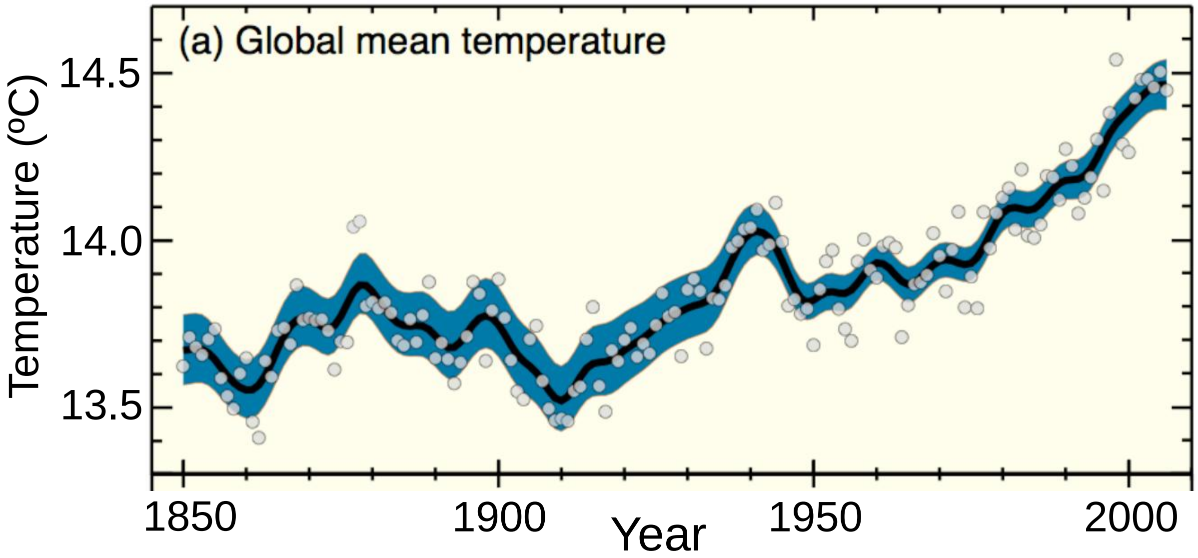
Uncertainty in Ecological Models of Climate Change Impacts

Richard Pearson

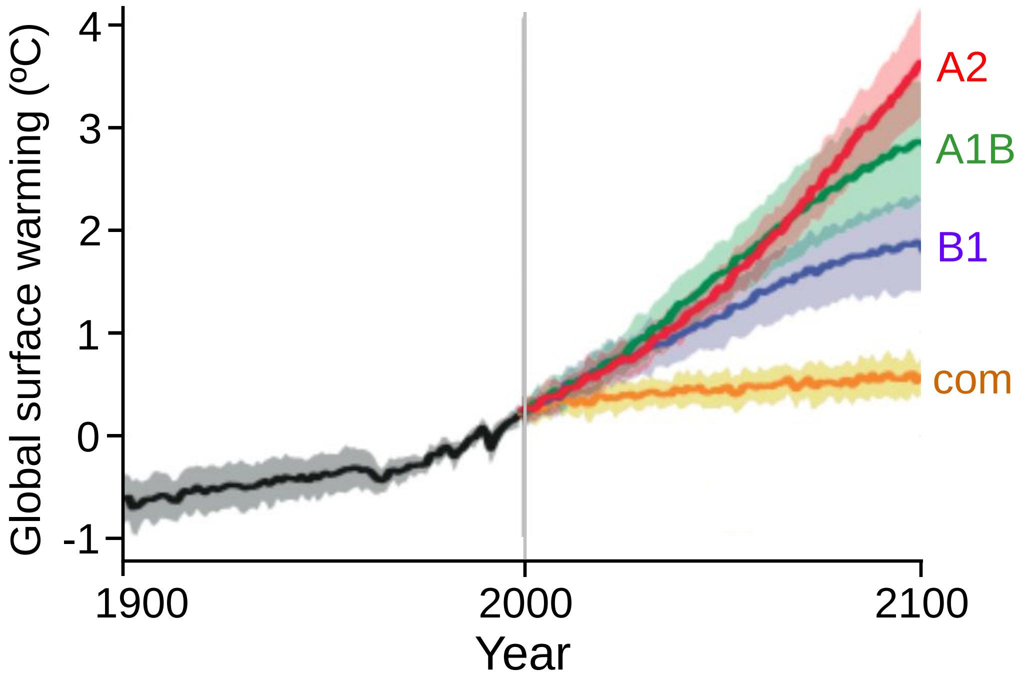
American Museum of Natural History

IPCC Fourth Assessment Report (2007)



Observed changes

AOGCM predictions



Session overview:

- Observed ‘fingerprints’ of climate change
- Predicting future impacts
- Some promising ways forward
- Communicating uncertainty

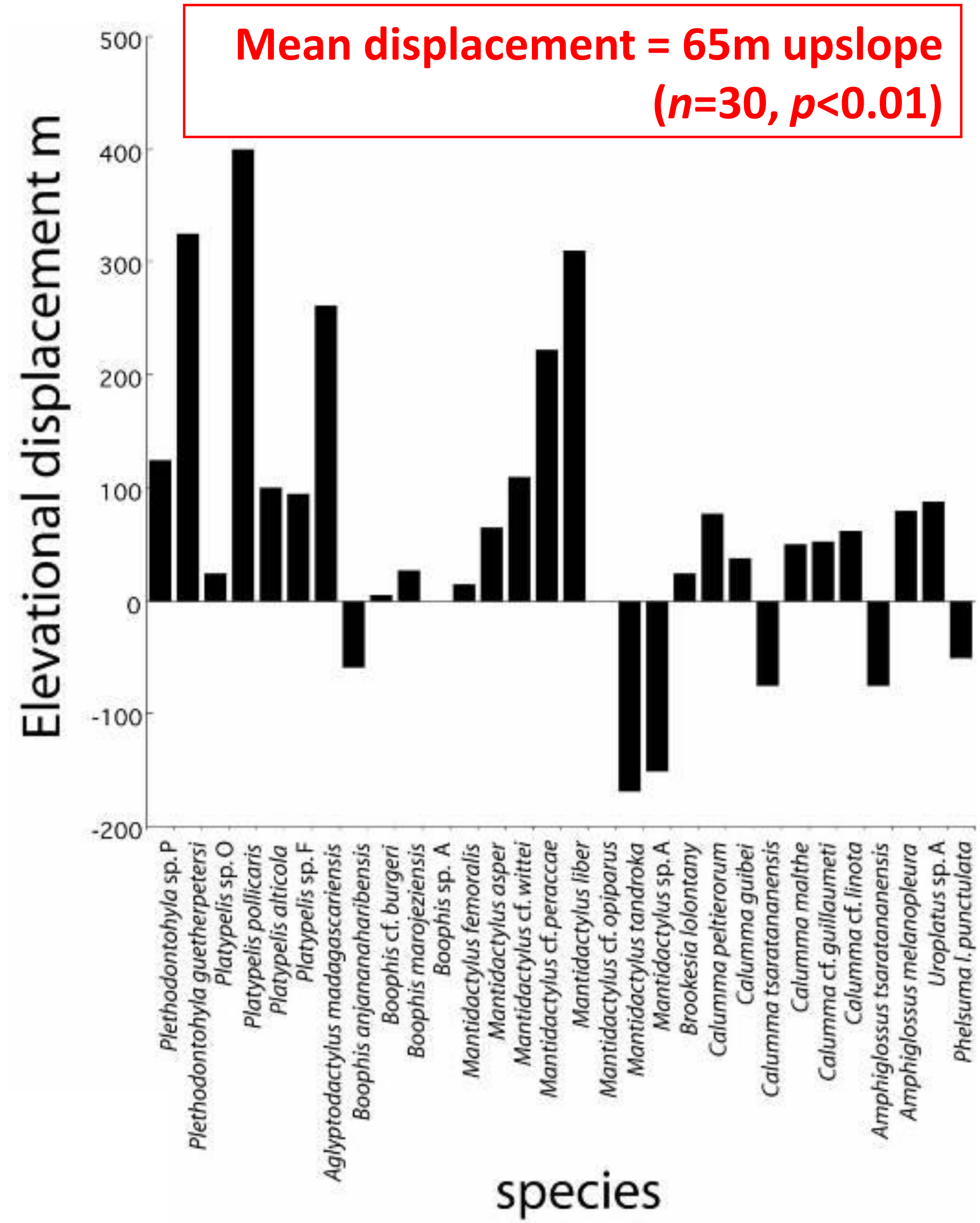
Data from two surveys in 1993 and 2003 that used the same transect and sampling strategy


Tsaratanana summit, 1993


Chris Raxworthy and team,
Tsaratanana, 2050 m, 20

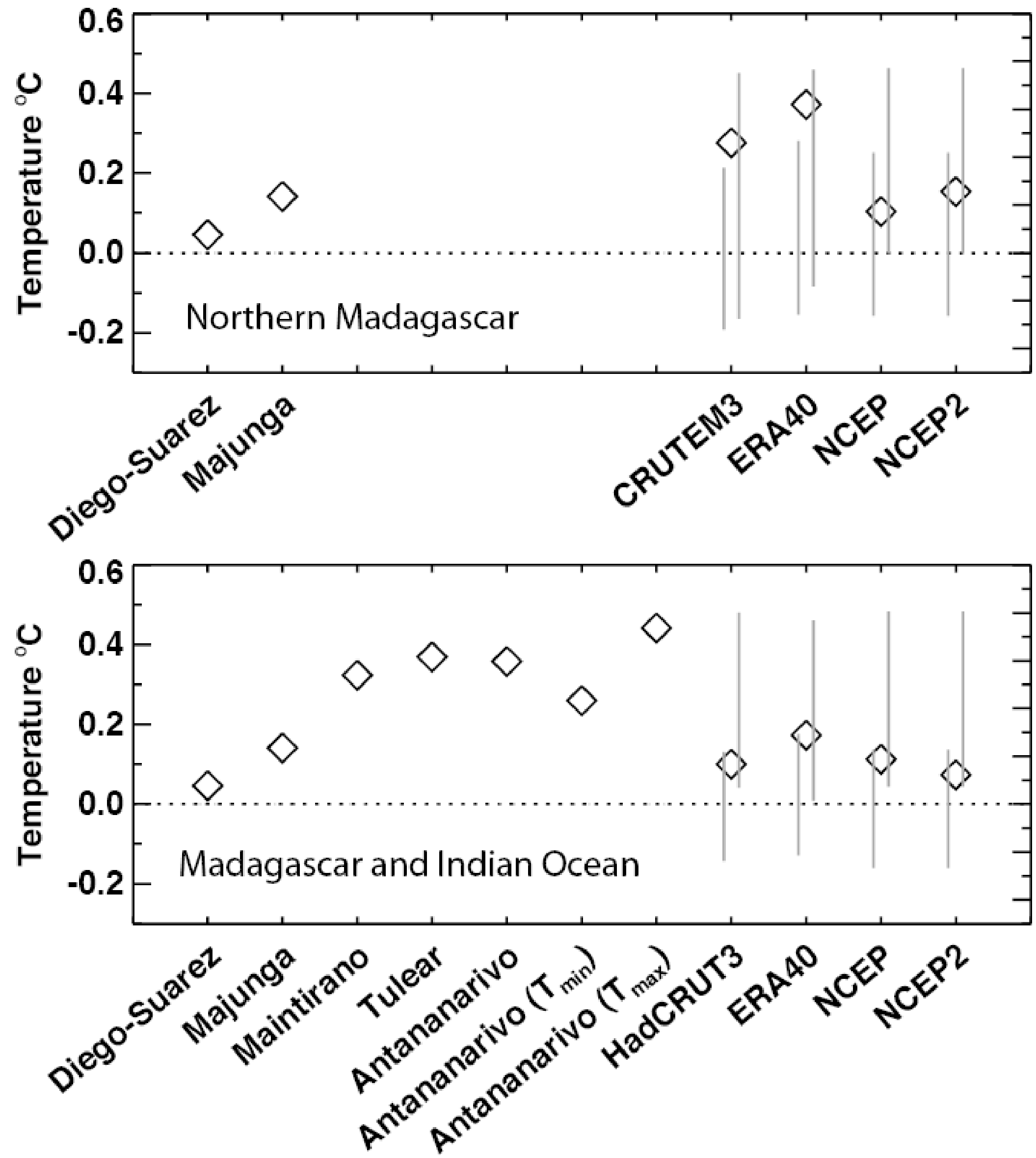
Elevational displacement of distribution midpoint between 1993 and 2003 for 30 species of reptiles and amphibians surveyed at Tsaratanana

(Raxworthy et al. 2008 *Global Change Biology*)



Evidence of recent warming in Madagascar

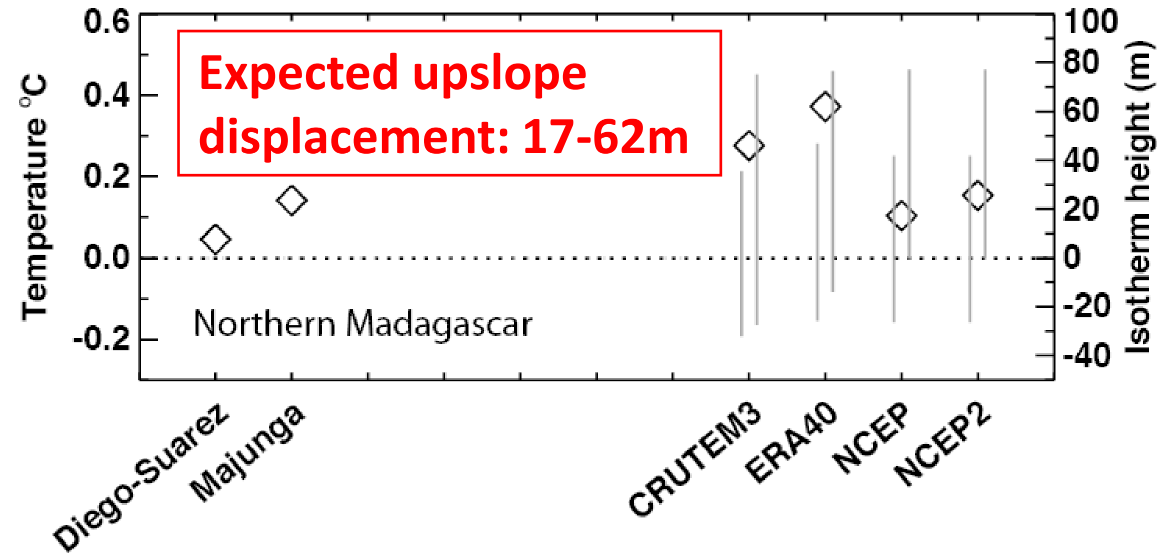
Changes in mean annual temperature between the decades 1984-1993 and 1994-2003

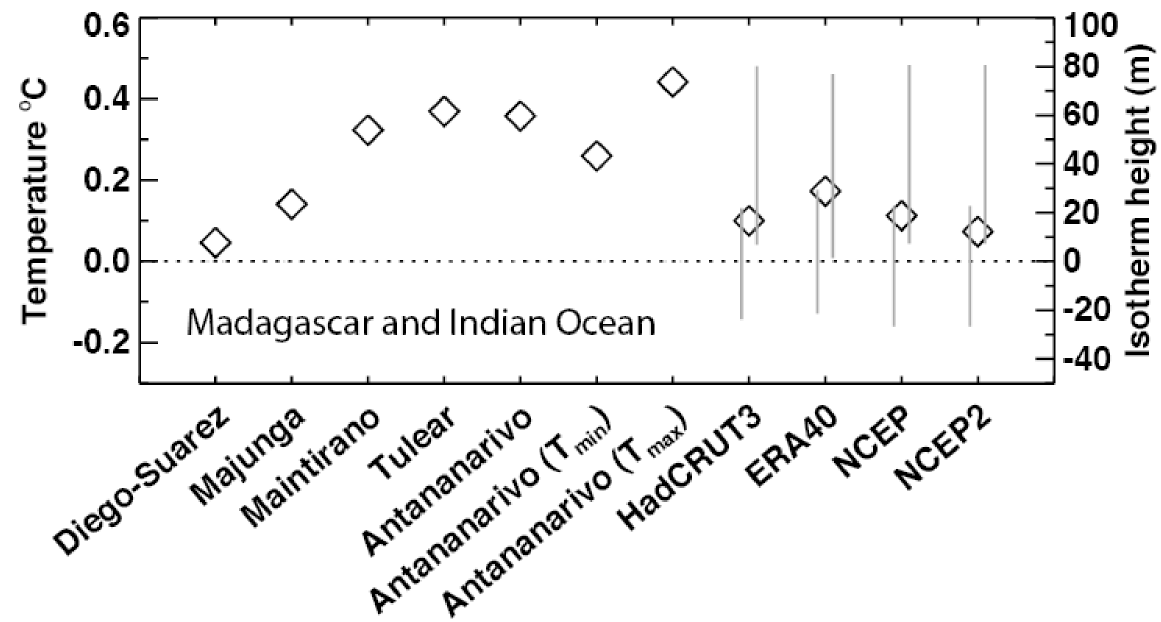


Evidence of recent warming in Madagascar

Changes in mean annual temperature between the decades 1984-1993 and 1994-2003

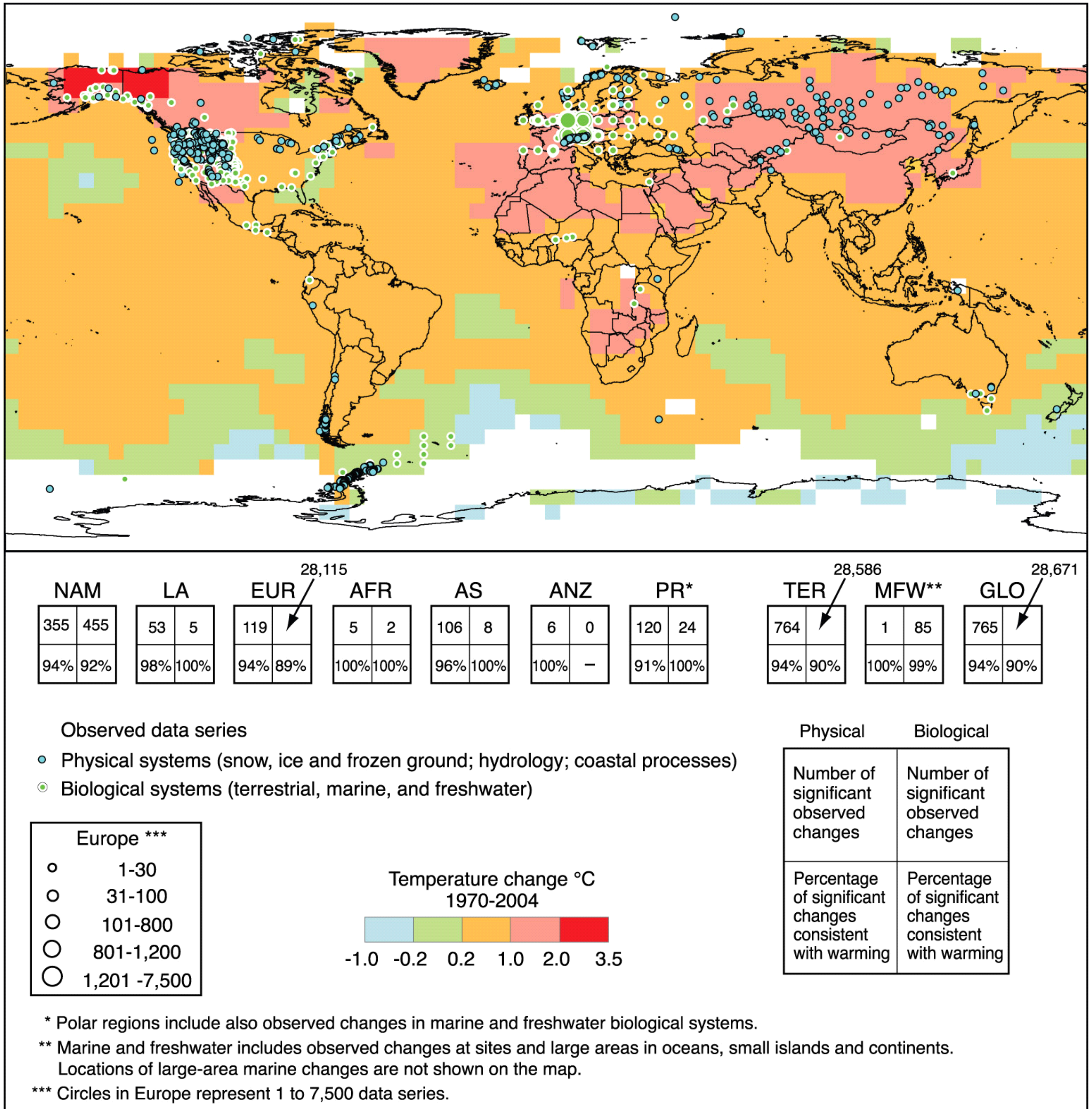
Right axis shows the corresponding change in isotherm height, lapse rate of 6ºC/1000m





Overall, similarity between observed (µ65m) and expected (17-62m) upslope displacement suggests distribution shifts are being driven by warming

But… *uncertainty*… only two points in time, a single massive, possible confounding effects of phenology…



There is *very high* confidence that climate change is already affecting living systems

IPCC 2007

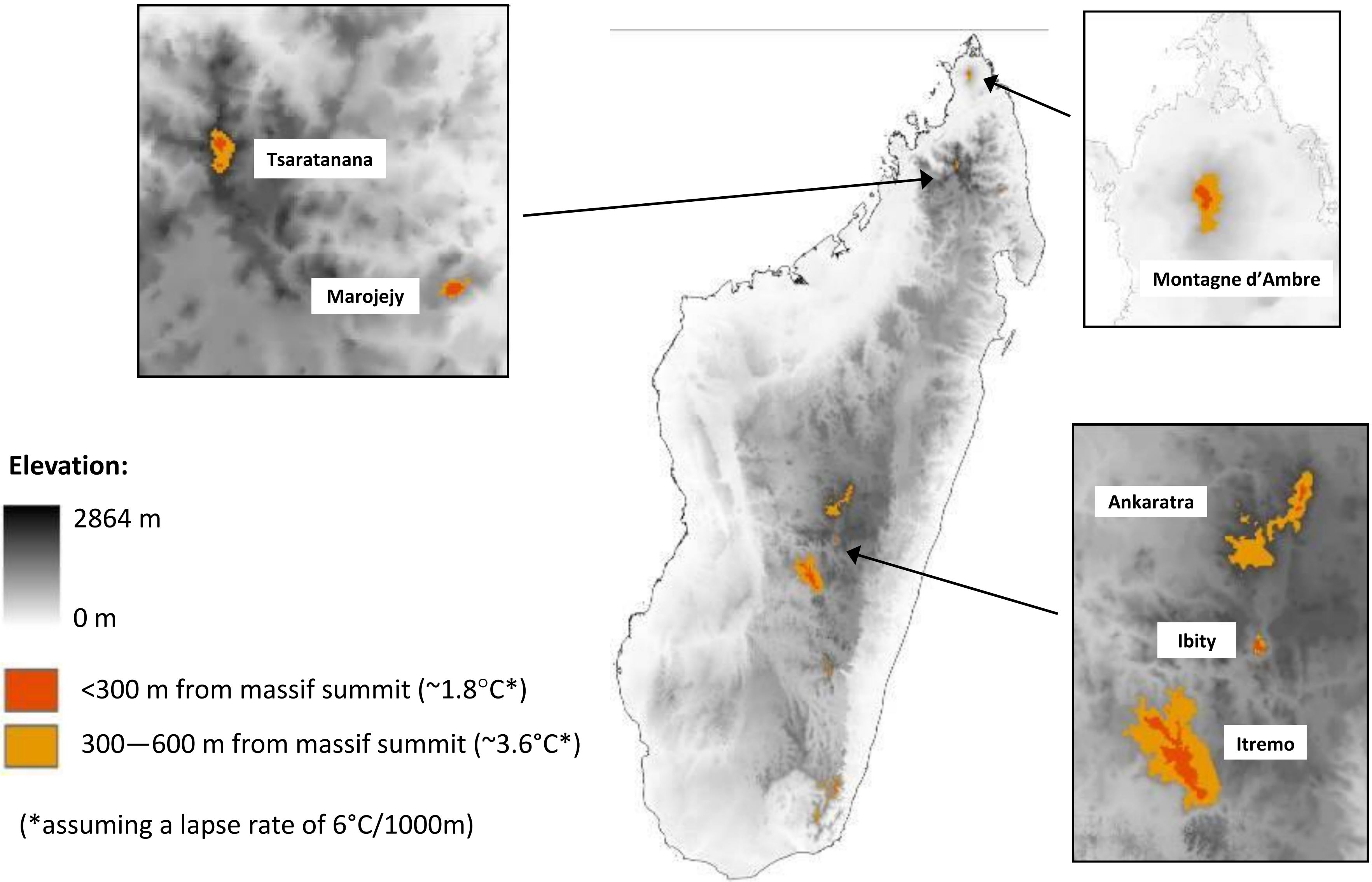
20-30% of species are likely to be at increased risk of extinction if global average warming exceeds **2.5°C**

IPCC 2007

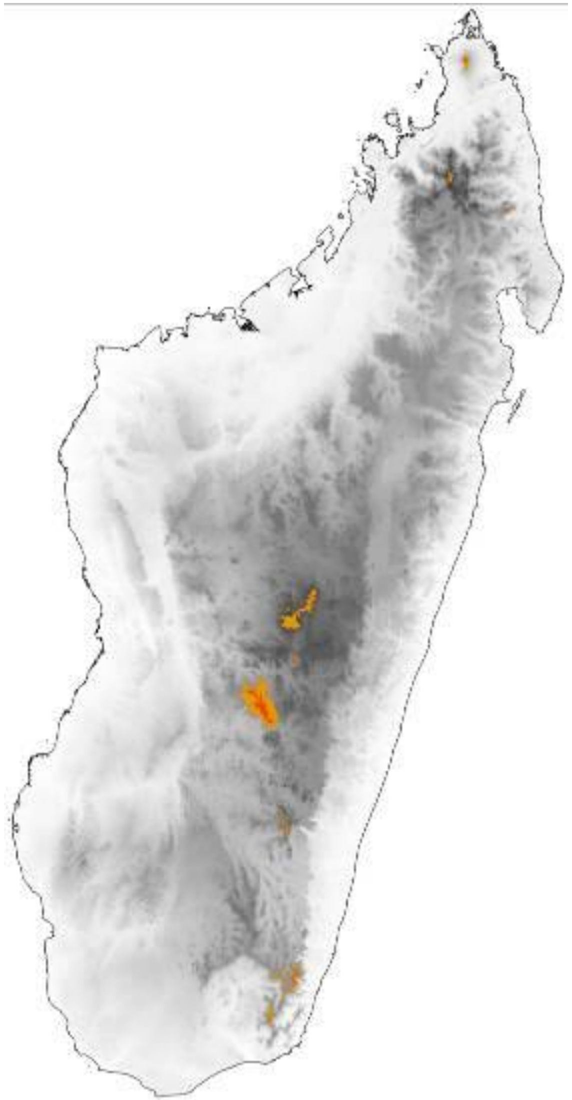
40-70% of species are likely to be at increased risk of extinction if global average warming exceeds **3.5°C**

IPCC 2007

Potential upslope extinction vulnerability in Madagascar



Potential upslope extinction vulnerability in Madagascar



Examples of species from massifs in Madagascar, known only from <600m from the highest summit:

Massif	Species	Group
Andohahela	*Spinomantis guibe*	Amphibians
	Calumma capuroni	Reptiles
Itremo	*Lygodactylus pauliani*	Reptiles
Ibity	*Lygodactylus arnoulti*	Reptiles
	Lygodactylus blanci	Reptiles
	Arundinaria ibityensis	Bamboos
Ankaratra	*Mantidactylus pauliani*	Amphibians
	Lygodactylus mirabilis	Reptiles
Marojejy	*Microgale monticola*	Tenrecs
	Calumma peyrierasi	Reptiles
	Calumma jejy	Reptiles
	Blechnum longepetiolatum	Ferns
	Cheilanthes sp. nov. 1	Ferns
	Cyathea alticola	Ferns
	Lindsaea sp. nov. 1	Ferns
	Arundinaria marojejyensis	Bamboos
Anjanaharibe-Sud	*Microgale monticola*	Tenrecs
Bemanevika	*Microgale jobihely*	Tenrecs
Montage d'Ambre	*Pseudoxyrhopus ambreensis*	Reptiles
	Calumma amber	Reptiles

(Raxworthy et al. 2008 *Global Change Biology*)

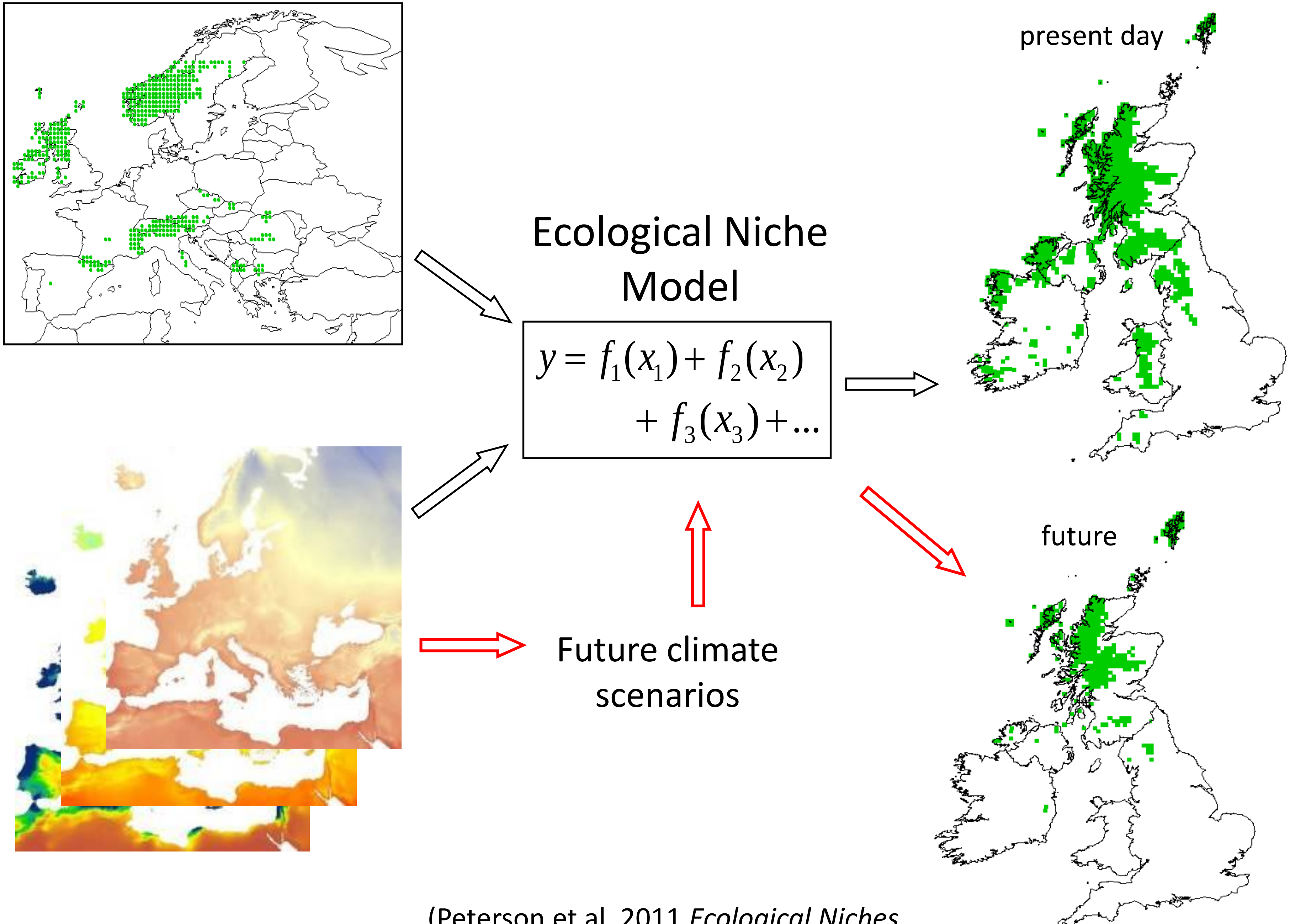
Models to predict future impacts

Correlative/statistical vs. Mechanistic/process-based

- 'Bioclimate envelope' models
- Assume current distribution gives a good indicator of ecological requirements
- Good for rapid 'first pass' assessment, can model many individual species at fine resolution

- E.g., Dynamic Global Vegetation Models
- Do not rely on 'realised' ecological niches
- Require detailed physiological data, tend to operate above the species level (e.g., biomes) at coarse resolution

(for a review see Kearney and Porter *Ecology Letters* 2009)

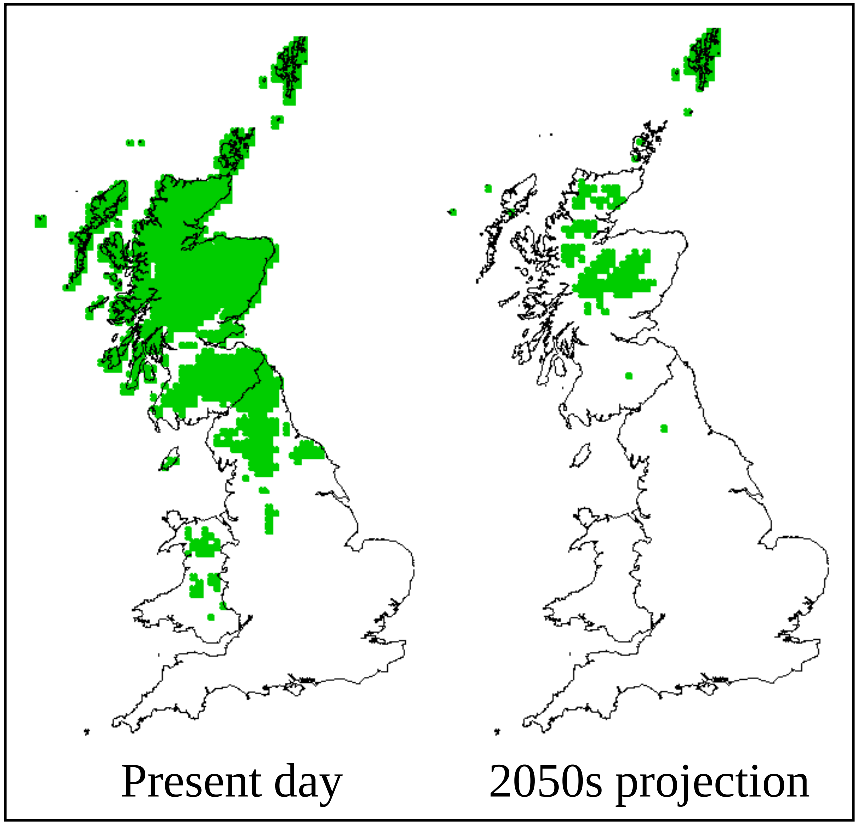


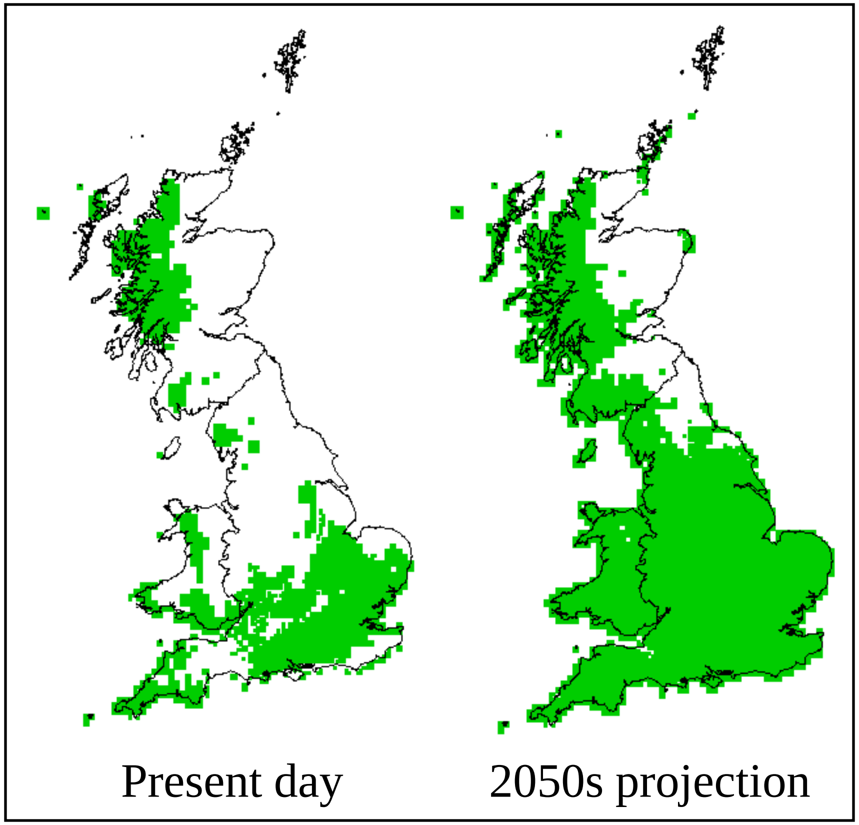
(Peterson et al. 2011 *Ecological Niches and Geographic Distributions*)

Predicted distribution shifts under climate change

Upslope range contraction

Pole-ward range expansion





'Bioclimate envelope' predictions for Twinflower (left) and White-beaked sedge (right)

(Pearson et al. 2002 *Ecological Modelling*)

Extinction risk from climate change

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Climate change over the past ~30 years has produced numerous shifts in the distributions and abundances of species[1,2] and has been implicated in one species-level extinction[3]. Using projections of species' distributions for future climate scenarios, we assess extinction risks for sample regions that cover some 20% of the Earth's terrestrial surface. Exploring three approaches in which the estimated probability of extinction shows a power-law relationship with geographical range size, we predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in our sample of regions and taxa will be 'committed to extinction'. When the average of the three methods and two dispersal scenarios is taken, minimal climate-warming scenarios produce lower projections of species committed to extinction (~18%) than mid-range (~24%) and maximum-change (~35%) scenarios. These estimates show the importance of rapid implementation of technologies to decrease greenhouse gas emissions and strategies for carbon sequestration.

The responsiveness of species to recent[1–3] and past[4,5] climate change raises the possibility that anthropogenic climate change could act as a major cause of extinctions in the near future, with the Earth set to become warmer than at any period in the past 1–40 Myr (ref. 6). Here we use projections of the future distributions of 1,103 animal and plant species to provide 'first-pass' estimates of extinction probabilities associated with climate change scenarios for 2050.

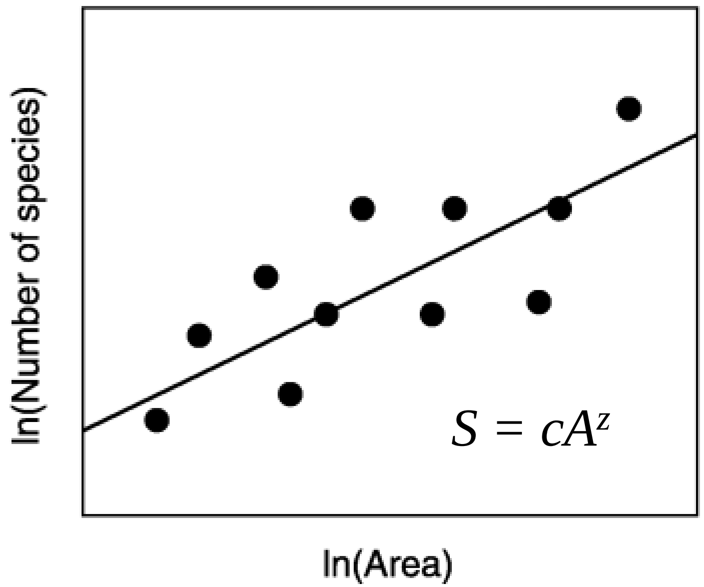
For each species we use the modelled association between current climates (such as temperature, precipitation and seasonality) and present-day distributions to estimate current distributional areas[7–12]. This 'climate envelope' represents the conditions under which populations of a species currently persist in the face of competitors and natural enemies. Future distributions are estimated by assuming that current envelopes are retained and can be projected for future climate scenarios[7–12]. We assume that a species either has no limits to dispersal such that its future distribution becomes the entire area projected by the climate envelope model or that it is incapable of dispersal, in which case the new distribution is the overlap between current and future potential distributions (for example, species with little dispersal or that inhabit fragmented landscapes)[11]. Reality for most species is likely to fall between these extremes.

We explore three methods to estimate extinction, based on the species–area relationship, which is a well-established empirical power-law relationship describing how the number of species relates to area ($S = cA^z$, where S is the number of species, A is area, and c and z are constants)[13]. This relationship predicts adequately the numbers of species that become extinct or threatened when the area available to them is reduced by habitat destruction[14,15]. Extinctions arising from area reductions should apply regardless of whether the cause of distribution loss is habitat destruction or climatic unsuitability.

Because climate change can affect the distributional area of each species independently, classical community-level approaches need to be modified (see Methods). In method 1 we use changes in the summed distribution areas of all species. This is consistent with the traditional species–area approach: on average, the destruction of half of a habitat results in the loss of half of the distribution area summed across all species restricted to that habitat. However, this analysis tends to be weighted towards species with large distributional areas. To address this, in method 2 we use the average proportional loss of the distribution area of each species to estimate the fraction of species predicted to become extinct. This approach is faithful to the species–area relationship because halving the habitat area leads on average to the proportional loss of half the distribution of each species. Method 3 considers the extinction risk of each species in turn. In classical applications of the species–area approach, the fraction of species predicted to become extinct is equivalent to the mean probability of extinction per species. Thus, in method 3 we estimate the extinction risk of each species separately by substituting its area loss in the species–area relationship, before averaging across species (see Methods). Our conclusions are not dependent on which of these methods is used. We use $z = 0.25$ in the species–area relationship throughout, given its previous success in predicting proportions of threatened species[14,15], but our qualitative conclusions are not dependent on choice of z (Supplementary Information). As there are gaps in the data (not all dispersal/climate scenarios were available for each region), a logit–linear model is fitted to the extinction risk data to produce estimates for missing values in the extinction risk table (Table 1). Balanced estimates of extinction risk, averaged across all data sets, can then be calculated for each scenario.

For projections of maximum expected climate change, we estimate species-level extinction across species included in the study to be 21–32% (range of the three methods) with universal dispersal, and 38–52% for no dispersal (Table 1). For projections of mid-range climate change, estimates are 15–20% with dispersal and 26–37% without dispersal (Table 1). Estimates for minimum expected climate change are 9–13% extinction with dispersal and 22–31% without dispersal. Projected extinction varies between parts of the world and between taxonomic groups (Table 1), so our estimates are affected by the data available. The species–area methods differ from one another by up to 1.41-fold (method 1 versus method 3) in estimated extinction, whereas the two dispersal scenarios produce a 1.98-fold difference, and the three climate scenarios generate 2.05-fold variation.

Extinction risk from climate change



"we predict, on the basis of mid-range climate-warming scenarios for 2050, that 15-37% of species in our sample of regions and taxa will be 'committed to extinction'"

(Thomas *et al*. 2004, *Nature*)

Uncertainties in predictions of future impacts of climate change

Ecological

- Dispersal capacity
- Biotic interactions
- Non-analogue climates
- Rapid evolutionary adaptation
- Direct impacts of CO_2

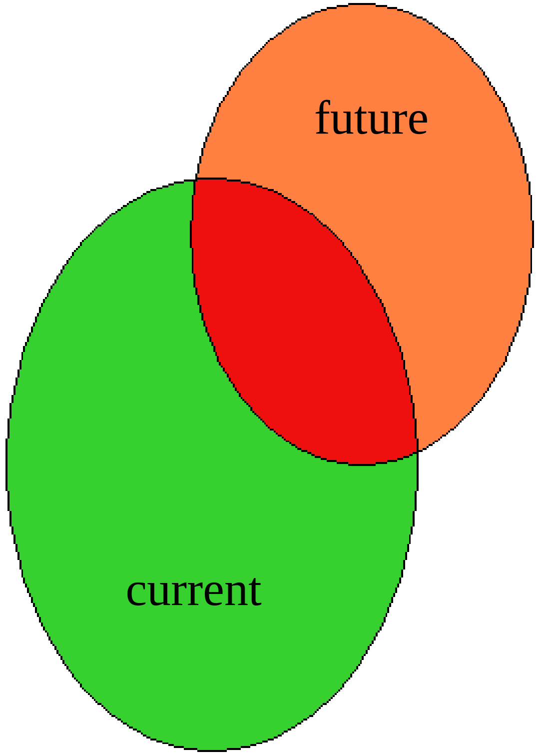
Algorithmic

- Model selection
- Coarse scale of analysis
- Climate scenarios
- Thresholding

Pearson & Dawson 2003, 2004 *Global Ecol. Biogeog.*
Thuiller, Araújo, Pearson *et al.* 2004 *Nature*
Pearson 2006 *TREE*; Pearson *et al.* 2006 *J. Biogeog.*

Uncertainty example 1: Dispersal ability

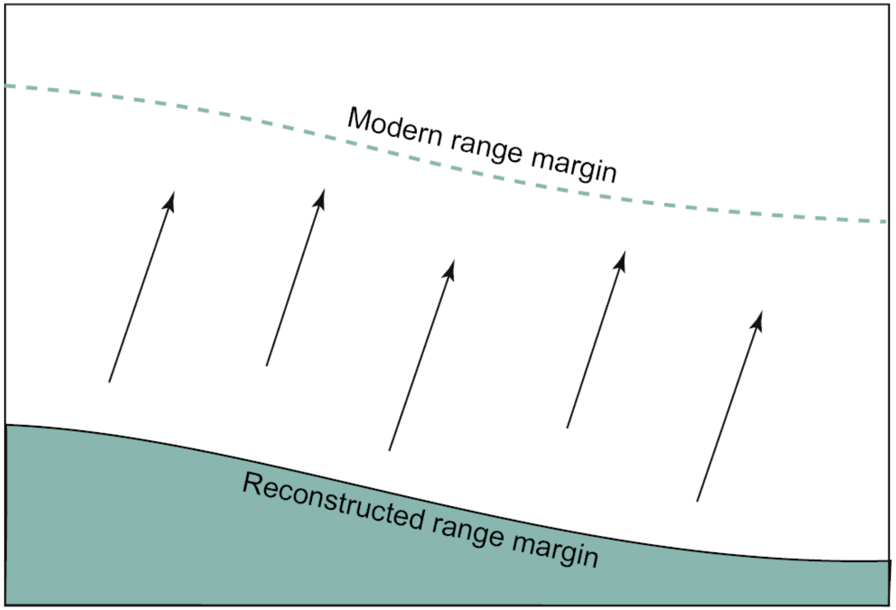
Will species be able to 'keep up' with changing climate?



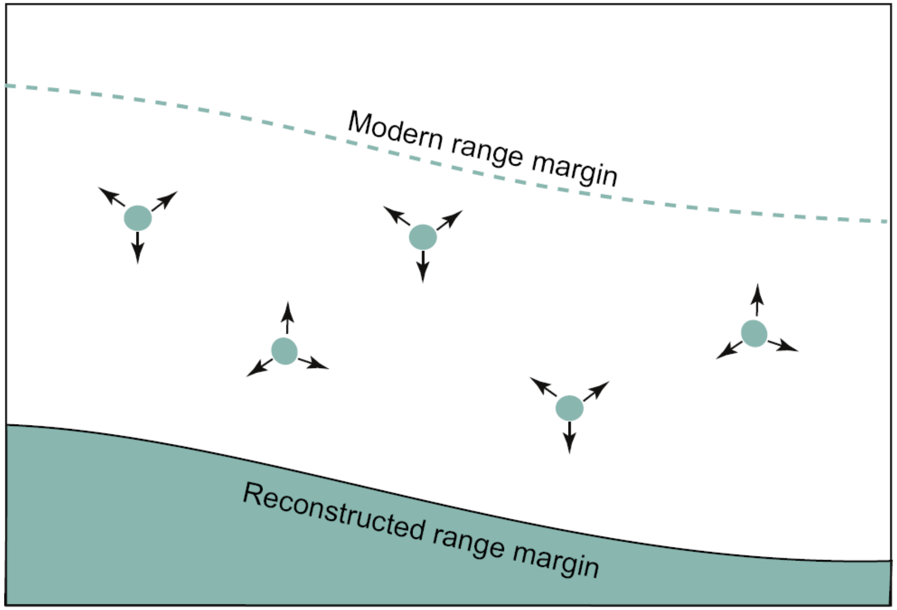
Thomas *et al* (2004, *Nature*):

species-level extinction estimated to be 21-32% with universal dispersal, and 38-52% with no dispersal (under maximum projected climate change)

Alternative mechanisms to explain rapid colonization of trees in response to late-glacial warming



1. Long-distance dispersal



2. Local dispersal from refugia

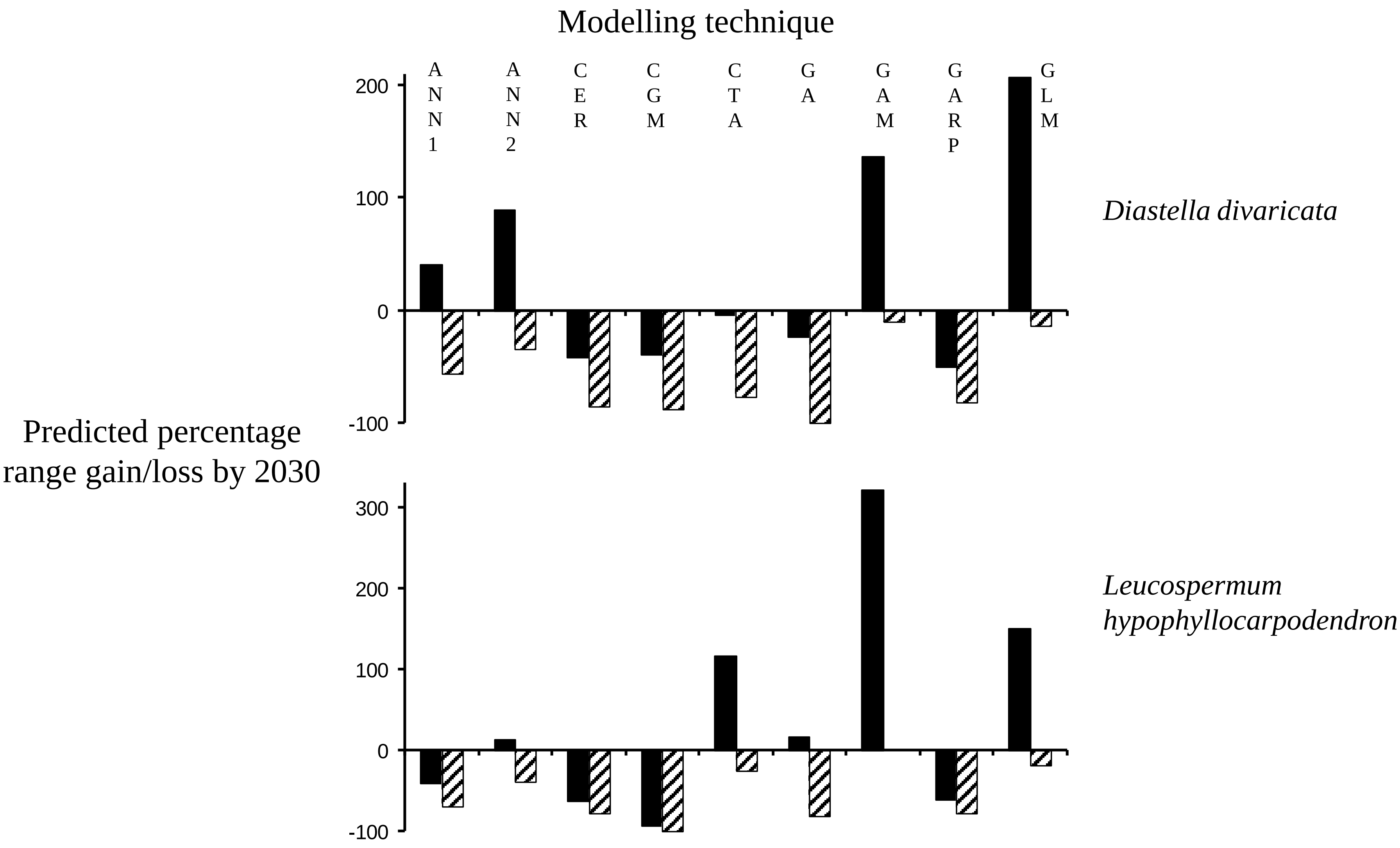
(Pearson 2006 *Trends in Ecology & Evolution*)

Uncertainty example 2: complex ecological networks

Uncertainty example 2: complex ecological networks

Linda J. Gormezano

Uncertainty example 3: Model-based uncertainty



(Pearson *et al.*, *J. Biogeog.* 2006; see also Thuiller *et al*. *Nature*, 2004)

Methods for dealing with uncertainty and improving predictions

Ensemble forecasting to reduce model-based uncertainty

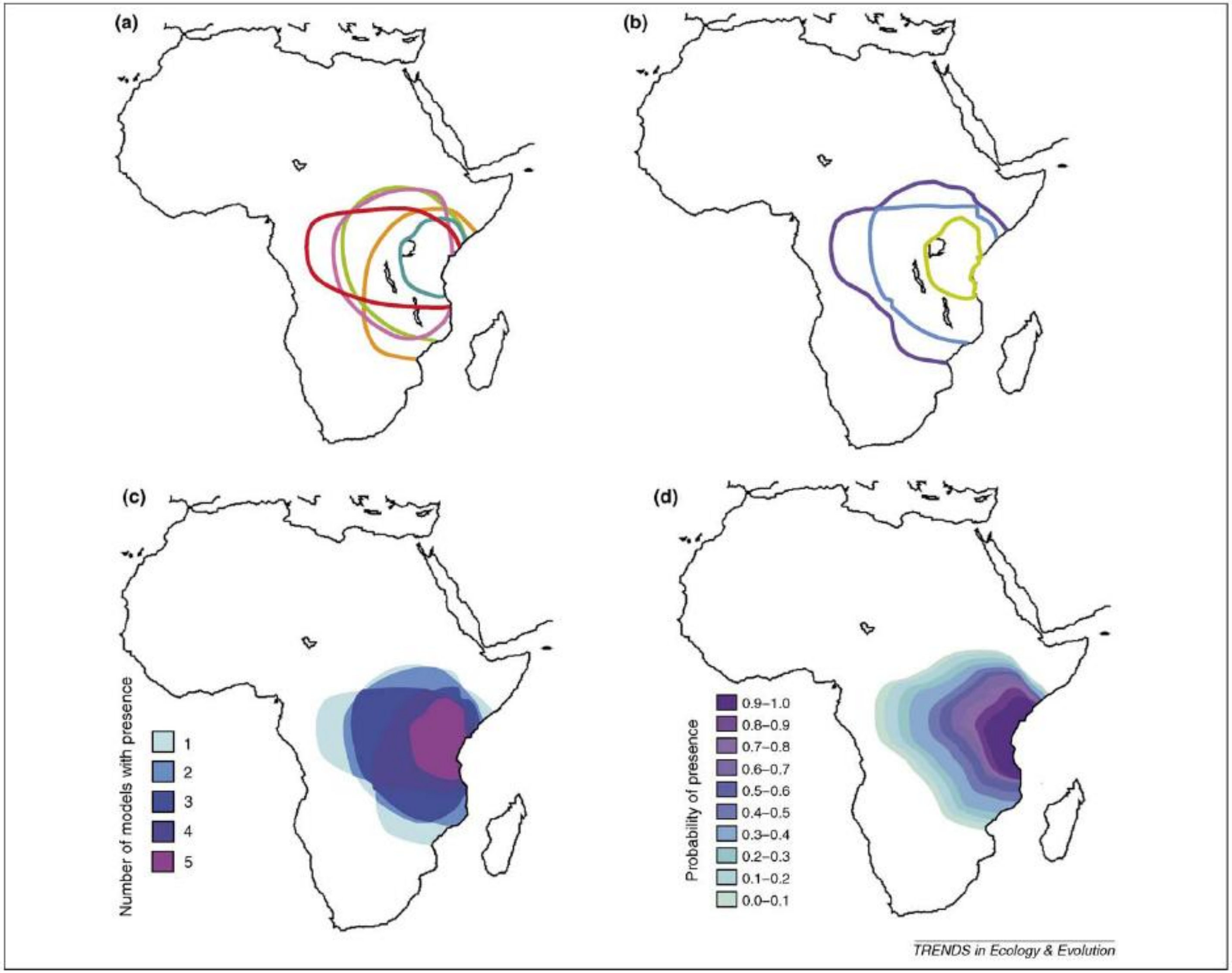
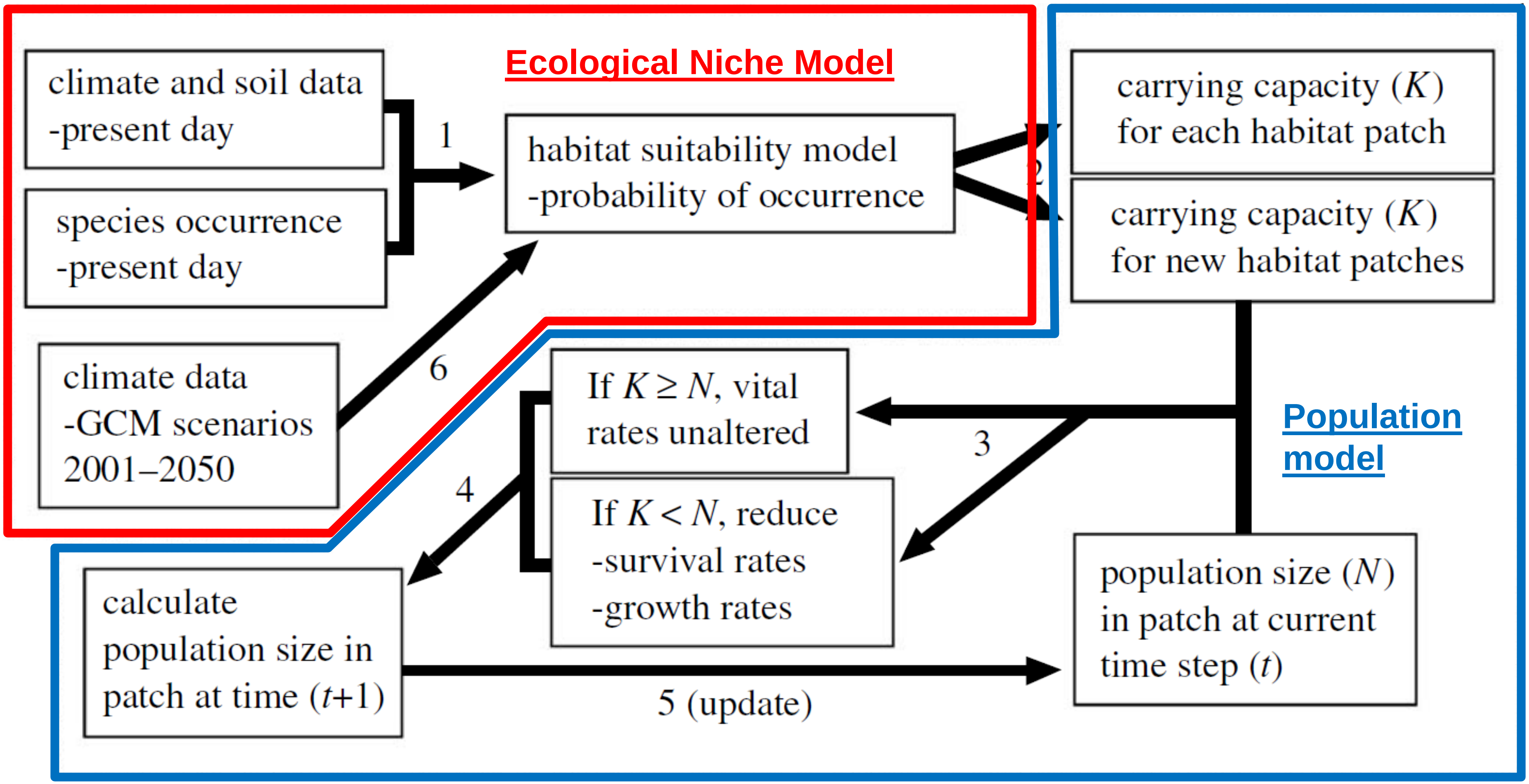


Figure 1. Examples of alternative approaches to analysing ensemble forecasts using artificial data projected onto the map of Africa: **(a)** Individual results from five hypothetical bioclimatic models (shown by coloured lines) predicting the area occupied by a key species under a climate change scenario (no combination of the ensemble forecast is performed); **(b)** a bounding box showing the area where at least one (purple) or all models (green) predict species presence in the future, and a consensus forecast (blue) showing the area where at least half the models (the median) forecast species presence; **(c)** a frequency histogram, showing the number of models (1–5) forecasting the presence of the species at any point; and **(d)** a probability density function showing the likelihood of species presence estimated from a large ensemble.

(Araújo & New 2007 *TREE*)

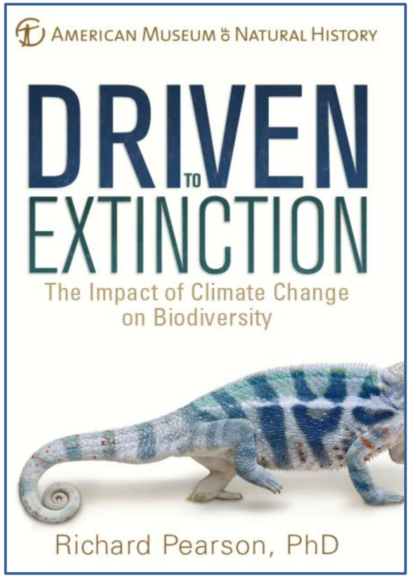
Linking Ecological Niche Models and Demographic Models



Keith *et al.* 2008 *Biology Letters*
Brook *et al.* 2009 *Biology Letters*
Fordham *et al.* 2012 *GCB*

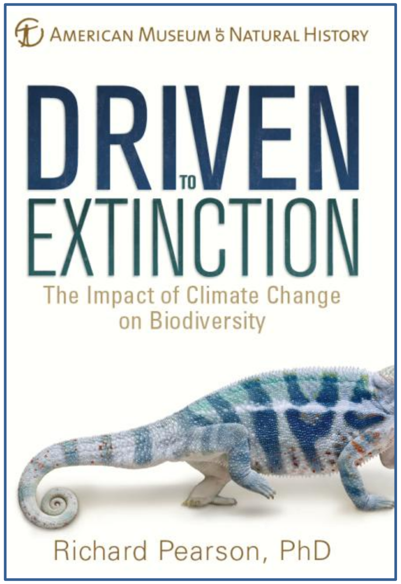
40-70% of species are likely to be at increased risk of extinction if global average warming exceeds **3.5°C**

IPCC 2007



The ongoing challenge is to communicate the state of knowledge concisely and accurately, avoiding exaggeration and hyperbole

In light of recent controversies, more measured and nuanced messages are needed to ensure that public trust in science is maintained



Are conservation scientists "crying wolf" over climate change?

we have enough

evidence to prove **wrong** the skeptic

who denies that climate change is a threat

… global warming will lead to

extensive and irreversible

transformations of ecosytems

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Jessica Stanton
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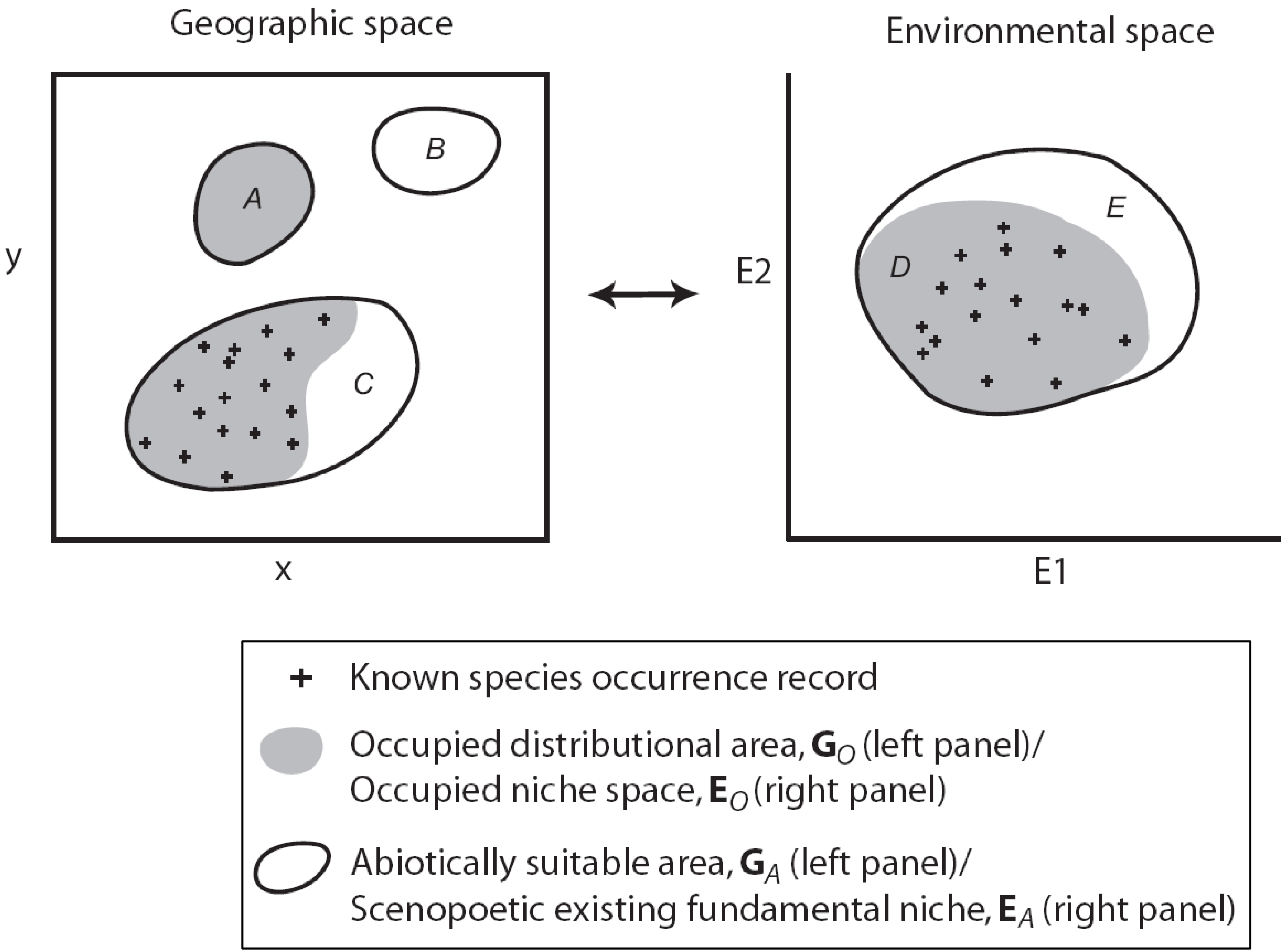
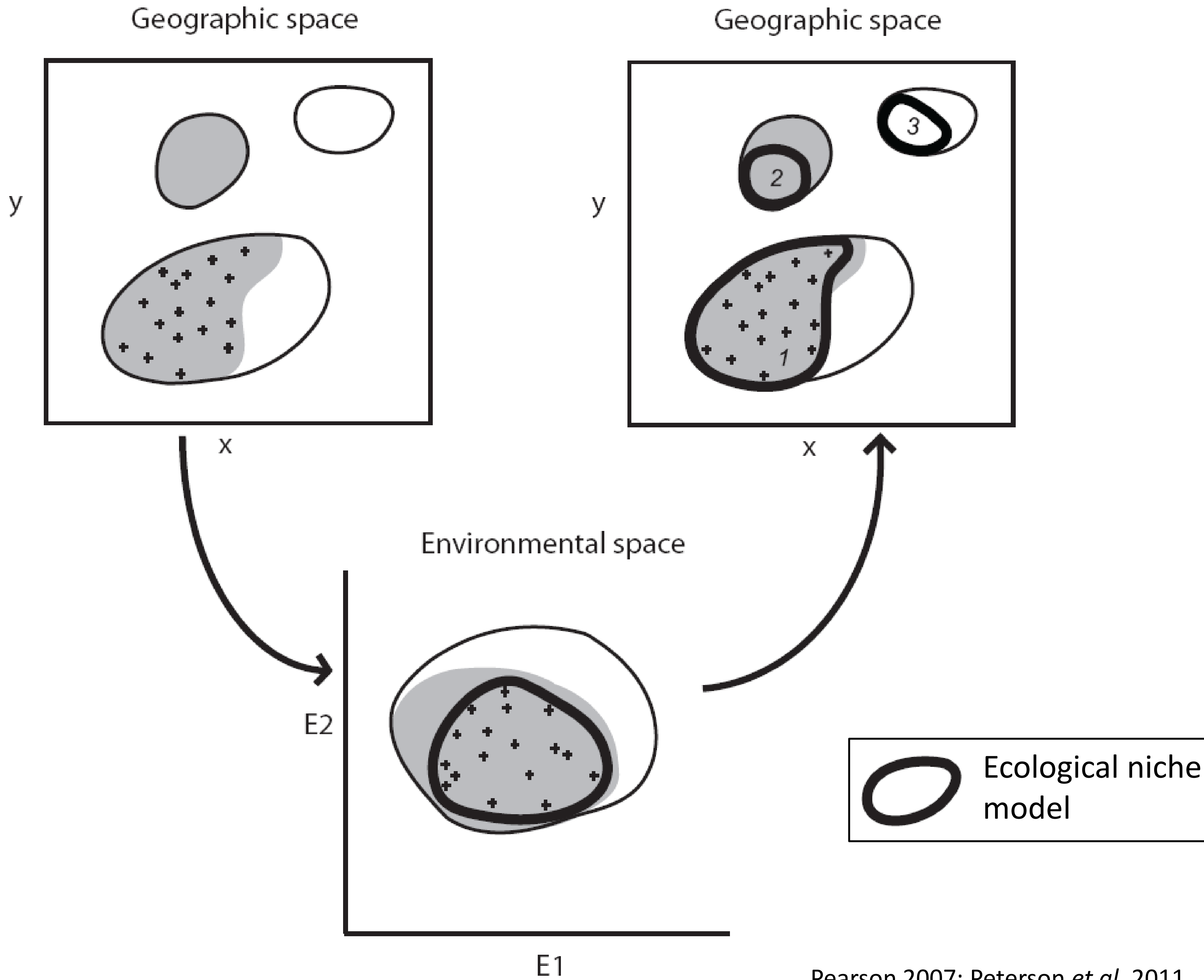
European flora
Pam Berry
Terry Dawson
Paula Harrison

Polar bear case study
Jouke Prop
Linda Gormezano
Robert Rockwell

Extramural funding



Pearson 2007; Peterson *et al.* 2011



Pearson 2007; Peterson *et al.* 2011