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Opinion

The Precision Problem in Conservation and Restoration

J. Kevin Hiers,[1,*] Stephen T. Jackson,[2,3] Richard J. Hobbs,[4] Emily S. Bernhardt,[5] and Leonie E. Valentine[4]

Within the varied contexts of environmental policy, conservation of imperilled species populations, and restoration of damaged habitats, an emphasis on idealized optimal conditions has led to increasingly specific targets for management. Overly-precise conservation targets can reduce habitat variability at multiple scales, with unintended consequences for future ecological resilience. We describe this dilemma in the context of endangered species management, stream restoration, and climate-change adaptation. Inappropriate application of conservation targets can be expensive, with marginal conservation benefit. Reduced habitat variability can limit options for managers trying to balance competing objectives with limited resources. Conservation policies should embrace habitat variability, expand decision-space appropriately, and support adaptation to local circumstances to increase ecological resilience in a rapidly changing world.

Trends

Inappropriately and unjustifiably precise management prescriptions are leading to unintended negative conservation outcomes.

Overemphasis on precision and specificity in management planning and policy – 'precisionism' – is also homogenizing conservation habitats and landscapes, as planners and policymakers strive to achieve 'optimal' target conditions at the expense of variation.

Variation in ecosystems and species habitat usage provide managers with crucial options for balancing often conflicting management directives and responding to local management constraints.

Managing for variation maintains options for responding to future climate change while making better use of limited resources in the present.

Can Precision Be a Prescription for Failure?

Ecological restoration and conservation are beset by an increasingly important paradox: narrowly defined restoration or conservation targets, intended to ensure successful outcomes, often lead to misdirected efforts and even outright failures. As an example, the red-cockaded woodpecker (RCW; *Picoides borealis*) inhabits fire-maintained pine forests of the southeastern USA, and is endangered owing to widespread habitat loss and conversion; currently, less than 3% of its original preferred habitat, *Pinus palustris* forest, remains intact [1,2]. Its plight was exacerbated by removal or mortality of old growth, cavity-bearing trees, which are preferred for roosting and nesting, and by fire suppression, which leads to a dense hardwood subcanopy that is unfavorable for foraging [3]. Habitat management under the Endangered Species Act was initially based on a narrow definition of target-habitat characteristics [4,5], which excluded significant existing habitat that is entirely suitable from the bird's perspective [6]. Conservation planning based on this narrow target continues to drive management for habitat properties that are more restrictive–and often more costly–than required to support healthy populations (Figure 1).

A second example arises in a completely different set of systems and scales. River restoration projects across widely-divergent ecosystem types are converging upon a narrow range of outcomes that interfere with underlying conservation goals [7] (Figure 2). A dominant approach used for river restoration throughout the developed world is natural channel design (NCD), a process used to engineer the dimension, form, and profile of degraded river habitats to achieve particular channel shapes, sinuosity, and stability [8]. NCD projects involve extensive–and expensive–earth-moving to reshape channels and reconnect rivers with their riparian areas [9,10]. Management agencies often pose strict controls over the success criteria and metrics by which such projects are judged. The tendency to construct single-thread, sinuous channels in nearly every landscape, regardless of the conditions of less-degraded rivers nearby, has been blamed for several outright management failures [7,11,12].

[1]Wildland Fire Science Program, Tall Timbers Research Station, Tallahassee, FL 32312, USA
[2]Department of the Interior Southwest Climate Science Center, US Geological Survey, Tucson, AZ 85721, USA
[3]Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA
[4]School of Plant Biology, University of Western Australia, Crawley, WA 6009, Australia
[5]Biology Department, Duke University, Durham, NC 27708, USA

*Correspondence: jkhiers@ttrs.org (J.K. Hiers).

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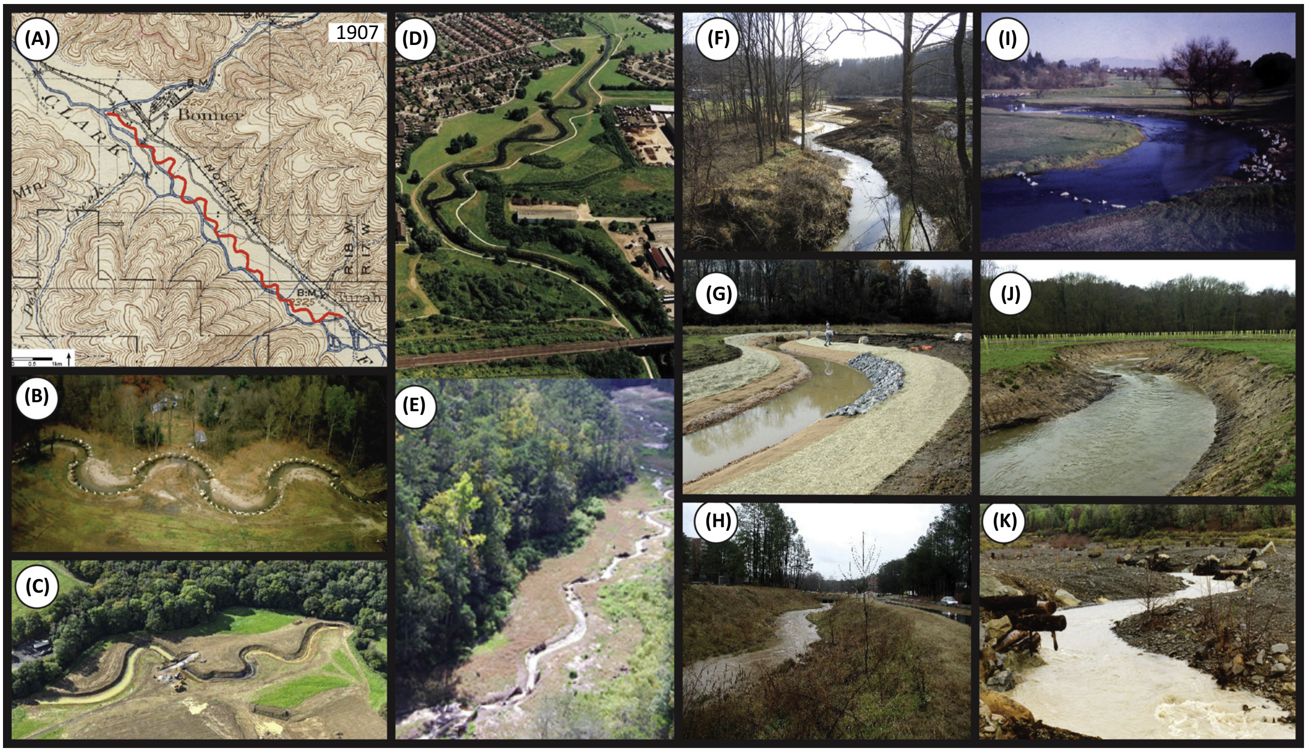
Figure 1. The Target Habitat Characteristics of Suitable Long-leaf Pine Habitat. (A) for the red-cockaded woodpecker (B) may be overly narrow in southeastern USA. The current prescribed regime of frequent burning in *Banksia* woodlands (C) reduces food availability for the Carnaby's cockatoo (D) in southwestern Australia. Photos by J. Ariail, K. Rose, L. Valentine.

These examples represent a widespread but little-recognized problem in which overly-precise policies and planning may interfere with conservation goals and desired outcomes (Table S1 in the supplemental information online). The problem arises in multiple contexts, including endangered species protection, habitat restoration, and climate-change adaptation. We discuss here why application of overly-precise targets may be attractive to scientists, managers, and policymakers, present diverse examples illustrating how precision can lead to adverse conservation consequences, and argue that more flexible and decentralized approaches may result in more effective management in a changing environment.

Precisionism and the Allure of Certainty

Expectations of precision are widely and deeply rooted in conservation culture, in the underlying scientific disciplines, in the public and private organizations charged with management, and in the broader regional, national, and global polities within which conservation takes place. We suggest that these expectations may arise from a narrow empirical foundation (whereby policy targets are based on incomplete and sometimes idiosyncratic empirical data) which may contribute to a collective culture of ‘precisionism’ (note, not to be confused with the 20th Century art movement of the same name) in which outcome precision represents a hidden and unquestioned assumption in conservation and restoration efforts. Problems are particularly acute when overly-precise prescriptions are established at broad policy or regulatory scales, leaving managers little discretion in interpretation and application.



Trends in Ecology & Evolution

Figure 2. The Planform and Cross-section Views of Restored Rivers Are Very Similar across Regions. Planform views of five rivers: (A) map of Clark Fork, MT, USA; (B) White Clay Creek, MD, USA; (C) Spring Meadow, UK; (D) Skerne River, UK; and (E) Kelly Branch, FL, USA, show similar sinuosity of channel shapes for natural channel design projects in very different physiographic regions. Similarly, the cross-section view of six restored rivers: (F) Little Sandy Creek, KY, USA; (G) Burd Run, PA, USA; (H) Sandy Creek, NC, USA; (I) Uvas Creek, CA, USA; (J) Spring Meadow, UK; and (K) Cuneo Creek, CA, USA, is nearly standardized across diverse regions. Photo credits as follows: (A) from [1]; (B) by Sean Smith, used by permission; (C,D,J) available for academic use from https://restorerivers.eu; (E) from http://www.nature.org, photo by Michael Hill of the Florida Fish and Wildlife Conservation Commission; (F) from http://www.bluegrassstream.com; (G) by Christopher Woltemade, used with permission; (H) by Barbara Doll, used with permission; (I,K) by Matthias Kondolf, used with permission.

The attraction of narrowly circumscribed outcomes has many sources. Conservation, restoration, and natural-resource management are applied sciences deriving from ecology, genetics, hydrology, climatology, and other sciences. Precision is generally considered a virtue and necessity in the physical and biological sciences; in their training, scientists are taught to embrace convergent solutions to problems, and to design rigorous research that will force unambiguous answers. The natural world, however, does not always accommodate this viewpoint. The ecological literature is full of cases in which theory or models that were rigorously tested in one setting were found to be lacking in another. In fact, throughout its history, ecology has been marked by a tension between a search for broadly applicable or even universal principles and a focus on the contingent and even idiosyncratic details of local populations and ecosystems [13]. At its core, our concerns about precision are twofold: (i) overly-prescriptive regulations, when applied to broad jurisdictions with limited local discretion, are leading to landscape homogenization; and (ii) local precision in planning or regulatory prescription-writing is often unjustifiably extrapolated from scientific study elsewhere, leading to wasted resources or unanticipated outcomes. Controls and dynamics of an ecological system in a particular place and time may not precisely apply at a different locale or at a different time, and scientific resources are rarely sufficient to support intensive study of a species or ecosystem in more than a few specific settings.

Furthermore, many species, particularly threatened or endangered species, live today in restricted habitats, and identification of their environmental tolerances and requirements may therefore already be artificially narrow. For instance, direct fossil evidence from a coastal cave on Kaua'i, Hawai'i, indicates that before human disturbance several passerine bird and vascular plant species that grow today only in the remote mountains of the island were growing along the coast [14]. These species have much broader habitat niches than has been assumed, and in the absence of disturbance and exploitation can occupy a much larger portion of the island [15]. In another case, crucial habitat designations and protection strategies for the Everglades snail kite (*Rostrhamus sociabilis*) were based on apparent habitat preferences for large marshlands [16]. However, during an extensive drought, the majority of birds sighted were using smaller, unprotected wetlands near urban areas, which played an important role in buffering species populations during a time of stress [17].

For simple, practical reasons, available scientific studies may systematically underestimate the range of conditions under which species populations or ecosystems can be sustained. In the case of the endangered black-capped vireo, management prescriptions based on limited scientific studies excluded or forced alteration of some of the most suitable habitats for the species [18,19]. Similarly, habitat management guidelines for the endangered golden-cheeked warbler (*Setophaga chrysoparia*) indicated that it exclusively used oak–juniper forests with high canopy cover/closure [20], but subsequent studies found that the species was successful not only across a wide range of canopy densities but also in other types of vegetation [21,22]. In these and other cases, artificial precision based on insufficient information led to management practices that worked against species conservation.

When science meets policy or practice, additional factors can narrow the focus of targets or objectives. Clear, precise, and quantifiable objectives are attractive to policymakers and managers, providing straightforward metrics to assess compliance and success. Specific goals and objectives are also a foundational principle of ecosystem management in applied ecology, creating an expectation of precision in conservation planning [23]. Guidelines that are unequivocal, easy to interpret, and uniformly applicable across diverse jurisdictions simplify management decisions and oversight, and provide bulwarks against controversy or litigation. Finally, narrowly-prescriptive guidelines resonate with cultural expectations of scientific precision and environmental stationarity.

How Narrow Targets Can Hinder Conservation

Precise conservation targets, however attractive from scientific or administrative standpoints, are often oversimplified when applied at policy or regulatory scales. They frequently fail to accommodate real-world variation and heterogeneity in the properties of species populations, habitats, and ecosystems. Targets may rely on detailed vegetation or habitat descriptions drawn from restricted sampling in a static framework. By focusing on goals that are easy to measure, overly-specific conservation targets have the potential to hinder conservation goals, and to cause net loss of suitable habitat and biological diversity by artificial homogenization of conservation areas.

Once set in place, overspecified habitat targets for endangered species can be difficult to modify. For example, management for the RCW has focused on the maintenance and restoration of longleaf pine forest with a very particular set of properties, including a narrow range of tree densities and sizes, cover of herbaceous understory, and absence of subcanopy or mid-story trees [5]. This optimal habitat structure was originally based on a 'niche gestalt' concept of exceptional habitat productivity [4]. This concept was codified into a regulatory approach called 'the matrix' that used restrictive habitat parameters from limited sites to define optimal habitat [5,24], despite some evidence of fitness under a wider range of conditions [13,25]. A detailed analysis of RCW habitat use indicates that the prescribed target habitat accounts for only a portion of the range of habitats actually used by the species (Box 1). While recent iterations of the

Box 1. Beyond the Bullseye

A non-metric multidimensional scaling analysis of ecological monitoring plots at Eglin Air Force Base (AFB), USA, (Figure I) [42] reveals that populations of the red-cockaded woodpecker (RCW) occupy habitats far outside those defined as optimal [4] or originally detailed in the recovery plan for restoration of suitable RCW habitat [5,7]. The rapid growth of the RCW population at Eglin AFB over the past decade now far exceeds legal recovery goals despite not meeting optimal habitat conditions. Simply put, the birds identify and exploit suitable habitats without reading the regulations [7]. Many populations are breeding successfully in a variety of stands well outside the optimal zone, but these sites remain targets of homogenization towards idealized optimal habitats at Eglin AFB and elsewhere. Moreover, because not all habitats within the targeted 'bullseye' are occupied, perfectly acceptable habitats (from the perspective of the RCW) are under risk of conversion to conditions that may not support RCW populations, such as clearing 'off-site' pine species in favor of young longleaf pine stands. While differences in habitat quality undoubtedly affect populations, many of the specific habitat parameters (e.g., growing-season fire, midstory oak density) not only comprise poor surrogates for RCW population success but may also compromise fitness in a variety of habitats. Habitat conversions are often accomplished through costly herbicide applications or mechanical treatments that reduce midstory stem densities [26]. In one case, midstory stems around RCW cluster sites in pocosin habitat in North Carolina were mechanically cleared to create a preferred habitat structure. Pocosin is subject to more intense fires than other longleaf pine habitats, and subsequent wildfire burned through the cluster sites killing all cavity trees owing to combustion of thinned debris and consumption of organic soil as a result of mechanical midstory thinning. Clusters on adjacent lands that received no mechanical treatment were largely unaffected. Habitat homogenization can result in inefficient use of limited conservation resources and has a potential harmful impact on other rare or threatened species that thrive on heterogeneity [62].

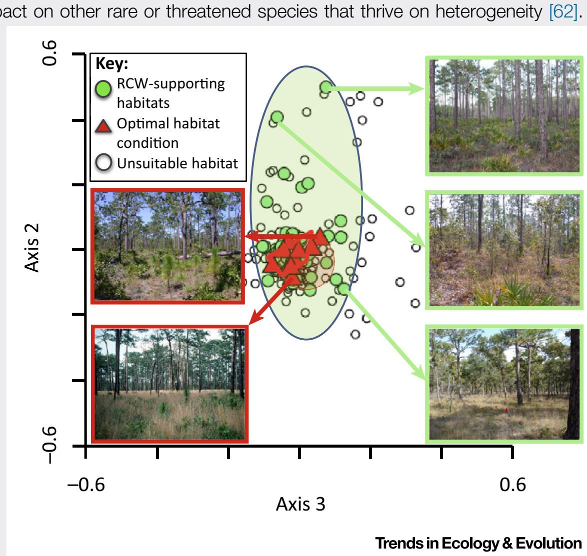


Figure I. A Non-Metric Multidimensional Scaling Analysis of Ecological Monitoring Vegetation Data at Eglin AFB (USA). Red triangles represent habitat that meets regional recovery guidelines for RCW; green circles are all habitats occupied by the RCW at Eglin AFB. Recognizing this variation in suitable habitat will be crucial for efficient management of the population. Photos by B. Herring and B. Williams.

recovery plan recognize some elements of habitat variability relative to regulatory suitability [5], managers are frequently still required to alter forests that currently support healthy RCW populations to match narrower habitat prescriptions [26].

In practice, many conservation resources are managed for multiple objectives, including societal constraints. Narrow and inflexible management prescriptions designed for one purpose can lead to habitat homogenization that compromises the outcome for other conservation objectives. For example, the endangered seed-eating Carnaby's cockatoo (*Calyptorhynchus latirostris*) relies on remnant native vegetation in southwestern Australia [27]. *Banksia* woodland in and around the Perth metropolitan area is nominally managed for multiple purposes, including cockatoo conservation. However, current management practice in the highly-flammable *Banksia* woodlands emphasizes high-frequency fire aimed at reducing fuel accumulation and minimizing risk to property [28]. These practices lead to habitat homogenization, actively eliminating older patches of *Banksia* woodland, which happen to be the most productive habitats for cockatoo foraging (Figure 1). Larger cockatoo populations could potentially be sustained in a more heterogeneous landscape, but this runs counter to current inflexible habitat-management guidelines [27]. Additional examples of homogenization resulting from narrow prescriptions intended to balance multiple objectives are plentiful. In tallgrass prairie habitats of the Great Plains (USA), patterns of treatments for fire and grazing recommended to managers, balancing the objectives of forage production and biodiversity [29], led to loss of crucial within-patch variation and declines in native bird communities despite no increase in forage production from patch homogenization [29,30].

Narrowly prescribed targets that fail to incorporate sufficient variability can also hamper adaptation to environmental change, particularly climate change (Box 2). Climate change in coming decades will inevitably force changes in local habitats, potentially shifting environmental baselines upon which current restoration projects rely. Climatic changes sufficient in magnitude to drive major physiognomic changes in vegetation are predicted to be widespread across a range of climate-change scenarios [31]. Similarly, hydrologic changes associated with climate or land-use change will fundamentally alter the timing and intensity of floods and sediment loads away from the historic levels that are used to design restoration projects [32]. Many place-based habitat-management plans will thus become anachronistic in the coming decades, and many may be rendered rapidly obsolete by short-term climate extremes and associated disturbances or transformations [32–36].

Box 2. Indeterminacy of Ecological Targets under Climate Change

Accurate characterization of targets for conservation under future climate change is hampered by several sources of indeterminacy in predicting future ecological states. The physical environment–a major source of uncertainty–comprises a multivariate point-cloud, with each point representing an individual site or locale (Figure IA). Environmental variables may be correlated within the point-cloud, but not all possible combinations of all variables are realized at any single time [63]. In the example figure, the variables are correlated in space (e.g., summer and winter temperatures) but do not necessarily change in the same direction or magnitude in time [36,63]. For a given site (e.g., point 1), the environment may vary from year to year, or over decades, within a local climate envelope (LCE) (green boundary in the figure). Conservation targets are relatively straightforward if the environment stays within the LCE. However, climate change may drive variation outside the LCE (point 2). In this case, conservation targets are more difficult, but if the future climatic state is well-characterized, and is within the range of conditions observed elsewhere in the region [i.e., within the regional climate envelope (RCE), blue boundary]–for example, at lower elevation or latitude–then a target can be identified for management and characterized by space-for-time substitution. Additional climate change along the same trajectory can move the site outside the RCE (point 3), where regional analogs are not available. Conservation targets might be drawn from environmentally analogous sites in other regions provided that the site remains within the universal climate envelope (UCE) (red boundary). Uncertainties are even greater in predicting both the environment of point 3 and the ecological states likely to result. Climate change along the same trajectory will eventually drive the site outside the UCE (point 4) (actually, the UCE itself shifts position [63]), whereupon there will be no current or historic analogs from which to predict and develop targets. Depending on the position of an individual site within realized climate space, and on the rate and directions of climate change, no-analog climates may arise rapidly (see 1' and 2' in Figure IA) according to projections for regions within the coming decades [31,39]. Even with perfect characterization of future climate states, further indeterminacies are imposed by ecological processes and by ecological legacies of climate variability at interannual to multidecadal scales [36,40]. Figure IB shows four possible trajectories of an ecological system under climate change. In scenario (i), the system state is unresponsive to climate change, allowing management for a narrowly prescribed target to be sustainable indefinitely. Under scenario (ii), the system evolves gradually in response to steady, unidirectional climate change. Provided that the environmental trajectory and the equilibrium system-response can be predicted accurately and precisely, a series of evolving targets (or a single end-state target at some arbitrary future time) can be constructed and managed. In scenario (iii), ecological stasis or equilibrium-change is punctuated by a series of events, each of which drives the system rapidly and irreversibly into a new state. Such events might include mass mortality from disturbances (fire, pest/pathogen outbreaks), which are often associated with transient climate events (e.g., extended, severe droughts), followed by expansion of other species. Periods between transformative events might be static or trendwise. Finally, scenario (iv) portrays a singular event that drives the system to an alternative, persistent end-state that contrasts strongly with plausible alternatives or predictions. This 'surprise-state' scenario might involve, for instance, a severe, widespread disturbance followed by colonization of a persistent 'ecosystem transformer' [64]. Because individual site or system might follow any number of different trajectories, unitary targets will only be useful in short-term or static situations, while greater nimbleness and adaptive capacity may be more effective for management in the long term.

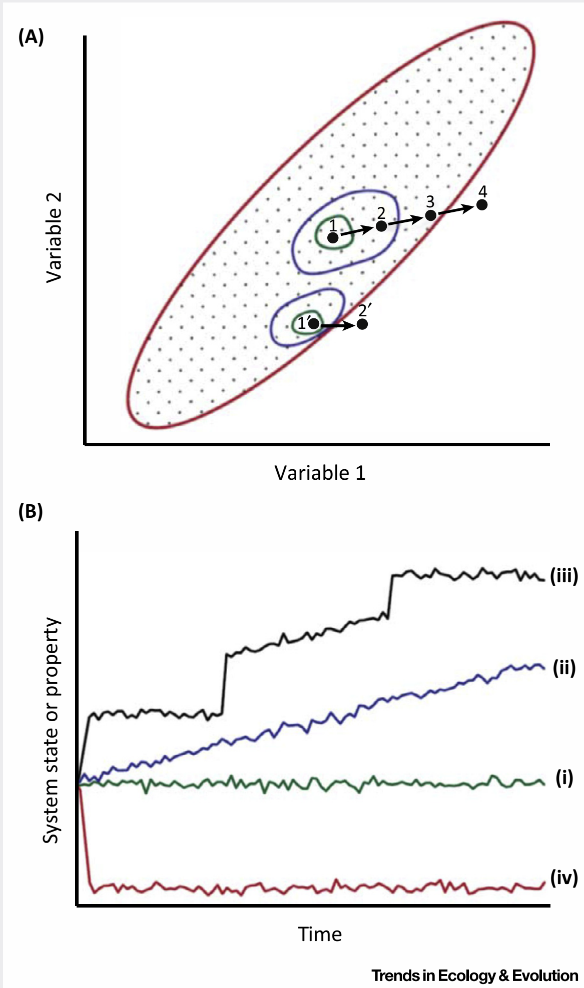


Figure I. Diagram A represents a theoretical multivariate point-cloud of the physical environment at a particular location. Green boundaries represent the current local climatic envelope; blue boundaries represent the current regional climatic envelope; red boundaries are the current universal climatic envelope. Diagram B illustrates many possible trajectories for any current ecological system under climate change, represented by four scenarios: a state unresponsive to climate change (i); one that responds gradually and directionally over time (ii); one that rapidly becomes a new irreversible ecological state in response to a series of events (iii); and one that responds as a tipping point to a single event by establishing a new persistent state (iv).

Although climate-adaptation planning is underway for many management units and regions, these efforts incur risks of overprecision in identifying future target-states. For example, niche-envelope models are increasingly applied to spatially-precise downscaling of climate-model predictions to produce fine-scale forecasts of habitat suitability for species of concern. Accuracy of forecasts does not necessarily accompany precision, however, and the limits of spatial precision and accuracy of climate downscaling in a complex terrain are not well known [37,38]. Finally, the emergence of climates lacking modern analogs [39] and the contingency of future states of vegetation structure and composition on high-frequency climate variability [36] and biotic interactions [40] will inevitably cloud understanding of future habitat states in a changing environment (Box 2). Narrow, precise targets may ultimately become dead-ends rather than paths to future sustainability.

Mimicking Nature in a Fuzzy Future

Overly-narrow policies and conservation objectives are part of a broader challenge facing conservation, which pitches traditional, relatively static, place- and species-based approaches against the increasing recognition of rapidly changing environments [41]. Conservation targets must not only be immediately effective, but they must also use available financial resources efficiently and provide flexibility as well as opportunity to bet-hedge and adapt to changing circumstances. This can be accomplished by adopting a more versatile approach to conservation that focuses on protection and restoration of heterogeneity and variability in ecological conditions [29,30] rather than maintenance of static endpoints (Box 2). While crucial features of ecosystem management such as monitoring, expecting the unexpected, and adaptive management [23] can aid in addressing the precision problem, our perspective contrasts with the current ecosystem-management application of sustainability principles to set conservation objectives. We assert that ecosystems, their underlying processes, and their constituent species may lack discretely defined management endpoints whose full range of variability can be characterized into precise management objectives–ecosystems represent a suite of moving targets. Sustainable conservation policy and practice must accommodate a wider array of current habitat variability, future outcomes, and end-states that are compatible with core goals of fostering populations of threatened species [42] and maintaining crucial ecosystem services [43]. Substitution of 'open-ended' restoration or habitat creation for particular, discrete end-states is under discussion for some systems: the idea is to reinstate ecological processes and allow ecosystems to develop on their own [44,45], as they have in the past [35]. Because variation within ecosystems will lead to innumerable potential outcomes, managing for variation is crucial for defining a new realm of the 'ecologically possible' without investing in artificial certainty of deterministic outcomes [42,46].

While some species are undoubtedly restricted in their habitat requirements, others appear to be less demanding than supposed. Threatened species may adapt to changing environmental conditions in unexpected ways. For instance, the Florida scrub jay has recently been shown to use regenerating pastures as supplemental habitat [47], and *Pinus radiata* plantations in New Zealand have been adopted by native forest beetles in the recent absence of native forests [48]. Indeed, Carnaby's cockatoo utilizes exotic *Pinus* plantations as a seed resource [49], and snail kites forage on exotic snails [50] while benefiting from perches provided by exotic trees and shrubs [51]. Historically, many crucial habitats are relatively young [35], indicating that many species have broader tolerances than might be apparent today [52]. Given that species distributions have changed in the past and are being altered in the present as a result of climate change [53], it is crucial to move beyond protection and restoration of historic habitats to consider the broader arrays of environments in which species of concern can be maintained [35,52]. Our proposal builds on existing discussions [54–57], but it goes further to embrace and leverage spatial heterogeneity, environmental variability, and ecological processes simultaneously at policy and project scales.

Current practices in conservation policy and regulatory management may be poorly matched with the ecological complexity of the natural systems those practices aspire to conserve. Broadly applied regulatory prescriptions are likely to result in simplified ecosystems and landscapes–the opposite of what is required for maintaining management options and preparing for an increasingly uncertain future [58]. A careful balance is required between developing conservation and management policies that assist in conserving threatened species, habitats, and ecosystems, while at the same time maintaining and promoting variability of natural systems.

Although expanding conservation goals to encompass a more pluralistic management approach may appear unduly complicated [55,56], it can actually make management easier by reducing unnecessary intervention. For the redcockaded woodpeckerRCW, an approach

Outstanding Questions

Will increasingly novel assemblages and ecosystem processes drive changes in policy and planning directives that embrace heterogeneity in conservation?

How can managers use variation in species habitat preferences and ecosystems to build a more resilient future for conservation of biodiversity?

How can variation and heterogeneity be incorporated into planning and policy to meaningfully protect biodiversity, in particular rare species, in a rapidly changing landscape?

Will the increasing management costs of maintaining static or 'optimal' conservation outcomes lead to an effective reduction in land area managed for conservation?

As specific targets for management become more difficult to achieve through invasive species, climate change, mega-disturbances, sea-level rise, or other perturbations, what tools can be developed for planners to adjust expectations and measure restoration success?

Are monitoring programs sufficiently robust to track local changes in composition and ecosystem function to allow managers and planners to document the realm of the 'possible' in a dynamic and uncertain future?

that recognizes options outside the putative optimal habitat (Box 1) reduces the need for habitat manipulation, while at the same time addressing other conservation objectives [26]. Similarly for Carnaby's cockatoo, moving from a uniform short-rotation fire regime to a more zoned approach may better serve the needs of property protection while also leading to longer unburnt habitat with more seed resources for cockatoos [27]. In river restoration, the adoption of a more pluralistic approach is likely to lessen the need for expensive engineering options and ongoing maintenance of engineered structures. Broadened targets can thus help managers make the best use of their resources: rather than being boxed into a single outcome, they can balance multiple costs and benefits. In view of the large uncertainties of climate change and ecological responses, managing for variability will impart resilience–species populations may be differentially buffered across habitat properties. Furthermore, careful study of how climate events affect species populations in different habitat settings provides opportunities for adaptive management (Box 2).

A high proportion of endangered species are now recognized as ‘conservation-reliant’–in other words, maintenance of viable populations of these species requires ongoing, species-specific intervention [59]. Similarly, many restored habitats require continual and costly efforts to maintain their permitted or regulated physical state, while little is invested in evaluating whether such efforts are achieving stated ecological goals [9,60]. As habitat loss and fragmentation continue, new stresses imposed by climate change are likely to increase the number of conservation-reliant species and habitats. Financial and human resources for conservation are already limited, and are unlikely to keep pace with increasing demands in the coming years. Thus, it is crucially important to use resources efficiently, ensuring that only essential interventions are carried out and that they are maximally effective.

Aligning conservation practice with the complexity of the natural world poses many challenges. The push to obtain legal protection for a species or an ecosystem often leads to regulatory overprescription for its management. Any attempt to broaden a definition may be perceived as a weakening of regulations, and thus a as threat rather than an opportunity to adapt and incorporate new information. Strengthening protections is sometimes equated with increasingly narrow standards. Certainly, broader targets grant broader decision-space for managers, with potential for such expedient considerations as cost to weigh in, at least locally. Thus, dampening precisionism in prescription development may lead to increased tailoring of management options at the local scale through the flexibility of managers to balance competing objectives at those scales. Obviously, regional or landscape perspectives are necessary to ensure a balanced and resilient network of suitable habitats [61]. Although unitary or overly-narrow targets make it easier to formulate and enforce policy decisions, a more nuanced and ecumenical approach maps better onto the natural world, and is likely to yield greater conservation success ultimately at lower cost.

Recent work has focused on using spatial and temporal variation within the full range of ecological systems to delimit the domain of possible outcomes for conservation management over time [35,42,58]. One such approach, the dynamic reference concept [42], is organized around the principle that current targets of ecosystem management and restoration are more dynamic than has been generally assumed, and their response to suites of changes over time will dictate the pace and direction of potential trajectories. An approach of this type, by focusing on the variation of ecosystem responses rather than on the idealized or mean condition (i.e., precisionism), can provide a robust context to understand and yield desirable and realistic conservation outcomes in a rapidly changing future. This approach builds on the conceptual foundations of ecosystem management [23], but emphasizes variability and flexible response to change as paramount elements in conservation efforts. This dynamic approach to conservation management fundamentally contrasts with umbrella-species approaches to conservation: in novel environments and future contexts, the habitat relations of umbrella species, indicator species, and indeed all other species, are likely to change, exactly as they have in the past [35,40,62].

In summary, accumulating scientific understanding of species biology, ecosystem processes, and environmental history indicates that the world is more complex than our conservation policies or management recommendations often assume. This mismatch between reality and policy is leading to wasted resources, misguided efforts, and potential failures in our efforts to conserve and restore nature, and these will only become more prevalent in the face of ongoing climate change. Managers have limited discretion to work within more realistic frameworks. The broader policy frameworks need to evolve to allow more rapid adaptation to changing circumstances and quicker adoption of better information as it becomes available (see Outstanding Questions). This evolution will require continual rethinking and dialogue among scientists, conservationists, managers, policymakers, legislators, and lawyers. These dialogues must take place at many levels, employing approaches (e.g., scenario planning, decision analysis) that foster effective communication and ensure that participants step outside the prison of precisionism to see the broader possibilities that may lie beyond.

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Supplemental Information

Supplemental information related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tree.2016.08.001.

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