ON THE FRACTION OF LAND NEEDED FOR PROTECTED AREAS

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SUMMARY
Estimates of the target percentage of land required to be set aside as protected have typically emphasized representation for contemporary species' distributions and natural features within political, rather than ecological, regions. Further, targets for percentage protected area, and associated reserve selection algorithms, do not generally consider the minimum size of component reserves as a design constraint. Thus, protected areas systems that meet percentage targets will not necessarily effectively promote the long-term persistence of species. We used a minimum reserve size predicted to conserve historical mammal species richness in the Canadian portion of the Allegheny-Illinoian mammal province as a design constraint to approximate criteria for species persistence, and determined the minimum fractions of land required to be set aside as protected in a representative reserve network if both representation *and* minimum area criteria had been applied *a priori* to reserve design. Minimum percentage ranged from 2 to 58%, depending on the region, selection algorithm, and how the target for achieving representation was defined.

1. INTRODUCTION
Conservation biologists have long considered "How much protected area is enough?" (e.g., 1). Many jurisdictions in Canada have adopted the so-called "12%" target, both at the federal level (2), and in the provinces of Ontario (3) and British Columbia (4). The 3rd World Congress on National Parks first set percentage targets for conservation in 1983 and reported the global percentage of land in protected areas at about 4% (5). In 1987, the Bruntland Commission (6) supported the World Congress' call to triple the global percentage of land set aside as protected. The commission also noted that, while some regions of the world had recently increased their networks, other regions, such as the tropical forests, should have as much as 20% set aside in protected areas. In Canada, Hummel (2) multiplied the 4% listed in the World Congress report by the factor of 3, to set a target of 12% of Canada's land area.

Subsequently, while some (7, 8) continue to suggest 12% as a minimum target, based largely on 'expert opinion', others yielded targets for protected areas ranging from 33 to 99%, depending on taxa and landscapes (8-12).

None of these targets, however, were prescriptive about where protected areas should be distributed across a region. Conservation targets have typically been estimated based on attempts to ensure representation of a full suite of biodiversity in protected sites (1-16) within politically bounded areas (provinces or countries). However, efficient use of limited conservation funds may require that representation be based on ecologically bounded areas, since ecoregions often span political boundaries. Additionally, percentage targets for representation rarely address issues of persistence of species within proposed protected areas (17). Our premise is that, if the goal for a system of protected areas is to *maintain* that biota which is *represented* therein, then the minimum size of a protected area must be considered as a design constraint *before* the issue of how many protected areas (of such a size) may be needed to achieve representation is considered (1, 18, 19). Thus, we asked: "What is the fraction of land that is (a) in an ecologically relevant region; (b) contained in parcels of some minimum size that might enable persistence; *and* (c) distributed to achieve full species representation?"

We estimated percentage targets for the Alleghenian-Illinoian mammal province (20) in southeastern Canada (Fig. 1). Despite that we truncated the region at the international border because of data limitations, the Canadian portion of the Alleghenian-Illinoian mammal province comprises a region based on ecological, instead of political, boundaries (1, 2). We used mammals because of the availability of data on historical distributions (21), and because of all terrestrial vertebrates and plants, mammal density is most severely affected by reductions in area of habitat (22-24). Therefore, we consider mammals as a sensitive indicator of effects of variation in habitat size, and as a potential "umbrella species group" in that regard.

Several estimates of minimum sizes of protected areas that might ensure long-term persistence of species exist, based on minimizing extinction rates (25), sizes of minimally viable populations (26-28) and dynamic processes (29). In the Alleghenian-Illinoian mammal province, Gurd et al. (30) estimated the minimum reserve area (MRA) for disturbance-sensitive mammals at 5037 km^2 (95% CI: 2700 km^2 - 13,296 km^2) (30). The MRA was derived by estimating the intersection of an historical species-area relationship with a species-area relationship based on current species richness in Canadian parks in the mammal province. The MRA was thus the threshold park size above which no mammal extinctions have been detected since widespread European settlement, even in parks presumed to have been isolated from the surrounding habitat matrix (30). This estimate of the MRA coincides well with minimum area estimates based on minimum viable population analyses for several species of large mammals (26-28). Thus, the MRA estimate represents the minimum size of a reserve below which some disturbance-sensitive mammals will almost certainly become locally extinct. A representative network comprised of individual MRA-sized protected areas may not guarantee long-term persistence of mammals, but such a network would be the first designed to address simultaneously minimum size *and* representation criteria, and thus may provide for a more robust estimate of percentage targets for conservation than currently available.

All else considered equal, if the MRA is small relative to the size of a region for which a representative protected areas system is designed, then the fraction of the region required to be protected will be small relative to the case when the MRA is large relative to the size of the region. Further, if more protected areas are needed to achieve representation, then a greater fraction of land will have to be set aside as protected, than if only a few areas are sufficient to capture the full range of species diversity.

2. METHODS

The Alleghenian-Illinoian (AI) mammal province is divided into western and eastern portions by the Great Lakes (Fig. 1), and we considered these separately in this analysis. We used ArcInfo™ Geographic Information Systems (GIS) to sample the historical range maps of disturbance-sensitive mammals (31) within the region using square plots of three sizes: the MRA (5037 km^2) and its lower and upper 95% confidence limits (2700 and 13,296 km^2) (30). Sample MRAs were replicated four times in each size class, as the shape of each region of the AI province, together with the re-orientation of the square plots, allowed for repeated sampling with minimal overlap. Once plots had been sampled for their historical species richness and composition, those that would comprise the set of reserves were selected using two heuristic algorithms (10, 32, 33) – a richest-first, and a rarest-first, greedy reserve selection algorithm. Algorithms iteratively selected plots (reserves) to maximize either richness or presence of rare species until all species were represented in at least one plot.

Figure 1. *The mammal provinces of Canada, defined as faunistically homogeneous regions (20). This study focused on the two portions of the Alleghenian-Illinoian (AI) mammal province (solid area) east (420,192 km^2) and west (121,205 km^2) of the Great Lakes.*

Two stopping rules were used with each reserve selection 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" (34)). These plots might have a lower probability of actually capturing species than plots where species ranges overlapped entirely (35).

3. RESULTS

Results for the first stopping rule are summarized in Figure 2. Across both regions in the AI province, the average percentage area necessary to capture all mammal species at least once in a reserve system ranged from 1.9% in the eastern portion of the region when the smallest MRA (2700 km^2) was used with the first stopping rule, to 58.1% in the western portion of the region when the largest MRA (13,296 km^2) was used with the second stopping rule (not shown).

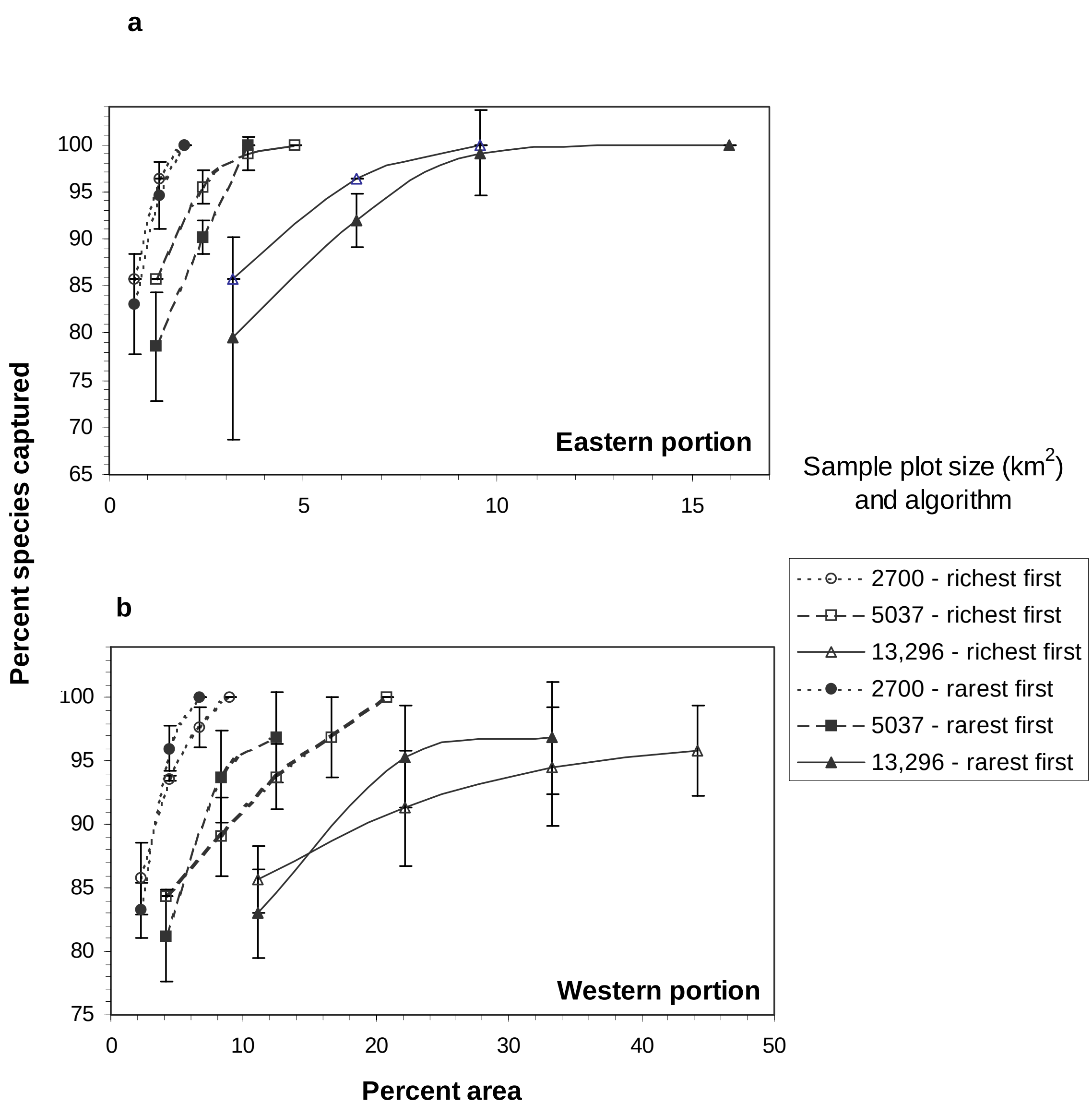

Figure 2. *Plots showing the average percentage (with standard deviations) of the total number of mammal species (n = 28 in the eastern portion and n = 32 in the western portion) captured in reserve systems as a function of percent of the region set aside as protected areas (comprised of replicates of MRA-sized plots). Analyses were run using each of three estimates of minimum reserve area (MRA) (2700 km^2 (circles/dotted line), 5037 km^2 (squares/dashed line) and 13,296 km^2 (triangles/solid line)) as a design constraint and using a richest-first (open symbols) and a rarest-first (closed symbols) greedy reserve selection algorithm for both the eastern and western portions of the Alleghenian-Illinoian mammal province. Reserve selection stopped when all species were represented at least once (100% of total species captured). In some replicates, standard deviations equaled zero, or were too small to been shown on the graphs.*

4. CONCLUSIONS

Protected area systems are to both represent *and* maintain species' assemblages, so consideration of the sizes of the individual reserves below which species are predicted to become extirpated due to the effects of habitat isolation (MRA, 30) is a critical design component. We show that the size of MRA selected strongly influences the estimate of the fraction of land area required to fully represent all of the land mammals present historically. The confidence limits around the estimate for the MRA for disturbance-sensitive mammals in the Alleghenian-Illinoian mammal province vary by an order of magnitude (30), and thus our estimates of the minimum percentage to achieve representation in this mammal province vary dramatically. Despite this, our results suggest that 3 to 6 MRA-sized protected areas are necessary to achieve representation of disturbance-sensitive mammals within either part of this ecological region.

Even if this number of protected areas to achieve representation holds for other ecological regions and taxa, the actual fraction of land area to be conserved will further depend on the size of the ecological region of interest. Moreover, it may be possible to have all species represented in even fewer areas, as greedy heuristic algorithms such as those used here may not always be the overall most efficient (36). It may be possible to identify a smaller set of reserves that are complementary to each other, which may not correspond to the most species rich, or those containing the most rare species (36).

Our results are based on the historical distributions of disturbance-sensitive mammals (31). Present-day locations of these species may be different, and thus the sites selected using the algorithms here may not conserve present-day distributions of these species. A comparison between the proposed reserve network based on our system of site selection and current distributions of species together with the locations of national and provincial parks that meet the MRA size criterion would constitute a gap analysis (37-39) that could help guide park planners and managers into selecting areas of the Alleghenian-Illinoian mammal province which would have a high probability of contributing to species conservation across the region.

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