Evaluating the Effectiveness of Representation as a Criterion for Selecting Conservation Areas

A Discussion Paper for the Canadian BEACONs Project

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The concept of representation has been applied widely to determine where conservation reserves should be established and how large the conservation reserves should be. The representation approach aims to maintain functioning examples of ecosystems, landforms, communities, populations, and species in perpetuity. Representation targets that are based on science rather than socio-political criteria provide a greater likelihood of meeting the ecological objectives of a conservation plan or reserve design. A clear conservation objective combined with ecologically relevant representation targets can lead to appropriate selection units and a framework for selecting the optimal location for new reserves. Representation alone does not address the longer-term persistence of species or communities, nor does representation ensure that a system is ecologically resilient. However, ecologically relevant representation targets and selection units enable conservation planners to run computer simulation programs and compare scenarios in an Adaptive Management framework. This process enables development of conservation networks that provide true controls to the management experiments of society.

Introduction

A protected area is any area of land or water that has been designated under legislative or other means to be managed primarily for the protection of ecological integrity and associated cultural values (Canadian Boreal Initiative 2005). Here, we consider protected area, conservation area, ecological reserve, and similar terms as equivalent. A conservation network or system of reserves is a collection of protected areas embedded in a landscape of relatively unrestricted human activity. One function of a conservation network is to represent characteristic natural features such as indigenous species, unmanaged landscapes, or ecological processes that have been lost or that are not expected to persist in the managed landscape. The specific features to be represented depend on conservation objectives that should have been established from the outset (Cabeza and Moilanen 2001; Redford et al. 2003) or, more commonly, after land conversion has already advanced. A common objective of conservation plans is to maintain biological diversity that includes the variety and variability of living organisms and the interactions among species and the environment (Margules et al. 1988; Noss 1999; Gaston et al. 2002; Reyers et al. 2002; Pressey et al. 2003; Redford et al. 2003).

In this paper, we evaluate how representation has been defined and applied to reserve selection and conservation planning. We examine ways that representation targets have been set for conservation objectives, how spatial units for representation have been selected, and discuss the appropriate use of representation targets and spatial units for representation in the boreal forest. We conclude by providing future direction for BEACONs work on representation and spatial units for representation.

Representation Targets

The units of representation are the specific features included in a conservation network. We define representation targets as

the proportion (for areas) or level (for populations) of a feature in the landscape deemed necessary and sufficient to meet the conservation objectives.

In setting representation targets, the broad objective of "maintaining biological diversity" is too vague. A more precise objective is that a reserve system should "maintain viable populations of all native species"; however, such precise and quantifiable objectives are difficult to achieve without first collecting data. Conservation planners rarely have a full catalogue of life-history data for native species in an area. The lack of such data has led conservation planners to use representation targets as a coarse filter for conservation (Noss and Cooperrider 1994). The coarse filter assumes that protecting land features or habitats also provides protection for the species that occur in these land features or habitats. Coarse filter targets are often combined with fine filter targets for focal species and special elements in order to provide a balanced approach to conservation planning (Noss 1996).

Warman et al. (2004) found that conservation networks were highly sensitive to the representation targets, yet despite their widespread use, there have been no empirical tests of the underlying assumptions of representation targets (Noss and Cooperrider 1994).

Setting Representation Targets

Olson and Dinerstein (1998) examined the representation of terrestrial, freshwater, and marine ecosystems at a global scale based on areas with similar environments, species, and communities. These ecoregions were stratified into Major Habitat Types (MHT) based on the structural complexity of the area, the environmental conditions, and the patterns of biological complexity. Each MTH was then subdivided by biogeography to represent different continents or oceanic basins. For each representation unit, Olson and Dinerstein (1998) determined biological distinctiveness using species richness, endemism, and rarity. The measure of biological distinctiveness was then used to objectively determine which representation units warranted protection, assuming that distinctive means irreplaceable. However, distinctiveness alone is not sufficient to guide conservation efforts because it does not consider current or future threats to the representation unit. By evaluating the conservation status of each representation unit, Olson and Dinerstein (1998) provided a mechanism for setting priorities based on irreplaceability, the level of biological distinctiveness, vulnerability, the level of threat, and the ability of a representation unit to maintain species or ecological processes. Since Olson and Dinerstein's (1998) study, the approach has been used in several conservation assessments of terrestrial ecosystems (e.g., Noss et al. 2002).

Wessels et al. (1999) introduced three models for representing biodiversity using land facets: Percent Area Representation (PAR), Species Assemblage Representation (SAR), and Assemblage Diversity (AD). PAR is a reserve-selection model that requires the amount of each landscape class in the outcome to be pre-determined. SAR is a reserve-selection model that requires a predetermined number of species in the smallest number of landscape classes. AD selects areas that contain classes that are most different to maximize diversity. Wessels et al. (1999) defined land facets as "the simplest units of a landscape", and the land facets are identified by uniform slope, soils, and hydrologic conditions. Because the land facets were strongly correlated with distinct bird and dung beetle communities, Wessels et al. (1999) argued that land facets were appropriate surrogates for biodiversity at a local scale (1:50 000 to 1:100 000). The SAR approach was more efficient in terms of total area because it did not select areas without distinguishing species (Wessels et al. 1999). This result is in contrast to the PAR approach that only incorporated the occurrence of land classes in the conservation solution (Wessels et al. 1999). However, SAR assumes that land classes adequately represent all the species that occur in an area, but this may not always be true. Furthermore, the SAR approach treats species in marginal habitats or population sinks similarly to species in core areas. This means that the SAR approach may underestimate the area required for the persistence of species.

Noss et al. (2002) set representation targets for areas with distinct vegetation, climatic, or geological characteristics (e.g., soils, elevation, or topography). For biogeoclimatic variation, Noss et al. (2002) set targets of 15 – 25% by area for terrestrial, wetland, and aquatic vegetation types, and 15% by area for each of 38 geoclimatic zones (ecoregions or subunits). This application of the representation approach assumes that all described vegetation or landscape types have an intrinsic value and that the contributions of the vegetation or landscape types to regional biodiversity are equal. The assumption of equal contribution follows from the premise that a complete conservation network should contain functioning examples of every ecosystem type (Redford et al. 2003). Noss et al. (2002) did not justify the representation targets that they used, nor did they demonstrate that all the units of representation were ecologically meaningful (Gering et al. 2003).

Pressey et al. (2003) set representation targets based on scientific principles such as habitat heterogeneity, rarity, vulnerability and the original extent of land features. They assumed that areas with high habitat heterogeneity, rarity and vulnerability required larger representation targets. They further suggested that representation targets reflect the original extent, preceding intensive land use, of the land features being protected. The final representation targets of Pressey et al. (2003) were between 10% and 55% of each broad habitat unit.

Using Representation for Gap Analysis

Representation has also been used to assess the adequacy of existing reserve systems, also known as gap analysis (Margules and Pressey 2000). Pressey et al. (2000) examined the representation of 1,486 landscape types in a system of nature reserves in New South Wales, Australia. They reported that the reserve system did not satisfy an established representation target of 15% by area. Reserves were concentrated in areas with high terrain ruggedness and little potential for human land use; this characteristic of parks and protected areas is common globally. As a result, landscape types of lower elevation areas with higher economic potential were underrepresented systematically in the reserve network (Pressey et al. 2000). Pressey et al. (2000) mapped landscape types that did not have adequate representation in the existing reserve system, and this gap analysis identified candidate areas that could be added to the reserve network to improve the desired levels of representation.

Setting Appropriate Representation Targets

The preceding examples illustrate the use of representation targets as criteria for the design of new conservation networks and the testing of the adequacy of existing conservation networks. These examples illustrate key problems with analyses using representation because the level chosen for representation targets and the units of representation frequently are set arbitrarily. In the absence of a clearly established scientific basis for targets, it is difficult to evaluate the results of such studies.

Some subjectivity may be inevitable when setting objectives for conservation areas, because conservation planners want to capitalize on the rare opportunities to establish reserves. Moreover, in a world dominated by the primacy of short-term economic values and in cultures that are uncomfortable with uncertainty, conservation planners want to downplay uncertainty and portray as high a level of certainty about conservation decisions as economists portray about economic decisions. In reality, the state of human knowledge is such that there is little certainty associated with either conservation or economics. Science, when used properly, is a tool that can help deal with uncertainty because the scientific method is a framework for observing the world and assessing these observations in a way that is open, transparent, repeatable, and universal. Additionally, clearly defined, ecologically relevant conservation objectives help to set targets for representation that 1) can be applied to immediate tactical and strategic decisions in conservation network design, 2) can be replicated, 3) are based on clear hypotheses about how conservation objectives will be stratified among targets, 4) are adaptive to ecological change, and 5) can be tested experimentally or through long-term monitoring.

Margules and Pressey (2000) derived seven principles from conservation biology that should be considered when setting quantitative representation targets: 1) theory of island biogeography, 2) metapopulation dynamics, 3) source pool effects and successional pathways, 4) spatial autocorrelation, 5) source-sink dynamics, 6) habitat modification, and 7) species as evolutionary units. These seven principles should be considered when setting representation targets for conservation planning in the boreal forest. We believe that the uncertainty in representation targets should be acknowledged and that targets without a scientific basis should not be used in conservation planning.

The equilibrium theory of island biogeography suggests that systems of reserves should have as many large elements as possible, and that the distance between reserve units should be minimized. Larger reserves are expected to contain higher numbers of species and, therefore, do a better job of capturing aspects of biodiversity. This species-richness approach to reserve design has been criticized for being overly simplistic: species richness considers only the equilibrium number of species and does not consider measures of species evenness that describe how many individuals of each species are present. Moreover, the theory of island biogeography does not consider the variability in habitat requirements among species or the genetic diversity of geographically distinct populations.

Metapopulation theory describes a model of species that depend on relatively small patches of distinct habitat that are embedded within an inhospitable matrix. Metapopulation dynamics captures the periodic extirpation of local populations and subsequent repopulation through migration and dispersal from neighbouring patches. Global persistence depends on the number and size distribution of patches and on their spatial arrangement. For species that naturally occur as metapopulations, an inadequate reserve system could contain too few patches that are too small or too far apart. With a disruption in colonization, metapopulation theory predicts eventual global extinction through chance events at the patch level. On the other hand, a reserve system could induce metapopulation dynamics in species that naturally do not exhibit metapopulation dynamics if changes to the matrix restricted populations within the reserve system. Therefore, conservation targets should consider the natural spatial structure of populations. In some cases, corridors may be necessary to allow individuals to move among reserve elements.

Source pool effects and successional pathways refer to landscapes where multiple seral stages exist at different levels of succession. In these systems, natural disturbance is typically the dominant ecological process that affects species assemblages and community composition. Conservation planners should determine representation targets by sampling along the successional gradient so that entire communities or species are not extirpated in a single disturbance event. Clearly, reserve units need to be larger than the spatial extent of natural disturbances to accommodate the dynamics of the process without the reserve being homogenized periodically by natural disturbance.

The concept of spatial-autocorrelation in ecology also has implications for conservation planning. For example, it is often necessary to procure enough space for a species to complete its entire life cycle in order to maintain viable populations. Soulé and Sanjayan (1998) demonstrated that existing reserves often were inadequate to ensure the long-term viability of some endangered species. When available, demographic information, such as reproductive rates and dispersal should be used for evaluating the long-term viability of species within the conservation network (Noss et al. 2002).

Incorporating source-sink dynamics in reserve design ensures that vegetation types are maintained at levels that will sustain viable populations. Without considering source-sink dynamics, the integrity of a reserve or conservation network is questionable. For example, if a reserve system does not contain sufficient source habitat for positive net productivity and gene flow, populations may be at risk of extinction even if large quantities of sink habitat are protected.

Land modification and alienation must be considered because, even if reserves do not change, the composition of the surrounding landscape will affect the quality of the reserve. Further, global warming will influence species and communities within reserves. These indirect effects or exogenous influences, although difficult to quantify, should be considered when determining targets for representation.

Finally, Rojas (1992) argued that species be regarded as dynamic evolutionary units rather than static groupings of similar organisms. This has implications for conservation networks as reserves must support conditions favourable to continuing the process of evolution. Taxa from phylogenies that are actively radiating could be represented differently that those that are more stable.

Spatial Units of Representation

The size and geometry of representation units has implications for the composition and configuration of resulting conservation areas (Warman et al. 2004). Smaller selection units are generally more economically and computationally efficient because conservation networks built from small selection units tend to achieve representation targets with less area and with lower conservation investment (Pressey and Logan 1995; Pressey and Logan 1998). However, smaller representation units may be inefficient for capturing large-scale processes and for conducting analyses at broader spatial extents. Units with complex geometry, such as hexagons, will take longer to process than simple shapes, such as squares, when computing configuration metrics or when using boundary length modifiers in a simulation. Therefore, additional processing time is required when connectivity among selection units is an essential component of the ecological system for which a conservation network is being designed. Cadastral features such as municipalities, private lands, and proposed parks and protected areas should also be considered when defining selection units for representation. It may be useful for the size of the selection units to approximate existing management zones to facilitate implementation (Pressey and Logan 1998). Conversely, land ownership may require that the size and shape of planning units do not identify private property, legal-land tenures, or ecologically sensitive areas. For example, conservation planners may wish to include the nesting area for a rare species in the conservation network without revealing the location on a map. Further, jurisdictional boundaries rarely conform to ecologically meaningful units.

Setting Appropriate Spatial Units of Representation

Pressey and Logan (1998) describe criteria to consider when constructing selection units, including: 1) the number of units that can be processed in the required time frame, 2) the scale of underlying map features relative to the size of the selection units, 3) the precision of the underlying map features, 4) neighbourhood relationships among units or interactions among the features that the maps contain, 5) the ease of regular-shaped grids for presenting densities across large spatial extents, 6) equal area of selection units over large spatial extents where map projections are an issue, 7) reserve configuration requirements, such as corridors, 8) the suitability for land-use management, 9) whether or not the selection units are likely to change in size or shape due to ownership or tenure, 10) the suitability for conservation objectives, 11) size-related issues such as edge effects and viable populations, and 12) public perception and the sensitivity associated with drawing "lines on a map". These twelve principles should be considered when selecting the spatial units of representation for conservation planning in the boreal forest. The enormous variation in classification systems and data availability across Canada poses significant challenges.

Conclusions

All human endeavours, including the setting of economic policy or the determination of a sustainable level of timber supply, are fraught with uncertainty. Accordingly, all management activities constitute "experiments" with uncertain outcomes. If society wants to know whether these management experiments are achieving stated objectives, controls are required; that is, areas that are not manipulated through management. Well-designed conservation reserves can act as controls for the land-use experiments of society.

The concept of representation has been applied widely to determine the geographical extent and distribution of conservation reserves. Broadly construed, the representation approach aims to provide functioning examples of ecosystems, landforms, communities, species, and populations at a level based on current or historical distributions. An implicit objective is to maintain the viability of populations in perpetuity. However, surrogates used in representation analyses have rarely been evaluated.

The levels of ecological features that should be protected are referred to as representation targets. Representation targets based on scientific rather than socio-political criteria provide a greater likelihood of meeting the ecological objectives of a conservation plan or reserve design. Conservation biology principles derived from island biogeography and metapopulation theory, source pool effects, successional pathways, spatial autocorrelation, source sink dynamics, habitat modification, and species as evolutionary units should be examined when setting levels for representation of species, communities, and ecosystems (Margules and Pressey 2000).

Once objective and ecologically relevant methods to determine representation targets have been established, selection units can suggest optimal locations for new reserves. Conservation planners should consider the spatial extent, grain, and configuration of reserves because the size and shape of the selection units affects the resulting network design. Some of these factors include the number of selection units that can be handled efficiently, scale of underlying map features, precision of the underlying map features, map projections, reserve configuration requirements, suitability for land-use management and conservation, fragmentation effects as well as presentation and public perception (Pressey and Logan 1998).

Representation alone does not address the longer-term persistence of species or communities, nor does representation ensure that a system is ecologically resilient. However, ecologically relevant representation targets and selection units enable conservation planners to run computer simulation programs and compare scenarios in an Adaptive Management framework (Walters 1986). This process enables development of conservation networks that provide true controls to the management experiments of society.

Future Work

We will continue our investigation of representation targets and spatial units of representation. Environmental non-governmental organizations (e.g., World Wildlife Fund, The

Nature Conservancy) have done a considerable amount of work on these topics in North America, but much of it is found in grey literature. We will review and incorporate relevant grey literature on representation targets and spatial units of representation. We will then examine more specific questions with regards to representation, including:

1) Do published representation targets vary predictably with system attributes?
2) How does heterogeneity affect representation levels targets from a functional perspective?
3) Are enduring features good surrogates for capturing other biophysical attributes?

Analysis of available broad-scale data (e.g. species range maps, forest inventory information) provides an initial method for answering these questions. More detailed empirical case studies are needed in order to evaluate these questions at a finer resolution.

Literature Cited

Cabeza, M., and A. Moilanen. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution 16:242-248.

Canadian Boreal Initiative. 2005. The boreal in the balance: Securing the future of Canada's boreal region. Canadian Boreal Initiative, Ottawa.

Gaston, K. J., R. L. Pressey, and C. R. Margules. 2002. Persistence and vulnerability: retaining biodiversity in the landscape and in protected areas. Journal of Biosciences 27:361-384.

Gering J. C., T. O. Crist, and J. A. Veech. 2003. Additive partitioning of species diversity across multiple spatial scales: Implications for regional conservation of biodiversity. Conservation
Biology 17:488-499.

Margules, C. R., A. O. Nicholls, and R. L. Pressey. 1988. Selecting networks of reserves to maximize biological diversity. Biological Conservation 43:63-76.

Margules, C. R., and R. L. Pressey. 2000. Systematic Conservation Planning. Nature 405:243-253.

Noss, R.F. and A.Y. Cooperrider. 1994. Saving Nature's Legacy: Protecting and restoring biodiversity. Island Press, Washington D.C.

Noss, R.F. 1996. Protected areas: How much is enough? Pages 91-120 in R.G. Wright and J. Lemons, editors. National parks and protected areas: Their role in environmental protection. Blackwell Science, Cambridge.

Noss, R. F. 1999. Assessing and monitoring forest biodiversity: a suggested framework and indicators. Forest Ecology and Management 115:135-146.

Noss, R. F., C. Carroll, K. Vance-Borland, and G. Wuerthner. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. Conservation Biology 16:895-908.

Olson, D. M., and E. Dinerstein. 1998. The global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. Conservation Biology 12:502-515.

Pressey R. L., and V. S. Logan. 1998. Size of selection units for future reserves and its influence on actual vs targeted representation of features: a case study in western New South Wales. Biological Conservation 85:305-319.

Pressey R. L. and V. S. Logan. 1995. Reserve coverage and requirements in relation to partitioning and generalization of land classes: Analyses for western New South Wales. Conservation Biology 9:1506-1517.

Pressey, R. L., R. M. Cowling, and M. Rouget. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation 112:99-127.

Pressey, R. L., T. C. Hager, K. M. Ryan, J. Schwarz, S. Wall, S. Ferrier, and P. M. Creaser. 2000. Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. Biological Conservation 96:55-82.

Redford, K. H., P. Coppolillo, E. W. Sanderson, G. A. B. Da Fonseca, E. Dinerstein, C. Groves, G. Mace, S. Maginnis, R. A. Mittermeier, R. Noss, D. Olson, J. G. Robinson, A. Vedder, and M. Wright. 2003. Mapping the conservation landscape. Conservation Biology 17:116-131.

Reyers, B., D. H. K. Fairbanks, K. J. Wessels, and A. S. Van Jaarsveld. 2002. A multicriteria approach to reserve selection: addressing long-term biodiversity maintenance. Biodiversity and Conservation 11:769-793.

Rojas, M. 1992. The species problem and conservation: what are we protecting? Conservation Biology 6:170–178.

Soule, M. E., and M. A. Sanjayan. 1998. Ecology -conservation targets: do they help? Science 279:2060-2061.

Walters, Carl. 1986. Adaptive management of renewable resources. Macmillan publishing company, New York.

Warman, L. D., A.R.E. Sinclair, G.G.E. Scudder, B. Klinkenberg, and R.L. Pressey. 2004. Sensitivity of systematic reserve selection to decisions about scale, biological data, and targets: Case study from Southern British Columbia. Conservation Biology 18: 655-666.

Wessels, K. J., S. Freitag, and A. S. Van Jaarsveld. 1999. The use of land facets as biodiversity surrogates during reserve selection at a local scale. Biological Conservation 89:21-38.