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EDITORIAL

What are the roles of species distribution models in conservation planning?

The development of species distribution models (SDMs) has benefited biodiversity conservation through their linkage of science to policy and decision processes. These models have evolved to provide scenarios of future landscapes based on known and projected environmental parameters. Whereas there are many caveats to their use, the persuasive power of the models for conveying the consequences of environmental change to the non-science community is immense. Scientists are obliged to convey the uncertainty of the futures depicted in their models, but also to involve the stakeholders who will shape those future conditions. Stakeholders can identify the natural resources they want to sustain, voice their priorities in environmental policy, and articulate the range of solutions they are willing to accept. The creation of alternative futures is an academic exercise if not linked to real viable decisions concerning important resources. SDMs only reach their full potential when they bring together scientists, public stakeholders and policy makers, and are used as an adaptive management tool to understand complex landscapes that are undergoing short- and long-term change.

Excellent reviews of the evolution of SDMs exist, and all aspects of the models will not be covered here (Guisan & Thuiller 2005; Elith & Leatherwick 2009; Franklin 2009, 2010; Iverson *et al*. 2011). The major points are that distribution models for single or multiple species are created based on survey data across a range of environmental variables. The process identifies critical environmental variables for each species or community, and then extrapolates from the known survey locations to the entire target landscape. These static models either display the predicted distribution as a binary function or as a probability landscape. SDMs can isolate variability due to imperfect detection of species from parameters shaping the species distribution. SDMs have been used to identify suitable habitat for cryptic species (Wilting *et al*. 2010), or for species distributed across broad and/or difficult landscapes that preclude detailed surveys (McShea *et al*. 2009; Liu *et al*. 2009). There is the caveat that mapping potential habitat should not be inferred to represent the actual presence of the species (Guisan & Thuiller 2005). For example, tropical wildlife are experiencing significant poaching pressure within forest reserves (Harrison 2011), and maps of suitable forest may not reflect the abundance of animals within that forest. An additional important limitation is that SDMs assume the surveys are detecting species across their potential range and that important environmental variables (including species interactions) have been considered in the model construction. For species currently confined to refugia, or which are so rare that they occupy only a small portion of their suitable habitat, the resulting distribution model does not reflect the true potential extent of the species and thus exaggerates the lack of potential habitat (Sinclair *et al*. 2010; De Ornellas *et al*. 2011). Despite these limitations, SDMs have advanced conservation efforts by allowing conservation planning for the current distribution of many critical species, such as large carnivores in North America (Carroll *et al*. 2001) and Europe (Corsi *et al*. 1999), and riverine fish communities in Mesoamerica (Esselman & Allan 2011).

Once adopted by the conservation community, static SDMs were almost immediately used to project shifts in distribution into the future due to changes in climate parameters or land-use activities (Guillan & Thuiller 2005). By using parameters that are either directly or indirectly linked to recently available world climate data (Hijmans *et al*. 2005), conservationists have employed SDMs to predict future landscapes (Pereira *et al*. 2010). SDMs have identified corridors between protected areas that would allow movement across temperature gradients (Nuñez *et al*. 2013), determined functional redundancy in protected area establishment (Gallagher *et al*. 2013), linked key demographic metrics with global change models and prioritized critical habitats (Bonnot *et al*. 2011), and allowed planning for increased frequency of extreme weather events in order to conserve an endangered species (Bateman *et al*. 2012). With effective conservation planning focused on insuring redundancy and resiliency for sustainable future populations (Redford *et al*. 2011), SDMs are a valuable tool to the conservation community.

This projection of SDMs into a contentious political arena has generated critical review on how the models are constructed and used to predict alternative futures. It is these future projections that have drawn the most criticism of SDMs, primarily because of inherent variability of the environmental parameters, the unknown migration ability of the species, and model uncertainty, which are not always incorporated into the predictions (Cayuela *et al*. 2009; Coreau *et al*. 2009; Elith & Leatherwick 2009; Franklin 2010; Sinclair *et al*. 2010). Many of the same limits to static SDMs are at issue when linking SDMs to climate models. For example, the scale of a species' environmental niche is often small relative to outputs of climate models and undetected climate refugia will exist within these future landscapes (Weins & Bachelet 2010). In addition, anthropogenic stresses may have complex interactions with projected changes in climate parameters (Singh & Milner-Gulland 2011) and the uncertainty values of critical parameters makes future predictions challenging for some species (Carvalho *et al.* 2011). Of particular note is that the persistence of organisms in future landscapes depends partially on their ability to migrate into newly suitable habitats, abilities that are poorly understood for most species (Franklin 2009, 2010).

These issues demand constant vigilance when selecting focal species and landscapes, but they are tractable with the development of new techniques and a critical scientific community. Of primary concern is that this predictive modelling often places species in future communities that do not exist at present, or into a parameter space not encompassed by the original SDMs (Coreau *et al.* 2009). Although most SDMs focus on single species, as the modelling environment approaches unique combinations of parameters, there is increased uncertainty over the interactions with other species and between the environmental variables, which can make predictions problematic (Carvalho *et al.* 2011). For broad-ranging species that occur across diverse and varied landscapes these conditions may never be reached, but for specialist (or rare) species caution is advisable before mapping future distributions.

SDMs linked to future landscapes are most credible when focused on well-studied species within systems where the important parameters are understood. Temperate forest communities are an excellent example where SDMs are linked to climate models to project future communities. Due in part to their large economic value, scientists have a better understanding of the physiology, species interactions and dispersal capabilities of temperate tree species than any other ecosystem (possibly temperate freshwater systems come close). Several successful SDMs have created future projections for forest (Iverson *et al.* 2011; Thompson *et al.* 2011), lake (Peterson *et al.* 2003) or riverine (Esselman & Allan 2011; Turak *et al.* 2011) communities. The challenge is to bring together the same level of knowledge when modelling other important communities, such as tropical forests or marine communities. The next difficult step is linking forest communities, which can be mapped remotely at broad scales, with animal communities, which are often loosely correlated to forest distributions and are often incompletely mapped at a much smaller scale. There are few animal communities understood to the degree that the distribution and extent of forest communities can serve as a surrogate for SDM purposes (Faaborg *et al.* 2010).

Modelling limitations should not dissuade conservationists from using the predictive power of SDMs. A dynamic SDM, based on well-surveyed populations responding to changes in known-critical parameters, is one of the best tools available for conservationists to visually convey future conditions. Users should be aware of limitations, but the model insights are an important starting point for decision making (Carvalho *et al.* 2011). It may be unknown which projection best reflects reality 100 years in the future, but presenting a range of possible outcomes to stakeholders may trigger action today. Scenario planning is a good example of how a SDM can be effectively used for conservation planning (Coreau *et al.* 2009; Foster *et al.* 2010; Periera *et al.* 2010; Thompson *et al.* 2012). With scenario planning, alternative futures are presented to stakeholders based on the policy actions available to them. This has been tried at regional (Spies *et al.* 2007; Shaw 2009; Foster *et al.* 2010) and global (Millennium Ecosystem Assessment 2005; Periera *et al.* 2010) scales. In my opinion, the regional efforts have been successful at conveying policy impacts on environmental services.

For the conservation community focused on endangered species, these future SDMs are analogous to population habitat viability analysis (PHVA), where population parameters are used to determine the current population growth rate and then are projected into future generations in the presence of known stressors (Akçakaya & Sjögren-Gulve 2000; Linkie *et al.* 2006; Redford *et al.* 2011). PHVA workshops for stakeholders then explore the minimum and maximum levels for each stressor that allow population persistence over the projected time span. The stakeholder process strives to recognize and accept the limits within which land and animal usage will allow persistence of the target population. PHVAs have been incorporated into a metapopulation schema, where sources and sinks for populations are temporally and spatially variable due to shifting resources (Bonnot *et al.* 2011). This linking of population parameters with environmental change across a landscape holds much potential for SDMs that seek to predict the future viability of critical species (Elith & Leatherwick 2009; Franklin 2010).

SDMs can accomplish conservation aims through several avenues:

(1) Many environmental threats are imminent and operate within known parameters. For many species and communities, impacts of forest loss, increased road density and dam construction are understood. Short-term projections of climate models do not bring species outside the parameter limits used for model creation. For many endangered communities, SDMs are of valuable assistance in projecting the short-term consequences of policy decisions.

(2) For some situations it is best to consider these future models not as predictions, but as scenarios. This is with the stipulation that, if known parameters stay within their limits, future landscapes can be projected, based on a limited number of policy decisions. These alternative futures do not make predictions of how likely each future landscape is, but provide a critical tool for stakeholders to discuss how today's decisions shape future landscapes.

(3) Spatial distribution modelling is a rapidly evolving field, with advances in technology for species' detection, modelling software and mathematical theorems, and an understanding of important parameters for an increasing number of species. SDMs should result from an iterative process for the conservation community, with important models revised and re-parametized on a regular basis. As

'current-state-of-knowledge', SDMs are one step toward bringing science into policy making.

(4) Hundreds of SDMs exist, from marine to terrestrial systems, yet the science is not well used by the conservation community. This community needs to take a more proactive role in the funding of SDM research. The research community is currently driving most SDM development, and the products are relevant to ecologists (understanding basic population and ecosystem principles) and produce meaningful products within the science community (namely papers for scientific journals and conference presentations). The conservation community often needs different products, such as usable applications and scientific input into policy development. Explicitly creating SDMs for policy development is more likely to produce applications that are useable and used by practitioners, and make better use of visualization tools (McIntyre & Strauss 2013). The development of joint ventures based around ecosystems (Bonnott *et al.* 2011) or species (Lynch & Taylor 2010), or multi-agency partnerships for migratory bird conservation (Faaborg *et al.* 2010), is a promising avenue for merging the science and management communities.

(5) The conservation community is not the final user of any SDM. The goal is to link the modelling to policy makers and managers (Euliss *et al.* 2011). There is insufficient effort to convey SDM outputs to decision-makers. Even this volume had limited success in finding research that moved from theory to practice. More research is needed on how to use SDMs in the service of informing public policy, stakeholder scenario analysis and applied conservation (Driscoll *et al.* 2012). The conservation community needs improved understanding of the relative merits of different modelling approaches in terms of their ability to influence policy and management.

The purpose of this thematic issue is to highlight the role of spatial simulation models in informing conservation planning for global change. The issue encompasses specialist organisms that require narrow environmental envelopes, mobile terrestrial species that rely on unrestricted movements across landscapes, and landscape-scale simulation studies that quantify changes in ecosystem services. I encourage the conservation community to embrace a reasoned use of species distribution model throughout the planning process as a means of engaging stakeholders in discussions of future scenarios and the decisions needed to reach their desired outcomes.

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