

The effect of target extent on the location of optimal protected areas networks in Canada

Yolanda F. Wiersma

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9 **Abstract** Various jurisdictions in Canada are
10 currently undertaking, or have recently completed,
11 planning exercises as part of implementation and
12 expansion of representative reserve networks (net-
13 works of provincial parks, national parks, ecological
14 reserves, etc.). These exercises have resulted in
15 recommendations to governments about which areas
16 of land should be set aside as protected areas, and
17 different levels of government have been involved in
18 the process of land acquisition. In some cases, planning
19 exercises have included implementation of new pro-
20 tected areas to complement existing reserve networks.
21 Many of these exercises have applied principles such
22 as complementarity, using heuristic algorithms that are
23 well-described in the literature. These planning exer-
24 cises may be conducted within politically or ecolog-
25 ically bounded target regions of varying extents. Here,
26 I develop candidate locations for representative
27 reserve areas for disturbance-sensitive mammals
28 across Canada. I use ecologically bounded regions
29 (within the national boundaries of Canada) at three
30 different levels of spatial hierarchy: mammal prov-
31 incies, ecozones, and ecoregions. I show that the extent

of the target region has an effect on the minimum
number of protected areas required to achieve repre-
sentation; a larger region requires fewer protected
areas than the sum of the protected areas required
to represent its component regions at a lower level of
spatial hierarchy. The results illustrate that selection of
sites for inclusion in a reserve network is highly scale-
dependent, and different spatial extents in the target
regions may introduce inefficiencies or redundancies
in selecting representative protected areas.

Keywords Ecoregions · Ecozones · Protected
areas · Representative networks · Redundancy ·
Reserve location · Scaling · Spatial scale

Introduction 46

Designs for representative protected areas networks
within target regions consist of goals for including
(representing) a given number of species or land
cover types from the target region within the
protected areas system. For the purposes of this
paper “representative protected areas networks” refer
to networks or systems of protected areas that are
designated by an agency to be representative of
regional biodiversity, that is, the protected areas
within the system/network will protect key examples
of species, landforms, and natural communities that
are found within the wider region. This research
focuses on the process of selecting sites that are

A1 Y. F. Wiersma
A2 Department of Integrative Biology, University of Guelph,
A3 Guelph, ON, Canada N1G 2W1

A4 Y. F. Wiersma (✉)
A5 Department of Biology, Memorial University
A6 of Newfoundland, St. John's, NL, Canada A1B 3X9
A7 e-mail: ywiersma@mun.ca

60 representative and which should be included in a
 61 proposed network. The “target region” in which
 62 representative protected areas are selected can vary,
 63 and is largely dependent on the political jurisdiction
 64 of the agency responsible for selecting and imple-
 65 menting protected areas. Thus, a target region can be
 66 politically bounded (state, province, country, and
 67 even continent), or within an ecologically defined
 68 region (ecozone, ecoregion) within a politically
 69 bounded region. For example representative pro-
 70 tected areas planning has been undertaken as part of
 71 systems planning across ecological regions of Canada
 72 (Parks Canada 1997). In some cases, regional plan-
 73 ning is linked to planning at national and even
 74 continental extents, such as with Europe’s EECON-
 75 ET program (Jongman 1995). Researchers have
 76 focused mainly on methods to select representative
 77 areas (e.g., Margules et al. 1988; Pressey et al. 1993),
 78 as well as on methods to ensure species persistence
 79 within representative networks (Cowling et al. 2003a;
 80 Kerley et al. 2003; Pressey et al. 2004). Relatively
 81 little attention has been paid to the effect of varying
 82 the size of the target region on the number of
 83 protected areas required within it to achieve a given
 84 level of representation, what research has been done
 85 has focused on varying the extent within geopolitical
 86 target areas, and not ecologically defined ones (e.g.,
 87 Pressey and Nichols 1989; Erasmus et al. 1999;
 88 Rodrigues and Gaston 2002).

89 A recent synthesis in *Landscape Ecology* suggests
 90 that some of key issues for the field in the twenty-first
 91 century include integration between research and
 92 application as well as increased outreach and
 93 communication with the public and decision makers
 94 (Wu and Hobbs 2002). Research about developing
 95 representative protected areas networks represents an
 96 avenue in which these issues are particularly relevant.
 97 Because of the inherent practical nature involved with
 98 protected areas design and planning, the research that
 99 has been carried out is often trans-disciplinary (*sensu*
 100 Tress et al. 2006), involving conservation and wildlife
 101 biologists, landscape ecologists, geographers, and
 102 social scientists (e.g., Lunney et al. 1997; Danby
 103 and Slocombe 2005; Margules et al. 2002). Moreover,
 104 such research represents a direct link between
 105 research and application, and generally involves
 106 participation with planners, managers, the public
 107 and politicians (e.g., Noss et al. 2002; Cowling et al.
 108 2003b).

Concepts of scale and scaling

109

The synthesis by Wu and Hobbs (2002) also
 110 described research priorities as identified by a panel
 111 of distinguished landscape ecologists, one of which is
 112 the issue of scaling. Scale issues are well understood
 113 among landscape ecologists, but the vast majority of
 114 the published papers on representative protected areas
 115 network design do not explicitly address issues of
 116 scale and scaling. Wu and Li (2006) provide a
 117 concise overview of the concept of scale and describe
 118 scale in terms of dimensions (e.g., space, time, and
 119 organizational level), kinds (e.g., intrinsic, observa-
 120 tional, and experimental), and components of scale.
 121 The aspects of scale within Wu and Li’s (2006)
 122 conceptual framework which are most germane to
 123 this study are the components of scale, specifically
 124 those most familiar to landscape ecologists; *grain*,
 125 defined as “the finest level of spatial resolution
 126 possible within a given data set” (Turner et al. 2001:
 127 29); and *extent*, defined as the “size of the study
 128 area...under consideration” (Turner et al. 2001: 29).
 129 Variation in either (or both) grain and extent has been
 130 demonstrated to have an effect on many different
 131 phenomena in landscape ecological research (Wiens
 132 1989; Wu et al. 2006), but the effect on representative
 133 protected areas networks has not been examined
 134 closely.
 135

Scaling examines whether and how information
 136 can be extrapolated across scales or between levels of
 137 organization (Wu 1999). Ecologists have long
 138 recognized that many systems are hierarchically
 139 structured, and suggest that relationships between
 140 levels within a hierarchy might be used to extrapolate
 141 patterns observed at one or more scales up or down
 142 different levels of spatial hierarchy (Urban et al.
 143 1987; Wu 1999). For example, many ecological
 144 landscape classification systems are hierarchically
 145 structured, beginning with broad units at large
 146 extents, such as biomes or ecozones. Within these,
 147 the landscape may be further subdivided based on
 148 finer-resolution data into classification units such as
 149 ecoregions, ecodistricts, and ecotypes (e.g., O’Neill
 150 et al. 1986; Ecological Stratification Working Group
 151 1996). In an overview of his hierarchical patch
 152 dynamics paradigm, Wu (1999) points out that
 153 ecological patterns and processes at one level in the
 154 hierarchy may not necessarily be the same at levels of
 155 hierarchy above and below it. Thus, in terms of
 156

157 planning for representative protected areas within
158 ecologically defined target units, plans at the ecodis-
159 trict level may not necessarily “scale up” to match
160 plans conducted independently at the level of the
161 ecoregion or ecozone.

162 Here, I examine how issues of scale and scaling
163 may affect the selection of representative protected
164 areas in Canada. A few studies have explicitly
165 examined how spatial scale affects delineation of
166 representative protected areas networks, but these
167 have either focused either on the effect of varying the
168 grain size (spatial resolution of data and/or size of
169 planning units) in the analysis (e.g., Kunin 1997;
170 Rouget 2003; Wiersma and Nudds 2004, 2006), or on
171 varying the extent of the target region (e.g., Pressey
172 and Nichols 1989; Erasmus et al. 1999; Rodrigues and
173 Gaston 2002), but not both. A review of the literature
174 on scale issues and protected areas design yielded
175 only one paper (Pressey and Nicholls 1989) that
176 addresses the issue of scaling within hierarchically
177 structured ecological target units, but independently
178 of an examination of the effects of variation in grain.

179 Scale issues and selection of representative
180 protected areas

181 Varying the size of the planning units (i.e., the grain)
182 on the selection of representative protected areas in
183 Canada has been shown to have little effect on the
184 number of protected areas required to represent
185 disturbance-sensitive mammal species within the
186 mammal provinces (Hagmeier 1966) of Canada,
187 when the planning unit size varied between 2,700
188 and 13,000 km² (Wiersma and Nudds 2004, 2006).
189 Similarly, Kunin (1997) found that spatial patterns
190 were scale-invariant at grain sizes ranging from 2 to
191 50 km² when modeling protected areas using Euro-
192 pean and British floral atlas data. However, Rouget
193 (2003) showed that the number of protected areas
194 varied when broad scale (3,900 ha planning units)
195 and fine scale (252 ha planning units) data were used
196 for conservation planning in the Agulhas Plain in
197 South Africa, although representation efficiency (i.e.,
198 the total amount of land required for inclusion in
199 protected areas) was similar.

200 To examine the effects of variation in spatial
201 extent, Pressey and Nicholls (1989) subdivided a
202 geopolitical unit (Western Division of New South
203 Wales) into ecologically defined regions, subregions,

204 and provinces (based on geology, vegetation and
205 rainfall). They conducted reserve selection algorithms
206 at different levels of spatial hierarchy, and found that
207 more than twice as many sites were needed in the
208 geopolitical unit when it was subdivided into regions
209 and subregions, than when the Western Division as a
210 whole was considered as a target region (Pressey and
211 Nicholls 1989). In a similar study, Erasmus et al.
212 (1999) looked at minimum representation require-
213 ments for mammals within four provinces in South
214 Africa, and across all four provinces combined. They
215 found that three times as many sites were needed in
216 the within-province analysis than in the across-
217 province analysis (Erasmus et al. 1999). Erasmus
218 et al. (1999) also showed that the sites identified
219 across provinces did not coincide with those selected
220 within-provinces. Rodrigues and Gaston (2002)
221 examined the effect of varying the extent of the
222 geopolitical target region and found that subdividing a
223 geopolitical region (i.e., a country) into smaller
224 geopolitical units (i.e., provinces) increased the num-
225 ber of sites required to represent bird species by over
226 ten times. However some of this may be due less to the
227 effects of scale, but rather to the fact that politically
228 bounded areas are often irrelevant from an ecological
229 perspective. Indeed, Rodrigues and Gaston (2002)
230 demonstrated that using geopolitical units as target
231 regions in which to implement representative pro-
232 tected areas resulted in the creation of “apparently
233 rare” species; species whose ranges were just within a
234 political unit, or which were vagrants or introductions,
235 but which had widespread distribution elsewhere.
236 These apparent rarities had a disproportionate influ-
237 ence on the selection of representative sites to be set
238 aside as representative conservation areas (Rodrigues
239 and Gaston 2002). Thus, it appears from these studies
240 that representative protected areas at one level do not
241 scale up or down levels of spatial hierarchy.

242 That a fuller examination and appreciation of the
243 effects of scale and scaling within ecologically
244 bounded regions on protected areas network design
245 has not yet materialized may be due to the simple and
246 practical reason that planning for protected areas
247 often is carried out in well-defined areas by individ-
248 ual jurisdictions (i.e., provinces, states, territories,
249 and countries) independently of any analysis of where
250 protected areas exist outside of the planning agency’s
251 political boundaries (e.g., YPAS 1998; Purchase
252 2003). This is likely not a strategic approach, as

253 several authors have pointed out that the scales at
 254 which ecological phenomena operate may not always
 255 coincide with scales at which socio-political systems
 256 operate (Haila 2002; Saunders and Briggs 2002). For
 257 example, because patterns of species distribution do
 258 not follow political boundaries, consideration of
 259 protected areas requirements independently of polit-
 260 ical boundaries may provide useful information to
 261 planners who are restricted to work within their
 262 respective jurisdictional boundaries. Initiatives such
 263 as the European EECNET that integrate planning at
 264 continental scales (Jongman 1995) are a positive step
 265 in this direction.

266 To be efficient, that is, to locate protected areas
 267 so as to maximize species representation with a
 268 minimum amount of area, landscape pattern should
 269 be optimized (which is another research priority
 270 identified by Wu and Hobbs 2002). Delineation of
 271 representative protected areas networks is most
 272 ecologically appropriate if carried out within eco-
 273 logically defined target regions, such as in the
 274 mammal provinces of Canada (Fig. 1; Hagmeier
 275 1966) or within ecozones or ecoregions (O'Neill
 276 et al. 1986; Ecological Stratification Working Group
 277 1996) rather than within politically bounded target
 278 areas. These ecologically defined regions can vary in

279 extent and in the characteristics and/or levels of
 280 complexity upon which they were delineated, and
 281 thus, determining which is most appropriate as a
 282 target extent for delineating representative protected
 283 areas can be difficult. Research has shown that the
 284 areas along the boundaries of the mammal provinces
 285 of Canada have a high degree of similarity in
 286 species composition with adjacent provinces (Glenn
 287 1990). Such spatial patterns in species turnover may
 288 result in representative protected area networks that
 289 are defined at smaller spatial extents, introducing
 290 redundancies compared to a network planned at a
 291 larger spatial extent. However, mammal provinces
 292 may not be the most appropriate target region for
 293 delineating protected areas, as other taxa and
 294 features that occur at different spatial scales than
 295 mammals have to be considered. In Canada, the
 296 hierarchically structured system of ecozones and
 297 ecoregions (Ecological Stratification Working Group
 298 1996) is seen as a potentially useful framework for
 299 target regions, as these have been delineated on the
 300 basis of landforms, soils, climate, and vegetation
 301 combined. Alternatively, Bailey's ecoregions (1989)
 302 are delineated across North America, independent of
 303 international boundaries, and may be a more appro-
 304 priate framework for planning at the continental

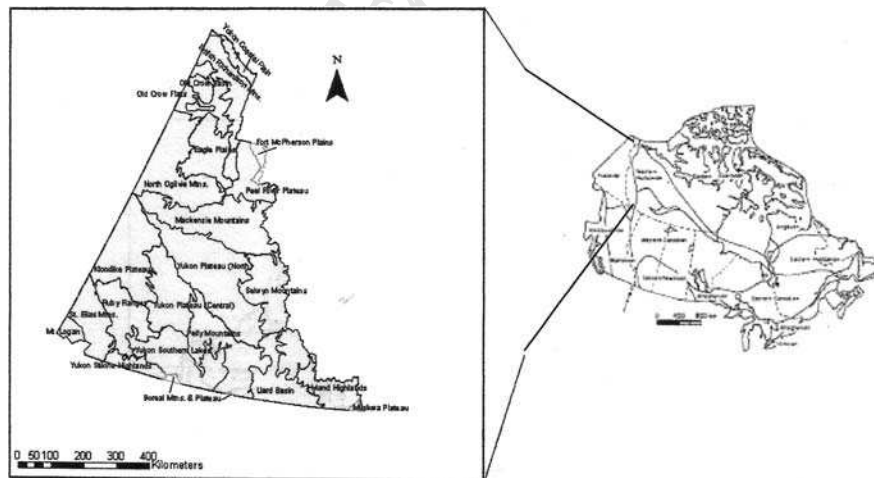


Fig. 1 Target regions in the analysis. Main map: the mammal provinces of Canada (Hagmeier 1966). For this study, the Eastern and Western Hudsonian, the Ungavan, and the Eastern Eskimoan mammal provinces were excluded because they have very low-mammalian diversity. The western portion of the Alleghenian mammal province was analyzed separately because it is geographically distinct from the eastern portion

of the Alleghenian mammal province. Due to its extremely small size, the Illinoian mammal province was combined with the eastern portion of the Alleghenian mammal province, yielding a total of eight replicate mammal provinces. Inset map: The Yukon Territory and component ecoregions (source: Oswald and Senyk 1977)

305 extent. While ecologically defined target regions
306 such as mammal provinces, ecozones or ecoregions
307 are intuitively more appropriate than politically
308 defined ones such as provinces, states or territories,
309 it is important to remember that ecologically defined
310 regions are still delineated by humans, and thus
311 from nature's point of view, may still be arbitrary
312 [see McDonald et al. (2005) for a discussion on the
313 potentially arbitrary nature of ecoregion boundaries].

314 Here, I examine whether and how spatial extent of
315 the target region affects the number and location of
316 protected areas selected for inclusion in a represen-
317 tative protected areas comprised of protected areas
318 (that are predicted to be large enough to contain their
319 historical complement of species even in the face of
320 habitat insularization) in Canada. I also examine how
321 patterns of representative protected areas vary be-
322 tween two levels in the land classification hierarchy.
323 An analysis of the effect of varying the grain size has
324 already been conducted on this data set (Wiersma and
325 Nudds 2006). Thus, this paper tests the effects on
326 representative protected areas selection of varying the
327 extent within hierarchically organized, ecologically
328 defined target areas. I compare the number and
329 location of representative protected areas between
330 three types of ecologically defined regions; ecozones,
331 ecoregions (which are nested within ecozones), and
332 mammal provinces (which are delineated independ-
333 ently of the ecozone/ecoregion hierarchy). I hypoth-
334 esize that there will be some similarity in the optimal
335 locations for protected areas between the three target
336 regions, because underlying hotspots of mammal
337 species richness or rarity will be relatively consistent
338 between scales. However, I predict that the number of
339 protected areas needed to represent a single large
340 target region will be less than the sum of the number
341 of protected areas needed to represent the smaller
342 target regions that are nested within the larger one. For
343 example, I predict that ecozones will require fewer
344 protected areas than the sum of the protected areas
345 needed to represent all the ecoregions that are nested
346 within the ecozone. This is based on the assumption
347 that representative protected areas delineated with
348 ecoregions will have redundancies between them in
349 terms of the suite of species represented. Thus,
350 assessing minimum representation requirements at a
351 larger extent (i.e., the ecozone) will result in fewer
352 total protected areas needed to represent the suite of
353 biodiversity elements.

Methods

354 The effect of spatial extent was examined using three
355 different target regions for selecting representative
356 protected areas. The largest target region examined
357 representation requirements within eight of the mam-
358 mal provinces of Canada (Fig. 1; Hagmeier 1966).
359 Mammal provinces were selected because they have
360 been the focus of recent research in Canada on
361 identifying protected areas design requirements (e.g.,
362 Glenn and Nudds 1989; Gurd and Nudds 1999; Gurd
363 et al. 2001). However, many planning agencies in
364 Canada prefer to examine representation issues within
365 the ecological hierarchy of ecozone, ecoregions, and
366 ecodistricts (Ecological Stratification Working Group
367 1996). These classifications are based largely on
368 similarities in vegetation, soils, climate, and topogra-
369 phy. Here, I used 12 of the ecozones of Canada that
370 approximately overlapped with the mammal prov-
371 inces analyzed as a second set of target regions
372 (Fig. 2). Finally, I examined representation require-
373 ments using ecoregions as the target region. However,
374 I constrained the analysis to the 18 ecoregions that lie
375 within the Yukon Territory (see inset map in Fig. 1).
376 Mammal provinces, ecozone, and ecoregion bound-
377 aries cross the Canada-US border, however this
378 analysis was confined to the Canadian portion of
379 these regions. In addition to comparing the number
380 and location of protected areas between these differ-
381 ent target regions, each set of target regions were
382 combined to test whether the number of protected
383 areas required within individual regions was less than
384 between regions (i.e., whether the number of sites to
385 represent a region as a whole was less than the sum of
386 the parts), as has been found with studies that
387 conducted similar analyses within and across geopo-
388 litical units (Pressey and Nicholls 1989; Erasmus et al.
389 1999; Rodrigues and Gaston 2002).

390 At the mammal province and ecozone extents, the
391 target regions were sampled for richness and com-
392 position of disturbance sensitive mammals (defined
393 by Glenn and Nudds 1989; *sensu* Humphreys and
394 Kitchener 1982) in candidate sites for protected areas.
395 This was obtained by an overlaying mammal range
396 data (Patterson et al. 2003) in a Geographic Infor-
397 mation System (GIS; ArcInfo v. 8, Environmental
398 Systems Research Institute, Redlands, CA, USA)
399 with sample plots that represented the lowest
400 (2,700 km²) estimate for minimum reserve area
401

Fig. 2 The ecozones of Canada included in this analysis



402 (MRA) below which species are estimated to have be
403 lost due to insularization (Gurd et al. 2001).

404 Representative protected areas at the national and
405 mammal province extents were selected from the
406 suite of candidate sites using a rarity-based heuristic
407 algorithm (Margules et al. 1988; Pressey et al. 1993).
408 Previous analysis (Wiersma and Nudds 2004) has
409 shown rarity-based algorithms to be a more efficient
410 solution for finding representative solution sets than
411 richness-based ones. Reserves were selected and
412 added to the system based on presence of rare species
413 in candidate plots, until all species were represented
414 at least once in a reserve (determined as full or partial
415 overlap between a species' range and a sample MRA
416 plot). Species richness of plots was used as the
417 criteria for breaking ties. The minimum sets for all of
418 the ecozones or mammal provinces combined (i.e.,
419 nearly all of the country; hereafter referred to as the
420 "national extent") were compared to minimum sets
421 for each of the component mammal provinces or
422 ecozones to test whether the sum of the protected
423 areas needed to represent the current distribution of
424 mammals in the component target regions was
425 greater than the number needed to represent the
426 country as a whole.

427 At the extent of the Yukon ecoregions, the shape
428 and smaller size of the ecoregions did not allow for

429 the use of the same suite of candidate plots as at the
430 extents of the mammal provinces and of the nation as
431 a whole. Instead, locations of rare species were
432 identified and 2,700 km² MRAs were delineated
433 around them. The composition of these plots was then
434 compared to the mammal richness of the ecoregions,
435 and an additional site was selected if needed (see
436 Wiersma and Urban 2005 for details), following the
437 same algorithm rules as in the ecozones and mammal
438 provinces. The minimum requirement for represen-
439 tative protected areas for the ecoregions of the Yukon
440 were compared to those for the Yukon territory and
441 the Yukonian mammal province as a whole to test
442 whether the sum of the protected areas needed to
443 represent the current distribution of mammals in the
444 component ecoregions was greater than the number
445 needed to represent the territory and mammal prov-
446 ince when considered as target regions on their own.

447 Results

448 All of the mammals of Canada, taken as a whole
449 (excluding the high arctic, which was excluded from
450 the analysis due to its very low mammalian diver-
451 sity), could be included in a few as 11 or 12 sites
452 (Table 1). Within the mammal provinces as a set, 28

Table 1 Three kinds of target regions with the number of sites required to represent them, as identified using a rarity-based heuristic algorithm

Target region	Area (km ²)	Number of sites to represent
Mammal provinces		
Alleghenian/ Illinoisian	420,192	3
Alleghenian (western portion)	121,378	2
Eastern Canadian	978,468	3
Western Canadian	2,089,818	6
Saskatchewanean	499,111	2
Montanian	558,468	5
Vancouverian	457,819	4
Yukonian	725,852	3
All provinces combined as a single target region	5,851,106	12 (sum of sites to represent component provinces: 28)
Ecozones		
Atlantic maritime	282,245	4
Mixedwood plains	168,913	3
Boreal shield	2,072,417	7
Boreal plains	737,397	6
Boral cordillera	468,093	5
Montane cordillera	488,013	6
Pacific maritime	250,094	6
Prairies	465,303	7
Taiga shield	1,445,900	5
Taiga plains	653,888	5
Taiga cordillera	265,233	2
Hudson plains	446,528	3
All ecozones combined as a single target region	7,744,024	11 (sum of sites to represent component ecozones: 59)
Yukon ecoregions		
British richardson mountains	22,989	2
Eagle plains	20,394	1
Hyland highlands	14,660	2
Klondike plateau	38,206	2
Liard basin	21,121	2
Mackenzie	190,238	1
Mountains		
North Olgilvie Mountains	39,203	1
Old Crow basin	14,589	2
Old Crow flats	5,964	1
Peel River plateau	14,812	1

Table 1 continued

Target region	Area (km ²)	Number of sites to represent
Pelly Mountains	34,194	2
Ruby ranges	22,720	1
Selwyn Mountains	35,541	2
St. Elias Mountains	17,603	1
Yukon Coastal plain	4,402	1
Yukon Plateau (central)	26,803	2
Yukon Plateau (north)	57,037	2
Yukon Southern Lakes	29,899	2
Yukon Stikine Highlands	6,972	1
Yukon Territory as a single target region	617,347	3 (sum of sites to represent component ecoregions: 29)

sites were individually considered, with individual mammal provinces needing between 2 and 6 sites (Table 1; Fig. 3). The sum of the ecozones considered individually was 59, with individual ecozones needing between 2 and 7 sites (Table 1; Fig. 3). The Yukon Territory and the Yukonian mammal province (which nearly overlap) each required three sites, while the sum of the individual ecoregions of the territory was 29, with individual ecoregions only needing 1–2 sites (Table 1; Fig. 3). Thus, at each successively higher level of spatial hierarchy, there is an “economy of scale,” with fewer protected areas needed as the extent of the target region increases.

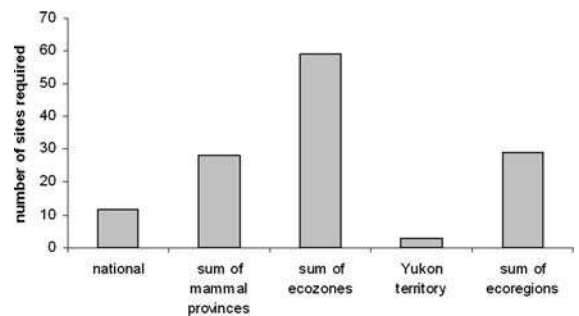


Fig. 3 Number of plots needed to represent all mammals in different target regions of different extents. The national extent can be subdivided into either mammal provinces or ecozones. The data for ecoregions is for those that fall within the Yukon Territory

466 The effect of varying the spatial extent seems to vary
 467 with the differences in extent; between the Yukon
 468 ecoregions, and the territory/mammal province as a
 469 whole, almost ten times as many sites were needed in
 470 the component parts, between the ecozones individ-
 471 ually and as a whole over five times as many sites
 472 were needed, whereas between the mammal provin-
 473 ces individually and as a whole, only slightly more
 474 than twice as many sites were needed.

475 In most cases, the plots selected at the national
 476 extent were also important at the extent of the
 477 individual mammal provinces (Fig. 4). The plots that
 478 were important within the Yukonian mammal province
 479 coincided with areas that were important within
 480 individual ecoregions of the Yukon Territory (Fig. 5).
 481 Of the representative sites at the national extents, 75%
 482 of the sites from the across-mammal provinces analysis
 483 were also found in the representative sets in the within-
 484 mammal province analysis, while 45% of the sites from
 485 the across-ecozone analysis were found in the repre-
 486 sentative sets in within-ecozone analysis (Fig. 6).

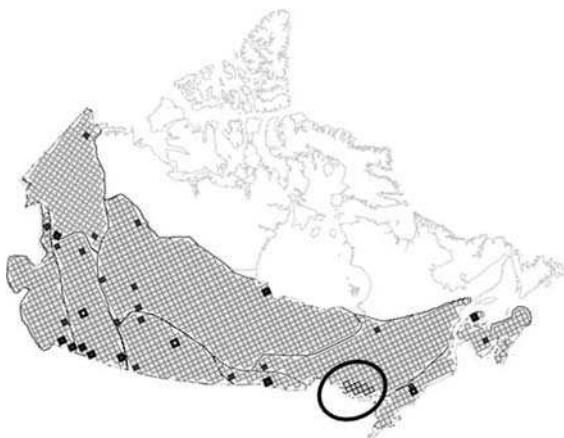


Fig. 4 Map of Canada showing output of sites that meet minimum reserve area requirements of 2,700 km² and which have been selected as representative for mammals based on output from a rarity-based heuristic reserve selection algorithms conducted using mammal provinces as target regions. Plots that are circled in the Eastern mammal province indicate a series of plots that are equivalent to each other in terms of meeting representation goals. Plots with *dark shading* are those that are part of a minimum representative set for each individual mammal province. Plots with *thick outlines* are those that are part of a minimum representative set for the country as a whole. Thus, those with *thick outlines* and *dark shading* are selected at the two different scales (national and within individual mammal provinces), while those with *thick outlines* and *no shading* were only selected at the national extent

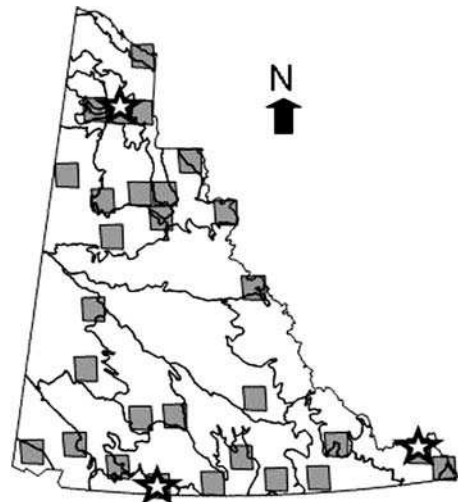
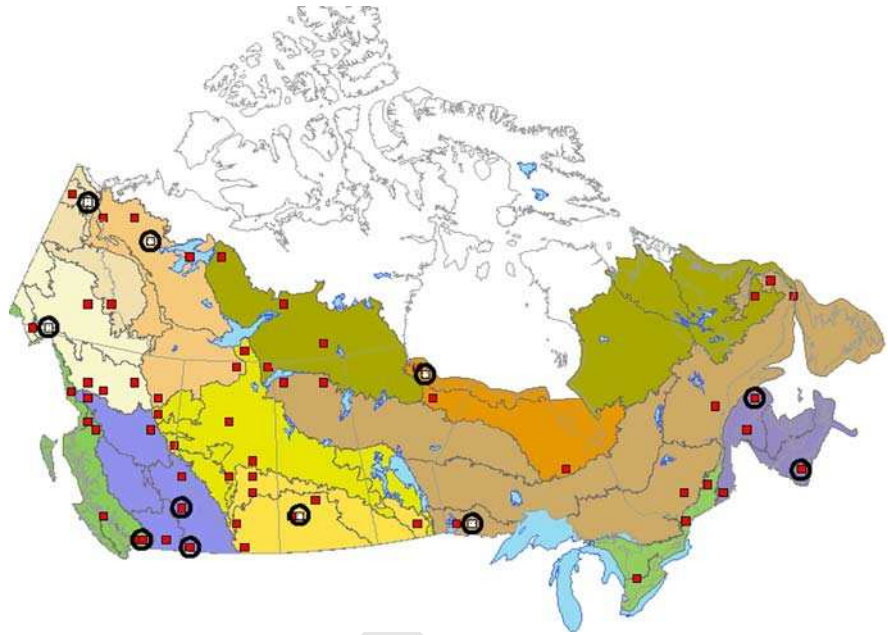


Fig. 5 The minimum representative network for the ecoregions of the Yukon (results using the richness based and rarity based algorithms were identical). Plots that are marked with a *star* indicate those that were needed to represent the Yukonian mammal province

Discussion

487
 488 A comparison of sites selected at the extents of
 489 individual ecoregions within an ecozone, or with
 490 ecozones or mammal provinces within the country as
 491 a whole, is useful for identifying high priority areas
 492 for conservation. Those sites that are important at
 493 more than one extent are predicted to be priority areas
 494 for conservation over sites selected at only one extent.
 495 This is because selection of a site as representative
 496 across spatial extents is presumed to be analogous to
 497 measures of irreplaceability (*sensu* Pressey et al.
 498 1994). A representative protected areas network at a
 499 national extent is much more efficient than networks
 500 in individual mammal provinces, as the total number
 501 of sites is 2–43% of the sum of the parts for ecozones
 502 and mammal provinces, respectively. The mammal
 503 provinces, in turn, appear to be more efficient than
 504 component ecoregions, at least for the Yukon. A
 505 similar result of gains in efficiency as larger target
 506 regions are considered has been demonstrated with
 507 subdivisions and agglomerations of geopolitical target
 508 units, with the total number of sites at the larger extent
 509 being anywhere from two to ten times as many as the
 510 sum of the parts (Pressey and Nichols 1989; Erasmus
 511 et al. 1999; Rodrigues and Gaston 2002). The
 512 comparison between the location of representative
 513 protected areas at spatial extents that are nested within

Fig. 6 Map of Canada showing output of sites that meet minimum reserve area requirements of 2,700 km² and which have been selected as representative for mammals based on output from a rarity-based heuristic reserve selection algorithm conducted using ecozones as target regions. Plots that are *circled* are those that are part of a minimum representative set for the country as a whole. Plots that are *stippled* are important at the national scale, but not within ecozones, while those that are *circled* and shaded in, are important at both spatial extents



514 each other (ecoregions within a territory, or mammal
 515 provinces/ecozones within the country) identifies
 516 those sites that are redundant with plots elsewhere
 517 when representation is constrained within smaller
 518 target regions. However, redundancies in species
 519 representation may be desirable as they may capture
 520 more genetic diversity of species, supply populations
 521 for a rescue effect in case of local extinctions,
 522 represent subspecies or unique types, or capture
 523 diversity of other taxa or physiographic features in
 524 addition to mammals (Stoms et al. 2004). The
 525 possibilities for redundancies may also assist in the
 526 case when a single political jurisdiction cannot
 527 allocate enough land to a protected area to achieve
 528 an adequate minimum size. In such a situation it is
 529 valuable to investigate whether the solution might be
 530 in optimally located transboundary protected areas.

531 The comparison of minimum requirements when
 532 the extent of the target region varies is useful in that it
 533 identifies high priority areas and possible redundan-
 534 cies. However, this analysis was constrained to mam-
 535 mals, the distributions of many of which cross more
 536 than one mammal province or ecozones/ecoregion.
 537 There are good reasons for developing representative
 538 protected areas networks within smaller target regions
 539 than mammal provinces, even if mammals remain the
 540 target organism. Representative networks for mam-
 541 mals within one ecozone may capture a different

542 assemblage of species and vegetation types than a
 543 representative network in another ecozone. Warman
 544 et al. (2004) showed that a representative network for
 545 mammals could capture between 33 and 96% of other
 546 taxa (reptiles, amphibians, and birds). Thus, redun-
 547 dancies between ecozones might capture more of these
 548 other taxa (which may not be as widely distributed
 549 across the country) than if a representative network for
 550 mammals are delineated only at the national, or
 551 mammal province, extent.

552 For practical reasons related to legislation and
 553 management, planning for protected areas will likely
 554 continue to be carried out within politically bounded
 555 areas. Nonetheless, it would be helpful for protected
 556 areas planners to consider analyses such as this one,
 557 at least with neighboring jurisdictions. This is being
 558 done in some parts of the world, such as the European
 559 EECONET initiative (Jongman 1995). Although
 560 collaboration across boundaries might carry slightly
 561 higher costs, in the end it may yield efficiencies if the
 562 two governments can share protection of areas along
 563 their borders and/or identify areas that are redundant
 564 between the two jurisdictions.

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