Representative reserve design in Canada: the contribution of existing protected areas

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Abstract

Given the limited resources to set aside protected areas for biodiversity conservation, as well as competing land use interests, it is prudent that networks of protected areas represent biodiversity effectively and efficiently. Effective networks represent all species in protected areas that are large enough to ensure species persistence. However, such a network may not be efficient in terms of the amount of land allocated for conservation. Reserve selection algorithms are tools that can be used to delineate optimal (or near-optimal) solutions to the problem of maximizing representation of species with a minimum amount of area. In this paper, I show how reserve selection algorithms can be used to determine whether existing protected areas that meet criteria for minimum reserve area are efficient and/or effective in terms of representing disturbance sensitive mammals in Canada. In general, existing protected areas do not effectively capture the full suite of mammalian biodiversity, nor are most existing protected areas part of a near-optimal solution set. The results of this analysis can help to identify targets for protected areas, and suggest priorities for establishment of new protected areas, or expansion of existing ones.

Keywords: representative reserve design, gap analysis, planning

Introduction

Forty years ago, participants at the first *Parks for Tomorrow* conference heard that "… if we were starting all over again, we would select a system of national parks somewhat different from what we have today" (Brooks 1969, 870). This comment was made in reference to the fact that, in 1968, many geographic and ecological features remained unrepresented in the national parks system. At the time of the first conference, the total number of national parks had remained relatively unchanged over the past four decades. Ten years later, at the second *Parks for Tomorrow* conference, it was noted that ten new national parks had been added to the system (Carruthers 1979). Since then, the national parks system has grown to 42, up from 22 at the time of the original conference. However, even with a growth in the number of national parks between 1968 and 1978, it was still noted that many areas of Canada were unrepresented (Carruthers 1979).

While Brooks opined that the national parks system had "evolved mainly through the sporadic efforts of a visionary few, through accidents of geography and by political expediency (Brooks 1969: 869), Carruthers noted that Parks Canada had developed a National Parks System Planning Manual in 1971 to provide a framework which "enabled the identification of gaps in the system; [and] provided a guide for the identification of potential areas to fill in the gaps" (Carruthers 1979, 648). The 1971 System Plan introduced the concept of ecosystem *representation*, and identified 39 terrestrial regions with a goal to have one national park to represent each region.

By the late 20th century, implementation of the concept of representation into park system planning worldwide was facilitated by the advance of Geographic Information Systems (GIS) and increased computer power. Beginning with work in Australia

(Kirkpatrick 1983), planners were able to engage in systematic parks planning – the planning of networks of protected areas that work together in a synergistic fashion to achieve biodiversity conservation and ecosystem representation goals.

Planning for representative protected areas networks involves the identification of a set of protected areas that captures a maximum number of species, communities or other biological units of interest within a pre-defined region (Margules et al. 1988; Pressey et al. 1996). The use of computer-based algorithms to facilitate this began to appear in the literature in the late 1980s and early 1990s as ecologists gained greater access to computers sufficiently powerful to complete such analyses. There are a variety of algorithms that have been presented, but all work on the premise of maximizing biodiversity representation with a minimum number of sites. In all cases, the algorithms examine a large set of potential protected areas within a larger region. Data for each site include details on the biodiversity feature that is to be represented (e.g., species lists, descriptions of vegetation communities). The algorithms analyze all (or most) possible combination of sites from the larger set to find the efficient configuration of sites that maximizes representation of the feature of interest (Margules et al. 1988; Pressey et al. 1996, 1997). An efficient (optimal) set is said to be the one that represents the most features with the fewest sites, thus leaving more land open for other competing uses. However, if the individual protected areas within the representative network have their ecological integrity compromised such that species can no longer persist within their boundaries, the network may become unrepresentative over time. Thus, when algorithms also include criteria that enhance species *persistence* within the individual protected areas and the network as a whole, the ensuing network should be one that effectively conserves and represents species in the region with minimum cost.

Theoretical exercises to identify representative networks of protected areas have been carried out in Canada for disturbance-sensitive mammals (Wiersma and Nudds 2006), species at risk in Québec (Sarakinos et al. 2001), threatened vertebrates in British Columbia (Warman et al. 2004a), and threatened and endangered species across Canada (Warman et al. 2004b). These exercises were carried out with the intent of identifying sites where protected areas should be located to efficiently protect biodiversity elements (referred to here as “optimal sites”). A simple comparison between the optimal sites chosen using heuristic algorithms to represent mammals in Ontario and the location of existing protected areas (Nudds and Wiersma 2004) shows very little overlap. This observation might lead to the conclusion that the existing suite of protected areas does not adequately represent biodiversity. However, an analysis of the gaps between sites selected using a heuristic algorithm and existing protected areas is really only a measure of the efficiency of the existing system of protected areas (Rodrigues et al. 1999; Stewart et al. 2003). In theory, there may be many combinations of sites, which, while not 100% *efficient* in terms of minimizing cost/area, will be *effective* in representing the desired assemblages of species (Rodrigues et al. 1999). Thus, existing protected areas should be evaluated in terms of their efficiency *and* effectiveness in meeting representation targets (Fig. 1).

Here, I build on previous work (Wiersma and Nudds 2006) that used heuristic reserve selection algorithms to delineate theoretical networks of a minimum set of protected areas that would represent disturbance-sensitive mammals in each of eight of the mammal provinces of Canada (Hagmeier 1966; Fig. 2). The theoretical analysis was doing using historical (Banfield 1974) data on species ranges, and thus represents where protected areas might have been optimally located prior to widespread European settlement. This allows for a test of the hypothesis put forth by Brooks forty years ago, when he wondered aloud whether we would have designated the national parks in the same areas as we had, given what we know today. In 1967, the Honourable Arthur Laing, Minister of Indian Affairs and Northern Development, suggested that 40-60 new national parks were necessary to achieve representation of Canada's natural regions (Nichol 1969). Currently, there are 40 national parks representing 28 regions. In total, Canada has over 3000 protected areas in IUCN class I-VI (Environment Canada 2002), which include provincial parks, wildlife reserves, conservation reserves and wildlife management areas. Not all of these are large enough to sustain ecological processes and species composition within them, however those that do have a reasonably high degree of ecological integrity, are contributing to biodiversity representation. This analysis then, examines how effective and efficient the current estate of these protected areas is with respect to representation of mammals.

The theoretical networks delineated by Wiersma and Nudds (2006) are comprised of proposed protected areas that meet minimum reserve area (MRA) criteria. The MRA was estimated by Gurd et al. (2001) based on island biogeography theory. Gurd et al. (2001) estimated the historical species-area curves for disturbance-sensitive mammals, using the same range data (Banfield 1974) applied in this analysis. They used current mammal species richness in existing national and provincial parks (some of which had become surrounded by human-dominated habitat) to derive a modern species-area curve.

The intersection of the historical and modern species-richness curves is taken as an estimate of the MRA, and can be thought of as how large a habitat “island” has to be before it stops acting like an island (i.e., before it will be too small to allow species to persist). Thus, species in protected areas that meet MRA requirement are predicted to persist within them, even in the face of habitat insularization (Gurd et al. 2001).

Methods

Target regions and mammal data

The analysis of the contribution of existing protected areas was carried out in seven of the mammal provinces of Canada (Hagmeier 1966, Fig. 2)[1]. Historical data on mammal distributions were obtained from Banfield’s Mammal Atlas of Canada (Banfield 1974), which represents the ranges of disturbance-sensitive mammals prior to widespread European settlement. Disturbance-insensitive mammals (e.g., racoons, coyotes) were deemed not to be a high priority for protection from anthropogenic threats, and thus only those species defined as sensitive to human disturbance (Glenn and Nudds 1989, *sensu* Humphreys and Kitchener 1982) were included in the analysis.

Existing protected areas data

Data on existing protected areas from the North American Conservation Areas Database (NCAD), the Canadian Conservation Areas Database (CCAD), and GeoGratis were compiled in a GIS. These data sets include spatially referenced points identifying the

[1] For a similar analysis, but using the more familiar ecozones of Canada see Wiersma Y.F. 2007. Protected areas in Northern Canada: identifying ecological areas to represent mammals. Phase 2 report. CCEA Occasional Paper No. 17. Canadian Council on Ecological Areas, CCEA Secretariat, Ottawa, ON, Canada. viii + 36 pp.

location and attributes of national, provincial, state, and territorial parks, as well as wildlife management areas, game preserves, and biosphere reserves (hereafter referred to as "existing protected areas"). Only those that met or exceeded the lower 95% confidence interval for the minimum reserve area (MRA) estimate (i.e., > 2700 km^2; Gurd et al. 2001) were used in the analysis (n = 29, Table 1).

Heuristic reserve selection

The mammalian species richness within each mammal province was compared to the aggregate species composition of the existing protected areas within that province to identify which species were not yet represented. I then identified the additional sites needed to capture each species at least once using a rarity-based heuristic reserve selection algorithm (Margules et al. 1988; Pressey et al. 1993). I iteratively selected additional MRA-sized sample plots that spanned across each mammal province, prioritizing for those sites that contained species with the highest rarity (in terms of range limit). I ran the algorithm for each replication of the sample plots used by Wiersma and Nudds (2006) in the theoretical exercise (n = 9). Reserves were selected and added to the system until all species were represented at least once in a reserve.

Results

In the seven mammal provinces analysed, the number of existing protected areas deemed sufficiently large to protect mammal diversity over time ranged from 1-10 (Table 1). These did not capture the full range of mammalian diversity in any of the mammal provinces (Fig. 3). Between 1-7 additional MRA-sized sample plots had to be added to the system before all mammals were represented at least once (Table 2). The total number of protected areas required in reserve systems was significantly higher when existing protected areas were included in all cases (Table 2).

Discussion

Existing large protected areas in Canada do not capture the full range of mammalian diversity in any of the mammal provinces. When existing protected areas were included in the system before application of the reserve selection algorithms, significantly more protected areas were required to achieve full representation than when they were excluded.

The fact that protected areas do not effectively or efficiently represent mammals in each province might be due to a holdover from the era when protected areas were established largely for their scenic and/or recreation values. The median year of establishment for the existing protected areas is 1975 (mean year of establishment: 1960), which is well before the concept of minimum representation and reserve selection algorithms first appeared in the literature in the early 1980s (Kirkpatrick 1983). Thus, the majority of the protected areas were not designated with the goal of biodiversity representation in mind. Certain features of the landscape (such as mountain ranges in the western mammal province) are over-represented, while other features are not captured.

The sites identified as being part of near-optimal solutions using the heuristic algorithms did overlap with some existing protected areas that are smaller than the minimum reserve area (MRA) estimate (these sites are listed in Appendix A). Thus, a prudent management strategy might be to expand the boundaries of these sites and or establish/maintain connectivity around them to bring their size up to at least the lower MRA threshold of 2700 km^2.

Across Canada, it appears that the existing protected areas that are large enough to conserve mammals are generally not located in the places where they can efficiently or effectively represent the diversity of mammalian species in each region. Thus, Brooks' comments forty years ago may been seen as quite prescient. Carruthers (1979) noted that the national parks as a whole would likely not ever represent a complete system, but that there would need to be coordination with other protected agencies. However, despite an expansion of a wide range of types of protected areas far beyond the number that Laing predicted might be necessary back in 1967, the assemblage of protected areas is not yet adequate to efficiently and effectively represent mammalian biodiversity. The results of this analysis can help identify where we would have put protected areas if we could do it all over. Whether the existing Canadian protected areas (or the theoretical network delineated by Wiersma and Nudds (2006)) adequately represent other taxa is not known, but should be the focus of future research. Warman et al. (2004b) examined how well a theoretical protected areas network across the country designed for one group of species (e.g., mammals) captured other groups (birds, reptiles, amphibians and COSEWIC listed species) and found that these represented other taxa better than a random selection, but that no one group was an effective surrogate for all other groups. Correlation between mammal species richness and richness of other groups varied from 33-96% (Warman et al. 2004b). Thus, a protected area network designed for mammals may capture some species well, but additional protected areas will be needed to represent other taxa.

In the meantime, if representation of all species in each mammal province is a policy goal, then it is evident that further expansion of the protected areas system beyond what is already in place in Canada is necessary. The use of heuristic algorithms such as the ones described here (that makes use of sample plots that meet MRA criteria) can be a useful tool to identify locations where protected areas should be established (or in the case where small protected areas exist, where they can be expanded) to efficiently create an effective representative network of protected areas that has a high probability of enabling species persistence.

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References

Banfield, A.W.F. 1974. *The Mammals of Canada.* University of Toronto Press, Toronto.

Brooks, L. 1969. Planning a Canadian national parks system – progress and problems. In *The Canadian National Parks: Today and Tomorrow*, eds. J.G. Nelson and R.C. Scace, Volume 2: 867-877.

Carruthers, J.A. 1979. Planning a Canadian national park and related reserve system. In *The Canadian National Parks: Today and Tomorrow. Conference II: Ten Years Later*, eds. J.G. Nelson, R.D. Needham, S.H. Nelson, R.C. Scace, Volume 2: 645-671.

Environment Canada. 2002. *Sustainable Development: A Canadian Perspective*. Earth Summit 2002 Canadian Secretariat. Government of Canada Depository Services Program. Accessed April 21, 2008 at http://dsp-psd.pwgsc.gc.ca/Collection/En40-668-2002E.pdf

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

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.

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.

Humphreys, W.F., and D.J. Kitchener. 1982. The effect of habitat utilization on species-area curves: implications for optimal reserve area. J*ournal of Biogeography* 9: 391-396.

Kirkpatrick, J.B. 1983. An iterative model for establishing priorities for the selection of nature reserves: an example for Tasmania. *Biological Conservation* 25: 127-134.

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

Nichol, J.I. 1969. The national parks movement in Canada. In T*he Canadian National Parks: Today and Tomorrow*, eds. J.G. Nelson and R.C. Scace, Volume 1: 35-52.

Nudds, T.D., and Y.F. Wiersma. 2004. Back to the future: designing protected areas using data on historical species distributions. In Planning Northern Parks and Protected Areas: parks and protected areas research in Ontario in 2004, eds. C.K. Rehben, J.G. Nelson, T.J. Beechey, and R.J. Payne, pp. 141-149. Parks Research Forum of Ontario, Waterloo, ON.

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

Pressey, R.L., H.P. Possingham, and C.R. Margules. 1996. Optimality in reserve selection algorithms: When does it matter and how much? *Biological Conservation* 76: 259-267.

Pressey, R.L., H.P. Possingham, and J.R. Day. 1997.Effectiveness of alternative heuristic algorithms for identifying indicative minimum requirements for conservation reserves. *Biological Conservation* 80: 207-219.

Rodrigues, A.S.L., R. Tratt, B.D. Wheeler, and K.J. Gaston. 1999. The performance of existing networks of conservation areas in representing biodiversity. *Proceedings of the Royal Society of London Series B.* 266: 1453-1460.

Sarakinos, H., A.O. Nicholls, A. Tubert, A. Aggarwal, C.R. Margules, and S. Sarkar. 2001. Area prioritization for biodiversity conservation in Québec on the basis of species distributions: a preliminary analysis. *Biodiversity and Conservation* 10: 1419-1472.

Stewart, R.R., T. Noyce, and H.P. Possingham. 2003. Opportunity cost of ad hoc marine reserve design decisions: an example from South Australia. *Marine Ecology Program Series* 253: 25-38.

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

Warman, L.D., D.M. Forsyth, A.R.E. Sinclair, K. Freemark, H.D. Moore, T.W. Barrett, R.L. Pressey, and D. White. 2004b. Species distributions, surrogacy, and important conservation regions in Canada. *Ecology Letters* 7: 374-379.

Wiersma, Y.F., and T.D. Nudds. 2006. Conservation targets for viable species assemblages: data independent targets are not appropriate. *Biodiversity and Conservation* 15: 4555-4567.

Zar, J.H. 1999. *Biostatistical analysis*. 4th edition. Prentice Hall, New Jersey.

Table 1. List of existing protected areas from the North American Conservation Areas database that meet minimum reserve area (MRA) requirements (Gurd et al. 2001) as of 2005.

Mammal province	**Name**	**Area (km^2)**
Allegheniań-Illinoian (eastern)	Algonquin Provincial Park	7723.00
Alleghenian-Illinoian (eastern)	Réserve de la biosphère Charlevoix (International Biosphere Reserve)	5600.00
Alleghenian-Illinoian (western)	Riding Mountain National Park	2978.00
Alleghenian-Illinoian (western)	Whiteshell Provincial Park	2720.90
Alleghenian-Illinoian (western)	Quetico Provincial Park	4757.83
Eastern Canadian	Wabakimi Provincial Park	8920.61
Eastern Canadian	Woodland Caribou Provincial Park	4500.00
Western Canadian	Wood Buffalo National Park	45,390.23
Western Canadian	Cape Churchill Wildlife Management Area (Provincial)	8488.15
Western Canadian	Caribou River Provincial Park Reserve	7640.00
Western Canadian	Cape Tatnam Wildlife Management Area (Provincial)	5311.82
Western Canadian	Atikaki Wilderness Provincial Park	3981.30
Western Canadian	Numaykoos Lake Provincial Park	3600.00
Western Canadian	Polar Bear Provincial Park	23,552.00
Western Canadian	Opasquia Provincial Park	4730.00
Western Canadian	Prince Albert National Park	3875.00
Western Canadian	Lac la Ronge Provincial Park	3361.97
Montanian	Banff National Park	6640.89
Montanian	Jasper National Park	19,878.15
Montanian	Willmore Wilderness Provincial Park	4596.73
Montanian	Spatsizi Plateau Wilderness Provincial Park	6960.91
Montanian	Wells Gray Provincial Park	5249.90
Vancouverian	Tweedsmuir Provincial Park	9810.00
Yukonian	Tatshenshini-Alsek Provincial Park	9470.26
Yukonian	Nahanni National Park Reserve	4800.73
Yukonian	Kluane National Park	22,015.00
Yukonian	Ivvavik National Park	10,170.00
Yukonian	Kluane Game Sanctuary (Federal)	6367.05
Yukonian	Fishing Branch Wilderness Preserve (Territorial)	5400.00
Yukonian	Vuntut National Park	4387.00

Table 2. Number of additional MRA-sized protected areas needed to capture all mammals in at least one protected area, derived by applying the rarity-based algorithm to the historical data. Results are shown when existing MRA-sized protected areas are excluded and included in the minimum set. Values reported are the mean from 3 replicates of 3 MRA estimates (total 9 replicates). Significance was tested using Student's t-test (Zar 1999).

Mammal province	**Mean number of sites needed based on rarity-based algorithms (n = 9 runs)**	**Number of MRA-sized protected areas**	**Mean number of additional sites needed (n = 9 runs)**	**Mean number of sites needed including existing protected areas (n = 9 runs)**	**Difference between number of sites with and without existing protected areas**	
					t	***p***
Allgehenian-Illinoian (eastern)	3.56	2	3.33	5.33	4.22	<0.001
Alleghenian-Illinoian (western)	2.67	3	0.56	3.56	2.27	0.05
Eastern Canadian	2.89	2	2.67	4.67	4.79	<0.001
Western Canadian	8.56	10	5.89	15.89	14.99	<0.001
Montanian	5.22	5	4.00	9.00	8.40	<0.001
Vancouverian	4.00	1	4.00	5.00	2.35	0.05
Yukonian	2.89	7	1.00	8.00	10.49	<0.001

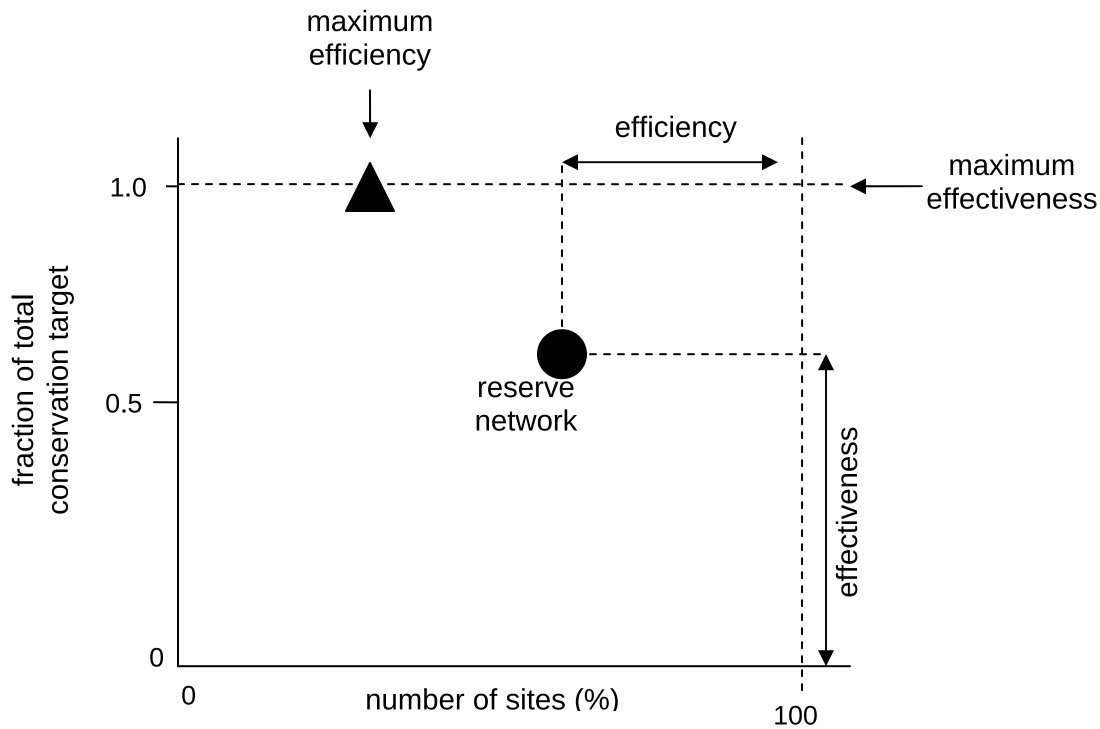

Figure 1. Illustration of the concepts of *efficiency* and *effectiveness*. Efficiency is larger when the number of sites in the protected areas network is smaller. Maximum efficiency is obtained by the minimum optimum set. Effectiveness is a measure of how close a protected areas network is to attaining the representation target. Thus efficiency is measured based on the size of the network (x-axis), while effectiveness is measured based on the performance of the network relative to the representation target (y-axis). (Figure and caption adapted from Rodrigues et al. 1999).

Figure 2. The mammal provinces of Canada (Hagmeier 1966). For this study, the Eastern and Western Hudsonian, the Ungavan, and the Eastern Eskimoan mammal provinces were excluded as they were not part of the original development of theoretical protected areas networks. The Saskatchewanean mammal province was also excluded as it did not contain any MRA-sized protected areas. The western portion of the Alleghenian mammal province was analyzed separately, and the eastern portion of the Alleghenian mammal province was combined with the Illinoian, yielding a total of eight replicate mammal provinces.

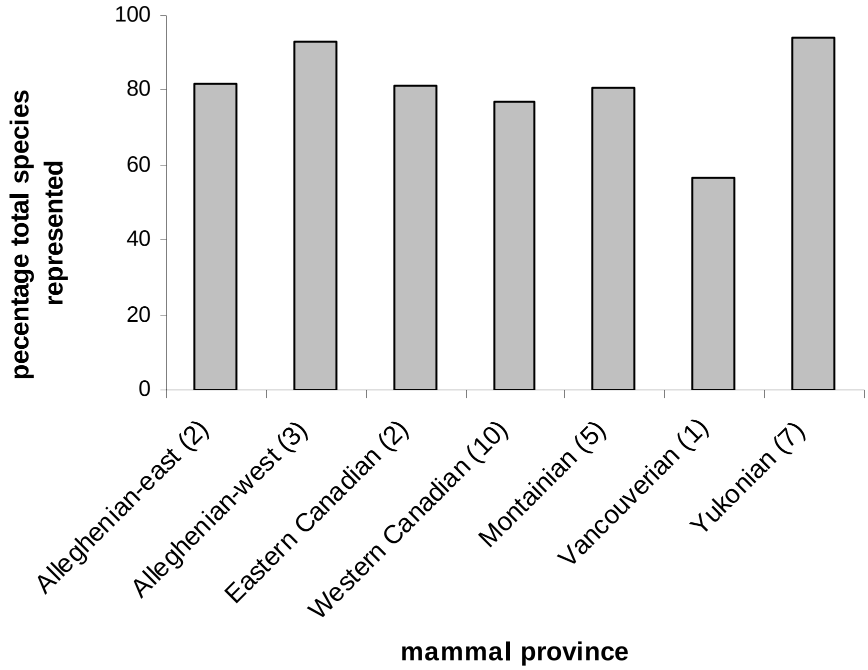

Figure 3. Effectiveness of existing protected areas. The number of protected areas in each mammal province is given in parenthesis on the x-axis. Effectiveness is expressed as a percentage of the total species richness of mammals in each mammal province.