

1 **Efficiency and effectiveness in representative reserve design in Canada: the**
2 **contribution of existing protected areas**

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16 **contribution of existing protected areas**

17
18 **Abstract**

19 To be effective, reserve networks should represent all target species in protected areas
20 that are large enough to ensure species persistence. Given limited resources to set aside
21 protected areas for biodiversity conservation, and competing land uses, a prime
22 consideration for the design of reserve networks is efficiency (the maximum biodiversity
23 represented in a minimum number of sites). However, to be effective, networks may
24 sacrifice efficiency. We used reserve selection algorithms to determine whether
25 collections of existing individual protected areas in Canada were efficient and/or
26 effective in terms of representing the diversity of disturbance-sensitive mammals in
27 Canada in comparison to (1) an optimal network of reserves, and (2) sites selected at
28 random. Unlike previous studies, we restricted our analysis to individual protected areas
29 that met a criterion for minimum reserve size, to address issues of representation and
30 persistence simultaneously. We also tested for effectiveness and efficiency using
31 historical and present-day data to see whether protected area efficiency and/or
32 effectiveness varied over time. In general, existing protected areas did not effectively
33 capture the full suite of mammalian species diversity, nor are most existing protected
34 areas part of a near-optimal solution set. To be effective, Canada's network of reserves
35 will require at minimum 22 additional areas of >2700 km². This study shows that even
36 when only those reserves large enough to be effective are considered, protected areas

37 systems may not be representative, nor were they representative at the time of
38 establishment.

39

40 Keywords: algorithms, Canada, gap analysis, mammal conservation, reserve planning

41

42 **Introduction**

43 It is well known that protected areas planning in North America and elsewhere has
44 historically been carried out on an ad hoc basis. Many of the earliest protected areas were
45 designated for their scenic, recreational, and tourism values (Runte 1997; Sellars 1997),
46 while others were designated to provide employment opportunities in impoverished
47 regions (Runte 1997; MacEachern 2001). Today, however, protected areas are assumed
48 to play an important role in preserving representative samples of ecosystem and species
49 diversity (e.g., Parks Canada Agency 2000). Recent research suggests that existing
50 protected areas do not perform well in this capacity (e.g., Pressey and Nicholls 1989;
51 Rebelo and Siegfried 1992; Saetersdal et al. 1993; Lombard et al. 1995; Pressey et al.
52 1996; Williams et al. 1996; Khan et al. 1997; Freitag et al. 1998; Jaffre et al. 1998;
53 Nantel et al. 1998; Sarakinos et al. 2001; Heikkinen 2002; Stewart et al. 2003; Branquart
54 et al. 2008). An analysis of what particular gaps exist in current protected areas networks
55 in relation to biodiversity representation can help planners identify priorities for
56 establishment of new protected areas and/or restoration of existing ones. With limited
57 resources for conservation, it is prudent to prioritize the siting of protected areas in places
58 where they will be efficient and effective (Fig. 1). In contrast to ad hoc planning for

59 protected areas, reserve selection algorithms can be used to identify sets of protected
60 areas that capture all species, communities or other biological units of interest at least
61 once within a pre-defined region (Margules et al. 1988; Pressey et al. 1996; Branquart et
62 al. 2008). The commonly used heuristic algorithms generally are based either on
63 maximizing species richness (richness-based) or the presence of rare species (rarity-
64 based) (Pressey et al. 1996). These types of approaches have recently been applied in
65 regional protected areas planning in various parts of Canada, for example in the central
66 coast of British Columbia (Gonzales et al. 2003).

67 The goal of reserve selection algorithms is to identify an efficient solution to the
68 challenge of *representation* of biodiversity within reserves; efficiency is defined as
69 achieving representation of all species with the lowest cost, often measured as the fewest
70 number of sites (e.g., Pressey and Nicholls 1989). Targets for representation within the
71 network of protected areas may include, for example, all of the species in a region, or all
72 of the variety of ecosystem types or vegetation/landform complexes (Pressey et al. 1993).
73 However, if individual protected areas within a network that is nevertheless
74 representative are too small, then the network may be rendered unrepresentative over
75 time by the loss of individual species within reserves. Thus, algorithms should also
76 include criteria that enhance species *persistence*; ensuing networks should then
77 effectively conserve *and* efficiently represent the regional diversity of species (Rodrigues
78 et al. 2000; Cabeza 2003; Kerley et al. 2003; Pressey et al. 2003; Solomon et al. 2003).

79 In Canada, Wiersma and Nudds (2006) postulated an efficient and effective
80 reserve network for representing all disturbance-sensitive mammals using individual

81 reserves that were expected to allow mammals to persist, even in the face of habitat
82 insularization. The individual reserves showed little overlap with existing protected areas
83 in Ontario (Nudds and Wiersma 2004), indicating that existing protected areas, in their
84 entirety as a network, are ineffective and/or inefficient (Rodrigues et al. 1999; Stewart et
85 al. 2003). Nevertheless, it might be that combinations of existing and new and/or
86 expanded areas, while necessarily constrained with respect to *efficiency*, (that is, result in
87 more sites than required for maximum representation), could be as *effective* in ensuring
88 persistence (Rodrigues et al. 1999). Thus, it is important to evaluate the contribution of
89 existing protected areas to the efficiency and effectiveness of reserve networks. The goal
90 of this study was to evaluate the efficiency and effectiveness of existing protected areas
91 across Canada for representation of disturbance-sensitive mammals, and where
92 necessary, identify how many additional protected areas might be necessary to achieve an
93 effective network.

94 Wiersma and Nudds (2006) used heuristic reserve selection algorithms to
95 delineate efficient and effective networks of protected areas for disturbance-sensitive
96 mammals in each of eight mammal provinces of Canada (Hagmeier 1966; Fig. 2), based
97 on both historical (Banfield 1974) and current (Patterson et al. 2003) species' ranges.
98 (Wiersma (2007a) showed that similar results are obtained when analyses are conducted
99 across other biologically-relevant regions, such as terrestrial ecozones.) The analysis of
100 species data from two different points in time allowed for a comparison of representation
101 requirements for a historical "benchmark" condition to the representation requirements at
102 present. The first resulted in estimates of where protected areas might have been

103 optimally located prior to widespread European settlement, and the second identified
104 optimal sites that account for species range shifts that may have occurred during the
105 intervening years. Both solutions were comprised of proposed protected areas that met a
106 minimum reserve area (MRA) criterion for mammals, and thus species are expected to
107 persist within them (Gurd et al. 2001). Here, we build on this work by assessing how well
108 existing protected areas represent mammals compared to these optimal networks.

109 Instead of a simple contrast of the optimal sites in the proposed networks with
110 existing MRA-sized protected areas, we “seeded” the algorithms with the existing
111 protected areas that were sufficiently large to allow for long-term species persistence, and
112 then identified where additional minimally-sized protected areas (if any) should be
113 located to represent all species in each mammal province. If the existing suite of
114 protected areas is an efficient (or nearly-efficient) *and* effective network for meeting
115 representation targets in each mammal province, then there should be no difference in the
116 number of protected areas required in the optimal network when existing protected areas
117 are included, compared to the proposed optimal network when they are excluded.
118 Further, if existing protected areas are an important component of near-optimal solutions
119 to representation, then even in cases where more protected areas might be needed, these
120 should be fewer than the number required to represent species when existing protected
121 areas are excluded from the algorithms. This is the case observed with a representative
122 protected areas analysis for reptiles and amphibians in north eastern India (Pawar et al.
123 2007). However, given the historical documentation attesting that establishment of many
124 national and provincial parks was motivated by scenic, recreation, and economic values

125 (Runte 1997; Sellars 1997; MacEachern 2001), we expected that existing protected areas
126 would not necessarily contribute parts of an efficient solution to effective biodiversity
127 representation. Other regions globally have shown a bias to over-representation of high
128 altitude habitats (Oldfield et al. 2004; Martinez et al. 2006) and less populated areas
129 (Sarakinis et al. 2001). Evidence in Canada of a bias towards large protected areas at
130 northern latitudes (Rivard et al. 2000), and historical and anecdotal evidence that many
131 parks were located in areas with high scenic value (and not necessarily high ecological
132 value), lead us to expect that existing protected areas may not even be effective, let alone
133 efficient.

134

135 **Methods**

136 *Target regions and mammal data*

137 Analysis was carried out in ecologically defined target regions (mammal provinces) in
138 Canada (Fig. 2). The Alleghenian-Illinoian mammal province in Canada spans east and
139 west of the Great Lakes and so was analyzed as two provinces. The Saskatchewanean
140 mammal province did not include any existing MRA-sized protected areas and was
141 excluded, yielding a total of seven mammal provinces for analysis. Northern mammal
142 provinces were excluded because of low mammalian diversity. Historical data on
143 mammal distributions were obtained from Banfield's Mammal Atlas of Canada (Banfield
144 1974), which represents the ranges of disturbance-sensitive mammals prior to widespread
145 European settlement. Recent atlas data (Patterson et al. 2003) were used to account for
146 those species whose ranges may have contracted or expanded in response to human-

147 induced habitat changes. Only those species defined by Glenn and Nudds (1989) as
148 sensitive to human disturbance (sensu Humphreys and Kitchener 1982) were included in
149 the analysis, as disturbance-insensitive mammals (e.g., racoons, coyotes) were deemed
150 not to be a high priority for protection from anthropogenic landscape change.

151

152 *Existing protected areas data*

153 Data on existing protected areas were obtained from the North American Conservation
154 Areas Database (NCAD) and Canadian Conservation Areas Database (CCAD), available
155 online from the Canadian Council on Ecological Areas (www.ccea.org). We also
156 assembled polygon coverages of national and provincial parks for use in a GIS from a
157 Government of Canada website (source: www.geogratis.gc.ca). The NCAD and CCAD
158 data sets included spatially referenced points identifying the location and attributes of all
159 protected areas. We selected those areas in IUCN class I-VI (national, provincial, and
160 territorial parks, as well as wildlife management areas, game preserves, and biosphere
161 reserves; hereafter referred to as “existing protected areas”). Only those areas that met or
162 exceeded the lower 95% confidence interval for the minimum reserve area (MRA)
163 estimate (i.e., > 2700 km²; Gurd et al. 2001) were used in the analysis ($n = 29$). We used
164 the total protected area published in the above databases. Thus we considered the total
165 area as the MRA threshold, even though in some cases, the non-habitat areas (built
166 infrastructure and unsuitable habitat) might push the effective size of the protected area
167 below the MRA (e.g., Wiersma et al. 2004). Time and data constraints did not allow us to
168 measure effective area of all 29 sites, nor did Gurd et al. (2001) use effective area in their

169 analysis. Thus, we are confident that the MRA threshold is reasonable as a *minimum size*
170 criterion for effective protected areas. However, there will be some variation in the
171 effectiveness of the individual protected areas in meeting conservation goals. This
172 variation will be due in part to management strategies, amount of visitation, external
173 ecological stressors, etc. Although IUCN categories classify on strength of protection,
174 they do not comment on management effectiveness (CCEA 2008), and thus, we have not
175 attempted to further classify the existing protected areas based on conservation
176 effectiveness. Given the variation in effectiveness, it is possible that additional protected
177 areas may be required.

178

179 *Heuristic reserve selection*

180 Following Wiersma and Nudds (2006), we ran rarity-based heuristic algorithms on the
181 candidate MRA plots in each mammal province, but “seeded” each of the runs (three
182 replicates each of three MRA size estimates) with existing protected areas for a total of
183 nine runs per mammal province. MRA estimates (2700 km², 5000 km², 13,000 km²) were
184 based on values determined from analysis of disturbance-sensitive mammals in Canada
185 (Gurd et al. 2001). We did not discriminate between existing protected areas above the
186 larger thresholds because previous work (Wiersma and Nudds 2006) suggests that
187 variation in the “grain” (i.e., above the minimum 2700 km² MRA size as estimated by
188 Gurd et al. (2001)) of the analysis does not vary the number of sites in the optimal
189 solution. We included runs using the larger MRA sizes to boost the number of replicates
190 for comparison to the existing network. Restricting the protected areas used to “seed” the

191 algorithms to those above the 5000 km² and 13,000 km² thresholds would have
192 minimized the difference between sites needed when existing protected areas were
193 included or excluded, since there are fewer existing protected areas above the larger
194 MRA thresholds. Ultimately, we are interested in the contribution of existing protected
195 areas that meet the minimum MRA threshold, thus all existing protected areas >2700 km²
196 were included in all runs. Mammalian species richness within each mammal province
197 was compared to the aggregate species composition of the existing protected areas within
198 that province to identify which species were not yet represented. Additional sites needed
199 to capture each species at least once were identified using a rarity-based heuristic reserve
200 selection algorithm (Margules et al. 1988; Pressey et al. 1993). Additional sites were
201 selected iteratively, prioritizing those with species with the smallest extent of occurrence.
202 Reserves were selected and added to the system until all species were represented at least
203 once in a reserve.

204

205 *Comparison with the optimal reserve network*

206 Within each mammal province, the reserve network generated after “seeding” with
207 existing protected areas was compared to the results of nine runs that generated the
208 optimal reserve network without existing protected areas (Wiersma and Nudds 2006).
209 Network efficiency (total number of protected areas needed to represent all disturbance-
210 sensitive mammals at least once in the network) with and without existing protected areas
211 was compared with Student’s t-test (Zar 1999).

212 To compare the effectiveness of existing protected areas to that of the optimal
213 network within each mammal province, species-accumulation curves for the optimal
214 network and the existing protected areas were constructed. Curves were plotted in the
215 order in which the optimal sites were selected, and the chronological order in which the
216 existing protected areas were established, respectively. To test whether either resulted in
217 more effective networks than random site selection, curves based on equivalent numbers
218 of random sites as in each optimal set ($n = 9$) were compared. More effective networks
219 should represent a higher number of disturbance-sensitive mammals for a given number
220 of sites than less effective ones.

221

222 **Results**

223 The number of existing protected areas in each mammal province deemed sufficiently
224 large for persistence of mammal diversity ranged from 1-10; no existing sets of reserves
225 in any mammal province captured the full range of mammal diversity. Existing protected
226 areas captured between 57-94% of the total historical species richness in each province
227 and between 68-99% of the total modern-day species richness in each mammal province
228 (Fig. 3). Between 1 and 7 additional MRA-sized sites (for a total of ~22 across all
229 mammal provinces) were required to represent all mammals at least once in each network
230 within a mammal province when the analysis was applied to the historical distribution
231 data (Table 1), and between 0 and 7 (for a total of ~23 across all mammal provinces)
232 additional plots had to be added when the analysis was applied to the modern distribution

233 data (Table 2). Numbers of protected areas required in reserve systems were significantly
234 higher when existing protected areas were included in all cases (Tables 1&2).

235 Effectiveness of optimal, existing, and random sets of sites was similar only in the
236 western portion of the Alleghenian mammal province (Fig. 4b), likely due to the small
237 size of this province, and hence the small number of candidate plots, compared to the
238 other mammal provinces. In all other mammal provinces, neither existing protected areas
239 nor random sets of the same number of sites were 100% effective (Fig. 4a, c-g). Of six
240 mammal provinces with more than one existing protected area, those areas were more
241 effective than sites selected at random in three cases: eastern Alleghenian (Fig. 4a),
242 Eastern Canadian (Fig. 4c), and Western Canadian (Fig. 4d). Effectiveness differed little
243 between existing protected areas and random sites in the western Alleghenian (Fig. 4b)
244 and the Yukonian (Fig. 4g); existing protected areas were less effective than sites selected
245 at random in the Montanian mammal province (Fig. 4e).

246 With respect to the location of sites identified by reserve selection algorithms
247 when existing protected areas were included and excluded, two additional patterns were
248 examined. The location of optimal sites with and without the inclusion of existing
249 protected areas was examined to see whether it differed when existing protected areas
250 were included. In the majority of cases, the same optimal locations were identified for
251 inclusion in the representative network when protected areas were included and excluded
252 from the analysis. In addition, optimal sites were overlaid with existing protected areas
253 that fell below the MRA threshold; the optimal sites overlapped with 540 existing smaller
254 protected areas (table available in the supplementary data online).

255

256 **Discussion**

257 As expected, existing large protected areas in Canada do not represent the full suite of
258 disturbance-sensitive mammals, and thus function as parts of neither effective nor
259 efficient networks. Interestingly, existing protected areas did a slightly better job of
260 representing the modern species assemblage than the historical one (Fig. 2). This may be
261 due to the fact that some of the more recently-established protected areas were designated
262 for conservation of a specific species, or were established with ecological values, rather
263 than scenic or economic values in mind. Certainly some of the protected areas in the
264 latter half of the twentieth century attempted to represent ecosystems other than the
265 scenic mountain ranges that were the focus of the earliest sites (Runte 1997; Sellars
266 1997).

267 In three mammal provinces, existing protected areas were either less, or no more,
268 effective than sites selected at random. Significantly more protected areas were required
269 to achieve full representation in each mammal province when the algorithms included the
270 existing protected areas. Thus, inclusion of existing protected areas decreases the
271 efficiency of a reserve network relative to when they are excluded, at least with respect to
272 representing mammalian diversity.

273 The locations for optimal sites did not differ in the majority of cases when
274 protected areas were included and excluded from the network. This suggests that when
275 considered in combination with the optimal sites, existing protected areas are almost
276 completely redundant with respect to mammalian diversity. That is, the optimal sites

277 appear to have high irreplaceability (sensu Ferrier et al. 2000), perhaps because they
278 contain unique species not found in any of the existing protected areas.

279 Protected areas might be rendered redundant when considered in combination
280 with the optimal sites due to the historical motivations for protected areas designation.
281 The median year of establishment for the existing protected areas is 1975 (mean year of
282 establishment: 1960), which is well before the concept of minimum representation and
283 reserve selection algorithms first appeared in the literature in the early 1980s (Kirkpatrick
284 1983). Thus, the majority of the protected areas were not designated with the goal of
285 biodiversity representation in mind. Certain features of the landscape (such as mountain
286 ranges in the western mammal province) are over-represented, while other features (such
287 as prairie ecosystems) are not captured. In Europe, representation and design criteria for
288 protected areas were developed in the 1980s and onwards. A recent survey there showed
289 that land managers and practitioners often are unaware of systematic approaches for
290 reserve selection or can not or will not apply them because of data, time and resource
291 constraints, scepticism about their effectiveness, or lack of coordination at a policy level
292 (Branquart et al. 2008).

293 A similar comparison of existing protected areas to an optimum set in Québec
294 yielded similar results. The Québec study examined representative sites for 394 species at
295 risk (both flora and fauna) in candidate plots that were 65-80 km² (Sarakinis et al. 2001).
296 The remote northern part of the province was over-represented and areas in the south
297 were under-represented (Sarakinis et al. 2001). These results are not unique to Canada.
298 Low elevation areas were under-represented, and high elevation areas over-represented,

299 by protected areas in England (Oldfield et al. 2004). However, a reserve network which
300 over-represented high elevation areas in Spain nevertheless adequately represented
301 threatened lichen species confined to high-elevation forests (Martinez et al. 2006).
302 However, even where there is a relatively high proportion of a protected area,
303 representation may not be adequate (Tognelli et al. 2008). Over 20% of the Chile's land
304 area is set aside for conservation, yet a recent study found 13% of terrestrial vertebrates
305 were unrepresented and approximately 45% were under-represented in the current
306 assemblage of protected areas. When the analysis included proposed protected areas,
307 which were selected based on expert scientific opinion, there was still a significant
308 number of vertebrate species unrepresented (Tognelli et al. 2008).

309 Results of other studies which measured the overall effectiveness of existing
310 protected areas at representing biodiversity elements, are similar to ours. Pawar et al.
311 (2007) examined representation of reptiles and amphibians in India and found that they
312 were not adequately represented in existing protected areas in India. They similarly
313 “seeded” algorithms with existing protected areas, but found that fewer additional
314 reserves were required for adequate representation than when existing protected areas
315 were not included (Pawar et al. 2007). In Finland, existing protected areas contributed
316 significantly to the network, although there was a gap in representation of certain types of
317 forests along waterways, which sometimes contained regionally rare species (Heikkinen
318 2002). Thus, it appears that worldwide, protected areas do make contributions to
319 biodiversity representation, but that no matter what the target organism or ecosystem

320 analysed, there appear to be gaps in the system and additional protected areas are
321 necessary to have effective biodiversity representation.

322 Many of the optimal sites for representing mammals in Canada are located near
323 borders of mammal provinces consistent with an “edge effect” (greater diversity in
324 transition zones between ecologically defined regions) of biogeographical proportions as
325 noted by others (Glenn 1990; Araújo and Williams 2001; Gaston et al. 2001). Thus, the
326 presence of optimal sites on both sides of the boundary of a mammal province might in
327 fact render either one of them redundant from the perspective of efficiency and
328 effectiveness. For example, Wiersma (2007b) completed an analysis of the minimum
329 representative set for these data at a larger extent, with all mammal provinces combined,
330 and identified which transition zones should be designated as priority areas for
331 biodiversity representation. However, it is debated whether to site protected areas along
332 transition zones (Araújo 2002). Alternatively, it may be more appropriate to disregard
333 arbitrary regional boundaries (political or ecological) altogether and to instead use
334 patterns in species distribution to assist in identification of representative sites (Wiersma
335 and Urban 2005; Gove et al. 2008). If “edge effects” are taken into account, and
336 redundancies in representative protected areas are eliminated, then the existing suite of
337 protected areas may be rendered relatively less effective than under the current analysis.

338 Sites identified as parts of near-optimal solutions using the heuristic algorithms
339 overlapped with 540 existing protected areas that are smaller than the minimum reserve
340 area (MRA) estimate. Thus, a prudent management strategy might be to expand the
341 boundaries of these sites and or establish/maintain connectivity around them to bring

342 their size at least to the estimated lower threshold of MRA (i.e., 2700 km²; Gurd et al
343 2001).

344 Across Canada, it appears that the existing protected areas that are large enough to
345 conserve mammals are generally not located in the places where they can efficiently or
346 effectively represent the diversity of mammals in each region. That they are not located
347 in the most efficient locations based on historical data may not be surprising, given that
348 many protected areas were established after much of the landscape had been altered by
349 widespread European settlement. However, neither are they optimally located with
350 respect to the modern distributions of mammals. If representation of all species in each
351 mammal province is a policy goal, then the results of heuristic algorithms such as the
352 ones described here may be useful to identify locations where protected areas should be
353 established (or in the case where small protected areas exist, where they can be
354 expanded) to efficiently create an effective representative network of protected areas
355 expected to enable the persistence of species in them.

356

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367

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515

516 **Figure and Table Captions**

517

518 **Table 1.** Number of additional MRA-sized protected areas needed to capture all
519 mammals in at least one protected area, derived by applying the rarity-based algorithm to
520 the historical data. Results are shown when existing MRA-sized protected areas are
521 excluded and included in the minimum set. Values reported are the mean from 3
522 replicates of 3 MRA estimates (total 9 replicates). Significance was tested using
523 Student's t-test (Zar 1999).

524

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

531

532 **Figure 1.** Illustration of the concepts of *efficiency* and *effectiveness*. Efficiency is larger
533 when the number of sites in the protected areas network is smaller. Maximum efficiency
534 is obtained by the minimum set. Effectiveness is a measure of how close a protected areas
535 network is to attaining the representation target. Thus efficiency is measured based on the
536 size of the network (x-axis), while effectiveness is measured based on the performance of

537 the network relative to the representation target (y-axis). (Figure and caption adapted
538 from Rodrigues et al. 1999).

539

540 **Figure 2.** The mammal provinces of Canada (Hagmeier 1966). For this study, the Eastern
541 and Western Hudsonian, the Ungavan, and the Eastern Eskimoan mammal provinces
542 were excluded as they have low mammalian diversity. The Saskatchewanian mammal
543 province was excluded because it did not contain any large protected areas. The western
544 portion of the Alleghenian mammal province was analyzed separately, and the eastern
545 portion of the Alleghenian mammal province was combined with the Illinoian.

546

547 **Figure 3.** Effectiveness of existing protected areas. The number of protected areas in
548 each mammal province is given in parenthesis on the x-axis. Effectiveness is expressed as
549 a percentage of the total species richness of mammals in each mammal province based on
550 historical (grey bars) and modern-day (hatched bars) species data.

551

552 **Figure 4.** Species accumulation curves generated from modern species' distribution data
553 for: optimal sites (closed squares, thick lines) selected via a rarity based-heuristic
554 algorithm; existing protected areas (open squares, dashed lines) selected in chronological
555 order; and a random sample of sites (open triangles, thin lines) in the mammal provinces
556 of Canada. **a.** Alleghenian (eastern portion) **b.** Alleghenian (western portion) **c.** Eastern
557 Canadian **d.** Western Canadian **e.** Montanian **f.** Vancouverian **g.** Yukonian

558

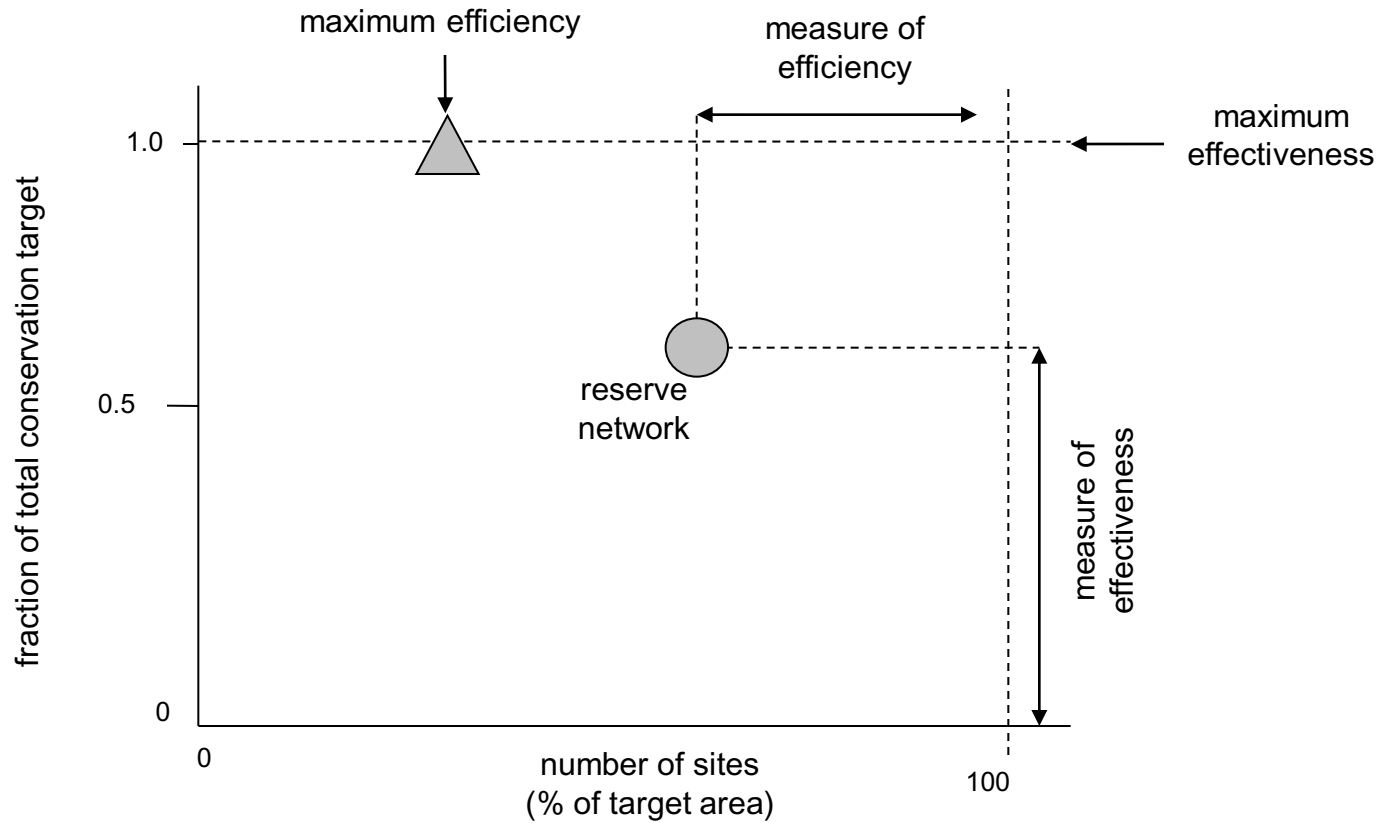
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Table 1

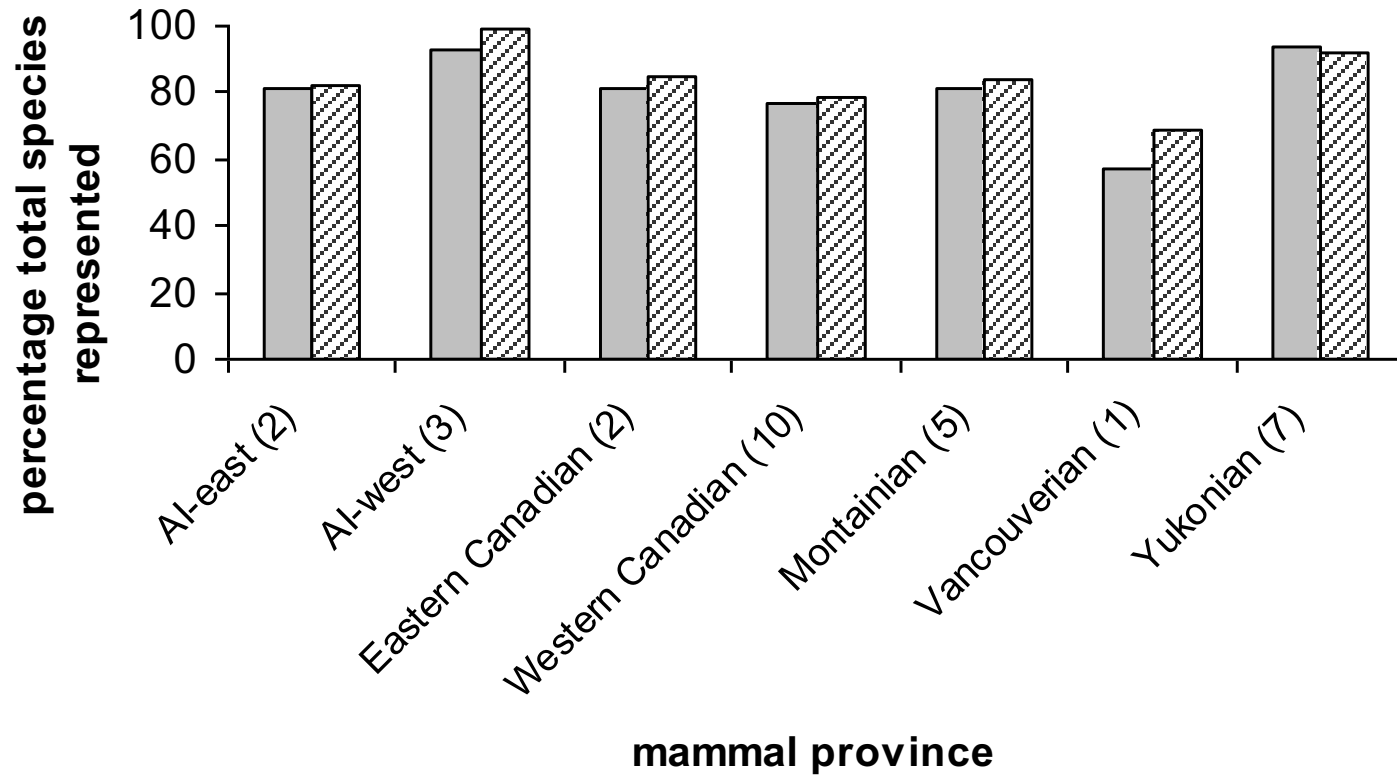
Mammal province	Mean number of sites needed based on rarity-based algorithms (n = 9 runs)	Number of MRA-sized protected areas	Mean number of additional sites needed (n = 9 runs)	Mean number of sites needed including existing protected areas (n = 9 runs)	Difference between number of sites with and without 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

Table 2

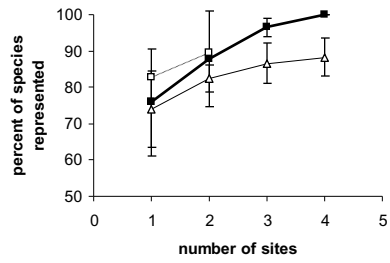
Mammal province	Mean number of sites needed based on rarity-based algorithms (n = 9 runs)	Number of MRA-sized protected areas	Mean number of additional sites needed (n = 9 runs)	Mean number of sites needed including existing protected areas (n = 9 runs)	Difference between number of sites with and without existing protected areas	
					t	p
Allgehenian-Illinoian (eastern)	3.00	2	2.67	4.67	7.07	<0.001
Alleghenian-Illinoian (western)	2.11	3	0.22	3.22	5.55	<0.001
Eastern Canadian	3.11	2	2.22	4.22	6.03	<0.001
Western Canadian	6.33	10	4.33	14.33	33.94	<<0.001
Montanian	6.11	5	4.22	9.22	11.94	<0.001
Vancouverian	3.44	1	3.33	4.33	8.00	<0.001
Yukonian	3.00	7	1.78	8.78	26	<<0.001



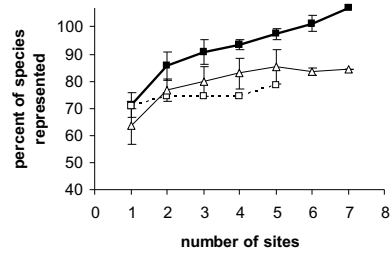




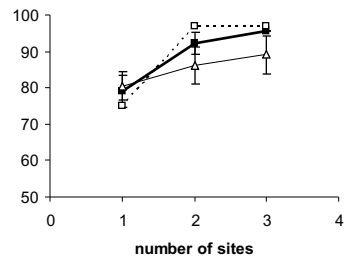
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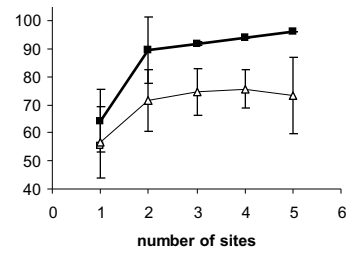
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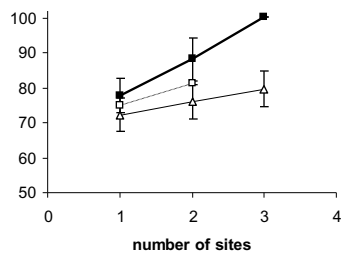
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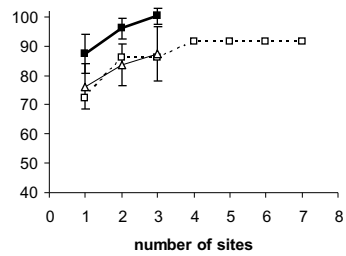
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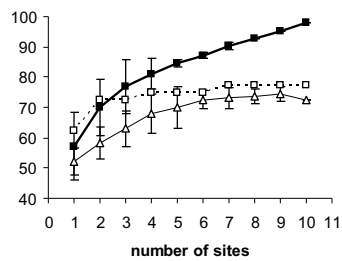
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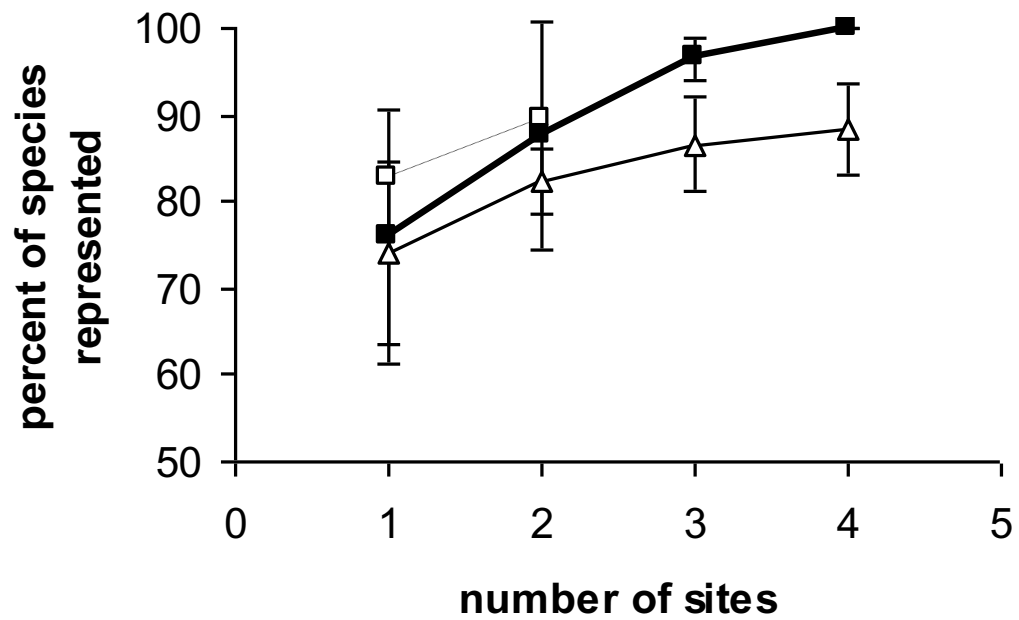
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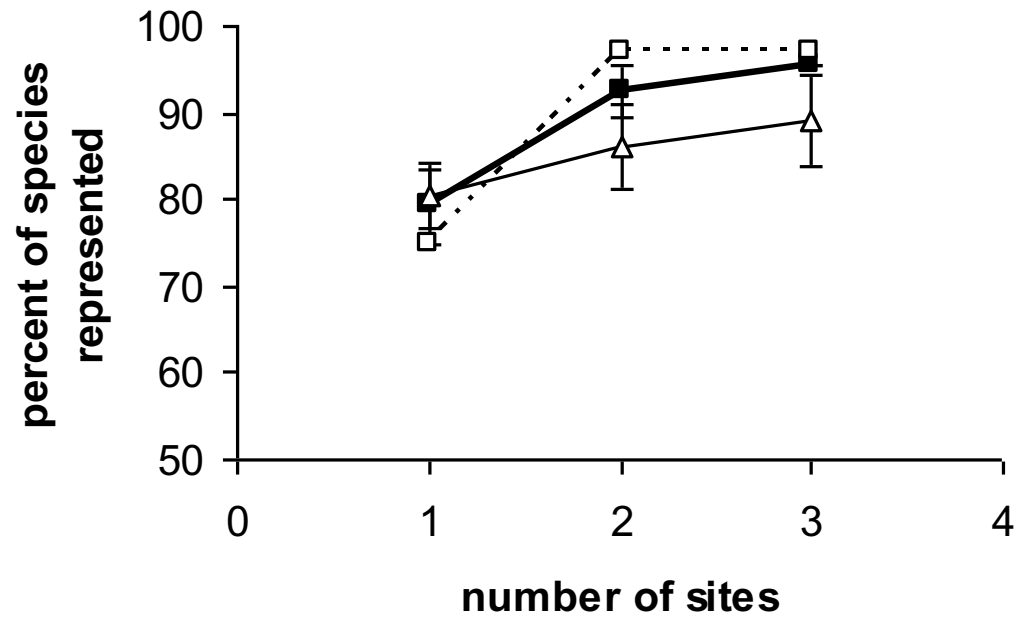
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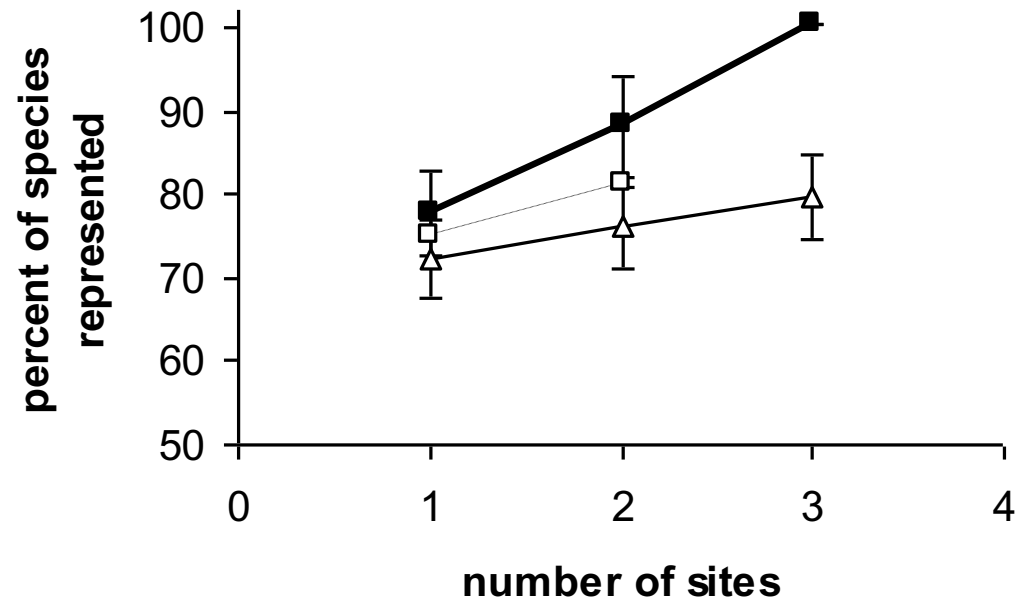
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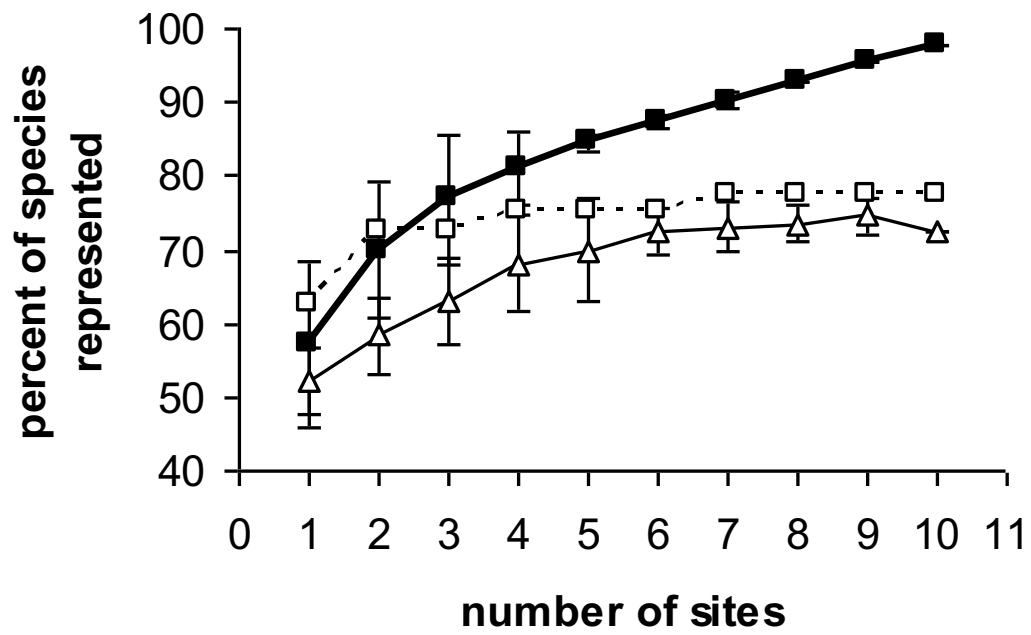
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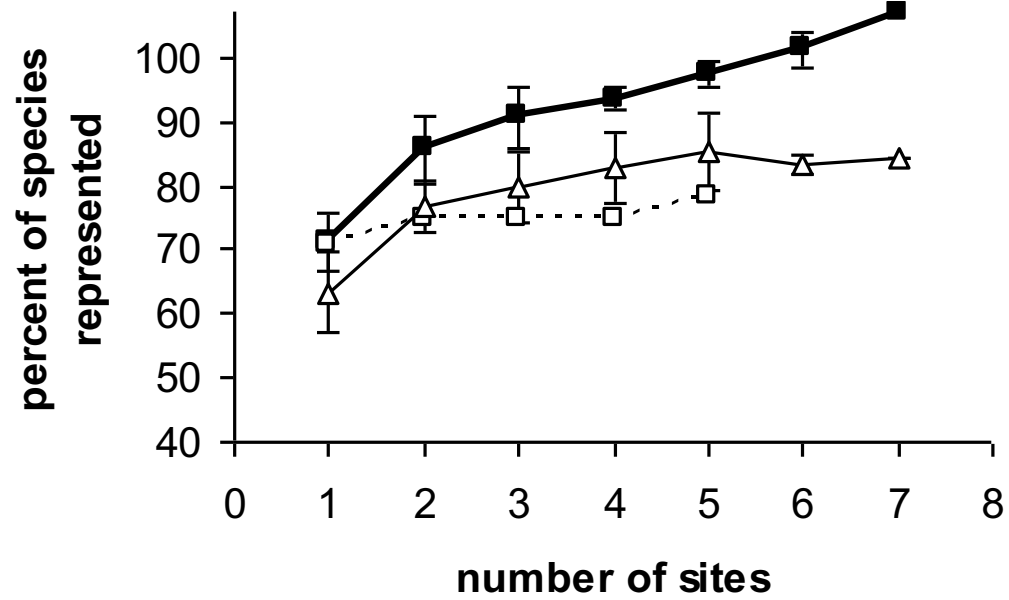
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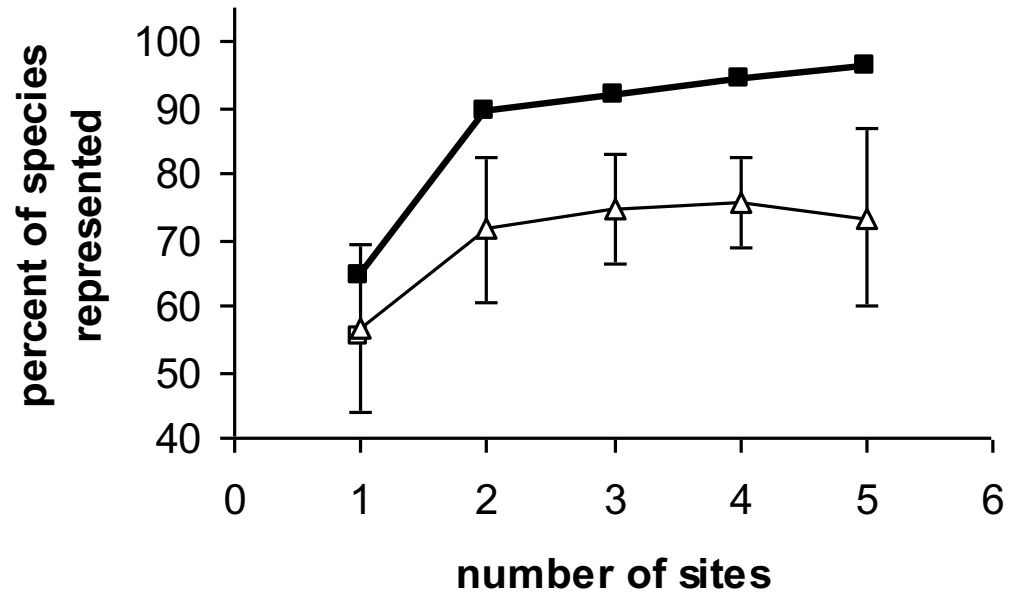
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