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Conservation targets for viable species assemblages in Canada: are percentage targets appropriate?

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Abstract

Percentage targets for conservation have become a popular tool (advocated in both the scientific literature and the conservation community) for setting minimum goals for the amount of land to be set aside as protected areas. However, there is little literature to support a consistent percentage target that might be widely applied. Moreover, most percentage targets have not taken into account issues of species persistence. A recent study of herbivores in Kruger National Park took into account issues of representation and persistence in setting conservation targets and found that results were consistently about 50% and were unaffected by different permutations of the reserve selection process. Here, we carry out a similar analysis for representation of mammals within sites that are predicted to allow for their persistence, across eight ecologically defined regions in Canada to test whether we see similar consistent patterns emerging. We found that percentage targets varied with the different permutations of the reserve selection algorithms, both within and between the study regions. Thus, we conclude that the use of percentage targets is not an appropriate conservation strategy.

Keywords: Canada, conservation targets, heuristic algorithms, mammals, minimum reserve area, reserve design

Introduction

Percentage targets that aim to set aside a minimum fraction of land area have become common in the conservation biology and protected areas policy literature (McNeely and Miller 1984; WCED 1987; Soulé and Sanjayan 1998). These have been sometimes been termed “data-independent” targets (Solomon et al. 2003) or “policy-driven” targets (Svancara et al. in press) because they are often set independent of any empirical analysis. The most widely cited example of a data free conservation target, or policy-driven target is the so-called 10% (or 12%) target set by the World Parks Congress (McNeely and Miller 1984) and further supported by the Bruntland Commission (WCED 1987). However, percentage targets for land that should be set aside for conservation have also been based on empirical analysis. Svancara et al. (in press) cite 145 studies that propose what they term an “evidence based” percentage target. Empirical studies using reserve selection algorithms have yielded estimates of evidence-based percentage targets for conservation ranging from 33-99%, depending on the taxa and landscapes analyzed (Margules et al. 1988; Ryti 1992; Noss 1993; Saetersdal et al. 1993; Noss 1996; Soulé and Sanjayan 1998; see also summary in Svancara et al. in press). Recent work has pointed out that such percentage conservation targets for reserve networks are often arbitrary (Rodrigues and Gaston 2001; Pressey et al. 2003) and, more importantly, may not address issues of species persistence (Rodrigues et al. 2000a, b; Cabeza 2003; Cabeza and Moilanen 2003; Kerley et al. 2003; Pressey et al. 2003; Solomon et al. 2003).

There have been several suggestions as to how representation and persistence can be addressed simultaneously when designing reserve networks (e.g. Noss et al. 2002; Cowling et al. 2003; Kerley et al. 2003; Pressey et al. 2003). These are improvements over the initial reserve-selection algorithms that simply considered minimum-set requirements (e.g., Pressey et al. 1996); however each carries additional data requirements and costs, which may make their implementation difficult for some jurisdictions and/or groups of species. For example, Rodrigues et al. (2000a) used multi-year census data from the Common Birds Census in Great Britain to design a reserve network that might be more robust to temporal species turnover. They suggested that prioritization should be for sites containing rare species and those where species have high local abundance, that is, a high probability of persistence. While such a strategy will no doubt improve the persistence of species within a representative reserve network, it requires data on species' relative abundance across the landscape, data that is often unavailable.

In a follow-up study, Rodrigues et al. 2000b confined their analysis to the more commonly available presence/absence data and suggested the best strategy was to prioritize sites where species had experienced a high rate of permanence in the past. However, this strategy requires long-term data on presence/absence, which again, may not always be available. In the absence of data from multiple years, Rodrigues et al. (2000b) advocated setting a goal to represent species in more than one plot, where possible, but acknowledged that such a strategy comes at a cost of reduced efficiency (i.e., more land area needed to be contained in reserves). As well, setting criteria for how many times species should be replicated within a reserve network is arbitrary at best.

Cabeza (2003) used a different approach to conduct a reserve selection analysis for butterflies and moths in North Wales that took into account the spatial configuration and overall quality of habitat patches in the reserve selection process. Cabeza (2003) suggested that heuristic algorithms should incorporate the cost of excluding a site on the long-term persistence of species, in the event that area outside of reserves gets converted to unsuitable habitat (Cabeza and Moilanen 2003). However, this strategy requires detailed data on both habitat types, and the particular habitat and spatial requirements (e.g., area, connectivity) for each of the species of interest (Cabeza 2003). While this may be manageable for a small suite of well-studied species, it may not be a practical strategy elsewhere. Others (Cabeza and Moilanen 2003) have advocated incorporating spatially explicit metapopulation models into reserve selection procedures, but acknowledged that this may be difficult to do for a wide sample of species.

Finally, Solomon et al. (2003) examined the use of percentage targets (which they term “data free conservation targets”) and identified minimum conservation requirements for 12 species of herbivores in Kruger National Park, South Africa. They used data on species abundance to assemble selection units (grid cells) that contained a range of minimum population sizes. The percentage area required to conserve viable populations of the full assemblage of herbivores was 50% on average, and was consistent for all desired population sizes. As well, the percentage land required was only influenced in a limited way by the grain of the selection unit (cell size), although other studies suggest that the size of the selection unit will have an effect on the size of the area needed to conserve species (e.g., Pressey and Logan 1995, 1998; Warman et al. 2004). Thus, Solomon et al. (2003) concluded, that for their study area, percentage targets were consistent, albeit much larger than percentage targets advocated by conservation groups. Thus they predicted that data free (i.e., percentage) conservation targets might also be an appropriate tool elsewhere, but conceded that if results from other studies varied from those in Kruger National Park, that perhaps the use of data free conservation targets should be reassessed.

Here, we develop representative protected areas networks for disturbance-sensitive mammals within eight ecologically defined regions across Canada. We use candidate protected areas that meet an empirically-derived estimate for a minimum reserve area (MRA) above which no mammal extinctions have been detected from existing protected areas since widespread European settlement, even in parks that have become insularized from the surrounding habitat matrix (Gurd et al. 2001). Thus, these proposed protected areas networks simultaneously address representation and persistence requirements for a wider sample of species than used in previous studies. Contrary to the bulk of other published studies that have derived a percentage target for conservation, Solomon et al. (2003) found a consistent percentage target land area that should be set aside to represent herbivores in sites that were large enough to allow for species persistence. Here, we test whether the percentage land area required to represent mammals in sufficiently-sized protected areas is consistent across Canada, as demonstrated in Kruger by Solomon et al. (2003), or whether such targets vary widely, as demonstrated in much of the literature. We also test whether the magnitude of the percentage target for mammals in Canada is similar to the 50% target for herbivores observed by Solomon et al. (2003).

Methods

Study Area

Eight of the mammal provinces of Canada (Fig. 1) were used as individual units of analysis within which the minimum requirements for a representative reserve network were identified. Mammal provinces were chosen as they represented ecologically defined units of analysis (Hagmeier 1966) rather than politically defined ones. The Alleghenian mammal province was divided into two portions, east and west of the Great Lakes, and the Illinoian mammal province was combined with the eastern portion of the Alleghenian, yielding a total of eight replicates of the analysis. The northern mammal provinces, which have very low mammalian diversity, were not included in the study (Fig. 1).

Mammal Data

Terrestrial mammals were chosen as the group to test the hypothesis that consistent percentage (or data free) targets for conservation could be derived. Digital range maps (Banfield 1974) of 69 species of disturbance-sensitive mammals in the country were used as the data source. These range maps represent historical distributions of mammals prior to widespread European settlement in North America (Banfield 1974). Glenn and Nudds (1989) originally defined the list of disturbance-sensitive mammals (*sensu* Humphreys and Kitchener 1982) for Canada based on species' sensitivity to human disturbance. Disturbance-sensitive mammals were chosen since: (1) they may act as an 'umbrella' for other taxa due to their wide-ranging habitats and sensitivity to habitat insularization (Schmiegelow and Nudds 1987; Hager and Nudds 2001) and (2) minimum reserve area has been estimated for disturbance-sensitive mammals, at least in the southernmost mammal province of Canada (Gurd et al. 2001). In the absence of any similar empirical estimates for an MRA for mammals for other parts of the country we assumed this reserve size was appropriate for mammals generally. Estimates based on minimum viable population analyses yield reserve areas of a similar magnitude for many species, including wolves (1080 km^2; Schoenwald-Cox et al. 1998), cougars (2200 km^2; Beier 1993), and grizzly bears (8556-17,843 km^2; Wielgus 2002), thus lending credibility to the use of the MRA estimates from the Alleghenian-Illinoian mammal province for the mammal provinces analysed here.

Sampling Candidate Protected Areas

Sample plots representing the best-available estimates (± 95% confidence limits) of the minimum reserve area (MRA) that would still contain an historical complement of species – even when partly surrounded by human development (Gurd et al. 2001) – were delineated in ArcView^{TM} (v.3.2, ESRI, Redlands, CA) using the Samples extension (v 3.03, Quantitative Decisions, Merion Station, PA) within each mammal province. Square plots were used to be consistent with Gurd et al.'s (2001) sampling method. The square MRA-sized plots (2700 km^2, 5000 km^2, 13,000 km^2) were replicated three times for each size class at different orientations to maximize coverage of samples within each mammal province. An overlay analysis in ArcInfo^{TM} (v. 8.1, Environmental Systems Research Institute, Redlands, CA.) was conducted using these sample plots and the mammal range maps to identify the mammal composition of the suite of candidate protected areas.

Heuristic Reserve Selection Algorithms

Complementarity-based algorithms (e.g., Margules et al. 1988; Pressey and Nicholls 1989; Bedward et al. 1992; Pressey et al. 1996; Possingham et al. 2000) were used within each mammal province to select protected areas from each of the sets of candidate protected areas to determine minimum requirements for a representative protected areas network. Because candidate protected areas met MRA requirements (Gurd et al. 2001), the minimum representative network obtained using the algorithms is predicted to simultaneously address representation *and* persistence goals, and thus capture viable species assemblages. Selection was carried out using both richness-based and rarity-based greedy heuristic reserve selection algorithms (Margules et al. 1988; Pressey et al. 1993). Two stopping rules were used with each algorithm. First, reserves were selected and added to the system until all species were represented at least once in a reserve (determined as full or partial overlap between a species' range and a sample MRA plot). Second, reserves were selected until all species were represented at least once by occupying the full area of at least one reserve (determined as full overlap (where possible) between a species' range and a sample MRA plot). This was done to account for any plots selected using the first stopping rule which had only a fraction of the total plot area covered by a species at the edge of that species' historical range (which represents "extent of occurrence" rather than "area of occupancy" (Lawes and Piper 1998)). These plots might have a lower probability of actually capturing species than plots where species' ranges overlapped entirely (Habib et al. 2003).

The final percentage area required for each mammal province was calculated for each stopping rule and each algorithm to test whether there was convergence with the 50% target observed by Solomon et al. (2003).

Results

The average percentage area required for representation across all mammal provinces was 6.5% (s.d. = 5.7%) with the first stopping rule, and 9.7% (s.d. = 7.8%) with the second stopping rule. The percentage area required to represent each mammal province varied from a minimum of 0.8% (Figure 2a) using the rarity-based algorithm with the smallest MRA plot and the first stopping rule in the western portion of the Alleghenian mammal province to a maximum of 35.3% using the richness based algorithm with the largest MRA plot and the second stopping rule in the Eastern Canadian mammal province (Figure 2b).

While the percentage area required for representation varied, the mean *number* of protected areas needed to achieve representation did not differ by the minimum reserve size in all but the Vancouverian, the Western Canadian and the eastern portion of the Alleghenian mammal provinces (Figure 3a, Table 1). In these three provinces, significantly fewer sties were needed to achieve representation using the largest MRA sample size; there was no significant difference between the medium and small MRA sizes. The mean number of protected areas needed to achieve representation differed significantly depending on the algorithm used in all but the Vancouverian, Saskatchewanean and both portions of the Alleghenian mammal province (Figure 2b, Table 2). Although the rarity-based algorithm captured the full suite of species with fewer sites than the richness-based algorithm in the remaining mammal provinces, the actual locations of the MRAs selected using the richness-based and rarity-based algorithms converged on average 81.9% (range: 22%-100%) of the time for the first stopping rule and 92.03% (range: 67.9%-100%) of the time for the second stopping rule, and in many cases were located in adjacent plots. The first stopping rule required significantly fewer sites to achieve representation than the second stopping rule in all mammal provinces except the western portion of the Alleghenian mammal province (Figure 2c, Table 3), where there was no difference.

Discussion

We concur with those who advocate for advancing the process of reserve selection beyond simply optimizing representation, and who articulate the need to address issues of species persistence in reserve network design (Rodrigues et al. 2000a,b; Cabeza 2003; Cabeza and Moilanen 2003: Pressey et al. 2003; Solomon et al. 2003). Where data on species' relative abundance (Rodrigues et al. 2000a), persistence in sites over time (Rodrigues et al. 2000b) or spatial metapopulation dynamics (Cabeza and Moilanen 2003) are available, these should be incorporated into reserve selection algorithms. In the absence of such data, we advocate setting guidelines for minimum reserve area to meet criteria for persistence *a priori*, and then determining how many such areas are needed to achieve representation targets.

Our study of minimum representation requirements for mammals in Canada was similar to that of Solomon et al. (2003) for herbivores in Kruger National Park in that both studies attempted to design a reserve network to meet criteria for representation and species persistence. Nonetheless, there were several differences. Solomon et al. (2003) examined representation requirements within one region with an extent of ~20,000 km^2 for 12 species of herbivores, whereas we examined representation requirements in eight separate regions, ranging in extent from ~120,000 km^2 to 2,000,000 km^2 for a larger sample of mammals (n = 29-51 in each mammal province). Despite that we also used a different criterion for defining species persistence (use of a minimum reserve area vs. minimum populations), we believe that our study is similar enough in spirit to that of Solomon et al. (2003) to test their prediction that percentage (or data free) conservation targets are an appropriate conservation tool.

Solomon et al. (2003) found that the minimum percentage area required was consistently about 50% even when population size (stopping rule) and grain (size of sample unit) varied. In contrast, we found a high degree of variation in percentage targets, both between mammal provinces, and within mammal provinces when different sizes of sample units and different algorithms and stopping rules were used. Thus we disagree with Solomon et al.'s (2003) conclusion that the use of data free conservation targets should be increased. Part of the reason Solomon et al. (2003) may not have observed a significant degree of variation in percentage requirements with variation in the spatial grain might be due to the fact that the ratio of grain/extent in Kruger was smaller (0.0002-0.00125) compared to ours (0.0013-0.107). Nonetheless, when we considered the minimum number of sites required, rather than the minimum percentage, our results suggested that grain size did not have a significant effect in most cases. Although Solomon et al. (2003) claimed that stopping rule (population size) did not affect the percentage targets, Figure 1a in Solomon et al. (2003) did show variation within years, however, since they do not report any statistical analysis, it is not possible to determine whether this variation is significant.

Percentage targets, while politically appealing (McNeely and Miller 1984; WCED 1987; Soulé and Sanjayan 1998), have been shown in the literature to vary dramatically between study sites and taxa (Margules et al. 1988; Ryti 1992; Noss 1993; Saetersdal et al. 1993; Noss 1996; Soulé and Sanjayan 1998; Svancara et al. in press). In a study constrained to one study site with the same set of taxa, Solomon et al. (2003) concluded that percentage targets were reasonably robust to differences in reserve selection protocols. However, our study replicated a range of selection protocols across similar data sets within Canada, and concluded that percentages varied too much to be useful. Thus, we support a move away from data free percentage targets and one towards minimum replicates of sites that address species persistence.

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Table 1. Mean number and standard deviation of protected areas needed based on the size of the sample plot used (small: 2700 km^2, medium: 5000 km^2, large: 13,000 km^2). Differences are tested using analysis of variance (Zar 1999).

Province	Small	Medium	Large	F	p
Allegheniann – east	5.00 (0.0)	5.00 (0.63)	3.00 (0.0)	60	0.001
Alleghenian - west	3.50 (0.55)	2.50 (0.84)	2.50 (0.84)	3.52	n.s.
Eastern Canadian	5.00 (2.19)	4.50 (1.64)	4.83 (2.48)	0.085	n.s.
Western Canadian	10.17 (1.17)	10.00 (1.26)	7.83 (0.75)	8.63	0.01
Saskatchewanean	5.67 (0.82)	5.67 (0.82)	5.17 (1.17)	0.556	n.s.
Montanian	7.50 (1.76)	6.83 (2.56)	6.00 (1.79)	0.790	n.s.
Vancouverian	5.17 (1.17)	4.67 (0.82)	3.50 (0.84)	4.82	0.05
Yukonian	3.17 (0.75)	3.50 (0.84)	3.17 (0.41)	0.465	n.s.

Table 2. Mean number and standard deviation of protected areas needed based on the algorithm used. Differences are tested using a Wilcox ranked Z-test (Zar 1999).

Province	Richness-based	Rarity-based	Z	p
Alleghenian – east	4.44 (1.13)	4.22 (0.97)	0.496	0.620
Alleghenian - west	3.11 (1.05)	2.56 (0.53)	1.135	0.257
Eastern Canadian	6.67 (0.71)	2.89 (0.33)	3.738	0.0002
Western Canadian	10.11 (1.54)	8.56 (1.01)	2.036	0.041
Saskatchewanean	5.89 (1.05)	5.11 (0.60)	1.734	0.083
Montanian	8.33 (1.66)	5.22 (0.83)	3.328	0.0009
Vancouverian	4.89 (1.36)	4.00 (0.71)	1.509	0.131
Yukonian	3.67 (0.71)	2.89 (0.33)	2.543	0.011

Table 3. Mean number and standard deviation of protected areas needed based on the stopping rule used. Differences are tested using a Wilcox ranked Z-test (Zar 1999).

Province	First stopping rule	Second stopping rule	Z	p
Alleghenian – east	4.33 (1.03)	6.11 (1.88)	2.74	0.006
Alleghenian - west	2.83 (0.86)	3.28 (0.89)	-1.44	0.15
Eastern Canadian	4.78 (2.02)	7.11 (1.71)	-2.81	0.005
Western Canadian	9.33 (1.50)	14.39 (1.50)	-5.09	<0.001
Saskatchewanean	5.50 (0.92)	8.39 (1.75)	-4.12	<0.001
Montanian	6.78 (2.05)	11.56 (2.23)	-4.58	<0.001
Vancouverian	4.44 (1.15)	8.83 (1.79)	-4.98	<0.001
Yukonian	3.28 (0.67)	5.00 (1.19)	-4.26	<0.001

FIGURE CAPTIONS

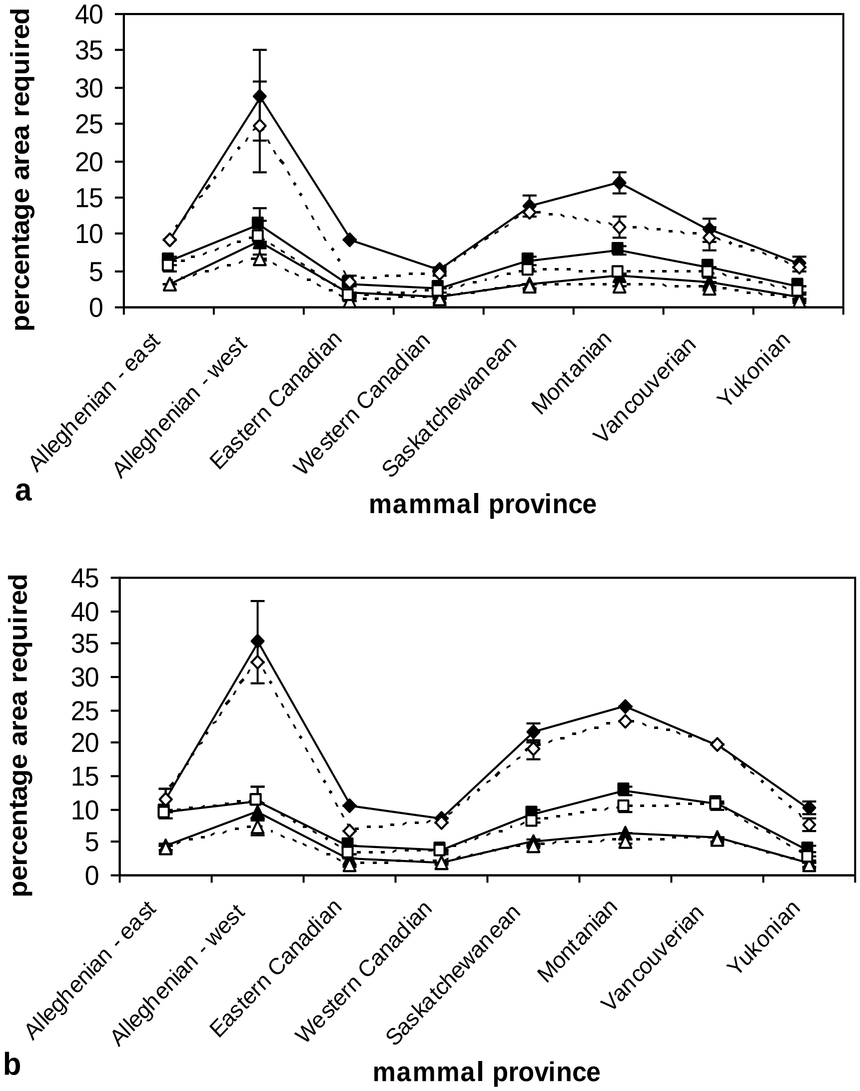
Figure 1. The mammal provinces of Canada (Hagmeier 1966). For this study, the Eastern and Western Hudsonian, the Ungavan, and the Eastern Eskimoan mammal provinces were excluded. The western portion of the Alleghenian mammal province was analyzed separately, and the eastern portion of the Alleghenian mammal province was combined with the Illinoian, yielding a total of eight replicate mammal provinces.

Figure 2. Minimum percentage targets (with standard deviations) for representative reserve networks within eight mammal provinces in Canada using three sample plot sizes (diamonds: 13,000 km^2, triangles: 5000 km^2, squares: 2700 km^2) and two heuristic reserve selection algorithms, a richness-based (solid symbols, solid lines) and a rarity-based (open symbols, dashed lines) greedy algorithm. **a.** Results using the first stopping rule (species ranges overlap with reserve plots) **b.** Results using the second stopping rule (species ranges are fully contained within reserve plots, where possible).

Figure 3. Variation in minimum number of sites required (with standard deviations) for representative reserve networks within eight mammal provinces in Canada. **a.** Using three sample plot sizes (diamonds: 13,000 km^2, squares: 5000 km^2, triangles: 2700 km^2). **b.** Using and two heuristic reserve selection algorithms, a richness-based (diamonds, solid lines) and a rarity-based (squares, dashed lines) greedy algorithm. **c.** Using two stopping rules, the first stopping rule, species ranges overlap with reserve plots (diamonds, solid lines) and the second stopping rule, species ranges are fully contained within reserve plots, where possible (squares, dashed lines).


Yukonian
Western Hudsonian
Eastern Eskimoan
Vancouverian
Western Canadian
Ungavan
Montanian
Eastern Hudsonian
Saskatchewanian
Alleghenian
Eastern Canadian
Alleghenian
Illinoian
N
0 400 800 km

Figure 1


percentage area required
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Alleghenian - east
Alleghenian - west
Eastern Canadian
Western Canadian
Saskatchewanean
Montanian
Vancouverian
Yukonian
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mammal province
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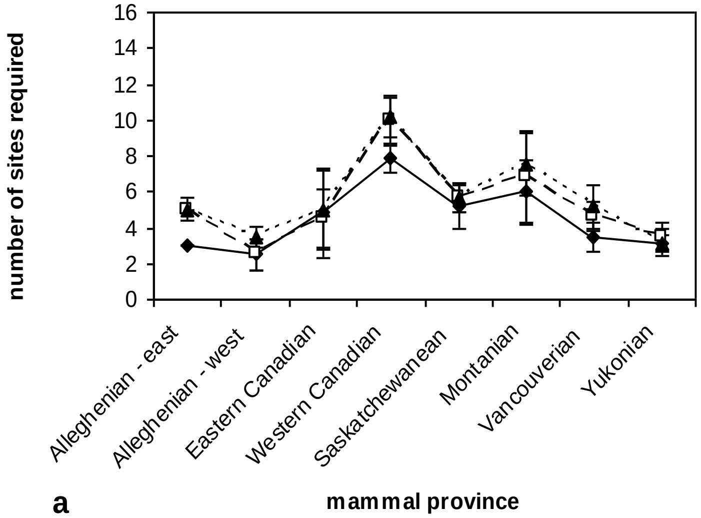
Figure 2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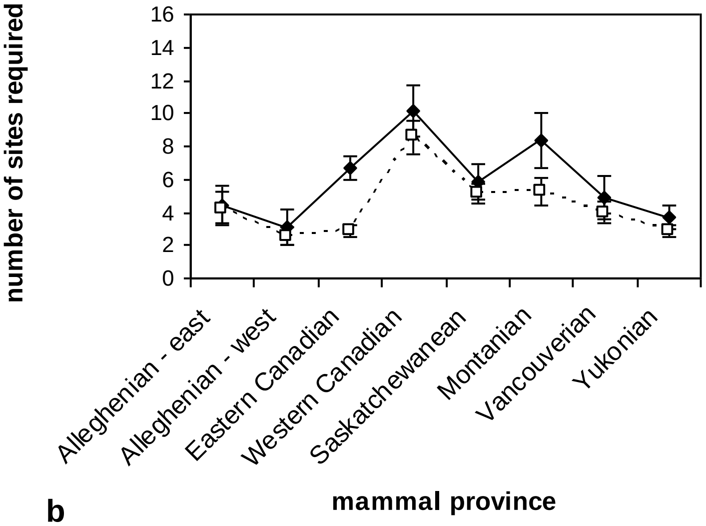
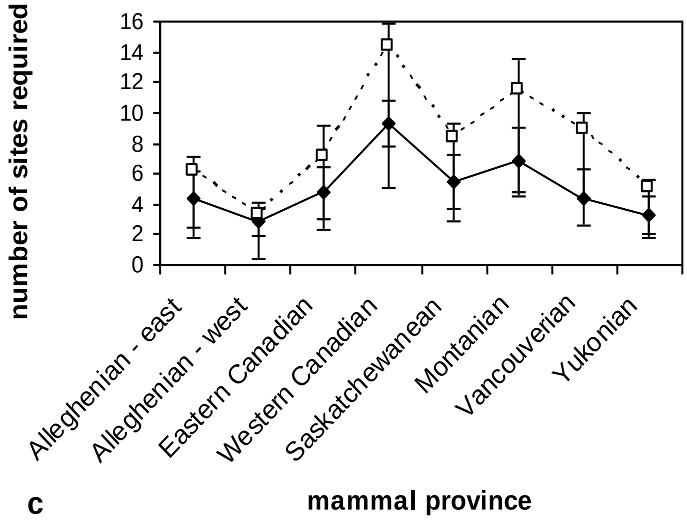
6
4
2
0
number of sites required
Allegheniam - east
Alleghenian - west
Eastern Canadian
Western Canadian
Saskatchewanean
Montanian
Vancouverian
Yukonian
mammal province

a


16
14
12
10
8
6
4
2
0
number of sites required
Alleghenian - east
Alleghenian - west
Eastern Canadian
Western Canadian
Saskatchewanean
Montanian
Vancouverian
Yukonian
mammal province

b


16
14
12
10
8
6
4
2
0
number of sites required
Alleghenian - east
Alleghenian - west
Eastern Canadian
Western Canadian
Saskatchewanean
Montanian
Vancouverian
Yukonian
mammal province

c

Figure 3.