Conservation Beyond Crisis Management: A Reverse-Matrix Model

A Discussion Paper for the Canadian BEACONs Project

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In many regions of the world, failure to plan effectively for conservation of biological diversity has led to irretrievable losses of ecosystem structure and function or, at least, a need for expensive and risky restoration efforts. In relatively intact systems, planning pro-actively for biological conservation requires a systems approach that integrates the fields of conservation biology and resource management. We evaluate current conservation paradigms and describe an alternative, reverse-matrix model for regional conservation that exploits the strengths of systematic conservation planning and adaptive resource management. We explore application of this model for boreal regions of Canada, where opportunities for large-scale conservation are virtually unparalleled.

Introduction

Challenges to conservation of biological diversity are immense. Increasing globalization of markets, in combination with policies that promote unlimited economic growth, threatens to produce an international tragedy of the commons (*1*). History reveals repeated failures to prevent overexploitation of resources (*2*), and dire predictions of species loss and ecosystem collapse have resulted in a triage strategy that channels conservation resources to biological hotspots and imperiled species. Conservation biology emerged as a crisis discipline, focused largely on emergencies. While necessary, these reactive efforts are not sufficient. Conservation in many regions of the world will not be well served, nor the concept of ecological sustainability realized, without fundamental changes in society's response to these problems. Pro-active conservation planning must bridge the chasm between biological conservation and resource management and apply a systems approach that addresses the complexity and uncertainty inherent to both fields. Here, we present a reverse-matrix model for landscape planning. We first review the theoretical and empirical foundations for establishing conservation targets. We then describe evolving concepts of the landscape matrix and propose an integrated approach to pro-active planning. Finally, we explore application of this approach in boreal regions of Canada, which contain significant portions of the world's remaining intact forests (*3*).

Our premise is that the ultimate goal of conservation planning is to identify human activities that are compatible with maintenance of biological diversity and ecological integrity. Four objectives for regional conservation have been identified (*4*), which are particularly appropriate for large, wild regions such as Canada's boreal forest: 1) represent, in a system of protected areas, all native ecosystem types and seral stages across their natural range of variation; 2) maintain viable populations of all native species in natural patterns of abundance and distribution; 3) maintain ecological and evolutionary processes, such as disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions, and 4) design and manage the system to be resilient to short-term and long-term environmental change. These serve as a guide for evaluating conservation targets, i.e., the amount of a feature or proportion of a region devoted to conservation.

Establishing Conservation Targets

Protected areas are considered the cornerstone of conservation. In many instances they bear the full burden of achieving conservation goals. Perhaps the most widely cited target for protected areas is the 12% recommended (albeit indirectly) by the Brundtland Commission *(5)*. This global target was not based on science and was ad hoc with respect to explicit conservation objectives, yet it has been uncritically adopted by many political jurisdictions and conservation organizations. From an ecological perspective, the 12% target is grossly inadequate (6,*7*,*8*), with predictions that 50% of all species would be committed to extinction if conservation lands were restricted to this level (9). This raises the question "how much is enough?"

Approaches to reserve selection and design in the 1970s through 1990s were based largely on island biogeographic theory (*10*). Rates of faunal collapse derived from species-area relationships were used to estimate the size of reserves required to maintain species over time. The use of focal species as surrogates to evaluate broader conservation requirements has expanded from estimating minimum viable areas based on extrapolation of generic home range requirements, through complex, data-intensive population viability analyses, and more recently, the exploration of ecological thresholds. The choice of focal species is contentious, and resultant conservation targets vary considerably. A coarser use of the surrogate concept is the representation approach to reserve selection, where goals for inclusion of all features in reserve networks are identified. Sophisticated analytical procedures for optimizing site selection based on quantitative criteria have been developed (*11*), but decisions concerning the adequacy of representation remain largely subjective.

Most recently, multi-criteria approaches (protection of special elements, representation of environmental variation, and meeting focal species requirements) have been used to assess the adequacy of existing and alternate reserve systems for attaining conservation goals (*12*). Such analyses permit evaluation of the relative contribution of different criteria to reserve designs. Nevertheless, although considerable attention has been devoted to addressing the first two objectives of regional conservation - representing environmental variation and maintaining viable populations - the requirements for maintenance of ecological and evolutionary processes, and system resilience, have been neglected. The concept of minimum dynamic areas: reserves large enough to incorporate a natural disturbance regime and maintain internal recolonisation sources, was advanced over 25 years ago (*13*), yet few empirical evaluations have been conducted. Similarly, consideration of hydrological connectivity in the design and management of reserves (*14*) requires broader thinking. Area-based approaches alone will fail to capture aspects of the flow regime responsible for habitat creation and maintenance (*15*).

Irrespective of the approach, establishment of conservation targets is plagued by uncertainty. The choice of planning objectives, surrogates, representation criteria, planning units, and spatial extent of analyses all influence the resultant target levels. Failure to incorporate stochastic factors results in underestimates of the area or proportion of a planning region required to achieve goals. Similarly, the determination of thresholds in non-equilibrium systems is confounded by time lags in response, again arguing for conservative (i.e., large) estimates of requirements. However, despite variation in conservation targets in the literature, it is clear that large areas, accounting for a significant proportion of regions, will need to be managed with biological conservation as a priority in order to achieve conservation goals. Estimates of individual reserve requirements for mammal assemblages range from ~5 000 km^2 to > 20 000 km^2 (*16*,*7*); the largest of which is still insufficient to ensure hydrological connectivity and biological integrity if considered in isolation (*14*). The frequency distribution of percentage estimates is bimodal (Figure 1). Estimates in the lower range generally reflect less ambitious goals, such as the representation of a single occurrence of an element within a region, whereas the upper range reflects broader conservation goals. The median lies above 50%, even though large-scale ecological processes and uncertainty have not been considered, except qualitatively in some cases. Clearly, targets necessary to meet conservation objectives far exceed levels considered in most

Clearly, targets necessary to meet conservation objectives far exceed levels considered in most politically-determined conservation plans. However, the domination of policy discussions by un-

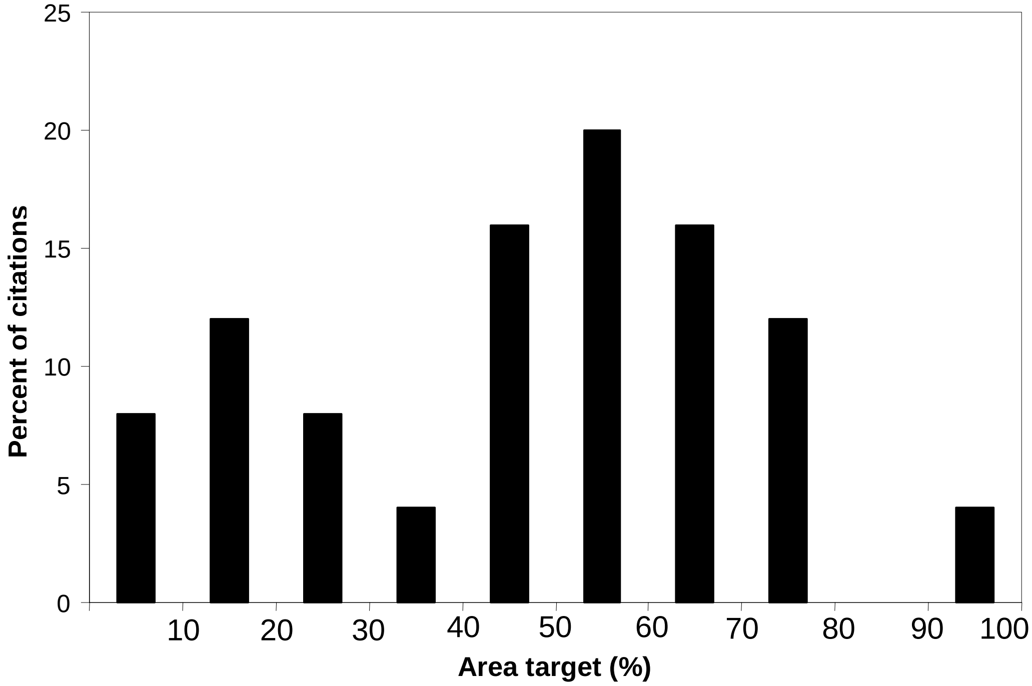

Figure 1. Frequency distribution of percentage-based area targets (N=24) from quantitative conservation assessments (*4*,*7*,*12*,*35*-*49*).

substantiated minimum targets has contributed to complacency that is reflected in societal perceptions of what constitutes adequate conservation. Minimum targets have a tendency to become political ceilings. Conservation science should make the assumptions, tradeoffs, and risks associated with different target levels explicit. Severe reductions in natural capital (e.g., ecosystem types or extents) cannot be absorbed without a loss of species and reduction in ecological services.

Evolving Concepts of the Landscape Matrix

The realization that current and prospective reserve systems, by themselves, are unlikely to achieve conservation goals has resulted in an increased focus on the conservation potential of "the matrix." In conservation biology, following the paradigm of island biogeography where islands of habitat are embedded in a sea of non-habitat, the matrix has typically been construed as the area outside of reserves, having little conservation value. Hence the classic conceptual framework for conservation emphasizing the identification of core areas connected by corridors, in isolation from the surrounding landscape. Nevertheless, even in highly modified landscapes, careful management of the matrix can increase the efficacy of conservation. Four major contributions of the matrix to conservation goals have been identified (*17*): 1) supporting populations of species, 2) regulating the movement of organisms, 3) buffering sensitive areas and reserves, and 4) maintaining the integrity of aquatic systems. Identifying matrix conditions that fulfill these roles is a research priority. However, in relatively intact systems, this strategy must move beyond efforts to mitigate the negative effects of human activities to a more pro-active approach.

In stark contrast to the notion of the matrix as an inhospitable environment, or one from which conservation values must be salvaged, the matrix is formally defined as the environment or surrounding substance within which something else originates, develops, or is contained (*18*) [from Latin *mãtrix*, womb, derived from *mãter*, mother]. We suggest that a fundamental tenet of pro-active conservation planning should be the use of the term matrix in this sense, consistent with a shift in the way landscapes are viewed. We forward this as a *reverse-matrix model* for conservation planning. Here, the paradigm of reserves as nodes within a largely degraded environment is inverted (*19*), such that conservation lands are the supportive matrix within which development activities are carefully managed so as not to erode other values. More intensive activities would occur on "islands" within the sea of conservation land. The high degree of uncertainty associated with both the establishment of conservation targets and the management of human activities is explicitly recognized, and a process implemented that minimizes the risk of unintended ecological outcomes, while acknowledging societal requirements for sustainable resource use. Within this framework, the same level of attention and sophistication applied to the design of conservation reserves is applied to identifying where, when, and how development activities occur.

Systematic Conservation Planning and Adaptive Resource Management

Attaining conservation goals requires a systems approach that considers both protected areas and those allocated for production of commodities. However, the sciences of conservation planning and resource management have evolved in relative isolation, and agencies charged with the establishment and management of protected areas often are separate from those responsible for management of natural resources. Fractured institutional arrangements reflect inconsistent government policies.

Combining the strengths of systematic planning for reserves (*20*) with the systematic process of adaptive resource management (*21*), offers a powerful mechanism for achieving integrated conservation planning over large regions. Within this conceptual framework, conservation reserves are designed not only to achieve established regional conservation goals, but also to serve as ecological benchmarks for management experiments (*22*, *23*). The uncertainty inherent to the establishment of reserves and implementation of management is acknowledged and addressed by design: from generation of hypotheses about ecological processes and system response, through monitoring of outcomes. In a science-based, pro-active approach to conservation planning, ecological reserves should be the *quid pro quo* of development activities.

The intent of proposing a reverse-matrix model is to promote a paradigm shift. Based on the precautionary principle, human activities are regulated in ways that permit identification of ecologically sustainable practices. Successful implementation requires that conservation goals are not perceived to inhibit activities unnecessarily. Thus, conservation planning should minimize, to the extent possible, the opportunity cost of sustainable resource use. Methods for developing effective strategies subject to these conditions exist, including the identification of appropriate policies given objectives and constraints (*24*). These approaches are derived from economic theory, and have not yet been widely applied spatially or in the ecological sciences.

We have proposed that the reverse-matrix model has substantial conceptual advantages, but can it be applied? We explore this in a case study of pro-active conservation planning for Canada's boreal regions.

Pro-active Conservation Planning for Canada's Boreal Forests

The circumpolar boreal forest is the most extensive terrestrial ecosystem on earth. Canada's boreal regions contain approximately one third of the world's boreal forest, and one quarter of all intact forest remaining globally (*3*). They support over one-third of the breeding populations of North American migratory land birds (*25*), a significant proportion of the continental breeding grounds for migratory waterfowl, and intact predator/prey assemblages that include the largest caribou herds in the world. Range contractions of many North American carnivores and ungulates highlight the increasing contribution of Canada's boreal regions to the persistence of these species (*26*). These forests are thus of international significance, with substantial potential for conservation.

To date, approximately 30% of Canada's boreal forests, which are comprised almost entirely of public lands, have been allocated for development. Historically, clearing for agriculture and hard-rock mining were the dominant land-uses. Forestry is currently the most widespread development activity, and whereas the majority of forestry tenures are recent, the rate and extent of development are unprecedented. Twenty forestry tenures in boreal Canada exceed 10,000 km^2 in size (*27*), the largest of which (> 91,000 km^2) surpasses the size of > 40% of all recognized nations (*28*). In western Canada, globally significant oil and gas reserves underlay substantial portions of the boreal forest, and major hydro-electric developments have occurred in eastern regions. To date, most development activities have been concentrated in southern portions of the boreal; however, interests are turning north to the rich mineral deposits, oil and gas reserves, and untapped waterways. The heated debate over construction of a major new pipeline across northern Canada to link oil and gas reserves in Alaska to markets in the south underscores the international context of development.

The consequences of not engaging in pro-active conservation planning are predictable. Perceived constraints on conservation opportunities are already apparent where large forest tenures, and associated timber supply, were predicated on calculations of maximum sustained yields for one class of resource values, without due consideration of natural disturbance events, such as stand-replacing fire. Similarly, the cumulative impacts of multiple resource extraction activities were given little consideration in the assignment of mineral leases. Nevertheless, substantial opportunities still exist on a scale that is unmatched globally. Canada has a unique opportunity to provide global leadership in conservation and ecological sustainability by adopting a reverse-matrix model.

Acknowledgement of uncertainty is a key step in the process of adaptive management. Boreal ecosystems are inherently dynamic, characterized by large to medium-scale natural disturbances such as fire, insect outbreaks, severe windstorms, and floods. The stochastic nature of these processes increases the uncertainty and risk associated with management actions. Effects of global climate change also are predicted to be severe in the northern hemisphere (*29*). Uncertainties regarding the effects of human activities on natural systems include: 1) direct and indirect effects of resource exploitation on target and non-target species, 2) alteration of key ecological processes, and 3) changes in ecosystem services. Reducing these uncertainties requires that control areas be established that are sufficiently large to permit monitoring of indicators at an ecosystem scale. In boreal systems, consideration of natural disturbance and hydrological regimes provides a basis for evaluating the necessary spatial extent for such ecological benchmarks. Such areas could anchor a reserve network, but in isolation do not represent a comprehensive reserve system, as the goals of regional conservation involve a broader set of objectives.

The first steps in both systematic reserve design and adaptive resource management are to assemble existing data and evaluate the probable outcome of alternative scenarios. Conducting such evaluations for the Canadian boreal requires stratification into smaller land units, given the variation in disturbance regimes, species distributions, land-use history, and management issues across Canada. Assessment units should be delineated by natural processes and features rather than political jurisdictions. The hierarchical mapping system applied by the Canadian Ecological Land Classification provides one possible foundation for this approach. Within each assessment unit, information must then be synthesized into models that predict the outcomes of alternative scenarios relative to explicit conservation and management goals. This process also identifies the key uncertainties that hinder selection among strategies. Changing demands for commodities introduces additional social and political uncertainty *(30)*, but the pro-active approach described here provides a basis for informed decision-making in the face of new economic opportunities. Choosing between alternatives involves implicit or explicit statements regarding acceptable levels of risk relative to stated goals; these are determined by societal values, not science.

Simultaneous assessment of conservation and resource values serves two important roles. First, it identifies irreplaceable elements of a reserve network that represent off-limit areas with respect to proposed developments and suggests priorities for conservation in sites requiring strict protection. Second, it permits evaluation of the substitutability of areas, such that the economic costs of conservation are minimized where possible. For significant portions of Canada, basic ecological data are extremely sparse, underscoring the need for a precautionary approach. Nevertheless, rapid assessment of potential benchmark areas in each assessment unit across boreal Canada is urgently needed, as these are the foundation for integrated conservation planning. Management strategies are then evaluated relative to risk and reduction of uncertainty. Critical to this process are the identification of key indicators of management success, monitoring the indicators in both benchmark and experimental areas, and a protocol to modify management and conservation strategies where necessary.

Major barriers to adaptive management arise when there is limited resilience in the ecological components of the system under study, or when institutions lack flexibility due to entrenched power relationships among stakeholders (*31*). The large spatial extent, relatively pristine condition, and inherently dynamic nature of boreal ecosystems in Canada suggest that ecological resilience, at present, is not limited. Substantial changes are presently occurring in institutional arrangements and power structures throughout northern Canada, in conjunction with settlement of First Nations land claims and the devolution of federal responsibilities. Concomitant with these changes are significant shifts in authority over resources. In southern boreal regions of Canada, commitments to adaptive management by most government agencies and resource industries already exist. The time is thus ripe for the development of institutions to advance adaptive management in the context of integrated conservation planning, through application of a reverse-matrix model.

Tangible examples of the feasibility of this approach exist in Canada. Representatives from major resource industries, environmental organizations, and First Nations recently endorsed a Boreal Conservation Framework (*32*). It promotes maintenance of all the ecological and cultural values of the region through at least 50% protection of the boreal in a system of large reserves, in conjunction with leading-edge sustainable management and stewardship practices. The Deh-Cho of the Northwest Territories and the Innu of Labrador, partners to the Framework, have designated areas approaching 60% of their traditional lands for protection, and are undertaking comprehensive land-use planning to identify ecologically sustainable development activities. A consortium of First Nations has proposed a World Heritage Site straddling the Manitoba/Ontario border, as part of a conservation accord signed by the groups to facilitate land-use stewardship throughout the region. These are significant examples of the potential for application of a reverse-matrix model over an immense area. Greater than 50% of the intact forests in Canada occur within settled land claims, with additional amounts in areas under negotiation (*33*). Establishment of cooperative agreements among industry and environmental leaders provides further impetus for institutional reform to address existing resource tenures.

Conclusion

If commitments to sustainable development and conservation of biodiversity are to be anything more than paper promises, conservation science must move beyond crisis management, and conservation planning must strive for something more meaningful than politically expedient targets. Given uncertainty associated with management, a credible, science-based approach integrates the disciplines of resource management and conservation planning through the identification of ecological benchmarks against which human activities are evaluated. Application of a reverse-matrix model facilitates pro-active planning in relatively intact systems by emphasizing the matrix as the supportive environment in which limited development occurs. Activities compatible with ecological sustainability are identified through an adaptive management framework applied to integrated conservation planning regions. Substantial opportunities for implementation of this approach remain in boreal regions of Canada. Moreover, the conceptual foundation has broad applicability in the design of ecological networks to facilitate biodiversity conservation and sustainable use (e.g., *34*).

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