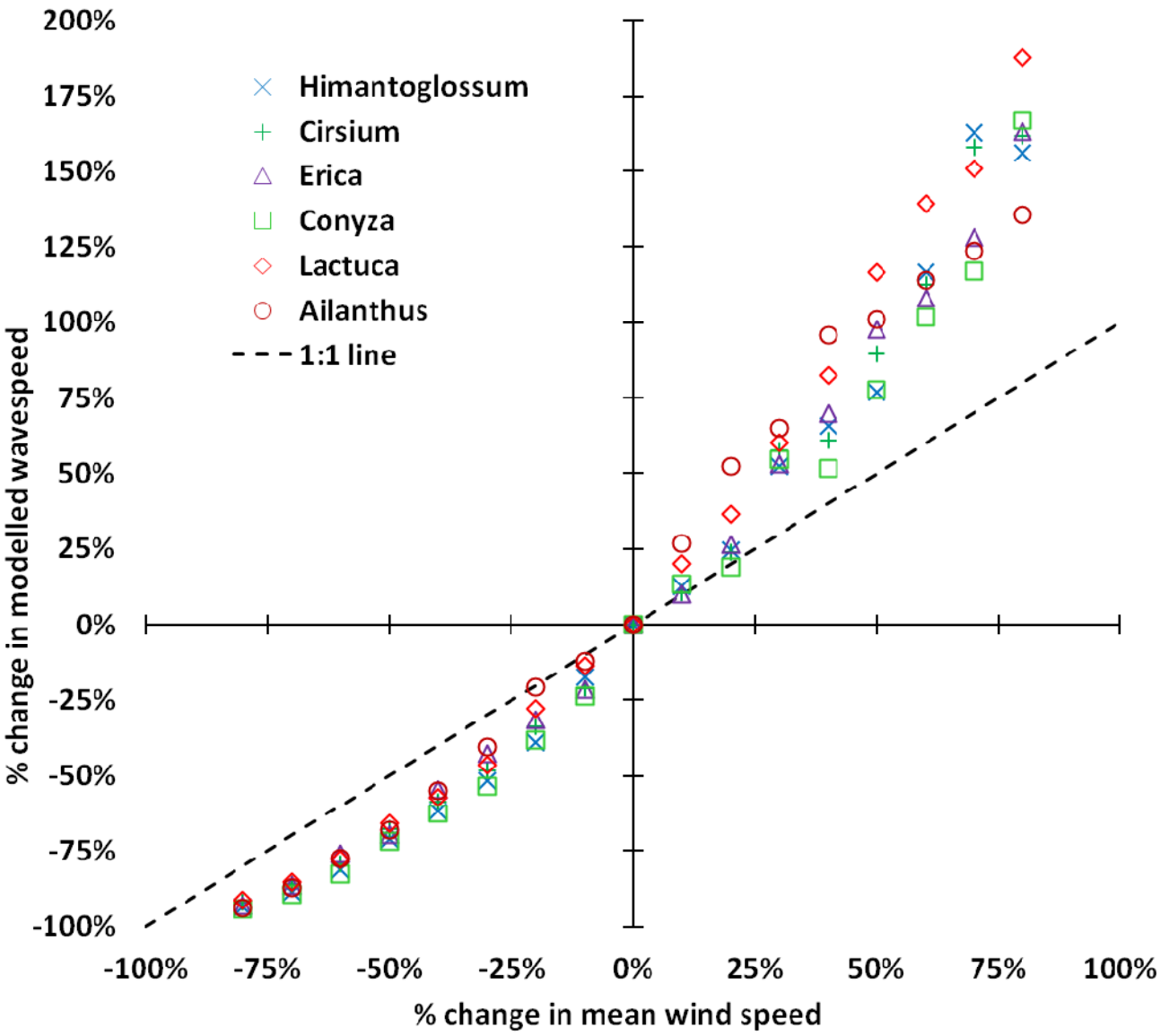


Bullock et al. (2012). J. Ecol

Uncertainty, uncertainty, uncertainty

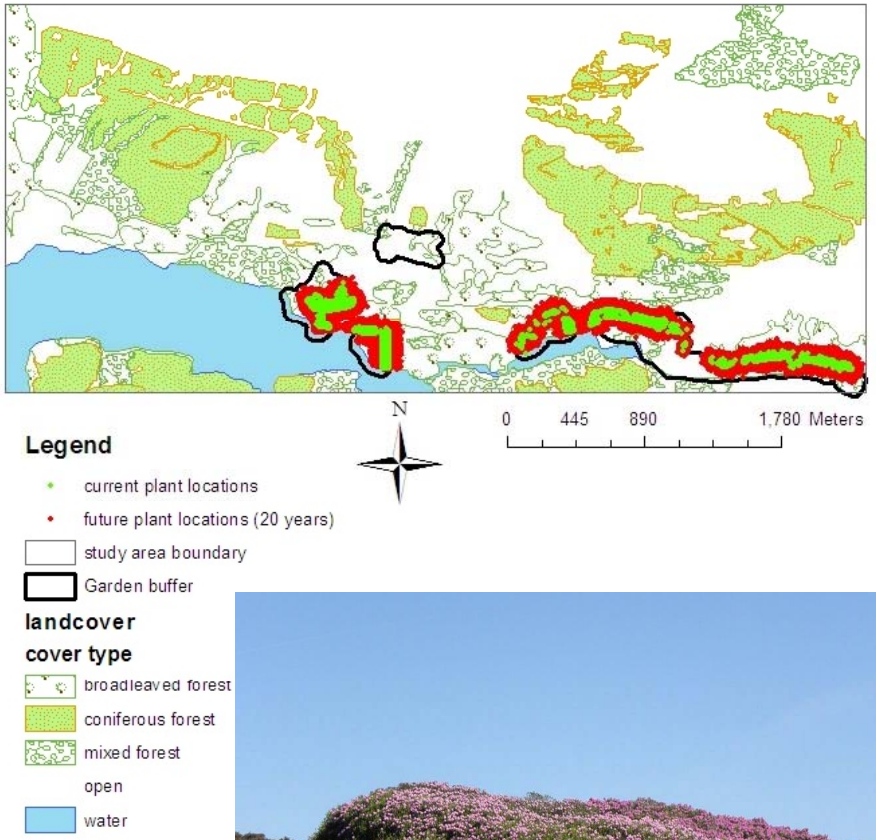
- Non-linear response of *c** to changed windspeed, through effect on dispersal
- Uncertainty in climate models leads to greater uncertainty in ecological projections
- But suggestion of decreased windspeed in this region
- And all *c** of all spp except *Ailanthus* < climate change velocity





Bullock et al. (2012). J. Ecol

Moving forwards 1: Using simulation and analytical modelling for applied questions



Rhododendron - Invasive in W. Europe, New Zealand, etc

Individual-based model

- **Individual seeds disperse, germinate, grow & produce seeds**
- **Real landscapes, with habitat-specific demography**

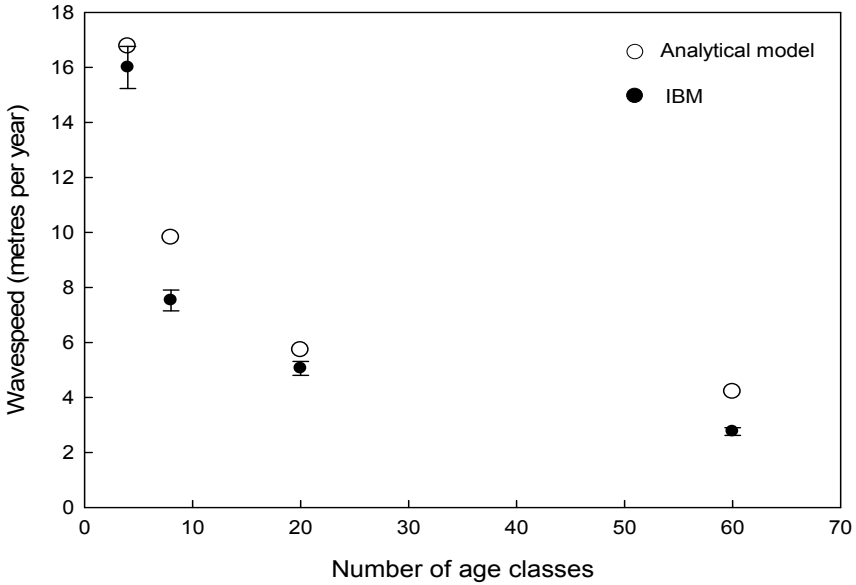
Wavespeed model

- **Generalised demography, etc**
- **But stage-structured, including age-specific dispersal (60 classes)**

Travis et al (2011) Methods in Ecology and Evolution

Moving forwards 1: Using simulation and analytical modelling for applied questions

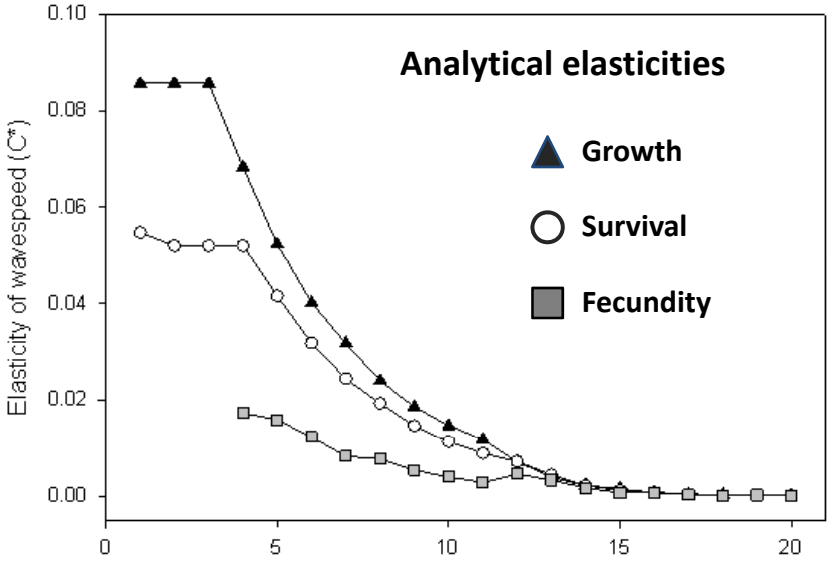
1) Wavespeed model can be used to 'validate' the IBM

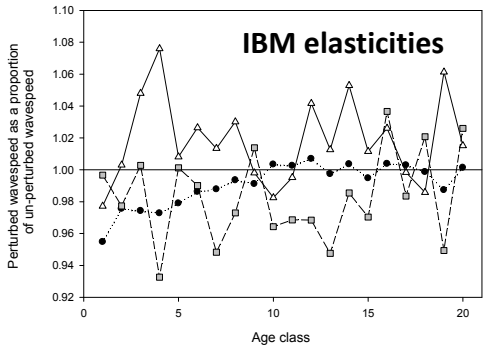


Wavespeeds from the IBM and the analytical model, for different formulations (number of age classes).

IBM standard deviations from 20 replicate simulations.

2) Wavespeed model can provide clear, generic guidance on control – elasticity analyses





Travis et al (2011) Methods in Ecology and Evolution

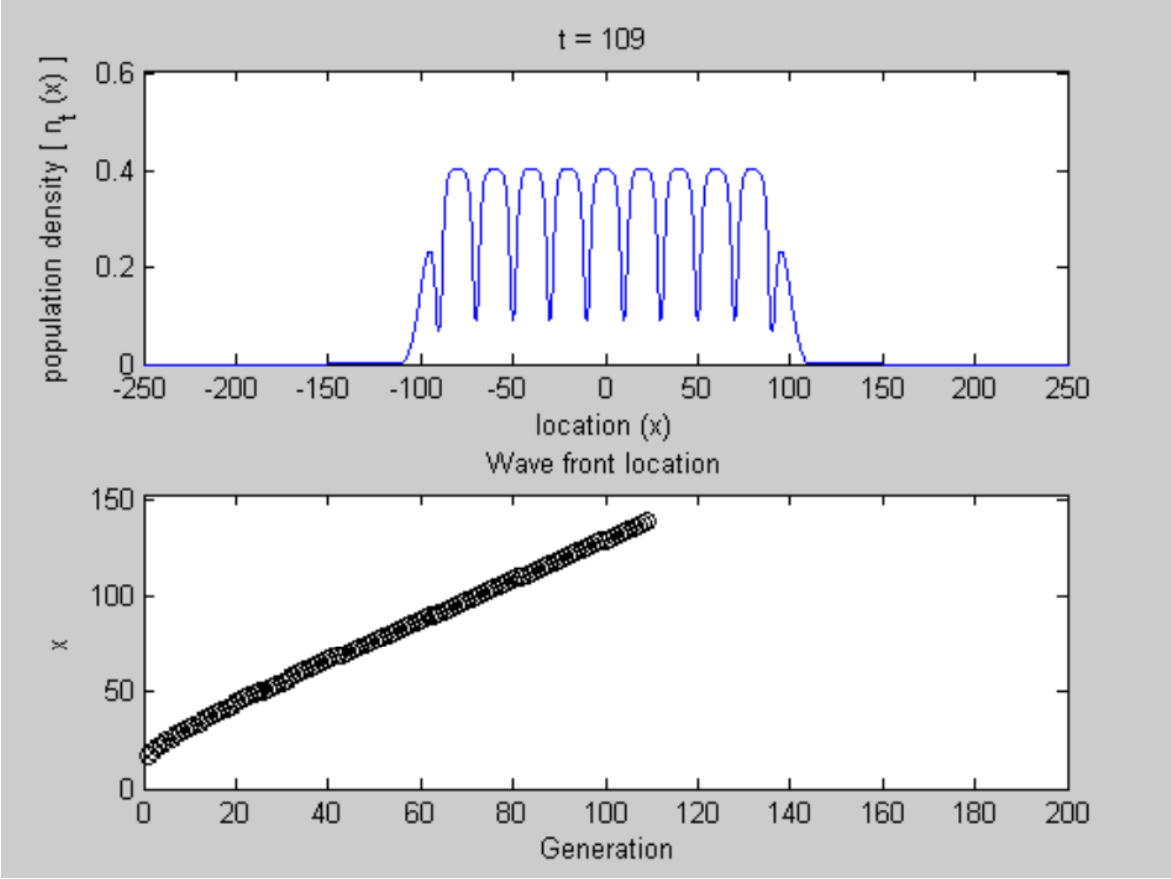
Moving forwards 2: Investigating spatial heterogeneity in analytical models

Inspiration =

Ecology, 90(5), 2009, pp. 1338–1345

Dispersal in heterogeneous habitats: thresholds, spatial scales, and approximate rates of spread

Sebastian Dewhirst and Frithjof Lutscher[1]



- Landscape = periodic good & bad habitat (affects population growth)
- Averaging techniques used to derive approximate spread rate for IDE model
- Also derive invasion threshold = minimal % of good habitat allowing spread
- PhD student Mark Gilbert – developing & applying this method

Thanks to

Dan Chapman
Steven White
Danny Hooftman
Justin Travis
Maria Delgado
& many others

Funders: EU, NERC, CEH, BBSRC