Back to the Future: Designing Protected Areas Using Data on Historical Species' Distributions

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Abstract

Design protocols for protected area networks typically consider representation before persistence, largely because appropriate metrics that might ensure persistence have been lacking. Nevertheless, without prior consideration of design criteria that enable persistence, reserve networks may not conserve what is represented over the long-term. Data on historical ranges of disturbance-sensitive mammals were used to develop empirical estimates of reserve sizes that might enable persistence of mammals. With plots of those sizes, we sampled the historical ranges of mammals throughout the three mammal 'provinces' that comprise Ontario, from which we selected minimum reserve networks using both richness- and rarity-based greedy heuristic algorithms. Full representation of disturbance-sensitive mammals was achieved with three to eight reserves on 5%-40% of the landbase, depending on region, plot size and algorithm. Most present-day reserves, larger than the minimum size, are not located where they would most efficiently conserve the full complement of mammals. Our results provide guidance for siting future reserves in the boreal region and/or for rationalizing existing reserve systems that may more efficiently represent and conserve species.

Introduction

Many protocols for the design of protected areas implicitly or explicitly begin with considerations of *representation* of features to be included in a network. These may be 'enduring' physical features (often assumed to be reasonable surrogates for ecological features, such as biodiversity), and/or ecological features (i.e., species or communities themselves). Regardless, reserve design is frequently based on recent information about the distribution and abundance of physical or ecological features of natural areas (Pressey *et al.,* 1993; Possingham *et al.,* 2000). Typically, reserve selection algorithms operate with such data to select the minimum combinations of potential reserves that will maximize the representation of physical and/or ecological features. Significantly, these approaches are often applied in circumstances where landscapes are highly altered by human land-uses, and where conservation is constrained to 'saving the best of the last'; less often, data from altered portions of the landscape are not considered as potentially part of a reserve system. These approaches to reserve selection emphasize *representation* first. Unfortunately, the most sobering lesson from MacArthur and Wilson (1967), who elaborated that high rates of extinction on isolated islands might apply to habitat patches as well, is that the mere presence of features, such as species' populations, in reserves is no guarantee of their future *persistence* there.

Less frequently, issues of size, shape and connectivity may be considered to attempt to address the persistence of species. By and large, these considerations are treated after-the-fact of reserve selection based on representation. Further, persistence is generally treated inadequately, in part, because appropriate metrics for minimum reserve size and connectivity that might ensure persistence have been lacking. Nevertheless, without prior consideration of the conditions that might ensure persistence, there is considerable risk that reserve networks are assembled from protected areas that are too small and/or disconnected to conserve what is represented.

Here, we provide an update on recent research into an alternative method for selecting among potential designs for reserve networks. Our approach also emphasizes reserve selection based on representation, but under constraints considered *a priori* to better ensure persistence of species. Efforts to design reserve systems based on persistence, rather than merely presence, are beginning to emerge (Cabeza and Moilanen, 2001). Often, however, these involve linking spatially-explicit demographic data with information on the distribution of habitats, and asking which reserve designs are predicted to minimize the risk of extinction for particular species (e.g., Carroll *et al.*, 2001). This approach relies on expensive data solely from a few well-studied 'focal' species. Further, the intent is that, by ensuring the persistence of 'focal' species, many other species persist as well, but it is seldom known whether, nor how many, other species might also be represented and persist in a reserve system designed for persistence of the 'focal' species.

We build on previous work (Glenn and Nudds, 1989; Gurd and Nudds, 1999; Gurd *et al.,* 2001) that used historical ranges of disturbance-sensitive mammals to estimate a minimum reserve size (5000 km^2; 95% C.L.: 2700-13 296 km^2) below which mammal extinctions have not been documented. These sizes are similar to those derived from a variety of demographic analyses of large, far-ranging species, including wolves (*Canis lupus*), cougars (*Felix concolor*), grizzly bears (*Ursus horribilis*) and woodland caribou (*Rangifer tarandus caribou*) (Gurd *et al.*, 2001; Lipsett-Moore *et al.*, 2003; Wiersma *et al.,* in press). We assume that mammals are an 'umbrella species group' because the distribution of mammals on isolated habitat fragments, relative to other taxa, suggests that, as homeothermic quadrupeds, they are at greater risk of extinction (Schmiegelow and Nudds, 1987; Hager and Nudds, 2001). It follows that if the mammal assemblage persists intact, so should a good deal of other species (Hager *et al.*, in prep). Subsequently, Wiersma *et al.* (in press) showed that mammal extinctions varied most with reserve size, with more extinctions in smaller reserves, and less when natural features of the landscapes remained intact around reserves.

In essence, we ask: "If we knew then what we know now about the effects of size and isolation on extinction risk in habitat fragments, would we have designed reserve networks the way they actually turned out, with respect to reserve sizes, numbers and locations?" Sufficient evidence exists to suggest that the answer is obvious: certainly not. However, by analyzing historical data, we can address how many reserves – each above an estimated minimum size threshold for persistence of the historical complement of mammals – would have been needed, and where they should have been located, to represent all of the species in a large ecological region. Here, we give the 'flavour' of this work with preliminary results summarized for three mammal 'provinces' in Ontario.

Methods

Using plots (reserves) corresponding to our estimate of minimum reserve size, and the upper and lower 95% confidence values of the estimate (2700, 5000 and 13 300 km^2), we sampled the historical ranges of disturbance-sensitive mammals (for sources of historical data, see Glenn and Nudds, 1989) in each of eight biogeographic 'mammal provinces' that span Canada (Figure 1), using ArcView™ with the Samples extension. We selected plots using both richness and rarity-based algorithms until all species were included in at least one reserve in a network of reserves for a particular mammal province. Here, we report results for those portions of three mammal provinces that span Ontario (the Alleghenian-Illinoian, the Western Canadian, and the Eastern Canadian).

Figure 1. *The mammal provinces of Canada (Source: Hagmeier, 1966). All analyses were conducted at the scale of whole mammal provinces. Here we report the results of the optimal number and location of reserves for those portions of three biological provinces within the political boundaries of Ontario.*

Results

Over all mammal provinces, 100% representation of disturbance-sensitive mammals could be achieved with three to eight minimum-sized reserves, depending on reserve size and region. Rarest-based algorithms were always more efficient than richness-based algorithms for selecting reserve networks, resulting in reserve networks of one to five fewer minimum-sized plots to achieve 100% representation of mammal species (Wiersma and Nudds, in prep). These reserve systems comprised 5-40% of the land base of the mammal provinces, further suggesting that rules of thumb, or data-independent targets (e.g., Solomon *et al.*, 2003) such as the ‘12% rule’, are inappropriate as design criteria (Wiersma and Nudds, 2003; in prep).

Except for the western portion of the Alleghenian-Illinoian mammal province in Ontario, most present day reserves larger than the minimum size are not located where they should have been to most efficiently represent *and promote persistence* of mammal species diversity (Figure 2). Somewhat counter-intuitively, the most efficient allocation of reserves (i.e., the best locations to have sited reserves in the past to achieve the greatest representation with fewest reserves), did not vary with minimum reserve size. In other words, if we knew then what we know now, fewer but bigger, reserves could have been designed and sited to most efficiently conserve all of Ontario's historical complement of mammals in a reserve network.

Discussion

The history of protected area establishment in Canada and elsewhere might be divided into three eras: the Era of Default, the Era of Desperation, and the Era of Design. With some exceptions (such as parks created for scenic, wilderness values), during the Era of Default the sizes and locations of protected areas were based largely on convenience and or/compromise with competing land-uses (Runte, 1987; Pressey *et al*., 1993); generally speaking, siting of protected areas often defaulted to areas of high topographic relief, low productivity, or areas otherwise unsuitable for development.

The latter part of the 20th century saw two important developments that heralded the Era of Desperation. First, MacArthur's and Wilson's (1967) seminal work on island biogeography had an extraordinary influence in re-shaping thought about protected area design, and why policies in vogue then were inadequate to conserve species in many protected areas. Second, the rise of the 'biodiversity crisis' catalyzed political and social will to provide protected area networks of adequate size and distribution to conserve representative flora and fauna across various regions of the country. In Ontario, for example, the government's position that the *Lands for Life* (e.g., Riley, 1998) initiative would result in 'final' lines on a map delineating protected areas resulted in a desperate flurry of activity to set aside areas considered to be of significant ecological value. Much of current protected area planning and management may continue to be constrained to practise as in the Eras of Default and Desperation – so long as it appears that opportunities to save the 'best of the last' continue to erode.

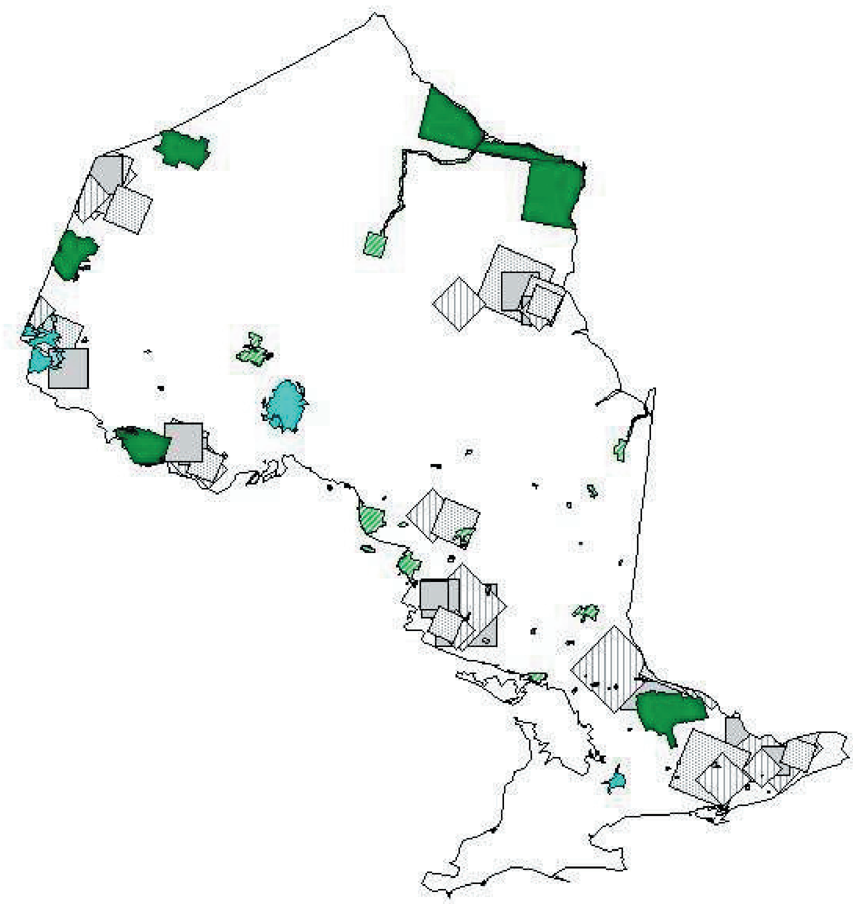

Figure 2. *The number, locations and sizes of reserves in Ontario, larger than the estimated minimum size to avoid mammal extinctions, and including all mammal species in at least one reserve, based on analysis of historical mammal distributions. Large squares, 13 300-km² reserves; medium squares, 5000-km² reserves; small squares, 2700-km² reserves. Differential shading of square plots represents results from different replications of the sampling and reserve selection algorithms. Present-day federal and provincial parks are shown dark if they exceed the estimated minimum size threshold, and cross-hatched if they are smaller. Other small parks do not represent an exhaustive inventory of parks in Ontario.*

However, we contend that approaches to selecting reserves that imply representation before persistence as design criteria put the 'cart before the horse'. The list of features to be represented is often derived by 'expert opinion' and compromise among sometimes competing interests. Further, a sense of urgency typically exacerbates the design and creation of protected area networks, particularly in highly altered landscapes. This may result in cobbling together collections of 'favourite places' for different reasons that may not, in fact, function to conserve biodiversity. Emphasis on conservation through representation of the best of the 'left-over bits' precludes an ability to rationalize protected area systems, and/or to target appropriate future expansion or restoration. Finally, emphasis on representation first, and persistence second, creates a quandary in the age of climate change, since what is chosen to be representative may be under- (or over-) represented in reserve networks in the future (Halpin, 1997; Hannah *et al*., 2002; Scott *et al*., 2002).

Parks and protected areas management is presently poised only on the threshold of the Era of (proactive) Design. The World Wildlife Fund has proposed to set aside significant natural areas in the north before the MacKenzie Valley pipeline is built; the Yukon Territory government has considered that each ecoregion might have at least one protected area; and the Canadian Council on Ecological Areas, in co-operation with federal, provincial and territorial agencies has initiated a project to assess planning and design for northern protected areas.

In Ontario, a coalition of Aboriginal and environmental non-government organizations and the forest industry announced in spring 2004, an agreement to plan to set aside 50% of boreal forest lands above 51^{o}N as protected areas prior to the expansion of industrial development. The *Northern Boreal Initiative* represents a significant opportunity to plan ahead of (apparently) inevitable development in the boreal forest. In these cases, where present conditions have not yet been too radically altered from the past, the application of design principles, and selection of reserves, such as we describe here may prevent a repeat of the past mistakes. However, even in southern settled landscapes, where most opportunities to expand/restore protected areas are severely constrained by existing alternative land uses, planning with persistence first, based on historical baselines, nevertheless may provide guidance about where to most effectively direct future acquisitions to reserve networks.

References

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

Carroll, C., R.F. Noss and P.C. Pacquet. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. *Ecological Applications* 11: 961-980.

Glenn, S.M. and T.D. Nudds. 1989. Insular biogeography of mammals in Canadian parks. *Journal of Biogeography* 16: 261-268.

Gurd, D.B. and T.D. Nudds. 1999. Insular biogeography of mammals in Canadian parks: A re-analysis. *Journal of Biogeography* 26: 973-982.

Gurd, D.B., T.D. Nudds and D.H. Rivard. 2001. Conservation of mammals in eastern North American wildlife reserves: how small is too small? *Conservation Biology* 15: 1355-1363.

Hager, H.A. and T.D. Nudds. 2001. Parks and protected areas as ecological baselines: establishment of baseline data on species-area relations from islands in Georgian Bay. Pp. 269-280. In: S. Parker and M. Munawar (Eds.) *Ecology, Culture and Conservation of a Protected Area: Fathom Five National Marine Park, Canada*. Backhuys Publishers, Leiden, The Netherlands.

Hager, H.A., R. Gorman and T.D. Nudds. In prep. Conservation of species richness: the relative performance of different types of umbrella species.

Hagmeier, E.M. 1966. A numerical analysis of the distributional patterns of North American Mammals. II. Re-evaluation of the provinces. *Systematic Zoology* 15: 279-299.

Halpin, P. 1997. Global climate change and natural-area protection: management responses and research directions. *Ecological Applications* 7: 828-843.

Hannah, L., G.F. Midgley, T. Lovejoy, W.J. Bond, M. Bush, J.C. Lovett, D. Scott and F.I. Woodward. 2002. Conservation of biodiversity in a changing climate. *Conservation Biology* 16: 264-268.

Lipsett-Moore, G., N. Bookey, S. Kingston and J. Shuter. 2003. Representation, focal species and systematic conservation planning for the Northern Boreal Initiative. Pp. 189-198. In: C. Lemieux, J.G. Nelson, and T.J. Beechey (Eds.) *Parks and Protected Areas Research in Ontario, 2003: Protected Areas and Watershed Management*, *Proceedings of the Parks Research Forum of Ontario Annual General Meeting, April 25-27, 2002, Ridgetown College, Ridgetown, Ontario.* Parks Research Forum of Ontario (PRFO), Waterloo, Ontario.

MacArthur, R.H. and E.O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton, New Jersey.

Possingham, H.P., I. Ball and S.J. Andleman. 2000. Mathematical models for identifying representative reserve networks. Pp. 291-305. In: S. Ferson and M.

Burgman (Eds.) *Quantitative Methods in Conservation Biology*. Springer-Verlag, New York.

Pressey, R.L., C.J. Humphries, C.R. Margules, R.I. Van-Wright, and P.H. Williams. 1993. Beyond opportunism: key principles for systematic reserve selection. *Trends in Ecology and Evolution* 8: 124-128.

Riley, J.L. 1998. Protected areas and *Lands for Life*: will protection policies be met and available information used. Pp. 98-104. In: J.G. Nelson and K. Van Osch (Eds.) *Parks and Protected Areas Research in Ontario, 1998: Proceedings of the Parks Research Forum of Ontario Annual General Meeting, February 5-6, 1998, Peterborough, Ontario*. Heritage Resources Centre, University of Waterloo, Waterloo, Ontario.

Runte, A. 1987. *National Parks: The American Experience, Third Edition*. University of Nebraska Press, Lincoln.

Schmiegelow, F.K.A. and T.D. Nudds. 1987. Island biogeography of vertebrates in Georgian Bay Islands National Park. *Canadian Journal of Zoology* 65: 3041-3043.

Scott, D., J.R. Malcolm and C. Lemieux. 2002. Climate change and modeled biome representation in Canada's national park system: implications for system planning and park mandates. *Global Ecology and Biogeography* 11: 475-484.

Solomon, M., A.S. van Jaarsveld, H.C. Biggs and M. H. Knight. 2003. Conservation targets for viable species assemblages? *Biodiversity and Conservation* 12: 2435-2441.

Wiersma, Y.F., and T.D. Nudds. 2003. On the fraction of land needed for protected areas. Chapter 7, CD-ROM. In: N.W.P. Munro, P. Dearden, T.B. Herman, K. Beazley and S. Bondrup-Nielson (Eds.) *Making Ecosystem Based Management Work, Proceedings of the Fifth International Conference on Science and Management of Protected Areas.* SAMPAA, Wolfville, Nova Scotia.

Wiersma, Y.F., and T.D. Nudds. In prep. Conservation targets for viable species assemblages: data independent targets are not appropriate.

Wiersma, Y.F., T.D. Nudds and D.H. Rivard. In press. (Online advance publication May 6, 2004.) Models to distinguish effects of landscape patterns and human population pressures associated with species loss in Canadian national parks. *Landscape Ecology*.