Conservation Biology

Special Section: Conserving Nature's Stage

> Life is a gloss on geography. And if you dig your fists into the earth and crumble geography, you strike geology. Climate is the wind of mineral earth's rondure, tilt, and orbit modified by local geological conditions. The Pacific Ocean, the Negev Desert, and the rain forest in Brazil are local geological conditions. So are the slow carp pools and splashing trout riffles of any backyard creek. It is all, God help us, a matter of rocks.
>
> The rocks shape life like hands around swelling dough. In Virginia, the salamanders vary from mountain ridge to mountain ridge, so do the fiddle tunes the old men play. All this because it is hard to move from mountain to mountain. These are not merely anomalous details. This is what life is all about: salamanders, fiddle tunes, you and me and things, the split and burr of it all, the fizz into particulars. No mountains and one salamander, one fiddle tune, would be a lesser world. No continents, no fiddlers. No possum, no soup, no taters. The earth without form is void . . .
>
> Annie Dillard (1982)

Introduction

The papers in this special section address the use of geodiversity as a coarse filter strategy for conserving biodiversity. A coarse filter strategy conserves representative samples of broadly defined environments as a way to conserve most species. However, geodiversity first entered conservation planning for its own sake, not for its ability to support biodiversity. For example, the first national park in the world (Yellowstone [established 1872]), the second national park in the US (Yosemite [1890]), Canada's first national park (Banff [1885]), and New Zealand's first national park (Tongariro [1887]) were each set aside primarily to protect spectacular geophysical features and their associated recreational and cultural values. This history helps explain why some protected area networks do a better job of protecting rocks than biodiversity (Scott et al. 2001).

Although ecologists have long recognized geodiversity as a key driver of biodiversity and species distribution patterns (Lawler et al. 2015), conservation biologists were slow to consider using geodiversity to prioritize areas for biological conservation. In 1982, The Nature Conservancy (TNC) launched the first coarse-filter approach to conservation (TNC 1982; Noss 1987). The TNC approach aimed to conserve examples of each vegetation community, under the assumption that most species would be protected using this filter. Six years later Hunter et al. (1988) summarized paleoecological evidence that vegetation communities are merely the ephemeral results of recent (often <8,000 years old in temperate zones) range shifts of individual plants species and argued that physical environments would make better surrogates for conservation planning: "we advocate basing the coarse-filter approach on physical environments as arenas of biological activity, rather than on communities, the temporary occupants of those arenas." This apparently was the first time that conserving geodiversity was proposed as a surrogate for conserving biodiversity and thus marks the beginning of conserving nature's stage (CNS).

Although Hunter et al. (1988) specifically proposed CNS as a coarse-filter strategy for conservation in the face of a changing climate, for the ensuing 20 years, when physical environments were used as coarse filters, they were primarily used as surrogates for contemporary biodiversity, not as a climate adaptation strategy (Belbin 1993; Kirkpatrick & Brown 1994; Wessels et al. 1999). A primary motivation was that data on abiotic physical variables were widely available and more consistently mapped than vegetation communities or species distributions. Indeed, CNS was attractive because it could be applied even in areas with no maps of land cover or species distributions.

The next conceptual advance in CNS occurred when Cowling et al. (2003), Rouget et al. (2003, 2006), and Pressey et al. (2007) proposed the use of physical features (e.g., upland-lowland gradients, interfaces between soil types, and sand movement corridors) as surrogates to conserve ecological and evolutionary processes, such as nutrient transport, interspecific interactions, intraspecific genetic diversity (needed for adaptation and speciation), and disturbance regimes (e.g., flooding and mass wasting).

Five years ago, 2 papers revived the idea of CNS as a climate adaptation strategy (Anderson & Ferree 2010; Beier & Brost 2010). Both papers proposed CNS as a coarse-filter alternative to climate-envelope modeling that has emerged as the dominant fine-filter (species by species) strategy for climate adaptation. Climate-envelope models are focused on individual species, and they chain together 5 highly uncertain models: emission scenarios, general circulation models, downscaled circulation models, species-specific climate envelope models, and species-specific range-shift models. The results are used to identify areas that might support persistence and range shifts of each species. Unfortunately, when the models are used responsibly (considering all plausible combinations of scenarios, models, and scales), large

Conservation Biology, Volume 29, No. 3, 613–617

DOI: 10.1111/cobi.12511

fractions of the landscape are identified as potential high-priority areas (Pearson et al. 2006; Araújo & New 2007). In contrast, CNS is focused on physical places and provides an attractive coarse-filter alternative, identifying areas of expected high climate resilience without complex modeling of climate and individual species' responses.

The CNS approach has gained traction among scientists and practitioners. The Doris Duke Charitable Foundation sponsored a workshop on CNS at ICCB 2013 and has committed US$31 million to conserve geodiverse lands in the eastern United States. The U.S. Landscape Conservation Cooperative program is assessing the availability of enduring features data in the coterminous USA and evaluating the potential use of geodiversity in planning. After lamenting the fact that many protected area networks over-represented rock and ice, conservation biologists are now asking, "which rocks, what ice, which soil?" (Sanderson et al. 2015). Furthermore, conservation biologists are increasingly investigating other aspects of the physical stage such as how topography modifies climate to create opportunities for species persistence.

Taking Stock of CNS

As proponents of CNS, in 2012 we recognized the need to examine its theoretical basis, its strengths and limitations, and evidence for its utility. In particular, we recognized the need to ground CNS in more than wishful thinking. The fact that conservation biologists desperately need a well-mapped surrogate for species conservation in areas lacking biotic information does not guarantee such surrogates exist. Similarly, aversion to house-of-cards climate envelope models for individual species might make CNS attractive, but it does not prove it is a reliable alternative.

The papers in this special section take stock of CNS as a coarse filter strategy for conservation planning, both for today's biodiversity and in the face of climate change. In these papers, we use the term *geodiversity* to refer to the diversity of conditions defined by geological, geomorphological, and soil features (Gray 2004); the term *abiotic diversity* refers to the union of geophysical diversity and climate diversity, and the term *environmental diversity* refers to combinations of biotic and abiotic factors or as a general term that references any or all of the abovementioned concepts.

Lawler et al. (2015) provide abundant evidence that geodiversity is a major driver of species distributions and ecological and evolutionary processes in terrestrial systems but that CNS might need to be adapted to particular situations. For example, the influence of geodiversity might be strongest at mid-sized spatial extents (landscape to region), whereas climate might dominate at continental extents and biotic interactions might dominate at local extents. Moreover, edaphic variables may be relatively strong drivers in low-latitude and semi-arid regions, whereas aspect and insolation may be stronger at mid-latitudes.

Hjort et al. (2015) explain that ecosystems are the product of 3 realms of diversity (geo-, bio-, and climate diversity) and that geodiversity underpins or directly delivers all types of ecosystem services. Thus, although CNS values geodiversity only for its contribution to biodiversity, geodiversity merits protection for its own sake. Hjort et al. also catalog "geosites"—physically unique sites generally smaller than 1 km^2 that support unique species. Although these sites are unlikely to be identified by multivariate approaches to CNS, practitioners can easily incorporate geosites (many of which are well mapped) into a CNS strategy.

Summarizing evidence from the last 2.6 million years, Gill et al. (2015) report that although past episodes of climate change produced many local extinctions, geodiversity apparently minimized the number of global extinctions caused by climate change. They conclude that CNS "explicitly acknowledges dynamic processes, including extinction, evolution, community turnover, and novelty. That is, it acknowledges change—not necessarily as a hindrance to conservation, but as intrinsic properties of the very nature we aim to conserve."

Sanderson et al. (2015) provide the first global map of land facets (geodiversity types) along with frequency distributions of the sizes of individual facets and then estimate how much of each of the 672 land facet types are in protected status in each of 8 biogeographic realms. Future conservation efforts should focus on the least protected types (low elevation mollisols and vertisols) that are also the most productive for agriculture.

Although most of the papers in the special section have a terrestrial focus, Sutcliffe et al. (2015) demonstrate that tropical marine sites selected to span abiotic surrogates would conserve most species in 11 marine phyla. Abiotic surrogates were especially effective when the variables used to define surrogates were weighted according to their influence on species turnover. Although studies to identify the abiotic drivers of species turnover made such biotically informed surrogates more expensive than surrogates using unweighted variables, the benefits to biodiversity and commercial fisheries justified the cost.

In their review of many tests of how well abiotic diversity (geodiversity and climate diversity combined) represents species, Beier et al. (2015) report that abiotic surrogates represent plant species well and that recently improved abiotic surrogates can greatly improve representation of plants, vertebrates, and marine organisms. This supports the use of abiotic surrogates in areas that lack data on species distributions. If additional tests using purely geophysical surrogates (i.e., excluding climate variables) find similar patterns, this would support use of CNS as a climate adaptation strategy.

In a compendium of 8 case studies that used geodiversity in conservation planning, Anderson et al. (2015)

found that adding geodiversity targets to a traditional conservation plan (i.e., a plan designed to represent vegetation types and species) usually does not increase the total area prioritized or decrease the achievement of other targets. Under these circumstances, using geodiversity surrogates is a low-cost type of bet hedging that results in networks more robust to climate changes but that are compatible and complementary to existing plans.

Comer et al. (2015) describe how geodiversity can be incorporated into the work of agencies with legal, political, and cultural mandates to focus on conservation of particular species. They suggest that a landscape can be classified into 1 of 4 classes of vulnerability to climate change (resistant, resilient, susceptible, and sensitive), depending on the landscape's current geodiversity, ecological intactness, and connectivity. For each class of vulnerability, Comer and colleagues suggest particular activities to manage disturbance, restoration, and connectivity.

Future Development of Conserving Nature's Stage

Conserving nature's stage has earned a place in the climate adaptation toolkit, complementing other approaches such as reducing non-climate stressors, augmenting genetic diversity in restoration plantings, climate envelope modeling, and assisted colonization (Groves et al. 2012; Schmitz et al. 2015). The papers in this special section also support use of CNS as a coarse-filter strategy to conserve species in today's climate in areas lacking data on where species occur. In the next 5 years, we would like to see the following developments related to the use of geodiversity in conservation planning. Our over-riding concern is less with advancing CNS in particular than with providing a strong scientific basis for adaptation strategies that will conserve biodiversity in a changing world.

Increased Use of Geodiversity in Systemic Conservation Planning

Because geodiversity is intended as a surrogate for biodiversity, CNS users are adopting many of the strategies used to set targets for species. Thus Rouget et al. (2003), Beier and Brost (2010), Brost and Beier (2012), Beier (2012), and Anderson et al. (2014, 2015) suggest setting higher targets for rare and distinctive geophysical settings that might support rare species; including large instances of some geophysical settings to support disturbance regimes and large, genetically diverse populations of species associated with that setting; having targets for interspersion of geophysical settings to promote community reassembly, transition to favorable climate during periods of rapid change, and opportunities for evolutionary diversification; and including targets for connectivity and compactness to facilitate range shifts. These provide a good start on making CNS a practical tool, but there is a lot of room for improvement.

We call attention to 2 understudied aspects of incorporating geodiversity into systematic conservation planning. First, 3 papers in this special section mention the use of geodiversity as a surrogate not only for species, but also for ecological and evolutionary processes. But we lack a theoretical or empirical basis to set quantitative targets to conserve such processes. For years conservation biologists have used the species–area relationships to suggest general guidelines for minimizing species loss. Can we develop similar rules of thumb for the optimum interspersion of geophysical settings or for the minimum proportion of a physical gradient needed to minimize loss of a region's ecosystem services or evolutionary potential? Although the correct rule may not exist, it would be helpful to develop broad sideboards to guide planning. Second, some geophysical settings are expected to be refugia during the coming decades of inevitable climate change, and this function needs to be incorporated into systematic conservation planning. For example, Shoo et al. (2011) noted that 45% of species in Queensland tropical rainforests were restricted to the coolest forest areas and used these relationships to prioritize sites for restoration. The prioritized sites were identified solely from nonclimate variables (elevation, latitude, distance to stream and coast, foliage cover, and solar radiation) and thus such planning fits within a CNS framework.

A More Charismatic Vocabulary

Geodiversity can be charismatic (Fig. 3 in Hjort et al. 2015), but terms like *land facets* and *ecological land units* are technical and sterile. Acceptance of CNS by managers and civil society would probably be advanced if its vocabulary conveyed the idea that the goal is conserving species and life processes. The term *niche* is a good example of a term that originally denoted a physical space, but now connotes multivariate space that is important to life. Might other terms take on similar utility for this new coarse-filter conservation strategy? The term *geodiversity* might be young enough (it was coined about 1993 [Gray 2004:5–6]) to take on a significant life-support flavor. We hope that *conserving nature's stage*, with its allusions to Hutchison's (1965) "ecological theater and the evolutionary play," might resonate with scientists, managers, and civil society and lead to greater appreciation of the link between geodiversity and biodiversity.

Increased Development and Evaluation of Adaptation Strategies

In the first 100 titles produced by Google Scholar for the keywords *climate change biodiversity*, at least 86 papers focused solely on predicting the vulnerability of biodiversity to climate change. No more than 14% of the papers developed or evaluated an adaptation strategy. This bias toward impact assessment over adaptation is not limited to the academic literature. For example, consider the United States' National Climate Change and Wildlife Science Center, 8 climate science centers, and 22 landscape conservation cooperatives—entities formed since 2009 explicitly to help society take steps to conserve biodiversity in a changing climate. Our perusal of projects listed on the websites of these entities suggests that >90% of their effort focuses on impact assessment and <10% on adaptation strategies such as CNS, climate envelope modeling, assisted colonization, mobile reserves, and enhancement of connectivity.

We advocate a shift of emphasis away from impact assessment and toward development and evaluation of adaptation strategies—including but certainly not limited to CNS. Unfortunately, the most rigorous evaluation of adaptation strategies would be to try various strategies (with replicates and controls) and observe the response of biodiversity over the next 50–100 years. But of course that course of action is too slow and too risky. As an alternative, we advocate a rigorous comparative evaluation of the theoretical foundations, risks, costs, practicality, and likely outcomes of each strategy.

In such comparative evaluations, CNS would probably fare well in terms of practicality and cost. Because it does not depend on a particular future climate (indeed it is hypothesized to work even if climate does not change), it is more likely to be perceived as practical by managers who are skeptical of climate models, or even the very fact of climate change. Because CNS relies heavily on existing protected areas to allow species to shift to new climate space (Beier 2012), it is less expensive than some alternatives. Because it focuses on real places on the landscape, it avoids the open-ended uncertainty of movable reserves or assisted colonization. Because it uses existing, freely available data, CNS avoids delaying conservation action to improve knowledge; priority lands often become unavailable or more expensive during such delays (Grantham et al. 2009).

On nature's stage, the next act has already begun: massive changes to human and natural systems caused by human alteration of the atmosphere. The degree to which the next act is tragic or triumphant depends primarily on how quickly humans reduce concentrations of greenhouse gasses. We hope our modest contributions will help produce adaptation actions that will complement these crucial mitigation actions.

Acknowledgments

We thank Doris Duke Charitable Foundation for supporting a 2013 workshop on conserving the stage and for defraying publication charges for this special section. We thank S. Nichol and an anonymous reviewer for reviewing all papers in the special section. Workshop participants included D. Ackerly, C. Albano, F. Albuquerque, B. Benito, A. Bowman, T. Brooks, C. Burns, S. Buttrick, P. Comer, M. Cross, D. Diamond, S. Dobrowski, K. Elowe, D. Faith, J. Forrest, J. Gill, N. Heller, J. Hjort, A. Keeley, J. Lawler, H. Possingham, B. Pressey, E. Sanderson, C. Schloss, M. Shaffer, P. Sutcliffe, J. Tirpak, J. Watson, and ourselves.

Paul Beier,* Malcolm L. Hunter,† and Mark Anderson, Guest Editors‡

*School of Forestry, Northern Arizona University, Flagstaff, AZ 86011-5018 U.S.A., email paul.beier@nau.edu
†Department of Wildlife, Fisheries, and Conservation Biology, University of Maine, Orono, Maine 04469, U.S.A.
‡The Nature Conservancy, 99 Bedford Street, Boston, MA 02111, U.S.A.

Literature Cited

Anderson MG, Clark M, Olivero Sheldon A. 2014. Estimating climate resilience for conservation across geophysical settings. Conservation Biology **28:**959–970.

Anderson MG, Comer PJ, Beier P, Lawler J, Schloss C, Buttrick S, Albano C, Faith D. 2015. Case studies of conservation plans that incorporate geodiversity. Conservation Biology **29:**680–691.

Anderson MG, Ferree, C. 2010. Conserving the stage: climate change and the geophysical underpinnings of species diversity. PLOS ONE **5** (e11554) DOI:10.1371/journal.pone.0011554.

Araujo MB, New M. 2007. Ensemble forecasting of species distributions. Trends in Ecology and Evolution **22:**42–47.

Beier P. 2012. Conceptualizing and designing corridors for climate change. Ecological Restoration **30:**312–319.

Beier P, Brost B. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology **24:**701–710.

Beier P, Sutcliffe P, Hjort J, Faith DP, Pressey RL, Albuquerque F. 2015. A review of selection-based tests of abiotic surrogates for species representation. Conservation Biology **29:**668–679.

Belbin L. 1993. Environmental representativeness: regional partitioning and reserve selection. Biological Conservation **66:**223–230.

Brost BM, Beier P. 2012. Use of land facets to design linkages for climate change. Ecological Applications **22:**87–103.

Comer PJ, Pressey RL, Hunter ML, Schloss C, Buttrick S, Heller N, Tirpak J, Faith DP, Cross M, Shaffer M. 2015. Incorporating environmental diversity into conservation decisions. Conservation Biology **29:**692–701.

Cowling RM, Pressey RL, Rouget M, Lombard A. 2003. A conservation plan for a global biodiversity hotspot, the Cape Floristic Region, South Africa. Biological Conservation **112:**191–216.

Dillard A. 1982. Life on the rocks: the Galapagos. Pages 108-129 in Teaching a stone to talk. Harper Collins, New York.

Gill JL, Blois J, Benito B, Dobrowski S, Hunter Jr ML, McGuire J. 2015. A 2.5-million-year perspective on coarse-filter strategies for conserving nature's stage. Conservation Biology **29:**640–648.

Grantham H, Wilson K, Moilanen A, Rebelo T, Possingham H. 2009. Delaying conservation actions for improved knowledge: How long should we wait? Ecology Letters **12:**293–301.

Gray M. 2004. Geodiversity: valuing and conserving abiotic nature. Wiley, United Kingdom.

Groves CR, et al. 2012. Incorporating climate change into systematic conservation planning. Biodiversity Conservation **21:**1651–1671.

Hjort J, Gordon J, Gray M, Hunter Jr ML. 2015. Why geodiversity matters in valuing nature's stage. Conservation Biology **29:**630–639.

Hunter Jr ML, Jacobson G, Webb T III. 1988. Paleoecology and the coarse-filter approach to maintaining biological diversity. Conservation Biology **2:**375–385.

Hutchinson GE. 1965. The ecological theater and the evolutionary play. Yale University Press New Haven, CT.

Kirkpatrick JB, Brown MJ. 1994. A comparison of direct and environmental domain approaches to planning reservation of forest higher plant communities and species in Tasmania. Conservation Biology **8:**217–224.

Lawler J, et al. 2015. The theory behind, and challenges of, conserving nature's stage in a time of rapid change. Conservation Biology **29:**618–629.

Noss RF. 1987. From plant communities to landscapes in conservation inventories: a look at The Nature Conservancy (USA). Biological Conservation **41:**11–37.

Pearson RG, et al. 2006. Model-based uncertainty in species' range prediction. Journal of Biogeography **33:**1704–1711.

Pressey RL, Cabeza M, Watts ME, Cowling RM, Wilson KA. 2007. Conservation planning in a changing world. Trends in Ecology & Evolution **22:**583–592.

Rouget, M, Cowling RM, Lombard A, Knight A, Kerley G. 2006. Designing large-scale conservation corridors for pattern and process. Conservation Biology **20:**549–561.

Rouget M, Cowling RM, Pressey RL, Richardson DM. 2003. Identifying spatial components of ecological and evolutionary processes for regional conservation planning in the Cape Floristic Region, South Africa. Diversity and Distributions **9:**191–210.

Sanderson E, Watson J, Segan D. 2015. Global status of and prospects for protection of terrestrial geophysical diversity. Conservation Biology **29:**649–656.

Schmitz O, et al. 2015. Conserving biodiversity: practical guidance about climate change adaptation approaches in support of land-use planning. Natural Areas Journal **35:**190–203.

Scott JM, Davis FW, McGhie R, Wright, R, Groves C, Estes J. 2001. Nature reserves: Do they capture the full range of America's biological diversity? Ecological Applications **4:**999–1007.

Shoo LP, Storlie C, Vanderwal J, Little J, Williams SE. 2011. Targeted protection and restoration in conserve tropical biodiversity in a warming world. Global Change Biology **17:**186–193.

Sutcliffe PR, Klein CJ, Pitcher C, Possingham HP. 2015. Using abiotic surrogates to prioritize sites that effectively conserve marine biodiversity. Conservation Biology **29:**657–667.

TNC (The Nature Conservancy). 1982. Natural heritage program operations manual. The Nature Conservancy, Arlington, Virginia.

Wessels KJ, Freitag S, van Jaarseld AS. 1999. The use of land facets as biodiversity surrogates during reserve selection at a local scale. Biological Conservation **89:**21–28.