SDMs: background and applications

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[and all present and future EG-ABi instructors]

A bit of cryptozoogeography…

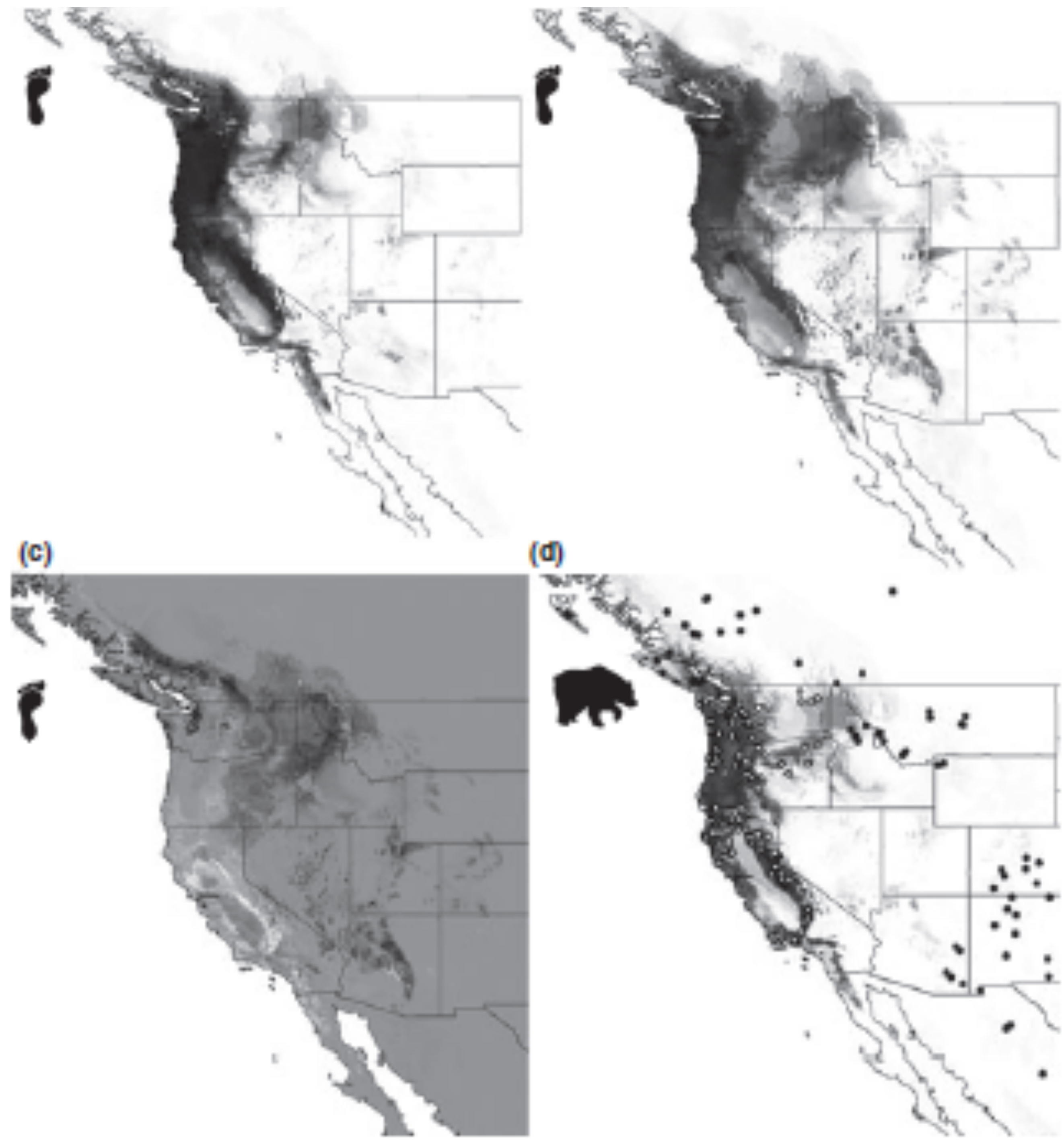


Figure 2 Predicted distributions of Bigfoot constructed from all available encounter data using MAXENT (a) for the present climate and (b) under a possible climate-change scenario involving a doubling of atmospheric CO_2 levels. Results are presented for logistic probabilities of occurrence ranging continuously from low (white) to high (black). Differences between (a) and (b) are shown in (c), with whiter values reflecting a decline in logistic probability of occurrence under climate change, darker values reflecting a gain, and grey reflecting no change. A predicted distribution of *Ursus americanus* in western North America under a present-day climate is also shown (d). White points indicate sampling localities in California, Oregon and Washington taken from GBIF (n = 113 for training, 28 for testing; compare with Fig. 1) used for the MAXENT model with shading as in (a) and (b); black points indicate additional known records not included in the model.

Lozier et al. 2009

Historical background

Historical background

- Explosive growth in the recent literature
- “The quantification of . . . species–environment relationships represents the core of predictive geographical modeling in ecology” (Guisan & Zimmermann, 2000).
- Species distribution modeling has its roots in ecological gradient analysis, biogeography, remote sensing and geographic information science.

Historical background

- Applied research is heavily used by governmental and non-governmental organizations
  - biological resource assessment
  - conservation at large spatial scales
- Development of digital databases for natural history collections, for example via the Global Biodiversity Information Facility (http://www.gbif.org/).
- Special features (collections of papers) in journals:
  - Ecological Modelling, 2002, and 2006;
  - Biodiversity and Conservation, 2002;
  - Journal of Applied Ecology, 2006;
  - Diversity and Distributions, 2007;
  - and much more…

If you like reading…

- Recent advances in conceptual issues:
    - general framework for species distribution modeling (Franklin, 1995; Guisan & Zimmermann, 2000; Mackey & Lindenmayer, 2001; Guisan & Thuiller, 2005; Elith & Leathwick, 2009)
    - links to ecological theory (Austin, 2002, 2007; Hirzel & Le Lay, 2008)
    - modeling methods (Guisan et al., 2002, 2006; Pearce & Boyce, 2006)
    - data and scale issues and statistical model selection (Rushton et al., 2004)
    - use of natural history collections data (Graham et al., 2004)
    - modeling ecological communities (Ferrier & Guisan, 2006)
    - influence of spatial autocorrelation on models of species distributions (Miller et al., 2007)
- Reviews on applications:
    - use of SDMs in land management under uncertainty (Burgman, 2005),
    - applicability to conservation planning (Ferrier et al., 2002a, b; Rodrigue´z et al., 2007)

Extensive efforts

- Government agencies and NGOs have implemented ambitious, large-scale species distribution modeling programs

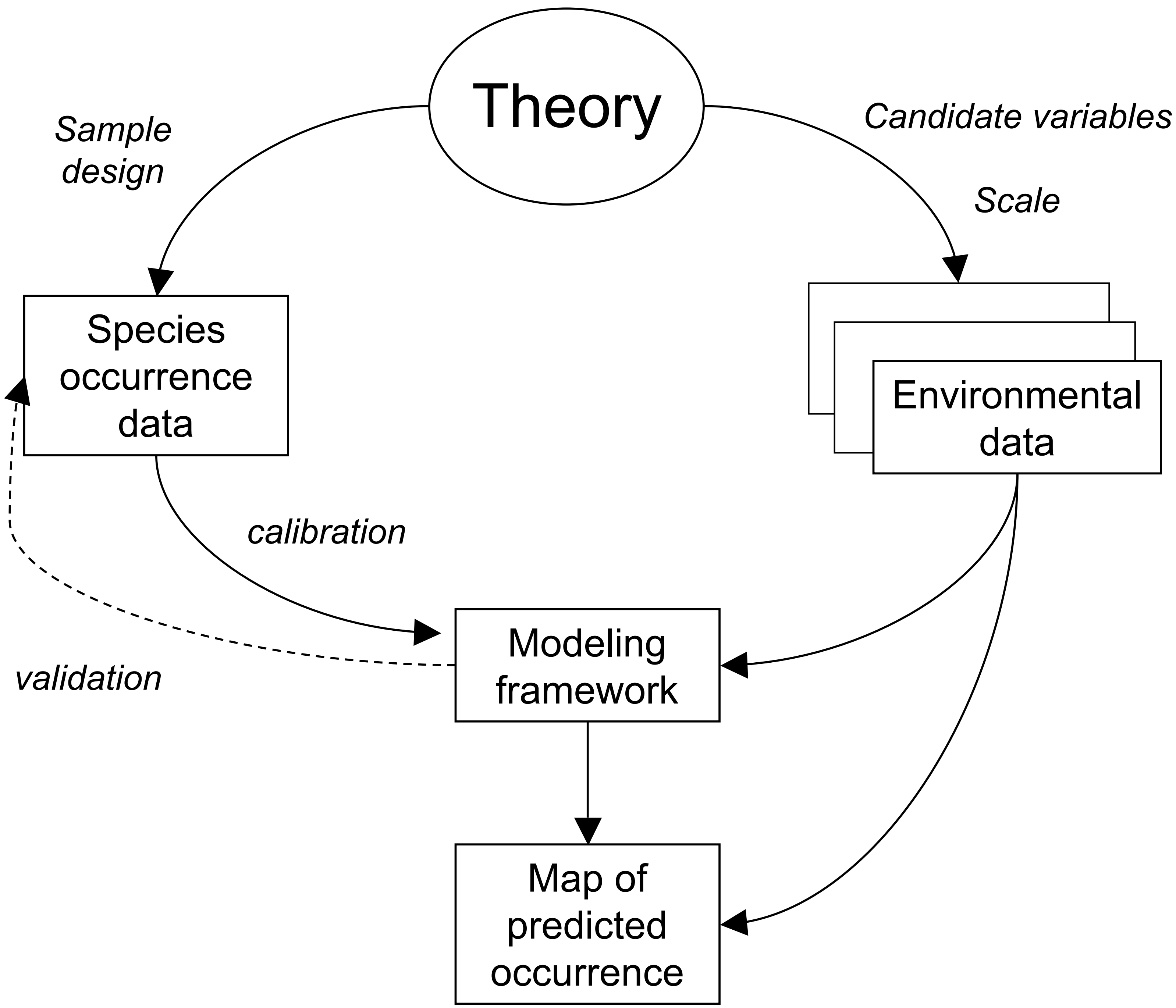
- => involve modeling the distributions of hundreds (even thousands) of individual species or ecological communities over large regions.

- These efforts are often extensive and influential, affecting regional and global conservation decision making, but they are *not necessarily reported in the scientific literature*

Extensive efforts: examples

- NatureServe
  - Run training workshops and provided tutorial materials on their website
  - The American Museum of Natural History, offered short courses in species distribution modeling for conservation biology
  - Clark Labs, in collaboration with Conservation International, has developed specialized commercial GIS software to implement both species distribution models and project the impacts of land cover dynamics on biodiversity => model the distributions of 16 000 species in the Andes.
- EG-ABi activities

Framework: components of SDMs



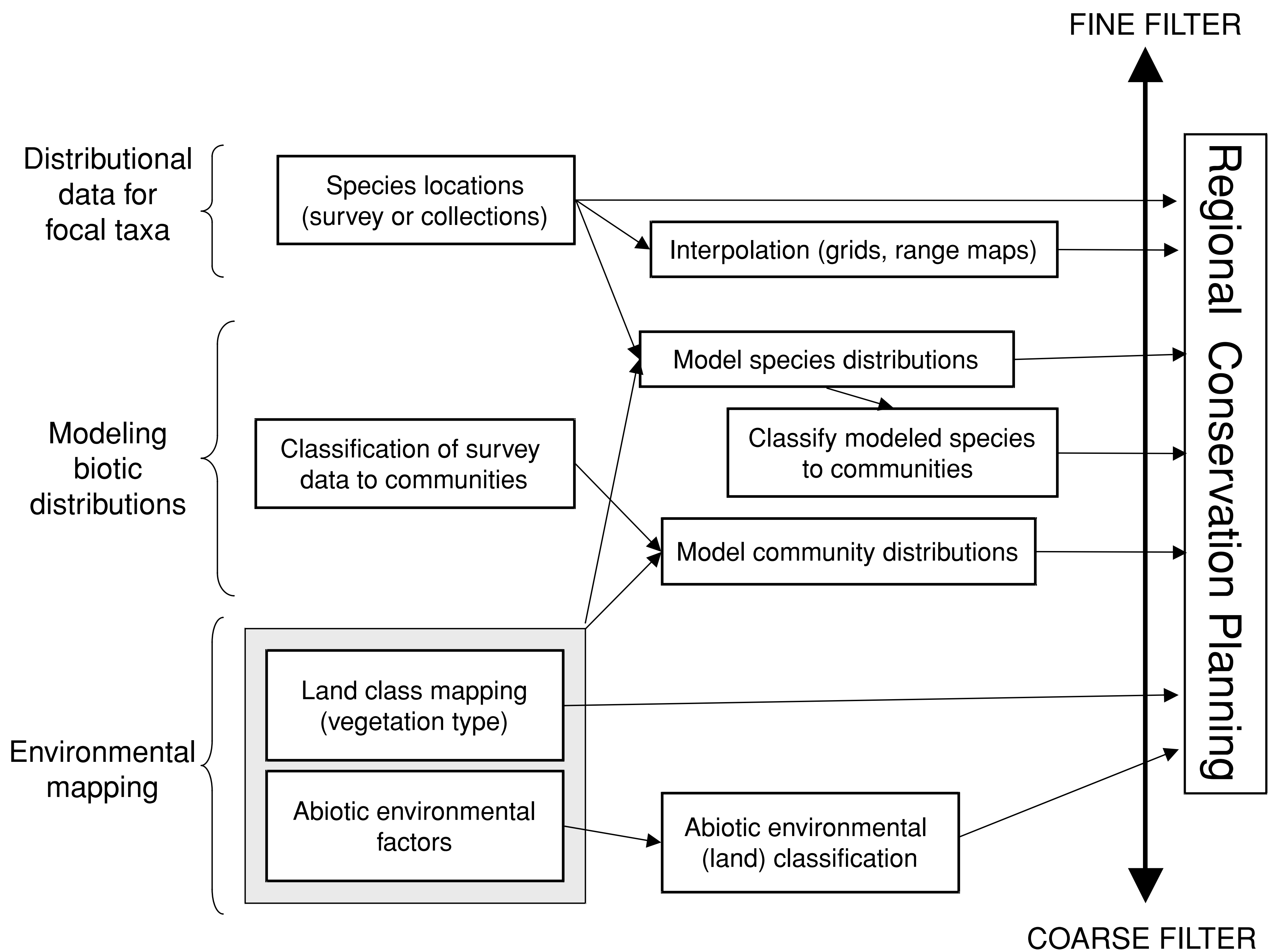
Franklin 2014

Applications

Why model species distributions?

- Understand/characterize the relationship between a species and its abiotic and biotic environment
    - for ecological inference;
    - to test ecological or biogeographical hypotheses about species distributions and ranges.
- SDMs are now being widely used to interpolate or extrapolate from point observations over space to predict the occurrence of a species for locations where survey data are lacking – including in the Southern Ocean.
- Maps of habitat suitability, or a predicted species distribution, are useful to test hypotheses about species range characteristics, niche partitioning or niche conservatism.
- Predictive distribution maps are also required for many aspects of resource management and conservation planning including:
    - biodiversity assessment, reserve design, habitat management and restoration, population, community and ecosystem modeling, ecological restoration, invasive species risk assessment, and predicting the effects of climate change on species and ecosystems;
    - A model calibrated for current conditions can be used to project potential species distributions at another point in time in order to predict the impacts of environmental change on species distributions

Reserve design and conservation planning



Ferrier, 2002

Applications: ressource management

- Once a reserve is designed, or land is managed to achieve conservation goals, planning may require an impact assessment or risk assessment

- SDM can be used to develop spatially explicit predictions of habitat suitability or quality In one of the first published applications of SDM, Kessell (1976, 1978, 1979) modeled the potential distribution of many plant and animal species in support of wildland fire management in Glacier National Park, USA.

- Another use of SDM has been to designate so-called critical habitat for species that have legally protected status. In these studies, the results of an SDM are used to define the location and extent of habitat required for the protection or recovery of the focal species

Applications: ecological restoration and modelling

- SDMs are increasingly being used to determine suitable locations for species reintroductions by associating maps of environmental factors with information on their historical ranges or habitat preferences using a model

- Population viability analysis (PVA) is used to forecast extinction risk and to predict the consequences of habitat loss and other threats for species of conservation or management concern. PVA can incorporate landscape dynamics, such as changing carrying capacities of habitat patches through time.

- Landscape modeling of plant community dynamics (e.g., forest succession), can require spatially explicit information on the distribution of potential habitat for the plant species comprising the community

    - Example: how do fire, logging, and climate change synergistically affect the distribution of late-successional forest patches on the landscape, and therefore on the distribution of old growth dependent species?

Applications: risks and impacts

- Invasive species can have major economic and ecological impacts,
- SDMs are used to determine locations where an invasive species is likely to establish
- Two kinds of distribution data (native range and invaded areas) are used, indicating the degree to which invading species are restricted to the environmental conditions in which they are found in their native range during invasion
- Some studies have specifically modeled factors associated with fitness of the invading species and multiscale environmental variables, including land use and other predictors in addition to climate, have been found to be important in predicting potential invasions.
- If the species whose potential habitat is being predicted is a pest or disease organism that affects plants, animals or humans, or its vector or host, then spatial prediction of its potential distribution serves public health goals and supports epidemiological studies.
- Predicting the potential location of alien species invasion, including pathogens, presents special challenges for SDM methods because the historical range or current distribution of the taxon may not fully represent the environments into which it might spread:
    - it can occupy environments outside its native range owing to competitive release, facilitation or genetic adaptations;
    - or it may occupy a more restricted set of environmental conditions in a new location due to competition or dispersal limitations.

Applications: effects of global warming

- Species distribution modeling has been used to project the potential effects of anthropogenic global warming on species distributions and ecosystem properties for more than a decade but has recently received a lot of criticism
  - Using SDMs to predict the impact of global warming on species distributions requires a number of limitations as they assume species distributions are in equilibrium with the climate and do not do not account for time lags.
  - Species distribution modeling, is a “static” approach and does not take into account species ability to move on the landscape (dispersal or migration), or typically does so in simple ways “all or nothing”
  - Static SDM usually does not account for species interactions such as competition or predation, for evolutionary adaptation, or for a number of other potentially confounding factors, and thus could either over or underestimate species range shifts.

Applications: effects of global warming

- Responses of most species to climate change are too poorly understood to estimate extinction risks solely from SDMs applied to climate change scenarios.
- Authors often recommend using multiple models to address the interactions among potential habitat shifts, landscape structure (dispersal barriers caused by land use patterns, landscape patterning caused by altered disturbance regimes), and demography for a range of species functional
- Some scientists also expressed concern that misrepresentation of that study in the media could be damaging to biodiversity conservation in the political arena. Specifically, exaggeration of the threat of climate change to biodiversity could result in conservationists being accused of "crying wolf." Some media reports were highly inaccurate, stating that the study predicted that a million species could be extinct by 2050 (Ladle et al., 2004).
- One thing ecologists do agree on is that assessing the consequences of anthropogenic climate change for biodiversity is an important task on which scientific talent and resources should be focused (Thuiller, 2007).

Ecological understanding

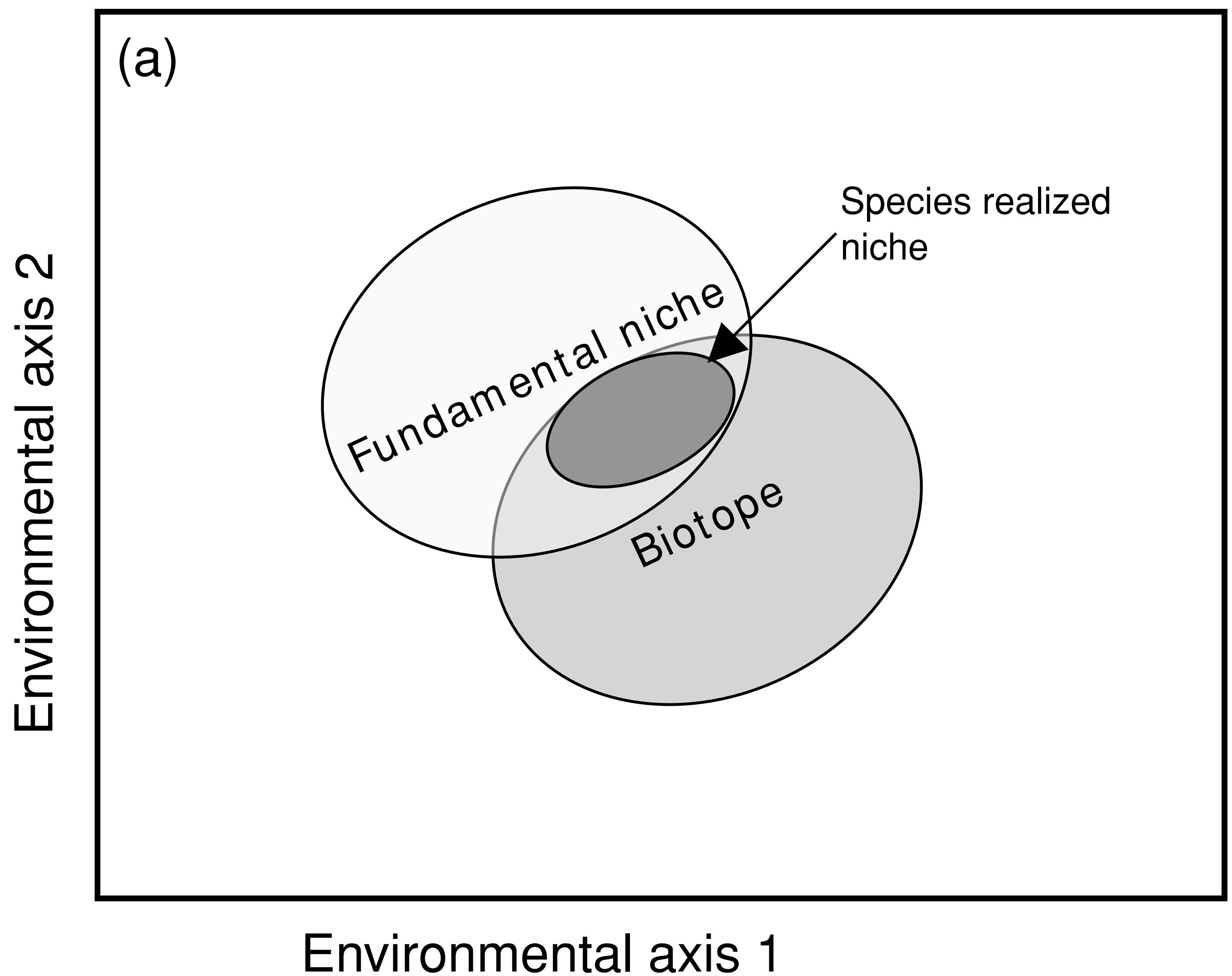
Ecological understanding

- Austin (2002) presented a framework for spatial prediction of species distributions that links ecological theory to implementation (statistical modeling).

- The ecological model portion of that framework – those ecological and biogeographical concepts and theories are needed to frame the empirical modeling of species distributions.

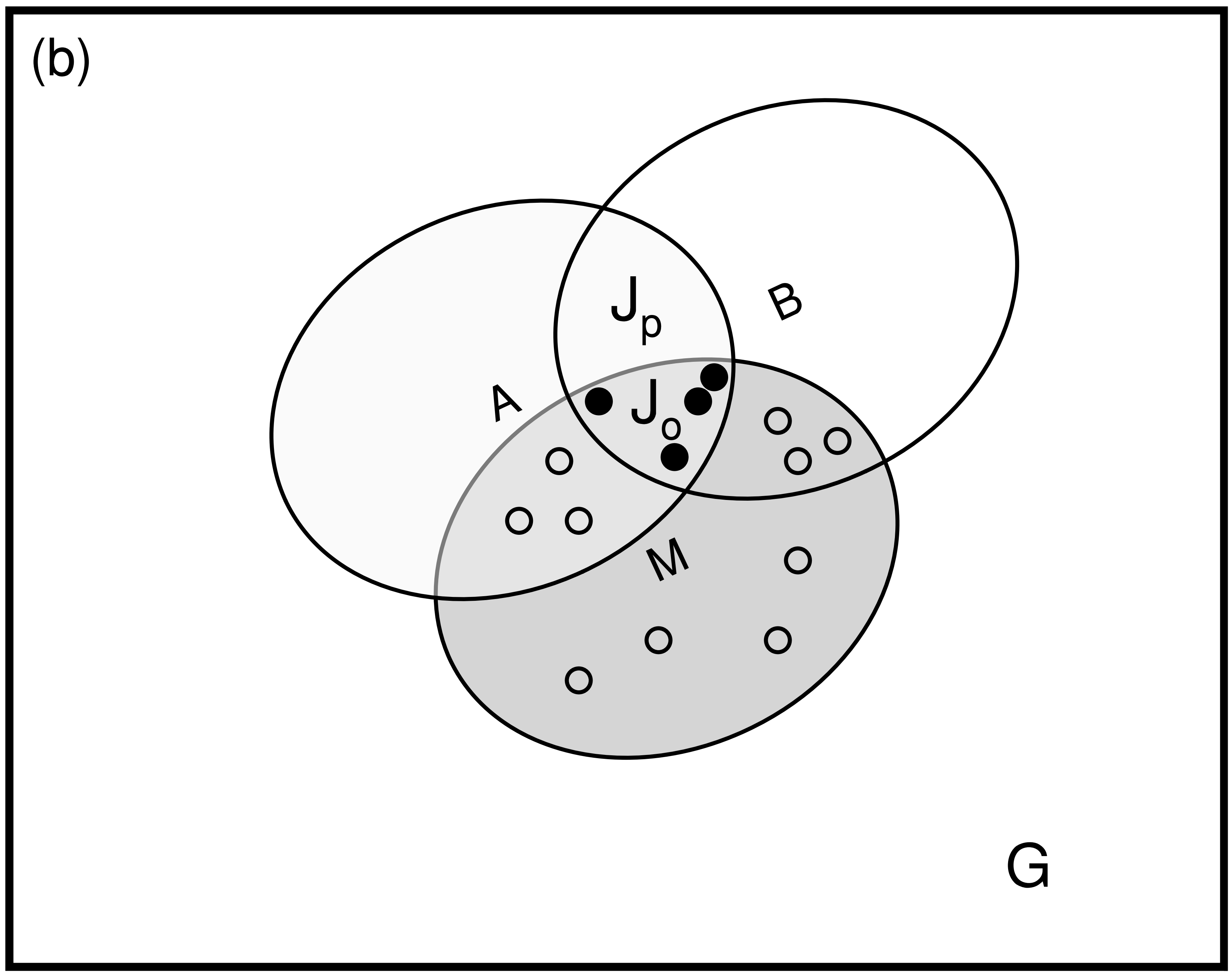
- The ecological model is required in order to identify the characteristics of species occurrence data that are appropriate for modeling, select explanatory variables or their surrogates, specify appropriate scale(s) of analysis, hypothesize the nature or form of the species-environment relationship (the shape of the response curve), and select an effective modeling method.

The species niche concept



Shugart (1998)

The species niche concept



Soberon (2007)

The species niche concept

- There has been a great deal of recent discussion about the relationship between the species niche concepts and species distribution modeling
- What is actually being modeled in SDM, the fundamental species niche, the realized niche, or the probability of habitat use?
- The connection to an underlying species niche concept should be made as explicitly as possible in the choice of predictors, interactions between predictors, response functions, model type, and interpretation of the resulting predictions.
- When applying the niche concept in static (statistical) species distribution modeling, we assume that species are in (quasi-) equilibrium with contemporary environmental conditions, and that observed distribution and abundance is indicative of environmental tolerances and resource requirements.
    - => The limitations of this assumption should be explicitly considered in each specific SDM study. For example, some species may still be spreading into suitable habitat following the last Glacial Maximum.

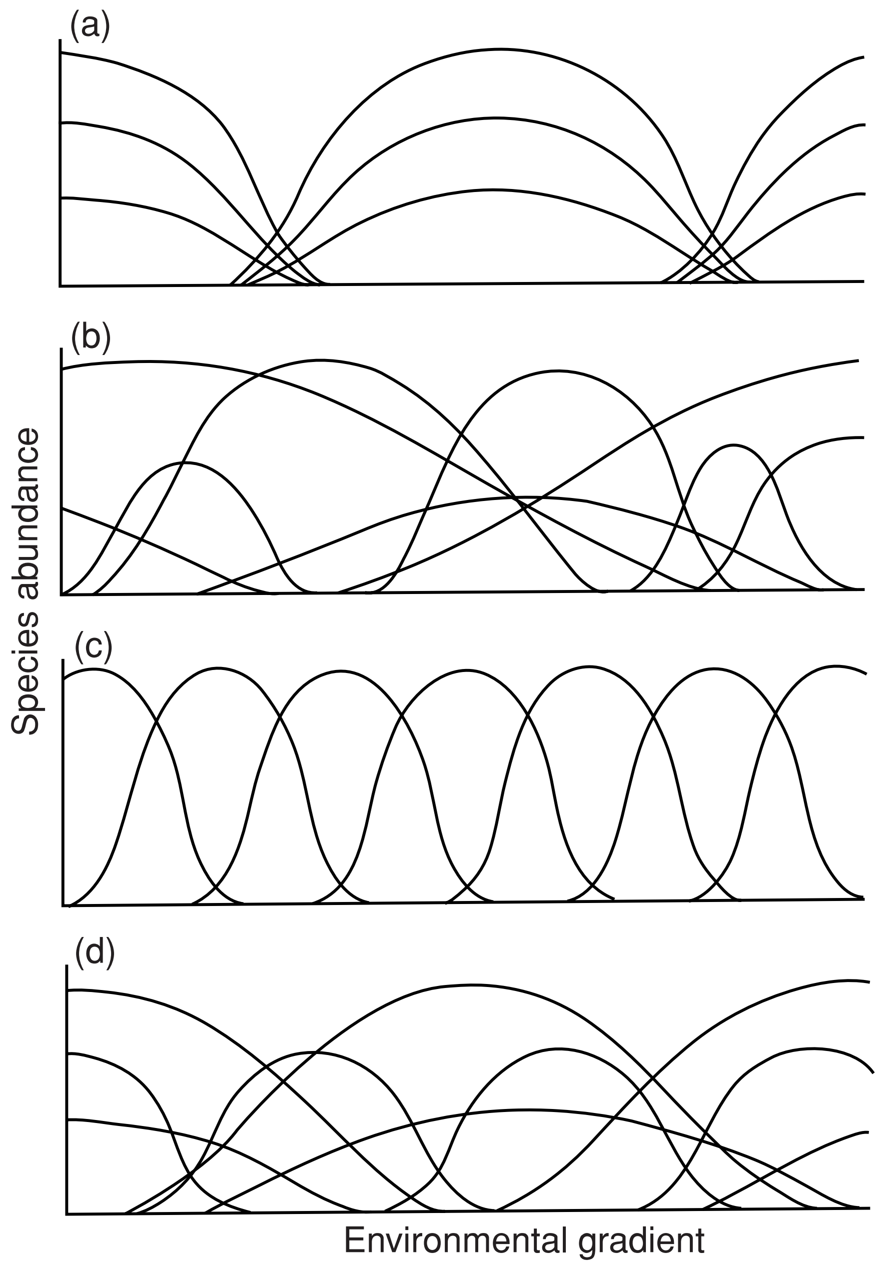
The species niche in evolutionary time

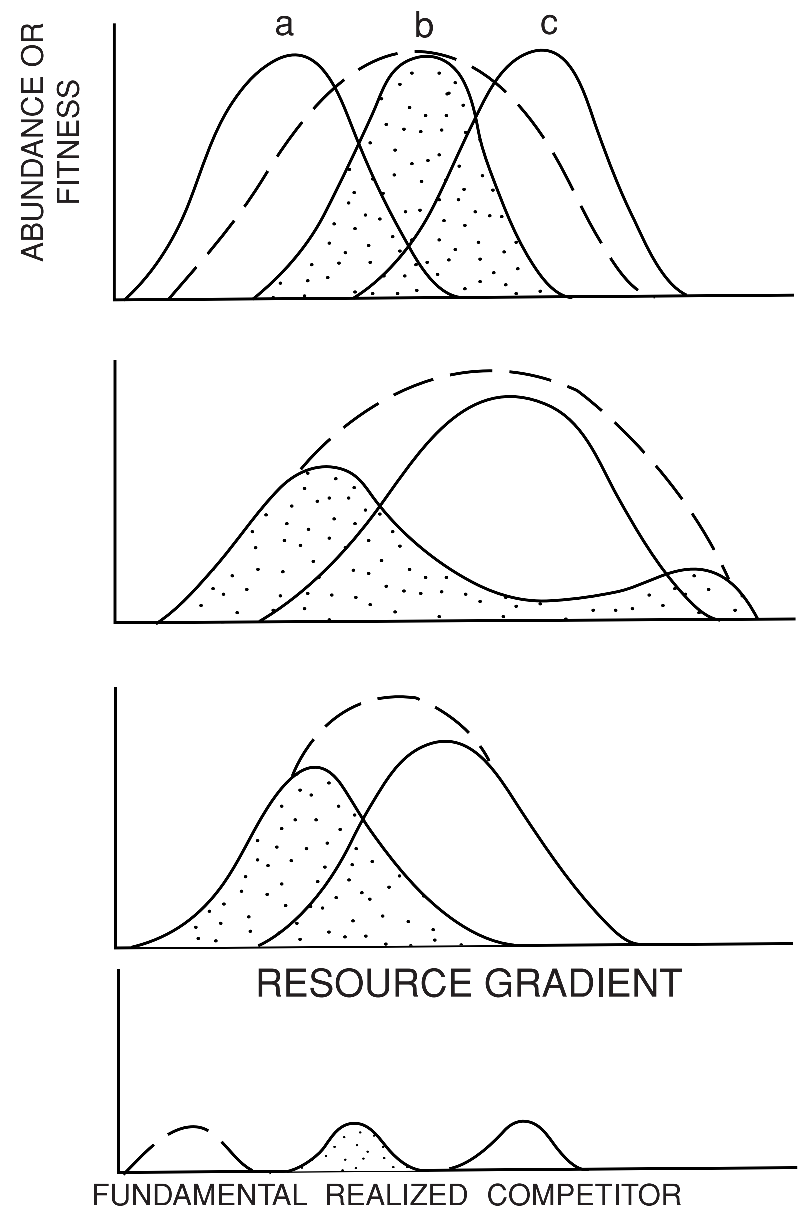
- SDM is being increasingly used to test hypotheses in evolutionary biology regarding niche and geographic range as species traits
  - Do closely related taxa share similar climatic tolerances even if their current distributions are disjunct?
  - Has been taken as evidence of“phylogenetic niche conservatism” – the tendency of species to retain characteristics of their fundamental niche over evolutionary time via stabilizing natural selection.
  - Niche conservatism is an assumption, rather than a hypothesis, in a growing number of studies that reconstruct contemporary and paleo-distributions in order to delimit species, especially in the case of morphologically cryptic species
  - Niche conservatism is also assumed when using SDM to reconstruct paleo-distributions in order to examine other research questions in phylogeography
- SDM carried out to answer these phylogeographical questions has focused almost exclusively on coarse-scale climate variables as the only predictors and has even been called phyloclimatic modeling – “combining phylogenetics and bioclimatic modeling”
- The “climatic niche” encompasses only a limited set of dimensions in Hutchinson’s “hypervolume”, and only at the broad scale
- While the growing use of SDM in phylogenetic research is an interesting development, the question of whether species niches are stable or not, over short (thousands of years) or long (millions of years) time periods, also has very practical implications for the use of SDM to predict the impacts of climate change on species.

Factors controlling species distributions

- Austin (2002) described the types of factors that affect species distributions, and distinguished proximal (causal) factors from distal (proxy or surrogate) factors.
- Distal factors are related to resources or regulators (proximal factors), and therefore correlated with species distributions, but may be easier to measure or observe than the proximal factors themselves.
- Indirect factor gradients have no direct effect on species distribution or abundance, and so always are distal variables. Examples are latitude, longitude, elevation, slope angle (steepness) and aspect (exposure)
- Ideally, variables describing direct and resource gradients would always be used as predictors in SDM. However, when only variables describing indirect gradients are available, it is important not to extrapolate the model results beyond the range of conditions used to develop the model.
- Further, there is no theoretical expectation for the shape of a species response curve on an indirect gradient (Austin, 2007).

Response curves

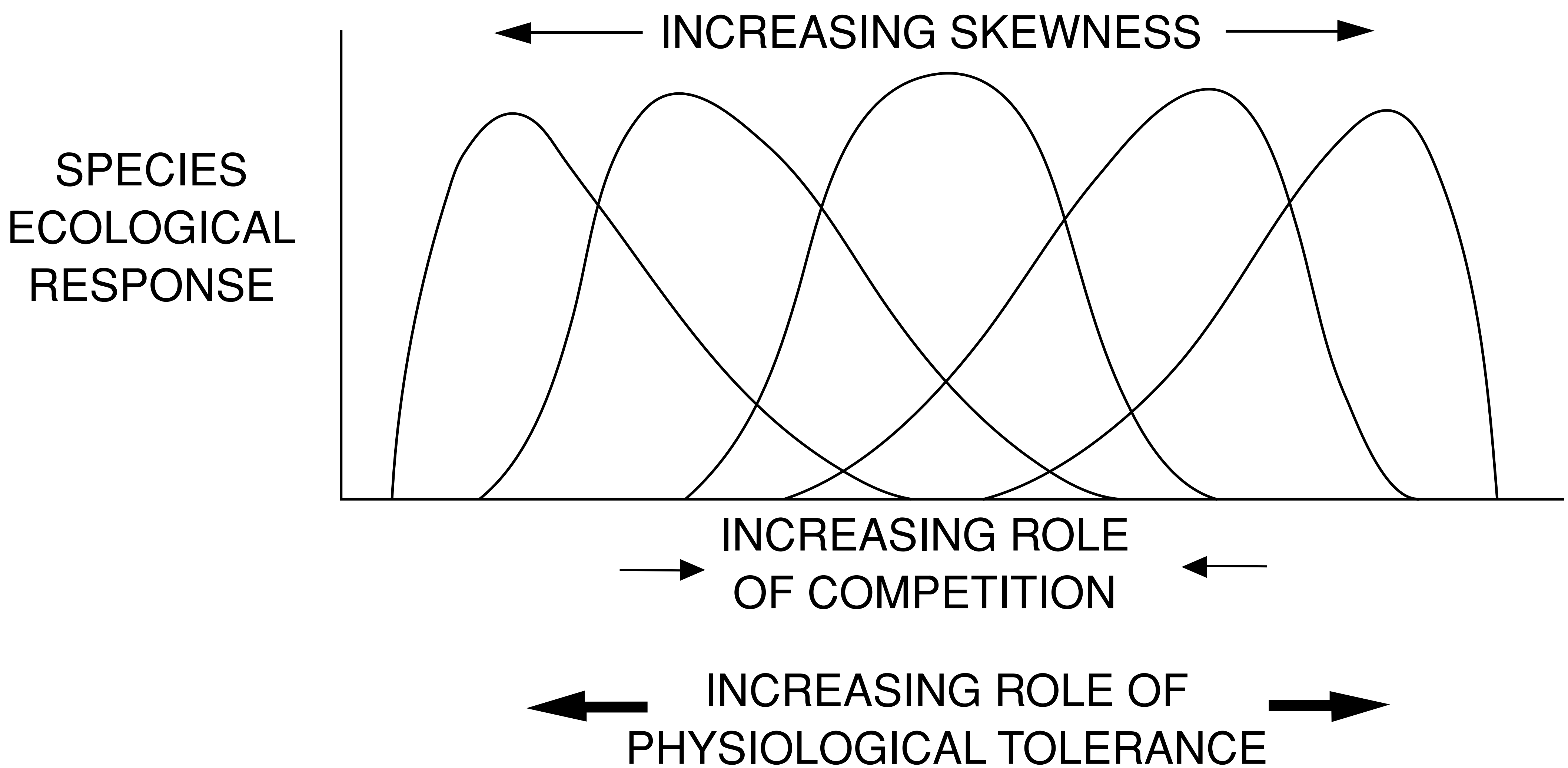




TYPES OF SPECIES RESPONSE CURVES

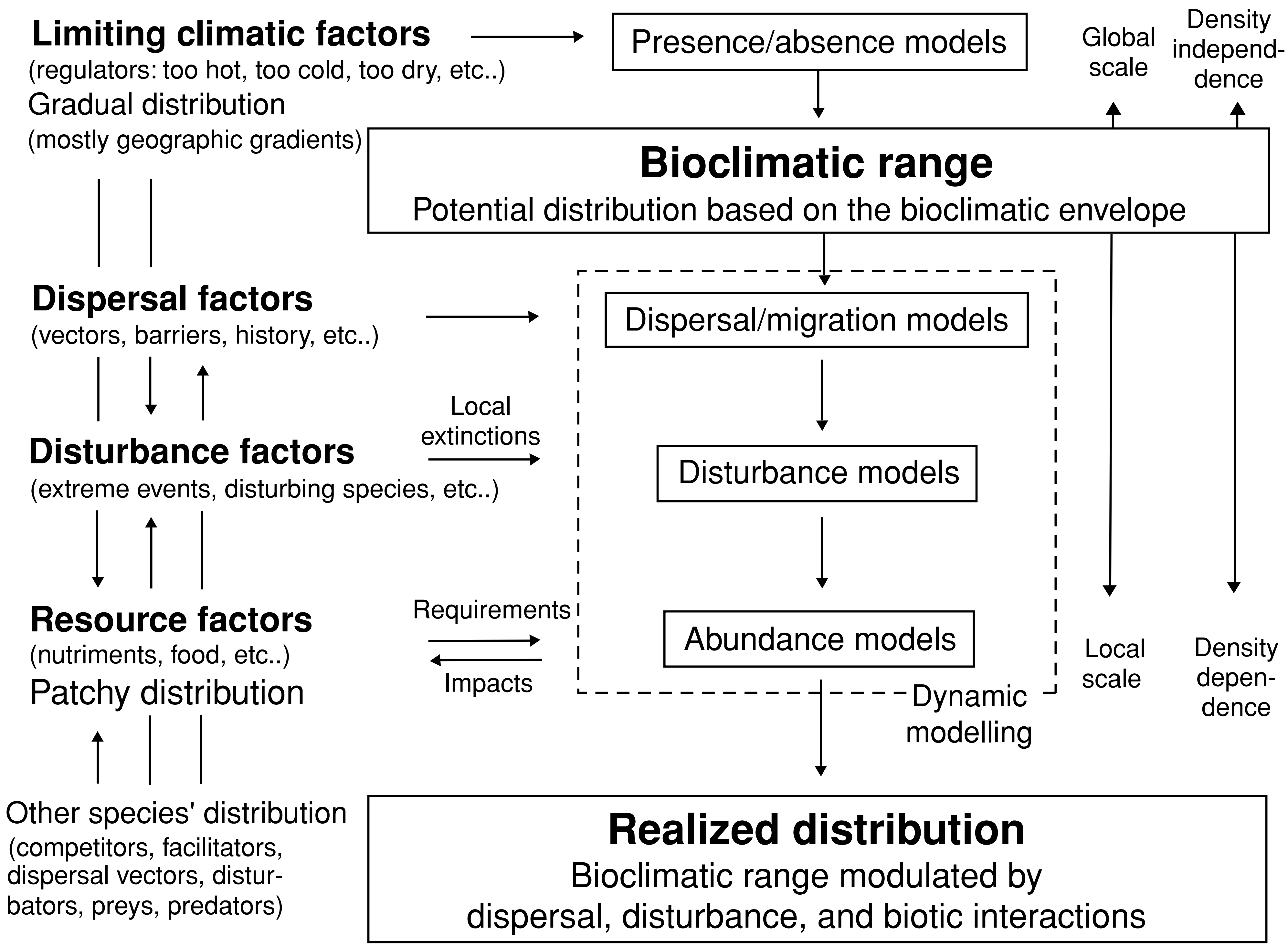
Austin, 1985

Response curves (skewness)



Austin, 1990

Static SDM and dynamic processes



Austin, 1990

SDMs in the Southern Ocean

- Modern Antarctic biodiversity displays unique biogeographic features and life history traits including high levels of endemism, adaptations to freezing water temperatures, and brooding.
- However, remoteness and extreme environmental conditions also make the SO a challenging region to carry out field work because of limited access and strong logistical and financial constraints
- Over the last 10 years, significant efforts have been devoted to improve our knowledge of the SO biodiversity (Census of Antarctic Marine Life (CAML) and of the International Polar Year (IPY)): 18 concurrent oceanographic campaigns were led to the Antarctic and new biodiversity data were aggregated
- New marine biodiversity data were compiled and datasets made openly available through the SCAR Marine Biodiversity Information Network and the Biogeographic Atlas of the SO. Nevertheless, major Linnean and Wallacean gaps still persist in our knowledge of Antarctic marine life.
- Under-sampled areas include the deep sea, the Amundsen Sea, and isolated islands such as Bouvet island
- Species distribution modelling (SDM) represents a valuable tool to fill in these gaps and are often applied to conservation issues and in Marine Protected Area designation processes
- A growing number of large-scale SDM-based studies have recently been published for the SO (plankton, top predators, fish, and cephalopods)
- SDM developed for Antarctic benthic organisms are restricted to few case studies including deep-sea shrimps, cirripeds and echinoids

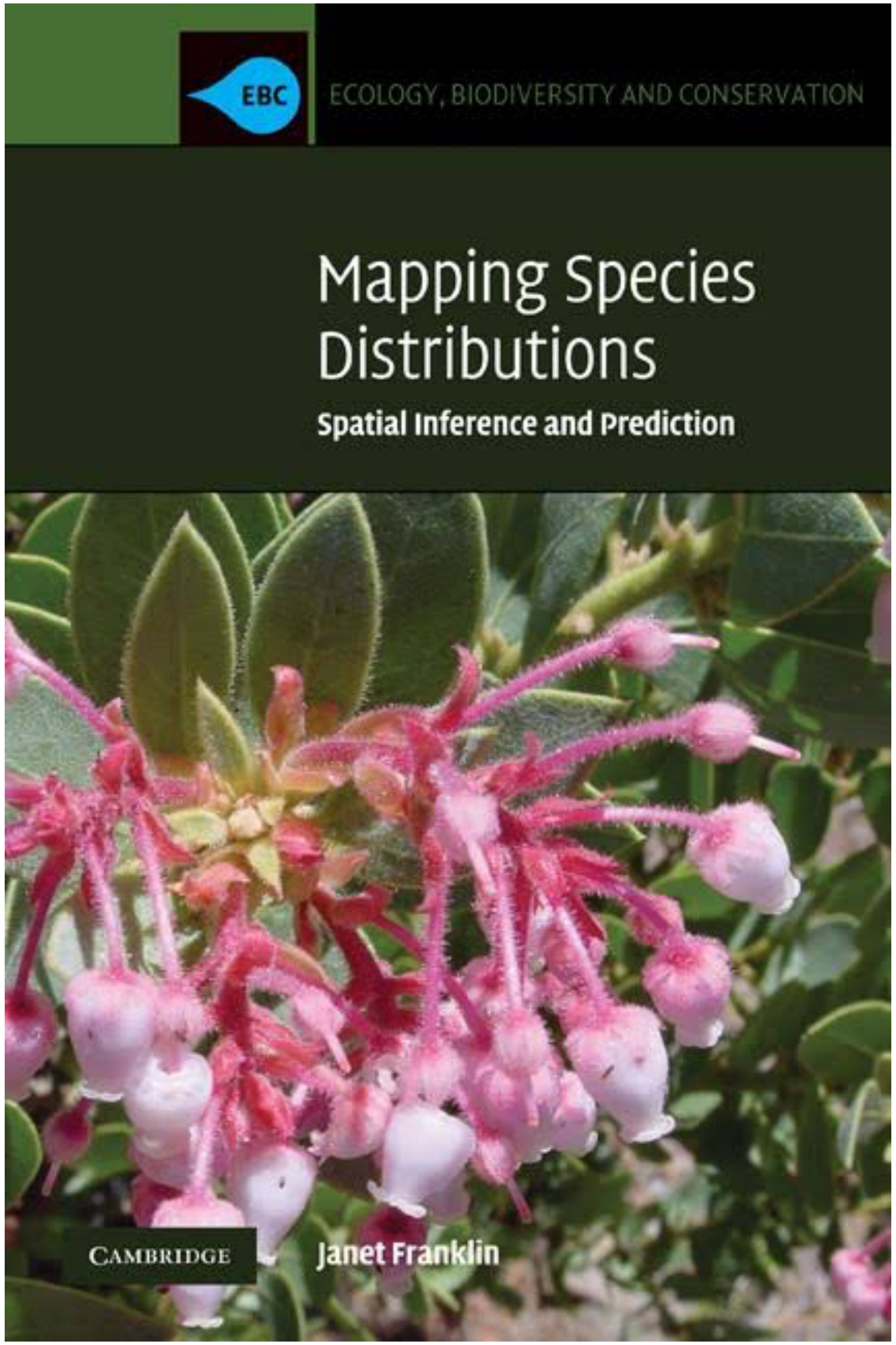
SDMs in the Southern Ocean

- Specific limitations for SDMs in the SO include the effect of sampling effort, sample size, and the addition of new records on model accuracy with the potential to impact model predictions and performance

- Recent studies have highlighted the effect of species niche width and biogeography on the performance levels of SDMs. SDMs carried out on broad-niche species with wide distribution range tend to be more sensitive to the quantity of data available than for narrow niche species with restricted distribution range

- We can assume species with high dispersal capacity should be more constrained by the environment as in Hutchinson's Dream distribution pattern, while endemic species should be more constrained by dispersal limitation as in the Wallace's Dream distribution model.

Find out more



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