

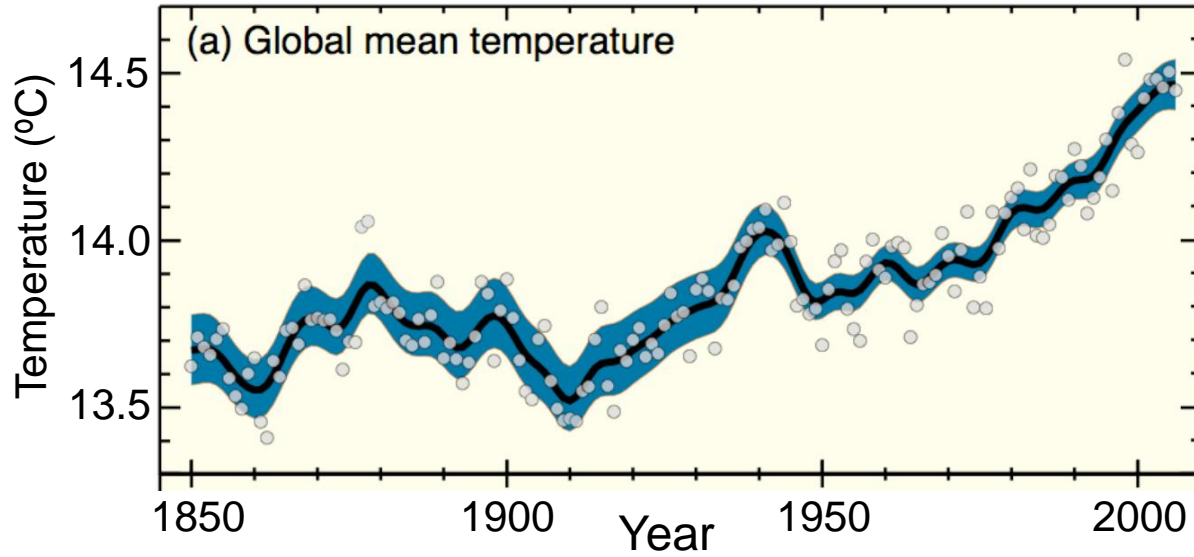
Uncertainty in Ecological Models of Climate Change Impacts

Richard Pearson



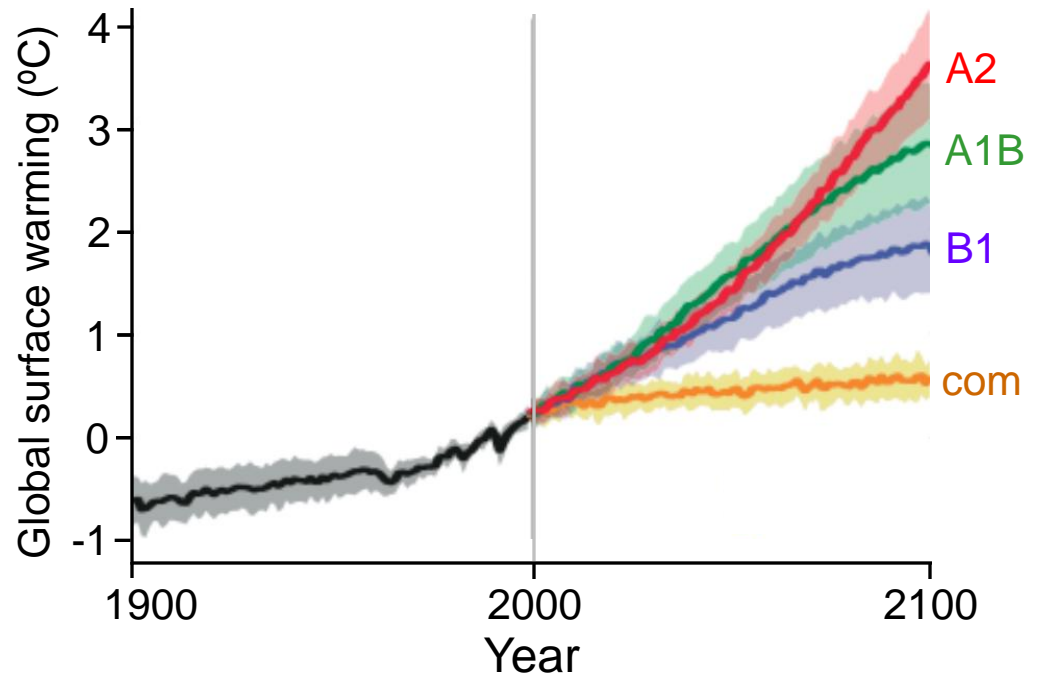
AMERICAN MUSEUM
OF NATURAL HISTORY

IPCC Fourth Assessment Report (2007)



Observed changes

AOGCM predictions



Session overview:

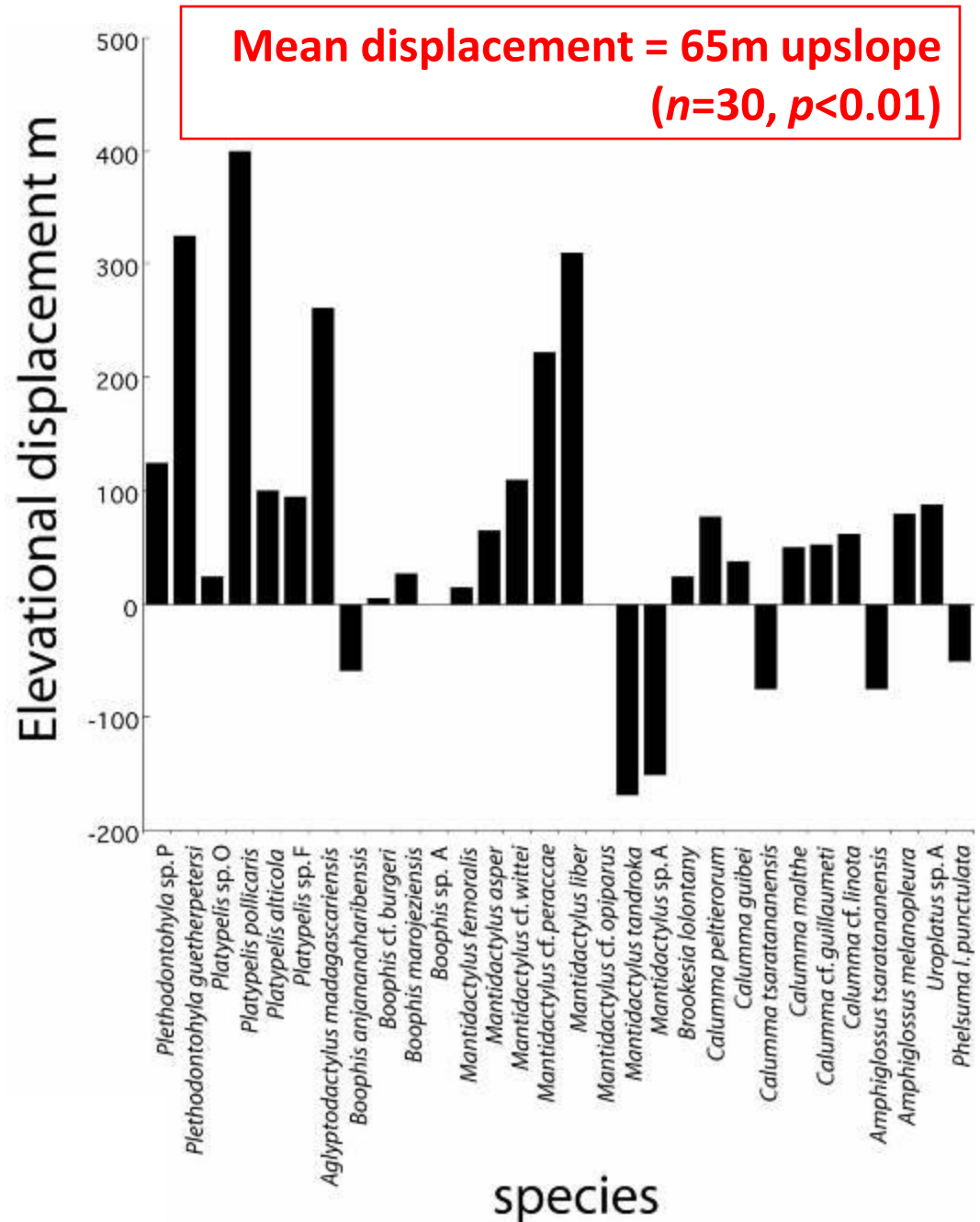
- Observed 'fingerprints' of climate change
- Predicting future impacts
- Some promising ways forward
- Communicating uncertainty

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



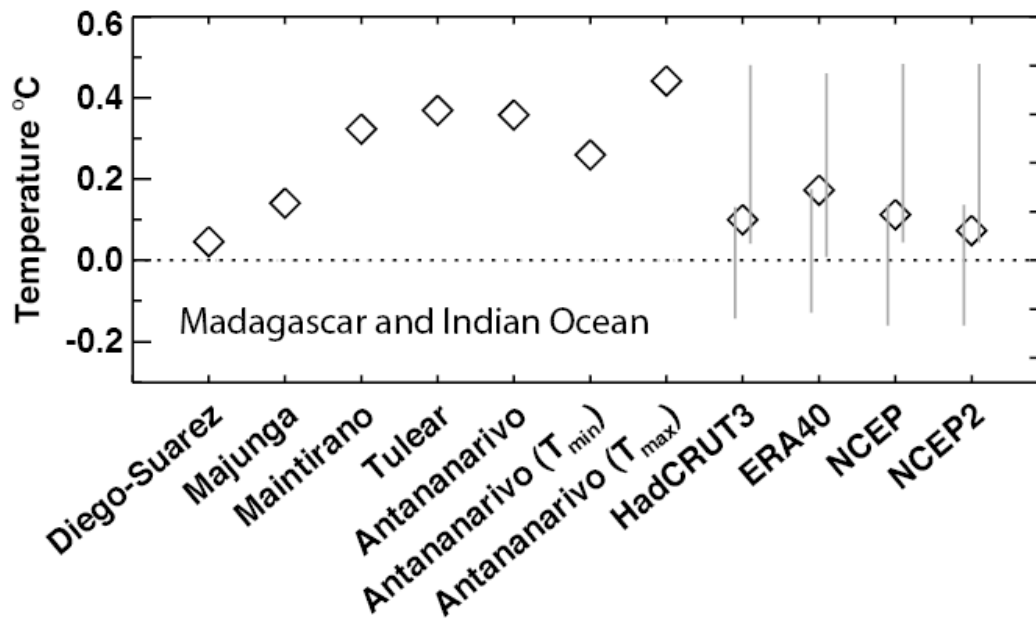
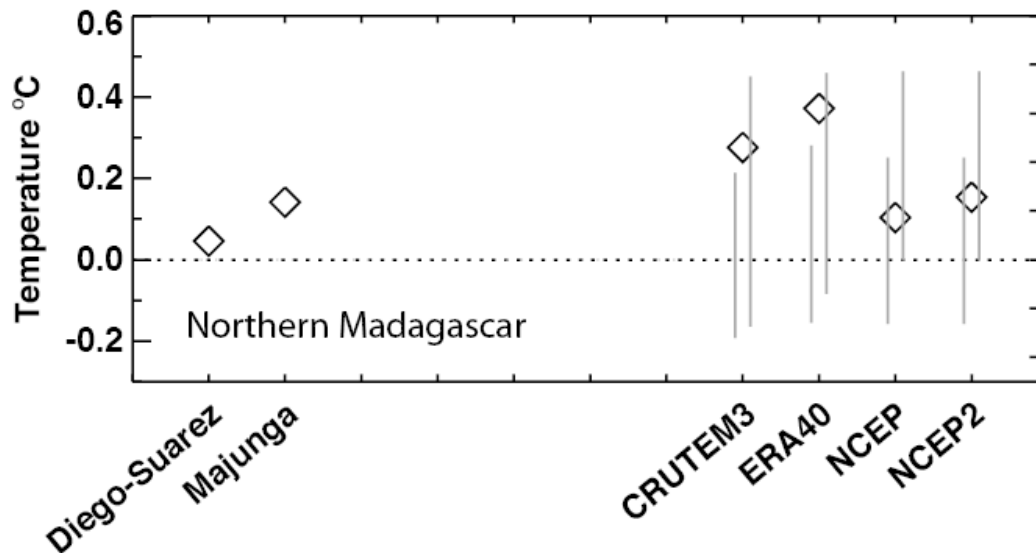
Elevational displacement of distribution midpoint between 1993 and 2003 for 30 species of reptiles and amphibians surveyed at Tsaratanana

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



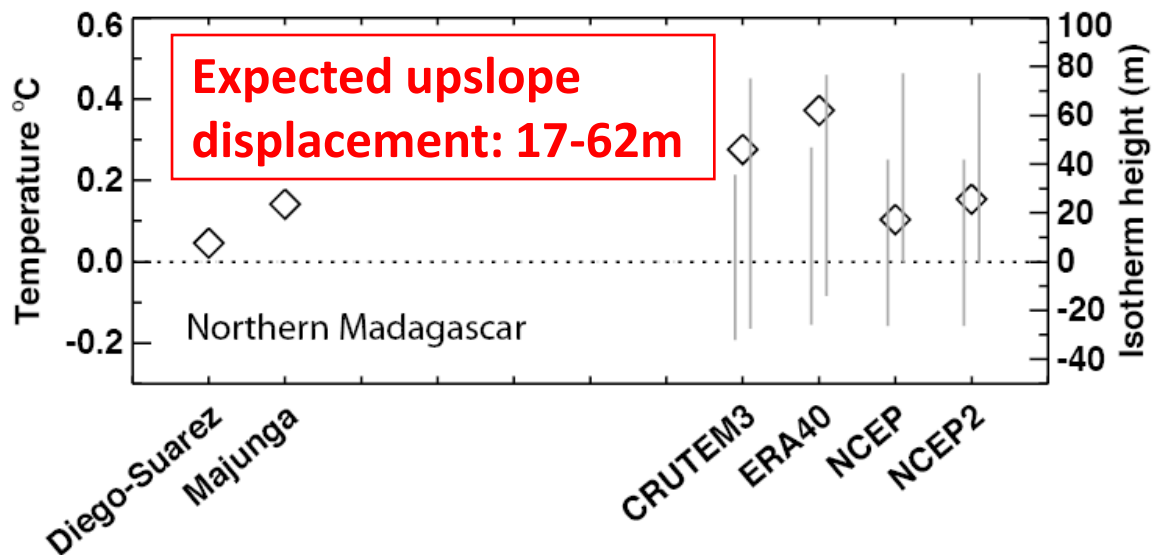
Evidence of recent warming in Madagascar

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

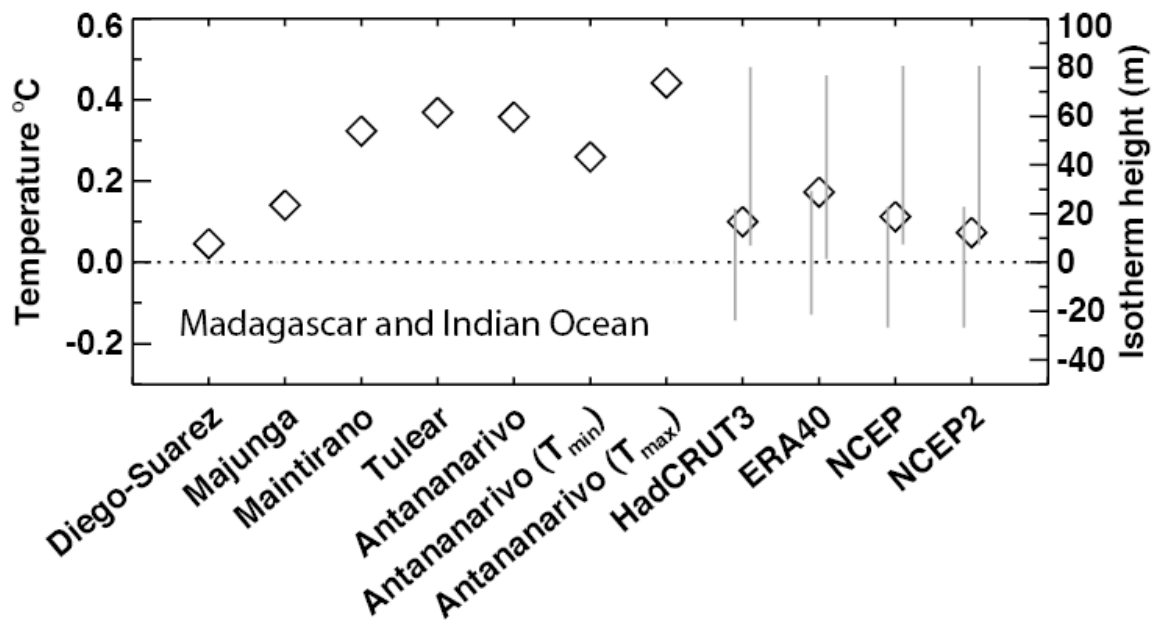


Evidence of recent warming in Madagascar

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

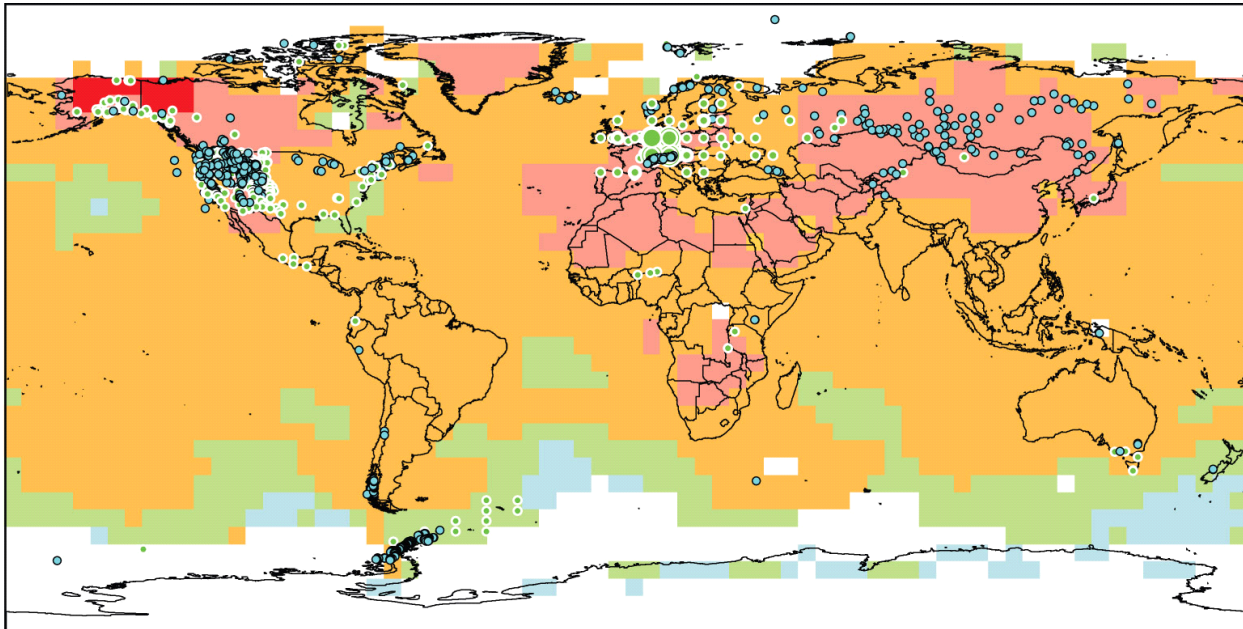


Right axis shows the corresponding change in isotherm height, lapse rate of 6°C/1000m



Overall, similarity between observed ($\mu 65\text{m}$) 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...



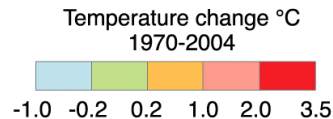
There is ***very high*** confidence that climate change is already affecting living systems

NAM		LA		EUR ^{28,115}		AFR		AS		ANZ		PR*		TER ^{28,586}		MFW**		GLO ^{28,671}	
355	455	53	5	119	28,115	5	2	106	8	6	0	120	24	764	28,586	1	85	765	28,671
94%	92%	98%	100%	94%	89%	100%	100%	96%	100%	100%	—	91%	100%	94%	90%	100%	99%	94%	90%

Observed data series

- Physical systems (snow, ice and frozen ground; hydrology; coastal processes)
- Biological systems (terrestrial, marine, and freshwater)

Europe ***	
○	1-30
○	31-100
○	101-800
○	801-1,200
○	1,201-7,500



Physical	Biological
Number of significant observed changes	Number of significant observed changes
Percentage of significant changes consistent with warming	Percentage of significant changes consistent with warming

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* Polar regions include also observed changes in marine and freshwater biological systems.

** Marine and freshwater includes observed changes at sites and large areas in oceans, small islands and continents. Locations of large-area marine changes are not shown on the map.

*** Circles in Europe represent 1 to 7,500 data series.

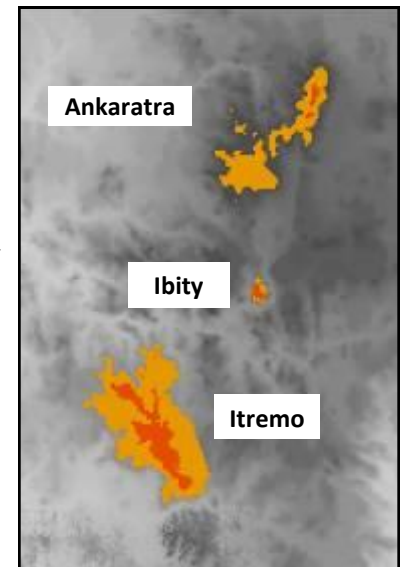
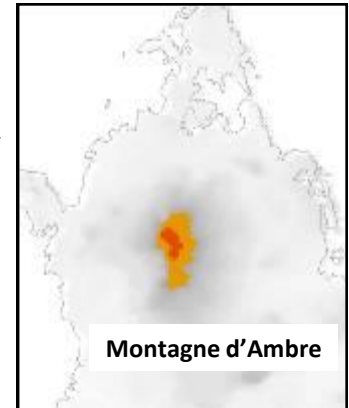
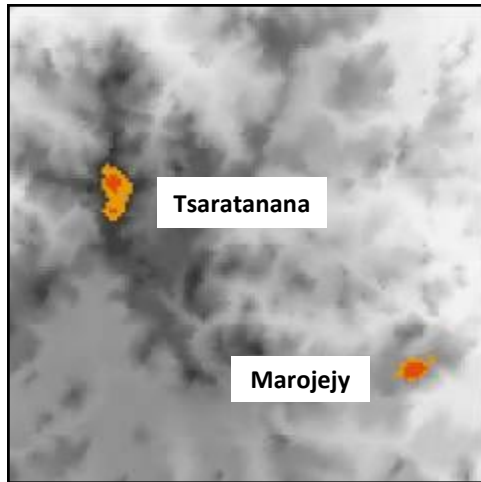
20-30% of species are likely to be at
increased risk of extinction
if global average warming exceeds **2.5°C**

IPCC 2007

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



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Potential upslope extinction vulnerability in Madagascar

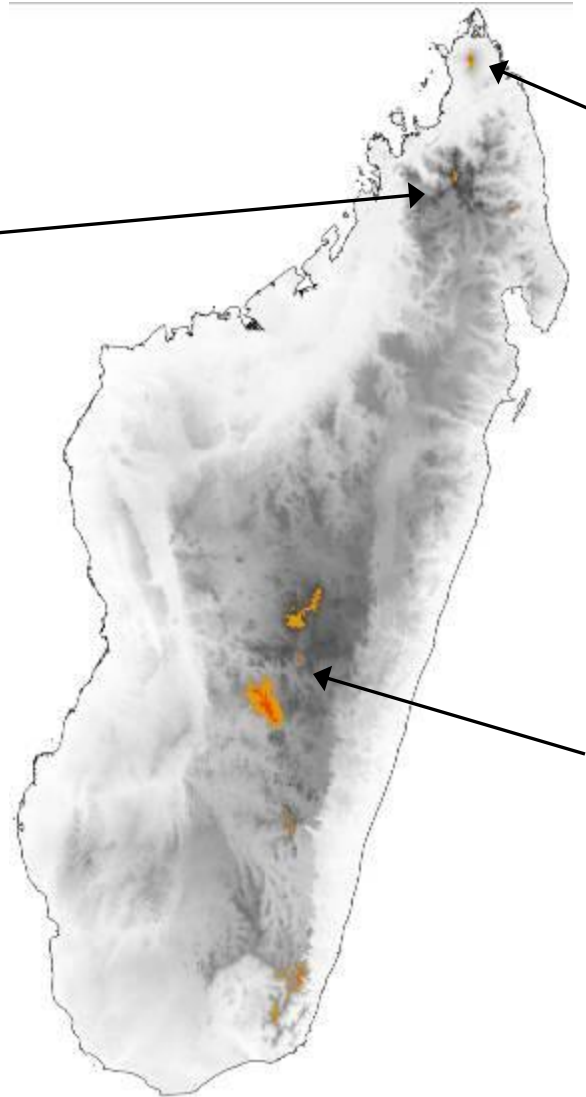


Elevation:



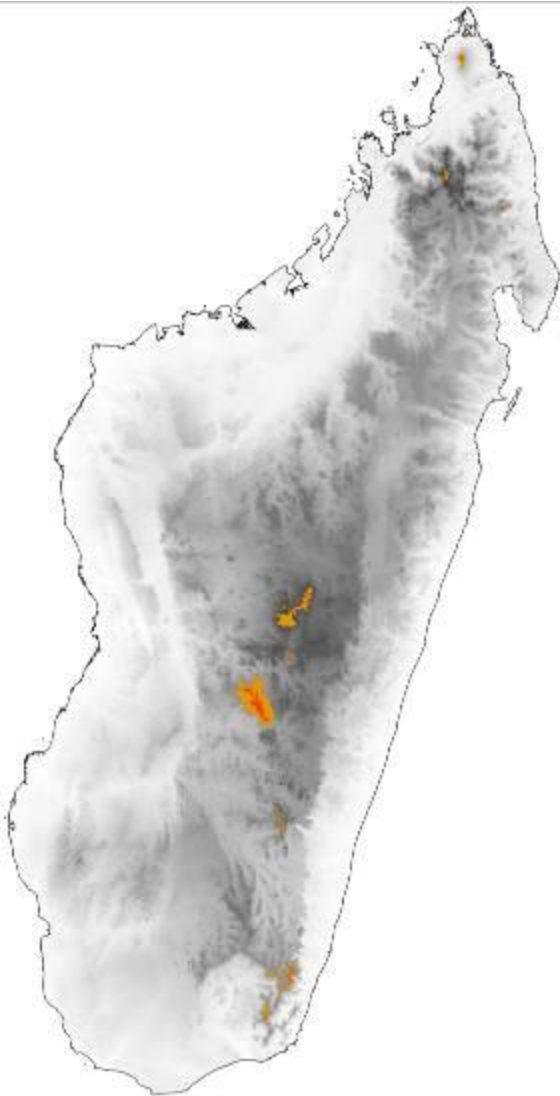
-  <300 m from massif summit ($\sim 1.8^{\circ}\text{C}^*$)
-  300—600 m from massif summit ($\sim 3.6^{\circ}\text{C}^*$)

(*assuming a lapse rate of $6^{\circ}\text{C}/1000\text{m}$)



Potential upslope extinction vulnerability in Madagascar

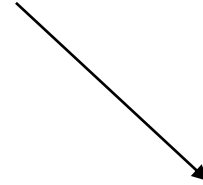
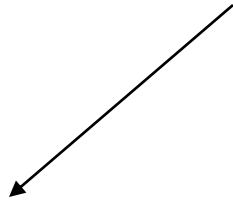
Examples of species from massifs in Madagascar, known only from <600m from the highest summit:



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

Models to predict future impacts

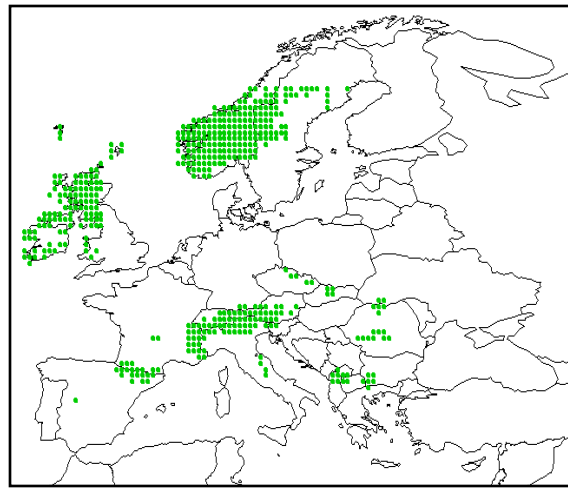
Correlative/statistical vs. Mechanistic/process-based



- '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

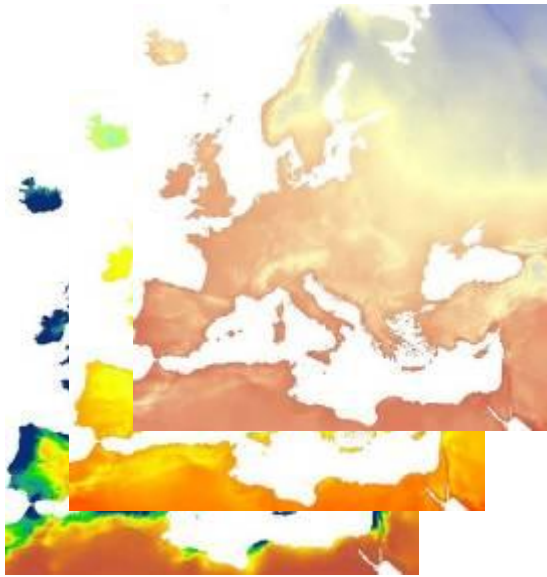
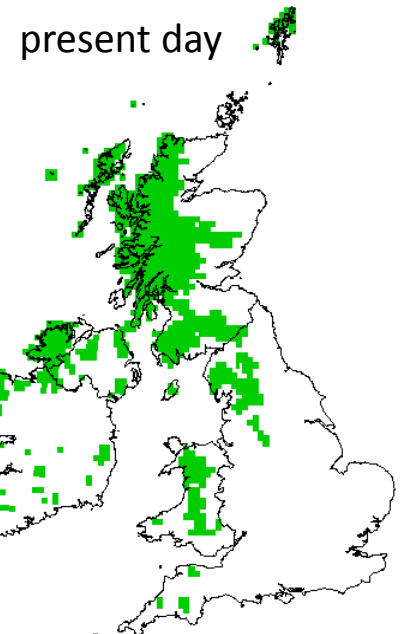
- E.g., Dynamic Global Vegetation Models
- Do not rely on 'realised' ecological niches
- Require detailed physiological data, tend to operate above the species level (e.g., biomes) at coarse resolution

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

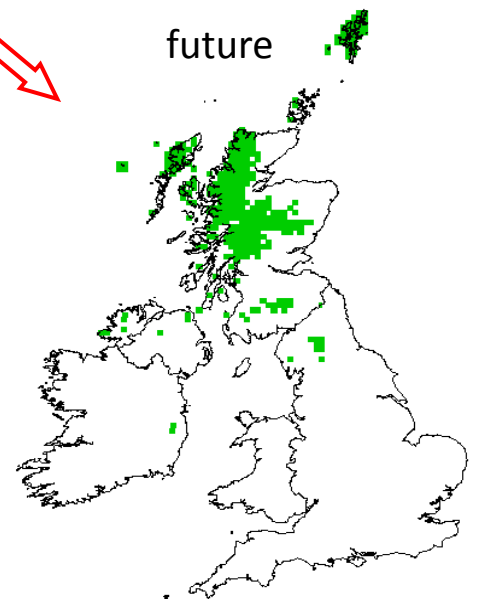


Ecological Niche Model

$$y = f_1(x_1) + f_2(x_2) + f_3(x_3) + \dots$$



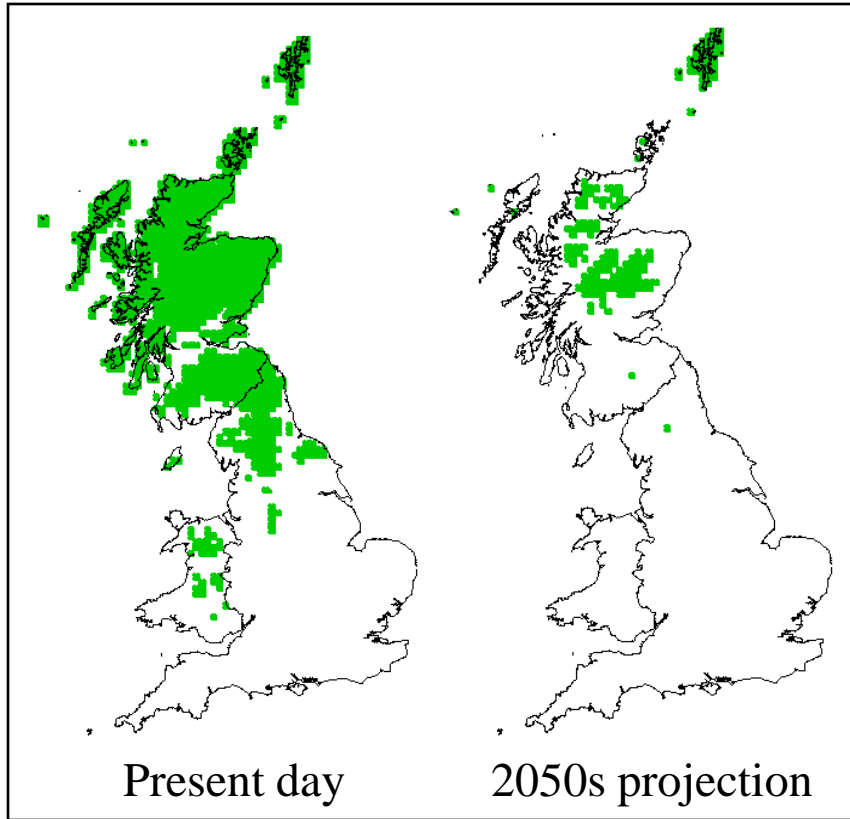
Future climate scenarios



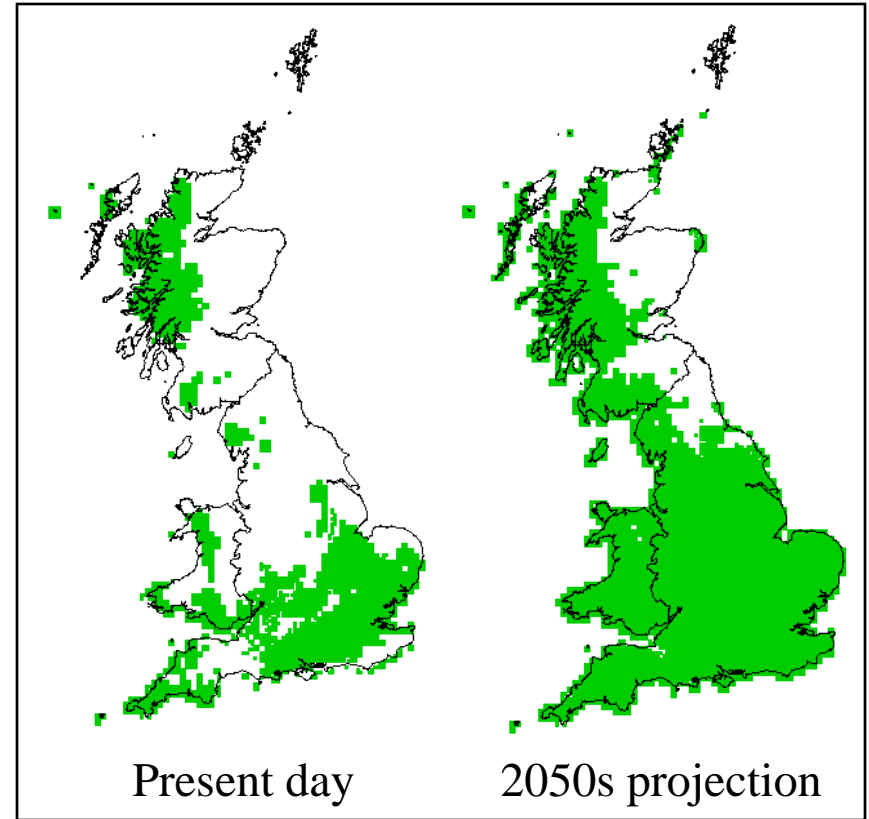
(Peterson et al. 2011 *Ecological Niches and Geographic Distributions*)

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*)

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LETTER

David G. Hole,^{1,2}
G. Willis,^{1,4} Debo
Lincoln D. Fishpo
H. M. Butchart,⁴
Collingham,¹ Car-
and Brian Huntle

INTRODUCTI

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³Royal Society fo
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LETTER

Climate
Abstract
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INTRODUCTION

With more than 100 000 sites across 54 c
protected areas than any other region in
protected areas (e.g. national parks, natu
protected landscapes, etc.), which are
countries, the European Union (EU) est
network to ensure the long-term survi
biodiversity. The Natura 2000 network i
Special Protection Areas (SPAs) are cl
Directive to help conserve important sit
birds; Special Areas of Conservation (SAC
Habitats Directive to conserve rare and vu
plants and habitats. In the 27 countries t
Natura 2000 contributes 27 661 sites cov
(17% of the EU surface) (E.C. 2009). I
conservation areas exist in Europe, a co
successful management is achieved by pro
from the processes that threaten them. Yet
in addition to providing sustainable ma
ecosystems, effective conservation strategie
of climate change. While actions to miti
impacts are being debated worldwide, bi
that across a wide range of taxonomic and
already are responding to climate change b
and geographical distributions (Hickling et
Forecasts project even greater changes i

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Extinction risk from climate change

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Marlene Ferreira de Siqueira⁷, Alan Grainger⁸, Lee Hannah⁹,
Lesley Hughes⁴, Brian Huntley⁵, Albert S. van Jaarsveld¹⁰,
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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 extinction³. Using projec-
tions 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

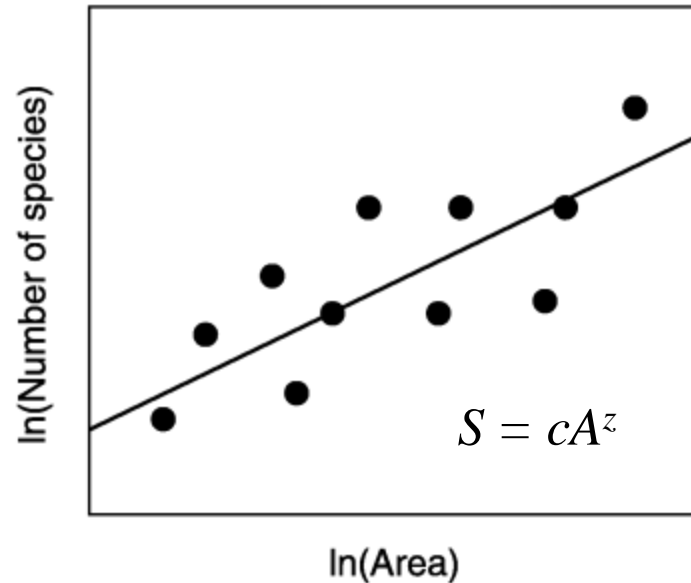
areas^{7–12}. This ‘climate envelope’ represents the conditions under
which populations of a species currently persist in the face of
competitors and natural enemies. Future distributions are estimated
by assuming that current envelopes are retained and can be
projected for future climate scenarios^{7–12}. 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 threat-
ened 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 distribu-
tional 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 extinc-
tion 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 con-
clusions are not dependent on choice of z (Supplementary
Information). As there are gaps in the data (not all dispersal/dimate
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

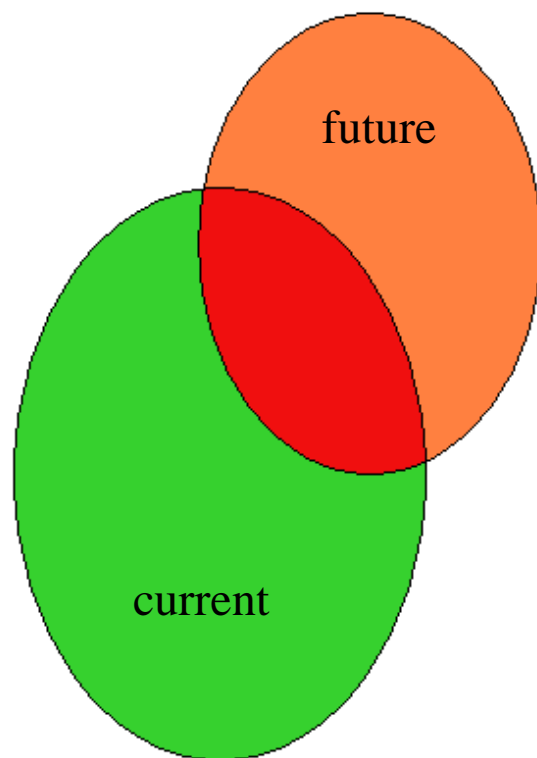
- Dispersal capacity
- Biotic interactions
- Non-analogue climates
- Rapid evolutionary adaptation
- Direct impacts of CO₂

Algorithmic

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

Uncertainty example 1: Dispersal ability

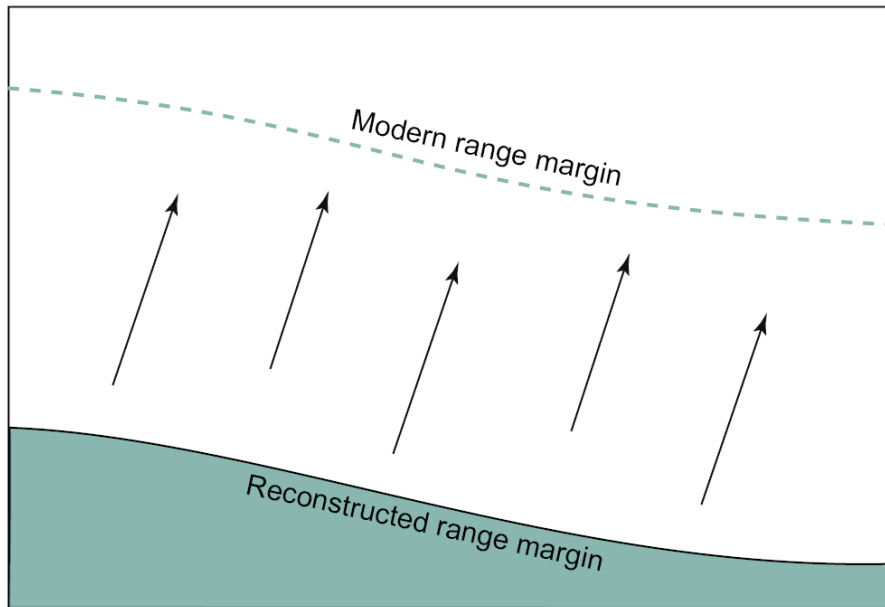
Will species be able to ‘keep up’ with changing climate?



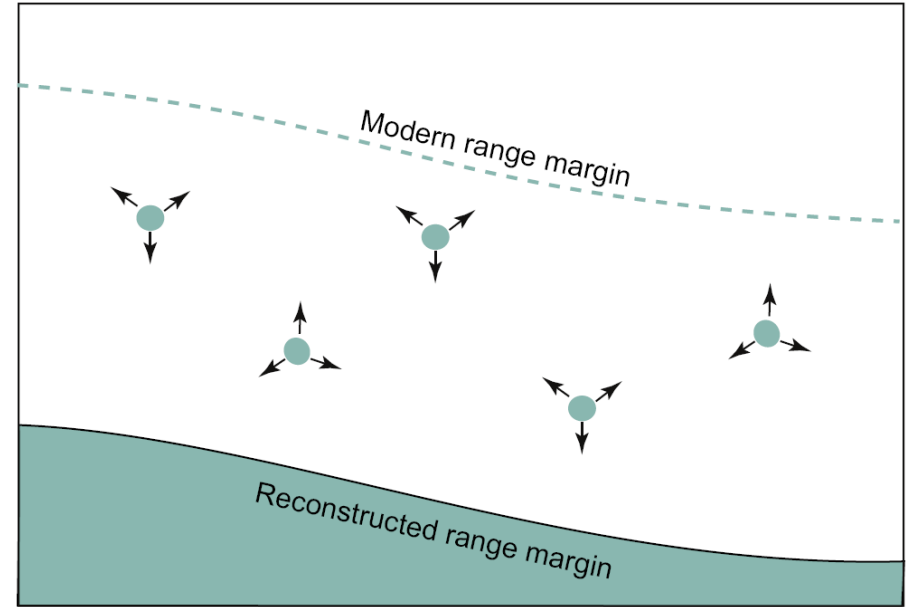
Thomas *et al* (2004, *Nature*):

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

APRIL 3, 2006 www.time.com AOL Keyword: TIME

SPECIAL REPORT GLOBAL WARMING

TIME

**BE
WORRIED.
BE **VERY**
WORRIED.**

Climate change isn't some vague future problem—it's already damaging the planet at an alarming pace. Here's how it affects you, your kids and their kids as well

EARTH AT THE TIPPING POINT
HOW IT THREATENS YOUR HEALTH
HOW CHINA & INDIA CAN HELP
SAVE THE WORLD—OR DESTROY IT
THE CLIMATE CRUSADERS



Uncertainty example 2: complex ecological networks

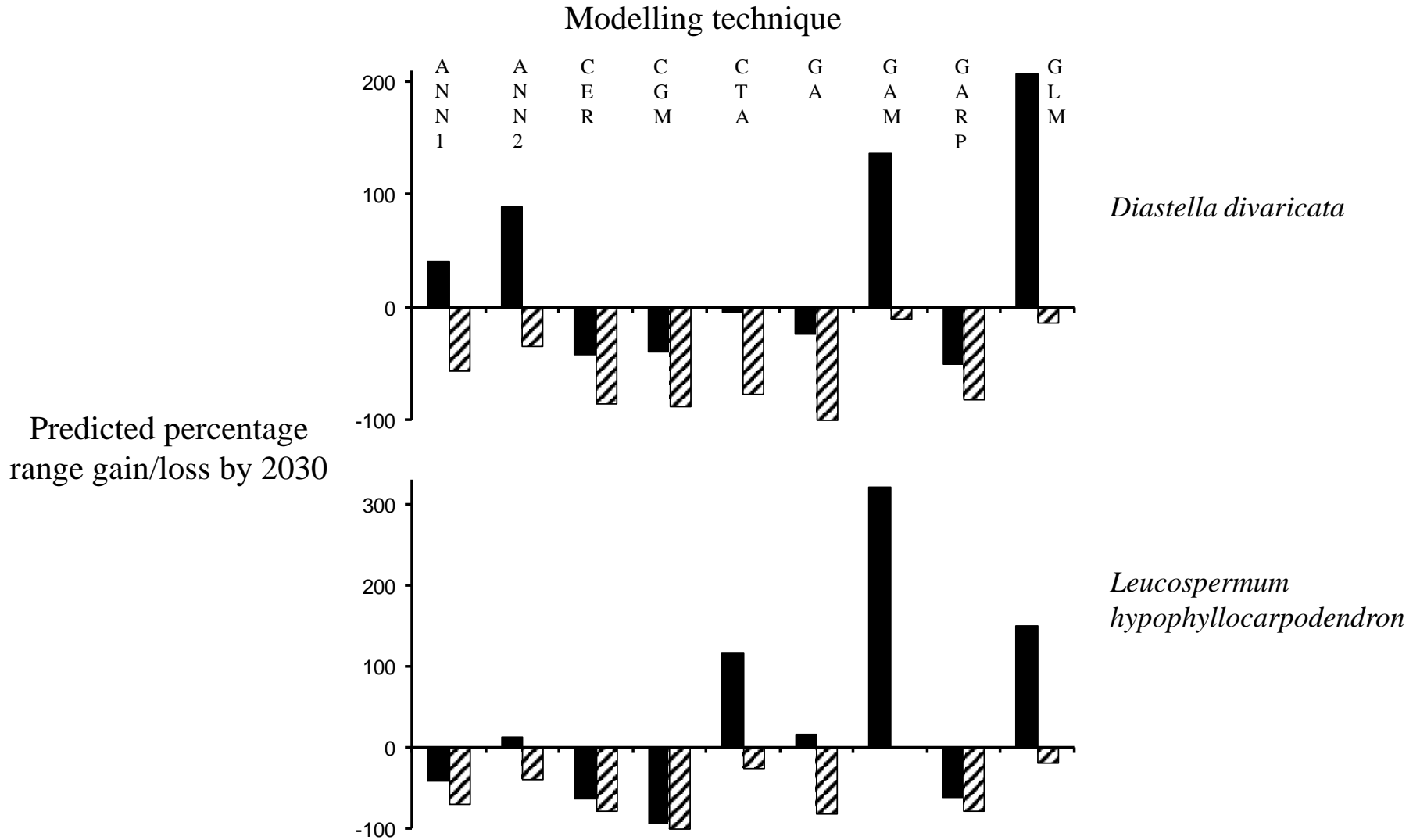


Jouke Prop



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

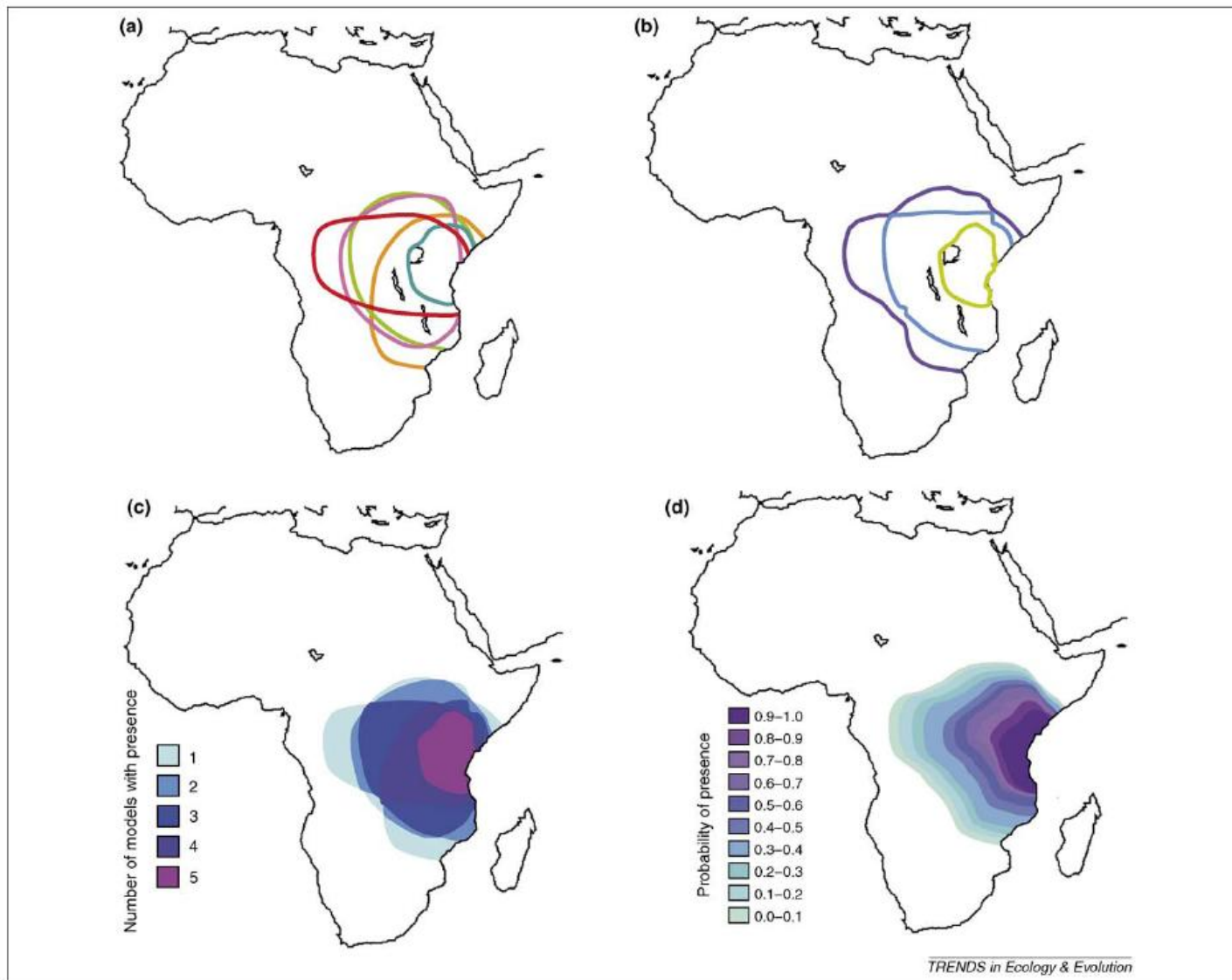
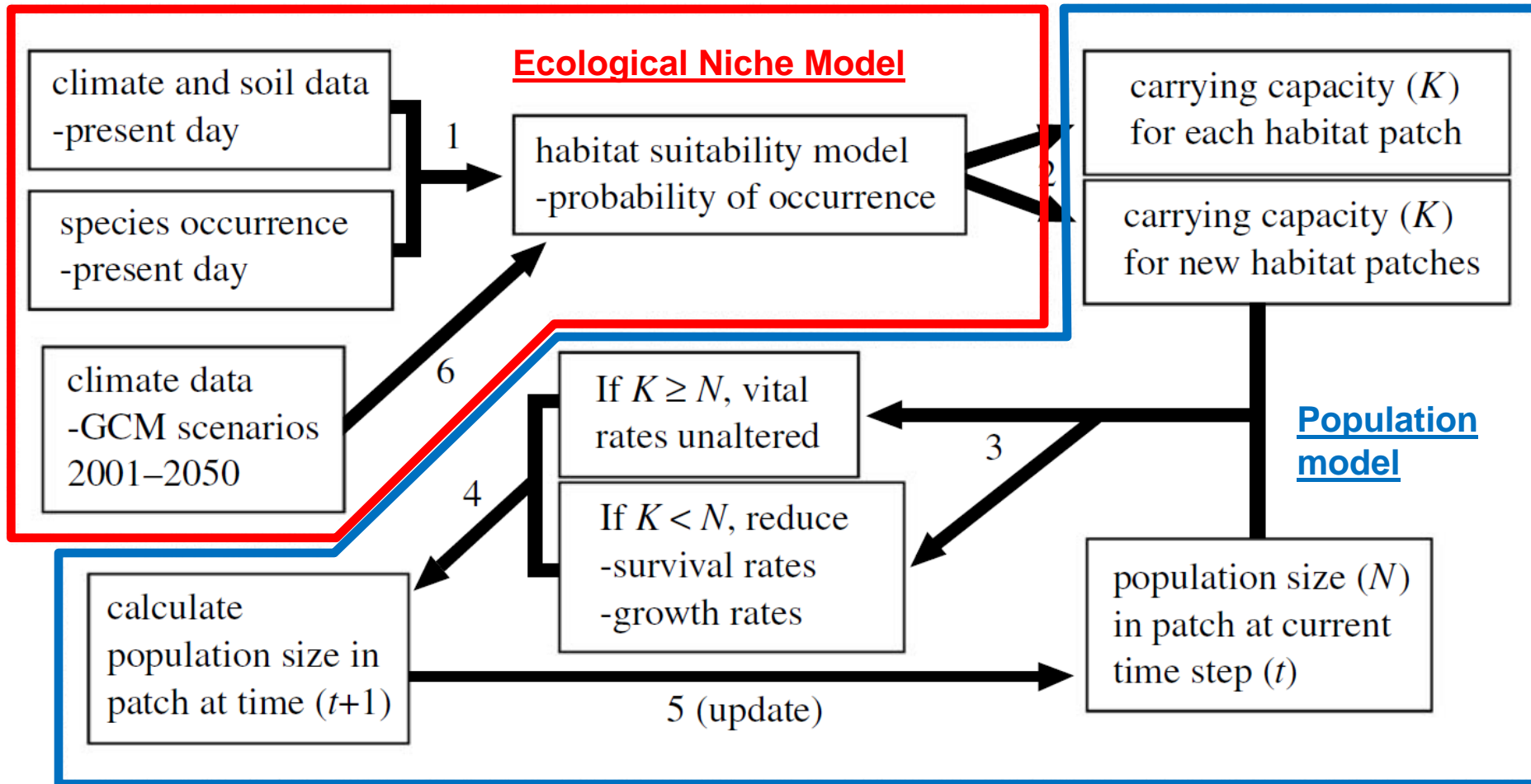


Figure 1. Examples of alternative approaches to analysing ensemble forecasts using artificial data projected onto the map of Africa: (a) Individual results from five hypothetical biodynamic models (shown by coloured lines) predicting the area occupied by a key species under a climate change scenario (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.

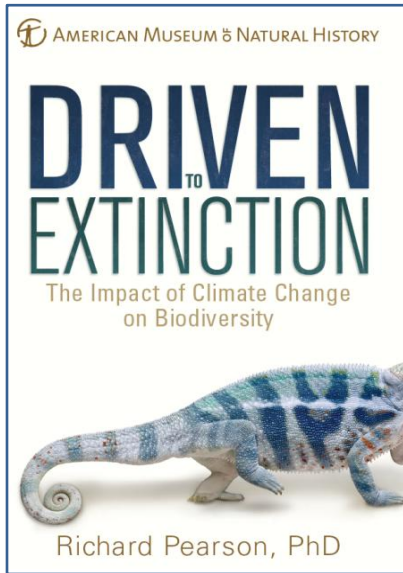
Linking Ecological Niche Models and Demographic Models



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

DRIVEN TO EXTINCTION

The Impact of Climate Change
on Biodiversity



Richard Pearson, PhD

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 ecosystems

Acknowledgements

Ecological Niche Modeling

Robert Anderson
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Madagascar case study

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Demographic modeling

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Ned Horning
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Chris Raxworthy
Jessica Stanton
Bruce Young

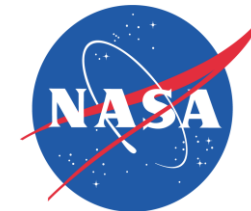
European flora

Pam Berry
Terry Dawson
Paula Harrison

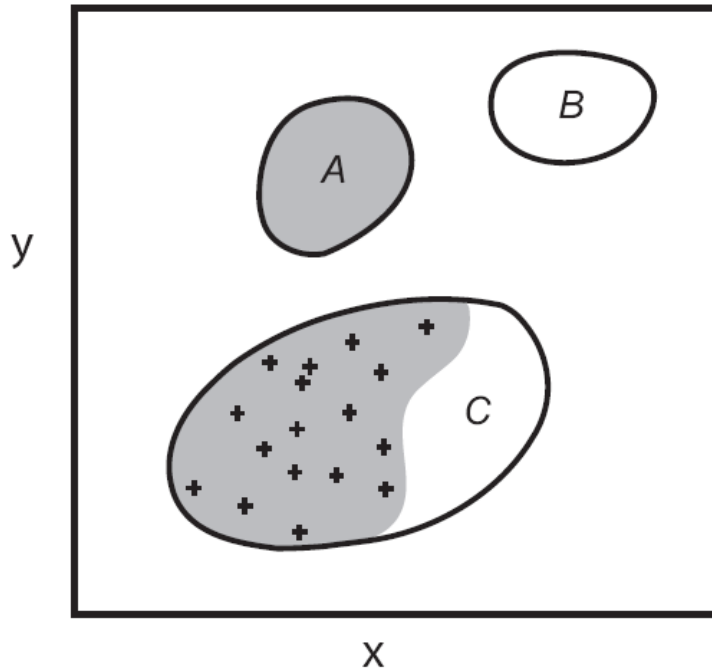
Polar bear case study

Jouke Prop
Linda Gormezano
Robert Rockwell

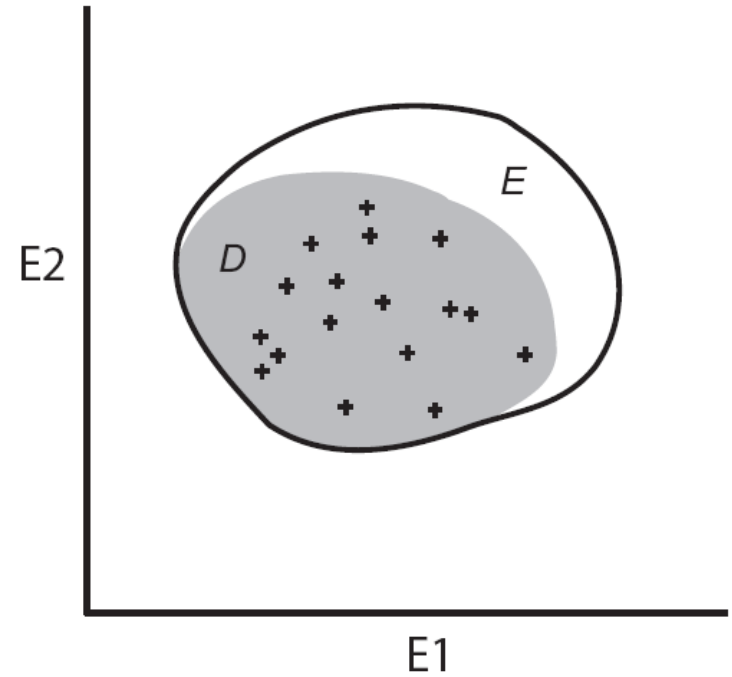
Extramural funding



Geographic space



Environmental space



- + Known species occurrence record
- Occupied distributional area, \mathbf{G}_O (left panel)/
Occupied niche space, \mathbf{E}_O (right panel)
- Abiotically suitable area, \mathbf{G}_A (left panel)/
Scenopoetic existing fundamental niche, \mathbf{E}_A (right panel)

