Climate change impacts on biodiversity: what we know and what we can do

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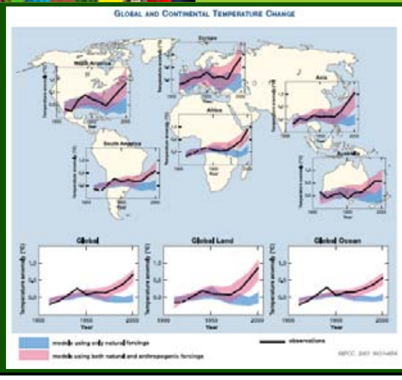
www.biochange-lab.eu

SEMCLIMED Workshop,
MAICh, Hania, 26 September 2007

20th century temperatures increased ~0.8ºC

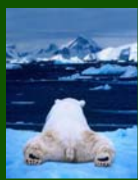


IPCC 2007

Outline

1. Observed impacts – 20th Century
2. Predicted impacts – 21st Century
3. Conservation under climate change

Impacts on world's biodiversity are already taking place



General pattern of climate change impacts

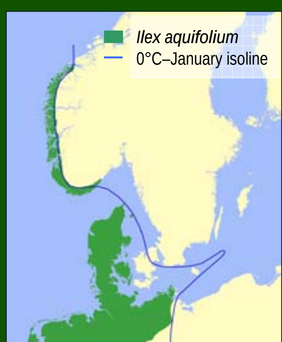
Latitudinal shift

Expansion in the northern distribution edge

Contraction in the southern distribution edge

Altitudinal shift

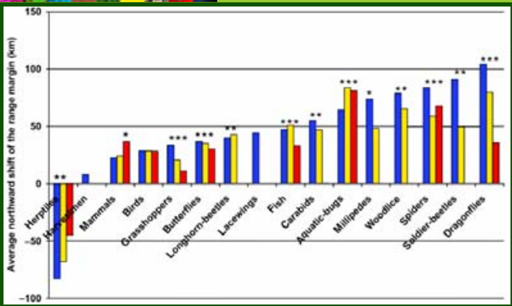
Evidence of shifts in the cold edge



(Walter & Straka 1970)

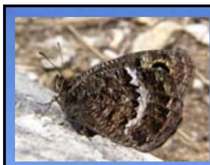
(Walther et al. 2006)

Evidence of shifts in the cold edge

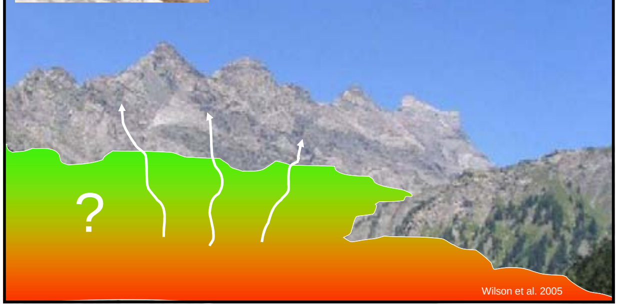


Average northwards shift across all 329 species of 31–60 km in Britain

Hickling et al. 2006

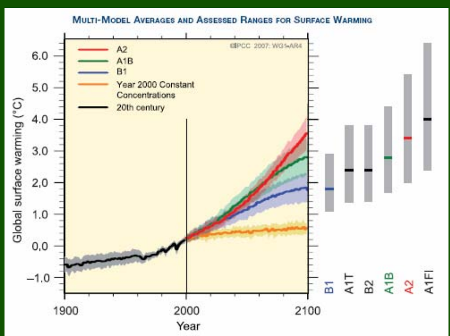


Lower elevation limits for 16 butterfly species in the “Sierra de Guadarrama”, central Spain, have risen on average by 212 m in 30 years, accompanying a 1.3 °C rise in mean annual temperature



Wilson et al. 2005

Models predict even greater warming during 21st century



IPCC 2007

A degree of warming seems inevitable

Even if emissions had been completely halted in 2000, the total temperature increase from greenhouse gases already in the atmosphere would be approximately 1.5°C globally.

Outline

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2. Predicted impacts – 21st Century
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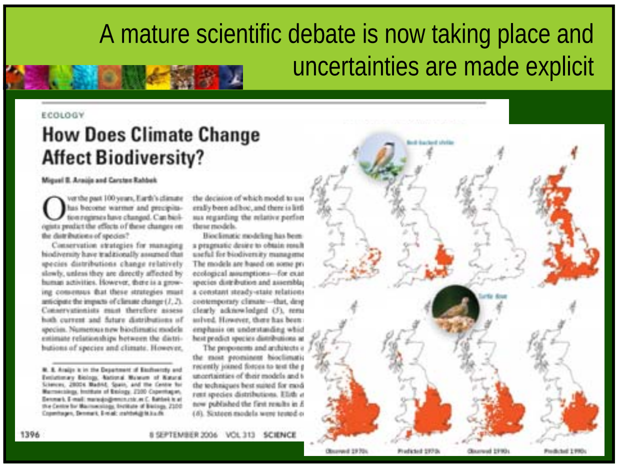
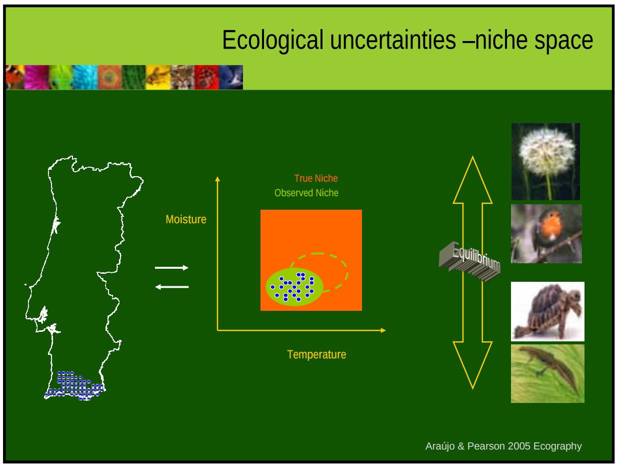
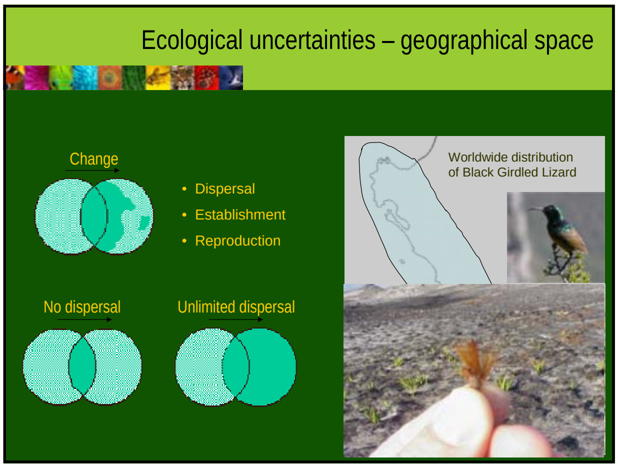
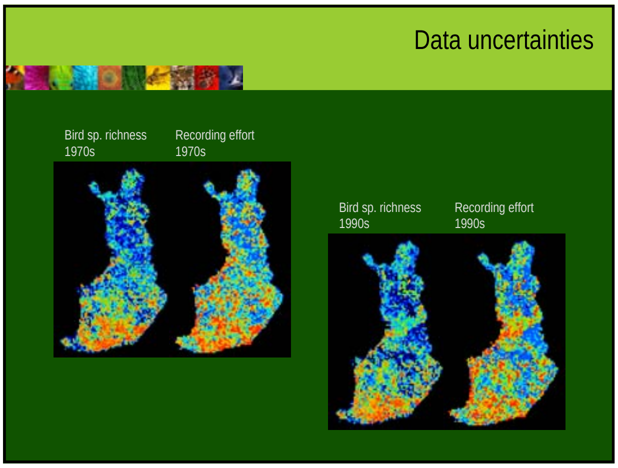
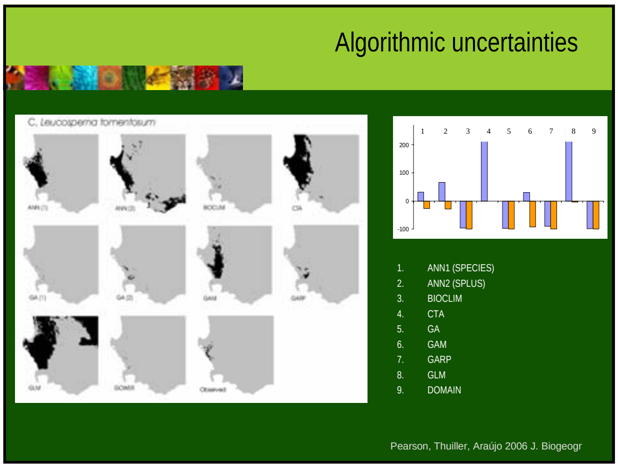
Can we predict climate change effects on biodiversity?

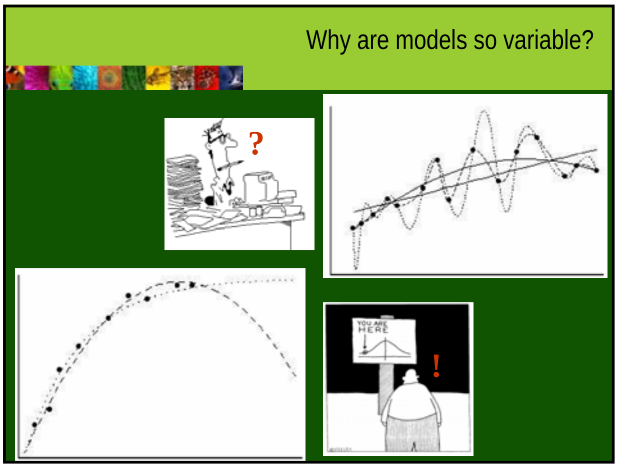

A mature scientific debate is now taking place and uncertainties are made explicit
ECOLOGY
How Does Climate Change Affect Biodiversity?
Miguel B. Araújo and Carsten Rahbek
8 SEPTEMBER 2006 VOL 313 SCIENCE


Ecological uncertainties –niche space
True Niche
Observed Niche
Moisture
Temperature
Equilibrium
Araújo & Pearson 2005 Ecography


Ecological uncertainties – geographical space
Change
• Dispersal
• Establishment
• Reproduction
No dispersal
Unlimited dispersal
Worldwide distribution
of Black Girdled Lizard


Data uncertainties
Bird sp. richness
1970s
Recording effort
1970s
Bird sp. richness
1990s
Recording effort
1990s

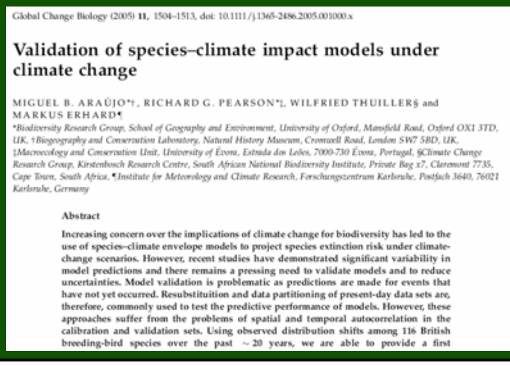

Algorithmic uncertainties
C. Leucospermo tomentosum
1. ANN1 (SPECIES)
2. ANN2 (SPLUS)
3. BIOCLIM
4. CTA
5. GA
6. GAM
7. GARP
8. GLM
9. DOMAIN
Pearson, Thuiller, Araújo 2006 J. Biogeogr


Why are models so variable?
?
!

Conceptual issues on validation

1. There is a fundamental difference between the ability of a model to describe a given situation by calibration of its parameters, and its ability to adequately represent new observations using existing calibration.
2. Failures to predict independent events expose the limitations of a calibrated model. It may reveal structural deficiencies, i.e. failures in the underlying conceptualisation of the problem, or data limitations, i.e. data that has failed to fully reflect the underlying environmental processes.

Why haven't people noticed?



Global Change Biology (2005) 11, 1504–1513, doi: 10.1111/j.1365-2486.2005.001000.x

Validation of species–climate impact models under climate change

MIGUEL B. ARAÚJO*†, RICHARD G. PEARSON*‡, WILFRIED THUILLER§ and MARKUS ERHARD¶
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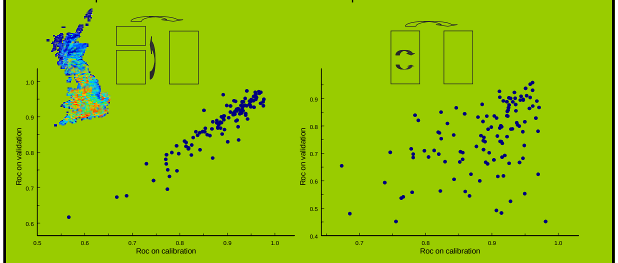
Abstract

Increasing concern over the implications of climate change for biodiversity has led to the use of species–climate envelope models to project species extinction risk under climate-change scenarios. However, recent studies have demonstrated significant variability in model predictions and there remains a pressing need to validate models and to reduce uncertainties. Model validation is problematic as predictions are made for events that have not yet occurred. Resubstituition and data partitioning of present-day data sets are, therefore, commonly used to test the predictive performance of models. However, these approaches suffer from the problems of spatial and temporal autocorrelation in the calibration and validation sets. Using observed distribution shifts among 116 British breeding-bird species over the past ~20 years, we are able to provide a first

Why haven't people noticed?

Performance on calibration versus non-independent validation set

Performance on calibration versus independent validation set



Araújo et al. 2005. Global Change Biology

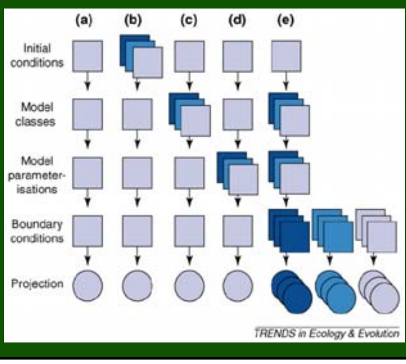
Skeptics warn: model can never be validated!

"If it rains tomorrow, I will stay home and revise this paper. The next day it rains, but you find that I am not home. You conclude that my original statement was false. But in fact it was my intention to stay home and work on my paper. The formulation was a true statement of my intent. Later, you find that I left the house because my mother died, and you realise that my original formulation was not false, but incomplete".

Oreskes et al. 1994. Science

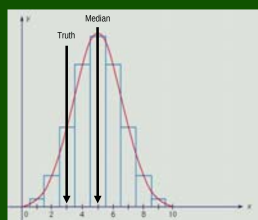
Producing large ensembles

Large numbers of simulations across initial conditions, model classes, parameters, and boundary conditions



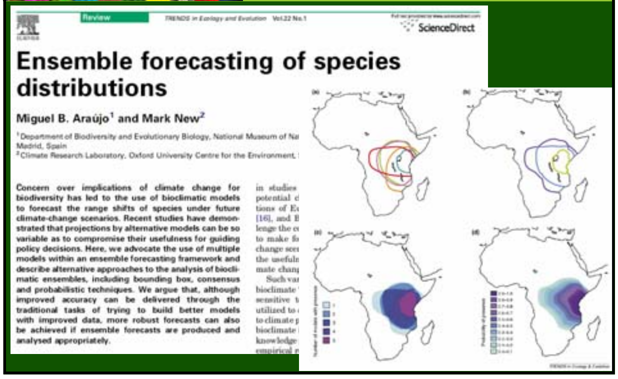
Ensemble forecasting

- Bounding box
  – range of uncertainties
- Consensus forecasting
  – central tendency of forecasts
- Probabilistic forecasting
  – central tendency + assumption of PDF



- Intermediate forecasting techniques
  – central tendencies in different sections of the frequency distribution of forecasts

A (relatively) new concept in ecology



Review TRENDS in Ecology and Evolution Vol.22 No.1 ScienceDirect

Ensemble forecasting of species distributions

Miguel B. Araújo[1] and Mark New[2]

[1]Department of Biodiversity and Evolutionary Biology, National Museum of Na... Madrid, Spain
[2]Climate Research Laboratory, Oxford University Centre for the Environment, ...

Concern over implications of climate change for biodiversity has led to the use of bioclimatic models to forecast the range shifts of species under future climate-change scenarios. Recent studies have demonstrated that projections by alternative models can be so variable as to compromise their usefulness for guiding policy decisions. Here, we advocate the use of multiple models within an ensemble forecasting framework and describe alternative approaches to the analysis of bioclimatic ensembles, including bounding box, consensus and probabilistic techniques. We argue that, although improved accuracy can be delivered through the traditional tasks of trying to build better models with improved data, more robust forecasts can also be achieved if ensemble forecasts are produced and analysed appropriately.

Consensus forecasts – shown to be superior than individual forecasts

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2005) 14, 529–538

RESEARCH PAPER

Reducing uncertainty in projections of extinction risk from climate change

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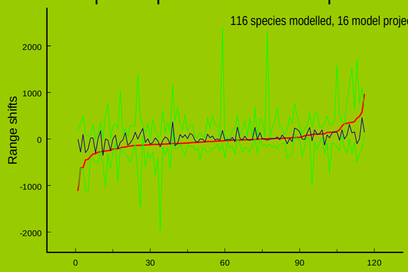
[1]Biodiversity Research Group, School of Geography and the Environment, University of Oxford, Mansfield Road, Oxford, OX1 3TB, UK, [2]Biogeography and Conservation Laboratory, Natural History Museum, Cromwell Road, London, SW7 5BD, UK, [3]Institute for Meteorology and Climate Research, Forschungszentrum Karlsruhe, Kreuzeckbahnstr, 19, 82467 Garmisch-Partenkirchen, Germany

ABSTRACT

Aim Concern over the implications of climate change for biodiversity has led to the use of species–climate 'envelope' models to forecast risks of species extinctions under climate change scenarios. Recent studies have demonstrated significant variability in model projections and there remains a need to test the accuracy of models and to reduce uncertainties. Testing of models has been limited by a lack of data against which projections of future ranges can be tested. Here we provide a first test of the predictive accuracy of such models using observed species' range shifts and climate change in two periods of the recent past.

Ensemble forecasting: test with British birds

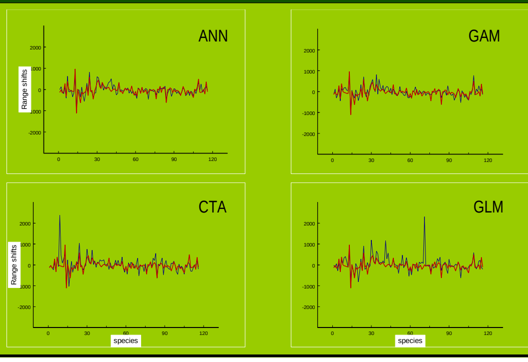
90% of species predicted to both expand and contract



10% of species had consistent predictions in all models

But 50% were wrong

Ensemble forecasting: test with British birds



Introduction to confusion matrices

The decision is: If the truth is:	Believe	Not believe
God exists	TRUE POSITIVE Consequence: *Heaven*	FALSE NEGATIVE Consequence: *Hell*
God does not exist	FALSE POSITIVE Consequence: *unmerited faith*	TRUE NEGATIVE Consequence: *Atheism*

"If God does not exist, one will lose nothing by believing in him, while if he does exist, one will lose everything by not believing... we are compelled to gamble..."

Blaise Pascal in 'Pensées', 1656-1658

Uses of confusion matrices in conservation planning

The prediction is: If the truth is:	Species contracted	Species did not contract
Species contracted	TRUE POSITIVE Action: *Conserve species* Consequence: *Persistence possible*	FALSE NEGATIVE Action: *Do nothing* Consequence: *Extinction possible*
Species did not contract	FALSE POSITIVE Action: *Conserve species* Consequence: *Misuse limited resources*	TRUE NEGATIVE Action: *Do nothing* Consequence: *Persistence probable*

Ensemble forecasting: test with British birds

Predicted: / Observed:	Contracted	Did not contract
Species contracted	TRUE POSITIVES All: 50% (LQ=31%; UQ=69%)	FALSE NEGATIVES All: 50% (LQ=31%; UQ=69%)
Species did not contract	FALSE POSITIVES All: 44% (LQ=12%; UQ=56%)	TRUE NEGATIVES All: 56% (LQ=44%; UQ=88%)

Araújo et al. 2005. Global Ecology and Biogeography

Ensemble forecasting: test with British birds

Predicted: / Observed:	Contracted	Did not contract
Species contracted	TRUE POSITIVES All: 50% (LQ=31%; UQ=69%) Consensus 1: 75% (LQ=50%; UQ=100%)	FALSE NEGATIVES All: 50% (LQ=31%; UQ=69%) Consensus 1: 25% (LQ=0%; UQ=50%)
Species did not contract	FALSE POSITIVES All: 44% (LQ=12%; UQ=56%) Consensus 1: 12% (LQ=0%; UQ=50%)	TRUE NEGATIVES All: 56% (LQ=44%; UQ=88%) Consensus 1: 88% (LQ=50%; UQ=100%)

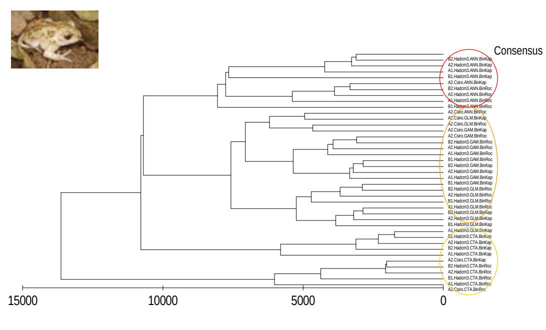
Araújo et al. 2005. Global Ecology and Biogeography

Ensemble forecasting: test with British birds

Predicted: / Observed:	Contracted	Did not contract
Species contracted	TRUE POSITIVES All: 50% (LQ=31%; UQ=69%) Consensus 1: 75% (LQ=50%; UQ=100%) Consensus 2: 100% (LQ=100%; UQ=100%)	FALSE NEGATIVES All: 50% (LQ=31%; UQ=69%) Consensus 1: 25% (LQ=0%; UQ=50%) Consensus 2: 0% (LQ=0%; UQ=0%)
Species did not contract	FALSE POSITIVES All: 44% (LQ=12%; UQ=56%) Consensus 1: 12% (LQ=0%; UQ=50%) Consensus 2: 0% (LQ=0%; UQ=0%)	TRUE NEGATIVES All: 56% (LQ=44%; UQ=88%) Consensus 1: 88% (LQ=50%; UQ=100%) Consensus 2: 100% (LQ=100%; UQ=100%)

Araújo et al. 2005. Global Ecology and Biogeography

Ensemble forecasting: intermediate techniques

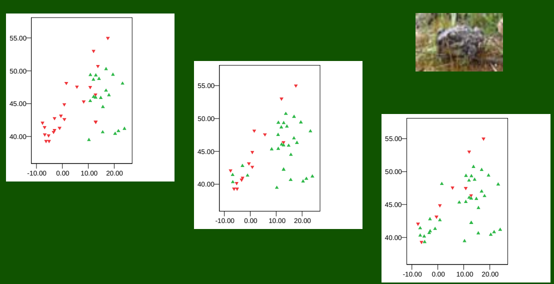


Distance

Araújo et al. 2006. Journal of Biogeography

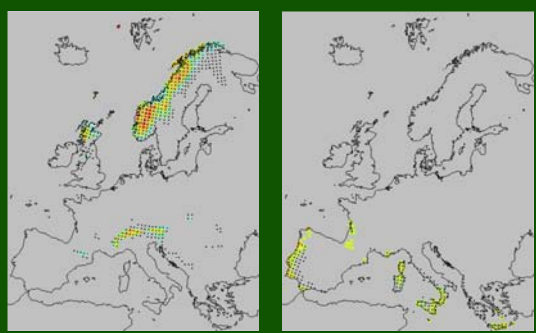
Ensemble forecasting: hybrid form

Consensus



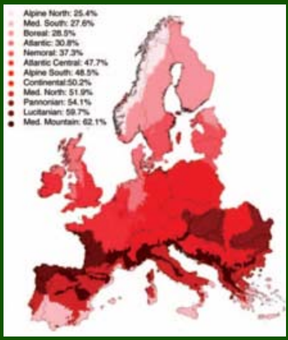
Araújo et al. 2006. Journal of Biogeography

Ensemble forecasting: impacts of climate change on European plants



Diphasium alpinum *Selaginella denticulata*

Ensemble forecasting: impacts of climate change on European plants



Areas of high risk for plant diversity under climate change:

Northern Mediterranean (52% loss),

Pannonian (54% loss),

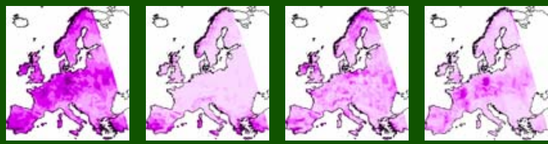
Lusitanian (60% loss)

Mediterranean Mountains (62% loss)

Thuiller et al. 2005 PNAS

Measuring sources of uncertainty

2294 plant species x 5 2050 climate scenarios x 4 modelling techniques x 2 thresholds = 91,600 models = 40 projections per species



PCA axis 1 = Aggreement among projections (52% variance)
PCA axes 2 and 3 = Disagreement among projections (44% variance)

90% of the disagreement is explained by model and choice of threshold

Outline

1. Observed impacts – 20th Century
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Purpose of systematic conservation planning

"...to identify the exact number, extent and spacing of various habitats for the survival of each species of plant, animal and fungus"

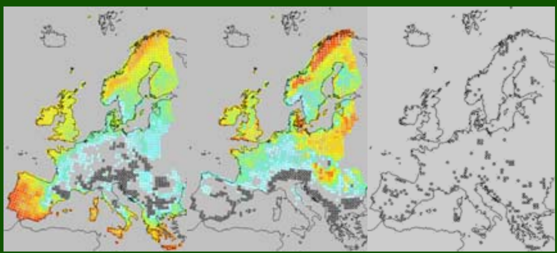
Hooper (1971)

"… to maintain, hopefully in perpetuity, a highly complex set of ecological, genetic, behavioural, evolutionary and physical processes and the co-evolved, compatible populations which participate in these processes"

Frankel & Soulé (1981)

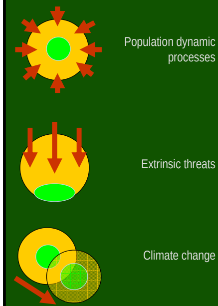
First rule of ecological tinkering: keep all pieces

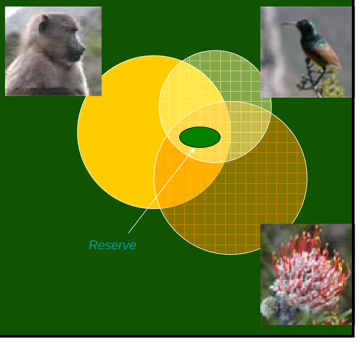
Hotspot strategies preserving 10% of grid cells for 1200 plan species



Richness hotspots	Rarity hotspots	Complementarity set
81.75%	92.77%	100%, ~6 representations

Reserve selection strategies





Are existing conservation strategies adequate?

Global Change Biology (2004) 10, 1618–1626, doi: 10.1111/j.1365-2486.2004.00828.x

Would climate change drive species out of reserves? An assessment of existing reserve-selection methods

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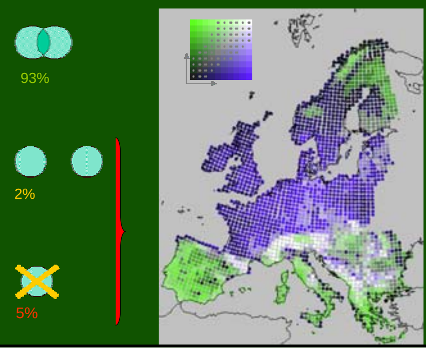
Abstract

Concern for climate change has not yet been integrated in protocols for reserve selection. However if climate changes as projected, there is a possibility that current reserve-selection methods might provide solutions that are inadequate to ensure species' long-term persistence within reserves. We assessed, for the first time, the ability of existing reserve-selection methods to secure species in a climate-change context. Six methods using a different combination of criteria (representation, suitability and reserve clustering) are compared. The assessment is carried out using European distributions of 1200 plant species and considering two extreme scenarios of response to climate change: no dispersal and universal dispersal. With our data, 6–11% of species modelled would be potentially lost from selected reserves in a 50-year period. Measured

Estimating risk for conservation planning



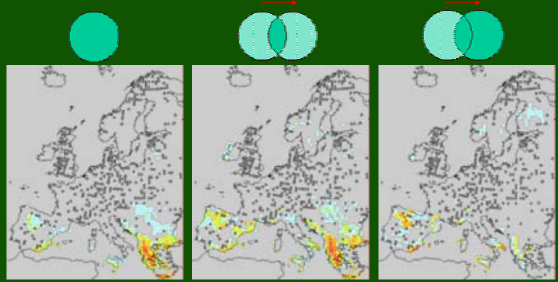
Low risk

High risk

High/low risk

Araújo, et al. 2004 Global Change Biology

New strategies are required to avoid biodiversity loss



3% of plant species are outside PA (now)

14% of species will be outside PA (2050)

7% of species will be outside PA (2050)

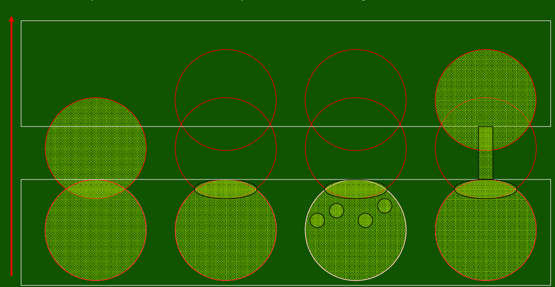
Araújo et al. In preparation

Effectiveness of reserve-selection with climate change

		Present	Future		$\Delta_{dispersal}$
	Method (315 areas)		No dispersal	Universal dispersal	
1	Presence	100	92.92	93.94	1.02
2	Presence clustered	100	88.88	92.15	3.27
3	Presence suitability	100	93.45	94.47	1.02
	Δ_{method}	-	4.57	2.32	-
4	Random (p<0.05)	99.75	90.44	93.58	

Araújo, et al. 2004 Global Change Biology

Planning for climate change



Planning for climate change

Planning for Climate Change: Identifying Minimum-Dispersal Corridors for the Cape Proteaceae

PAUL WILLIAMS,*§§ LEE HANNAH,† SANDY ANDELMAN,‡ GUY MIDGLEY,§ MIGUEL ARAÚJO,*††† GREG HUGHES,§ LISA MANNE,†† ENRIQUE MARTINEZ-MEYER,‡‡ AND RICHARD PEARSON††
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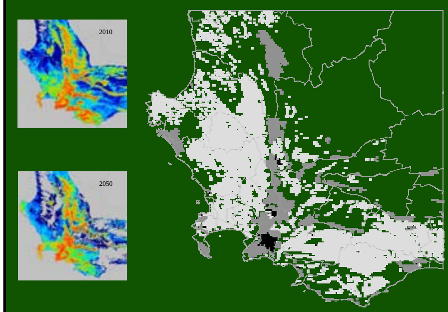
††Zoology Department, University of Toronto, Scarborough, 1265 Military Trail, Scarborough, Ontario M1C 1A4, Canada
‡‡Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, Circuito Exterior s/n, Ciudad Universitaria, Mexico City 04510, Mexico
†††Environmental Change Institute, School of Geography and the Environment, University of Oxford, 1A Mansfield Road, Oxford OX1 3SZ, United Kingdom

Planning for climate change

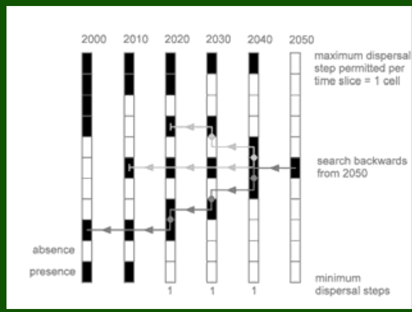


Transformed land (>66%)

Protected areas

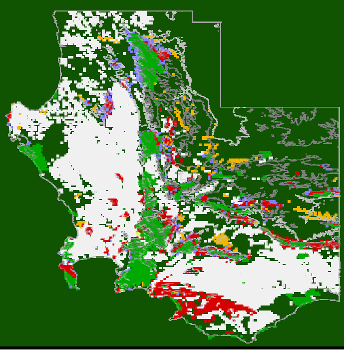
Both

Identifying minimum-dispersal corridors



Williams, et al. 2005 Conservation Biology

Selecting new reserves and corridors



Protected areas

New irreplaceable areas

Contiguous flexible areas

Other flexible areas

Williams et al. 2005 Conservation Biology

Are existing conservation strategies adequate?

RESEARCH COMMUNICATIONS RESEARCH COMMUNICATIONS

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Protected area needs in a changing climate

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Range shifts due to climate change may cause species to move out of protected areas. Climate change could therefore result in species range dynamics that reduce the relevance of current fixed protected areas in future conservation strategies. Here, we apply species distribution modeling and conservation planning tools in three regions (Mexico, the Cape Floristic Region of South Africa, and Western Europe) to examine the need for additional protected areas in light of anticipated species range shifts caused by climate change. We set species representation targets and assessed the area required to meet those targets in the present and in the future, under a moderate climate change scenario. Our findings indicate that protected areas can be an important conservation strategy in such a scenario, and that early action may be both more effective and less costly than inaction or delayed action. According to our projections, costs may vary among regions and none of the three areas studied will fully meet all conservation targets, even under a moderate climate change scenario. This suggests that limiting climate change is an essential complement to adding protected areas for conservation of biodiversity.

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Global climate is now rapidly changing, with consequent geographic rearrangement of species and recent climate-related extinctions (Root *et al.* 2003; Pounds *et al.* 2006). Yet protected areas (including national parks, nature

tion routines, known as "reserve selection algorithms", have been developed (Pressey and Cowling 2001).

The problem is more complex when species' ranges become dynamic as the result of climate change. One

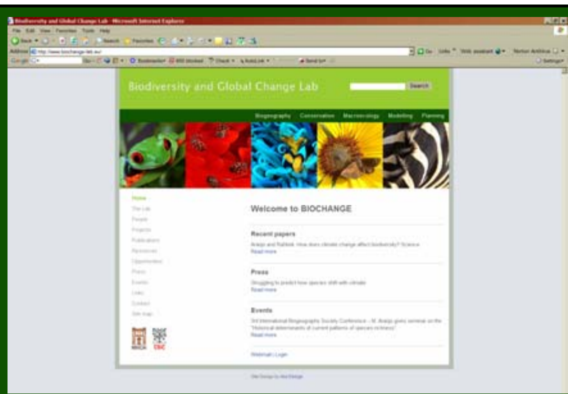
The cost of waiting

IUCN goal:

Achieve 100 km2 representation or 10% of range, whichever is larger

	Cost filling the gaps in protected areas now	Cost filling the gaps now, wait for impacts, then act	Cost anticipate impacts
Europe	18%	59%	35%

Hannah et al. 2007



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