IDENTIFYING MINIMUM SETS OF CONSERVATION SITES FOR REPRESENTING BIODIVERSITY IN CANADA: A COMPLEMENTARITY APPROACH

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TECHNICAL REPORT SERIES No. xxx

Headquarters **1999**

Canadian Wildlife Service

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TECHNICAL REPORT SERIES No. xxx
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This publication may be cited as:
Freemark, K., H.Moore, D.M. Forsyth, A.R.E. Sinclair, D.White, T.Barrett and R.L. Pressey. 1999. Identifying minimum sets of conservation sites for representing biodiversity in Canada: A complementarity approach. Technical Report No. xxx, Canadian Wildlife Service, Headquarters, Environment Canada, Ottawa K1A 0H3

SUMMARY

OBJECTIVES

- To construct an equal-area geo-referenced sampling grid for Canada.
- To digitise available range maps for common and COSEWIC species in Canada.
- To identify important sites for biodiversity in Canada using a new statistical predictor of conservation value.

METHODS

- An equal-area grid of 10,000 km^2 hexagons was constructed from the truncated icosahedron on a Lambert azimuthal equal-area map projection.
- The ranges of 697 common and COSEWIC mammals, birds, reptiles, and amphibians, and COSEWIC fish, plants, lepidoptera and molluscs were digitised within the equal-area grid.
- The areas of 217 ecoregions were also digitised within the equal-area grid.
- C-Plan, a conservation planning software program, was used to identify important conservation areas and minimum sets of sites required to represent either (i) each taxa once, and/or (ii) 12 % of the area of each ecoregion, using 10 combinations of taxa and ecoregions.

RESULTS

- An equal-area grid of 1,455 10,000 km^2 hexagons was constructed for Canada; 1,275 hexagons either completely or partially covered terrestrial Canada.
- There were significant positive correlations between the irreplaceability of sites (hexagons) for most of the focal groups.
- We identified four general areas of special importantance for biodiversity conservation in Canada; Okanagan Valley (British Columbia), mid-Prairies (Manitoba and Saskachewan) Niagara Peninsula (Ontario). Other important areas were also located near to the southern United States border.
- Minimum set analyses indicated that all mammals could be represented in 16 hexagons, all birds in 14 hexagons, all amphibians and all reptiles in 9 hexagons each, and all COSEWIC species in 55 hexagons. 12 % of all 217 ecoregions could be represented within 188 hexagons. All terrestrial vertebrates could be represented in 31 hexagons, and all terrestrial vertebrates and 12 % of all ecoregions in 187 hexagons.
- Of the sub-sets that we used as focal groups, using all mammals or all birds captured the greatest proportion of taxa in other focal groups.

CONCLUSIONS

- The most important sites for biodiversity conservation in Canada are located near the southern United States border. This is because (i) many non-COSEWIC species that are common in continental North America occur in southern Canada, and (ii) many COSEWIC species are also located in southern Canada. With increasing latitude there are fewer species, and these species have larger distributions (i.e., are generally common).
- Since there was high overlap in the distributions of important conservation sites between groups of taxa (birds, mammals, reptiles, and amphibians) deciding the location of protected areas on the basis of just one of these groups alone could also benefit other taxa.
- The 12 % area-target for ecoregion alone did not protect all species, indicating that area-based targets may not represent all biodiversity.
- The techniques developed during this study show considerable promise for identifying important areas for biodiversity conservation at different scales and in different parts of the globe. The principal limiting factor for the application of this methodology is the availability of suitable species distribution data.

INTRODUCTION

Considerable attention has been focused on the conservation and management of biodiversity in Canada, particularly since the Convention on Biological Diversity was signed in 1993. A recent international scientific review of biodiversity (Heywood & Watson, 1995), clearly indicates that past and projected human induced stresses pose significant risks to the biodiversity and functioning of ecosystems. These and other agreements and reviews (e.g. Environment Canada, 1994; CFS, 1997) emphasise the need to assess the status of biodiversity and to better understand the causes and consequences of changes in biodiversity. Furthermore, the economic benefits of conserving biodiversity are beginning to be recognised and documented (Perrings et al., 1995; Arrow et al., 1995).

Canada was the first industrialised nation to sign the Convention on Biological Diversity. Canadians are concerned about the degradation of ecosystems and loss of biodiversity from human activities for aesthetic, economic, ecological, cultural and educational reasons (BCO, 1995; Heywood & Watson, 1995). For example, degraded forest, agricultural and aquatic ecosystems are less productive and require greater inputs if they are to continue supporting the wildlife and human communities that depend on them. All of these concerns are ultimately related to the loss of genetic diversity, the primary raw material that is filtered by natural selection, resulting in evolutionary and ecological adaptation of biota to environmental conditions. Minimising additional loss of biodiversity will provide the best assurance that biota will adapt to the increasing rate and spatial extent of environmental change (Pratt & Cairns, 1992), and that societal values can be sustained.

Achieving the vision outlined in the Canadian Biodiversity Strategy (BCO, 1995) requires multiple-scale hierarchical approaches. Such approaches are inter-disciplinary and should include contributions from ecology, geography, agriculture and forest science, and social sciences such as economics, sociology and land-use planning (White et al., 1998). With collaboration from many perspectives, more appropriate databases and analytic approaches can be formulated. More significantly, a co-operative, cross-sectoral approach based on partnerships promises better linkage between scientific perspectives and the spatial, temporal, and political structure of decision-making (Lubchenco, 1995). Clarifying the scientific status of biodiversity can set the stage for moving the biodiversity debate from one primarily about the facts of the issue to one about values (c.f. Williams & Gaston, 1994; Williams et al., 1996).

In this project, we extend and apply new methods of spatial analysis for geo-referenced data in order to identify important areas for achieving national conservation goals. In other words, with limited resources to study or conserve biodiversity, we ask where are the best places for further investigation or conservation activity? At the national scale, our analyses will identify priority regions for conservation effort. Within regions, the study will identify locations of potential sites for conservation efforts such as establishing a network of protected areas representative of regional biodiversity, or implementing changes to forestry or agricultural practices that could benefit biodiversity. While protected areas are a key component to a biodiversity conservation strategy, their long-term value will depend on sound stewardship in remaining, and particularly adjacent, areas (Pressey et al., 1995; Flather et al., 1997). To improve the network of protected areas in Canada, comprehensive criteria need to be developed for determining priority sites for further conservation action. Examples of such sites might be areas supporting a high diversity of species, migratory species, representative species, or unique species (BCO, 1995) that occur outside current protected areas. This project will extend the focus of biodiversity conservation and management beyond from multiple single-species approaches to a single multiple-species approach. Analyses will provide insights into the ability of sites to

contribute to the representation of biodiversity at the national scale, and indicate gaps in existing conservation and management strategies. The approaches developed will aid in the process of decentralising resource management decision-making to the community level, while maintaining the larger-scale perspective necessary for integrated planning to ensure sustainable resource use.

GEOSPATIAL SAMPLING FRAMEWORK

For large-scale studies of the distribution of biodiversity, an analysis structure that provides comparability is most appropriate (see Conroy & Noon, 1996, on issues of using habitat polygons). This study extends a sampling framework that was designed to provide a regular, systematic, hierarchical hexagonal spatial structure for environmental monitoring and assessment by the U.S. Environmental Protection Agency (White et al., 1992). The hexagon tessellation is attractive because it minimises spatial distortion and, if constructed on an equal-area map projection, provides an equal-area sample (White et al., 1992). Furthermore, hexagons are generalisable to both larger and smaller spatial scales. This becomes important for extending regional and national assessments to continental and global scales. An equal-area grid also provides a common spatial unit for comparison of diverse data types whereas ecoregions, for example, are not comparable but by definition unique. Equal-area units also minimise confounding due to species-area relationships, a potential problem if other units such as ecoregions (Moore, 1997) or counties (Dobson et al., 1997) are used.

The sampling framework was a grid of hexagons, each of 10,000 km^2. The grid provided an accounting mechanism that serves several purposes. First, a single set of analysis units facilitated comparison of different data sets. Second, the uncertainty inherent within available range maps could be minimised by limiting the precision of location assignment to this scale. Furthermore, concerns about the confidentiality of precise locations of occurrence for some COSEWIC species was alleviated by using a 10,000 km^2 grid. Finally, there is a strong argument for generalising species distributions from the precise data of field observations in order to account for the biases in observation locations and sightability**.**

The size of the hexagons thus reflects a compromise between the desire for spatial detail and the constraints of reasonable spatial representation of species life histories, data collection, confidentially, and computational feasibility. Solutions to spatial analyses can depend, of course, on the sizes of units used (Stoms, 1994).

OBJECTIVES

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2. To digitise available range maps for common and COSEWIC species in Canada.

3. To identify important sites for biodiversity in Canada using a new statistical predictor of conservation value.

METHODS

Sampling grid and scale

We created grid-based distribution maps using equal-area hexagons of 10,000 km^2 developed for the US Environmental Protection Agency (White et al., 1992; see also Csuti et al., 1997). Briefly, the grid was constructed from the truncated icosahedron on a Lambert azimuthal equal-area map projection. Compared to other possible approaches to equal-area sampling this method has minimal distortion and deviation in area (White et al. 1992). We chose the 10,000 km^2 scale for our grid because, in our judgement, it best suited the scale of the range data available for the majority of taxa (see above). There were 1275 hexagons that were completely or partly enclosed by the terrestrial political boundaries of Canada.

Range data

Our range data for 796 taxa (Appendix 1; summary in Table 1) came from two sources. The ranges of terrestrial mammals, birds, amphibians, reptiles, fish, plants, molluscs and lepidoptera listed as endangered, threatened, or vulnerable by the Committee on the Status of Endangered Wildlife in Canada (hereinafter termed 'COSEWIC') were provided to us by that organisation (HAROLD TO PROVIDE DETAIL…). The ranges of 'common' (i.e. not listed by COSEWIC) mammals, birds, amphibians and reptiles were digitised from published range maps. (HAROLD TO PROVIDE REFERENCES FOR THE ACTUAL SOURCES USED…) Where range-maps specified winter-only ranges for birds these areas were not included in our analyses. Although marine species were excluded from our analyses, some coastal bird species that also breed inland were included. The presence or absence of taxa in each of the 1,275 hexagon was determined and formed the data used in subsequent analyses.

Table 1. Number of common, endangered, threatened and vulnerable taxa used in analyses.

	Status				
Taxonomic Group	Common	Endangered	Threatened	Vulnerable	Total
Mammals	123	5	5	19	152
Birds	342	14	7	20	383
Amphibians	37	2	0	7	46
Reptiles	33	2	4	7	46
Fish	-	4	15	39	58
Plants	-	33	36	38	107
Molluscs	-	1	1	0	2
Lepidoptera	-	1	0	1	2
Total	535	62	68	131	796

Ecoregions

The representation of distinct ecological areas has been assumed to also represent species diversity (e.g. Turner et al., 1992), but the limited empirical evidence does not support this, at least at small scales (Ferrier and Watson, 1997). In Canada, a target of 12 % has been specified for representing each of the country's ecosystems in protected areas (Turner et al., 1992). Hence, a further objective of this study was to evaluate the effectiveness of using a target of 12 % of ecoregions for achieving representation of the 796 taxa described above.

Canada has been classified into a total of 217 ecoregions (Appendix 2) based upon spatial differences in both abiotic and biotic factors. Ecoregions are "characterised by distinctive large order landforms or assemblages of regional landforms, small order macro- or mesoclimates, vegetation, soils, water, and regional human activity patterns/uses" (Ecological Stratification Working Group, 1996). For a detailed description of ecoregions see Ecological Stratification Working Group (1996). The area of each ecoregion present within hexagons was calculated from maps provided by the Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull.

Focal groups

We subdivided taxa and ecoregions into 10 'focal groups' in order to expand and better interpret our analyses (Table 2). The four taxonomic groups with comprehensive data for both common and COSEWIC species (i.e., mammals, birds, amphibians and reptiles) were each a focal group. This is because conservation decisions are frequently made on the basis of one or more of these well-studied groups with the assumption that other taxonomic groups might be similarly distributed (e.g., Kershaw et al., 1994). In other words, we wished to test how well these four focal groups act as surrogates for the distribution of taxa within other focal groups. Since many protected areas and conservation strategies in North America are based upon the location of legally defined endangered species (Dobson et al., 1997; Flather et al., 1998), we used three combinations of COSEWIC species as focal groups. We used COSEWIC Birds as a focal group because a new federal program, termed 'Partners In Flight', has been initiated to protect COSEWIC-listed birds in Canada (Dunn, 1997). We used COSEWIC plants as a focal group because in the absence of data for common plants we wished to explore how well plants acted as a surrogate for other focal groups. We pooled all terrestrial vertebrates (i.e., Mammals, Birds, Reptiles and Amphibians into a single focal group, 'Vertebrates', in order to identify important sites for vertebrate fauna in Canada.

We used the area of ecoregions as another focal group. As mentioned earlier, the target for this focal group was to represent 12 % of the area of each ecoregion. This was an approximation to the federal goal of representing 12 % of Canada's ecosystems (Turner et al., 1992). We then combined 'Vertebrates' and 'Ecoregions' into a single focal group, 'Vertebrates-Ecoregions', to explore how this combination affected the identification of important sites.

Table 2. Description of the 10 focal groups used in analyses. *n* = the number of taxa and/or ecoregions in the target (see text). For a list of taxa and ecoregions see Appendices.

Name	Target
Mammals	Common, endangered, threatened, and vulnerable mammals (*n* = 152).
Birds	Common, endangered, threatened, and vulnerable birds (*n* = 383).
Amphibians	Common, endangered, threatened, and vulnerable amphibians (*n* = 46).
Reptiles	Common, endangered, threatened, and vulnerable reptiles (*n* = 46).
Vertebrates	Common, endangered, threatened, and vulnerable mammals, birds, reptiles and amphibians (*n* = 627).
COSEWIC	Endangered, threatened, and vulnerable mammals, birds, amphibians, reptiles, fish, plants, molluscs and Lepidoptera (*n* = 261).
COSEWIC Birds	Endangered, threatened, and vulnerable birds (*n* = 41).
COSEWIC plants	Endangered, threatened, and vulnerable plants (*n* = 107).
Ecoregions	12 % of the area of each of 217 ecoregion (*n* = 217).
Vertebrates-Ecoregions	Common, endangered, threatened, and vulnerable mammals, birds, reptiles and amphibians, and 12 % of the area of each ecoregion (*n* = 844).

Analyses

We used a recently developed predictor of conservation value, termed *irrepleceability*, to identify important sites (i.e., 10,000 km^2 hexagons) for the representation of focal groups (S. Ferrier, R.L. Pressey and T.W. Barrett, New South Wales National Parks and Wildlife Service, unpublished manuscript). Irrepleaceability is a statistical approach to estimating the importance of a site to achieving a specified conservation goal. If $R_{x\_included}$ is the number of representative combinations that include site *x*, $R_{x\_excluded}$ is the number of representative calculations that do not include site *x*, and $R_{x\_removed}$ is the number of representative combinations that include site *x* and would still be representative if site *x* was removed. The calculation of irreplaceability for site *x*, Irr_x, is thus:

$$Irr_x = \frac{(R_{x\_included} - R_{x\_removed})}{(R_{x\_included} + R_{x\_excluded})}$$

The predictor uses a statistical approach based on the central limit theorem to estimate, for a given feature or combination of features, the expected frequency distribution of the area protected by all possible site combinations of a given size. The expected distribution is then used to estimate the proportion, and hence number, of these combinations that would achieve the specified target for the feature(s). The individual taxa irreplaceabilities within a site are then added to give a summed irreplaceability value for each site (S. Ferrier, R.L. Pressey and T.W. Barrett, New South Wales National Parks and Wildlife Service, unpublished manuscript).

We calculated summed irreplaceabilities for the focal groups listed in Table 1. We then tested for the strength of focal group congruence in summed irreplaceabilities using Spearman's rank correlation coefficients (Zar, 1996).

All irreplaceability and minimum set analyses were performed using C-Plan (Finkel, 1998; New South Wales National Parks and Wildlife Service, PO Box 402, Armidale, NSW 2350, Australia). Statistical testing was performed with SPSS® 8.0 (Norušis, 1998).

Minimum-set algorithms

We used heuristic algorithms to identify approximate minimum-set solutions of sites required to represent combinations of taxa and ecoregions. Although heuristic algorithms seldom provide optimal solutions (Camm et al., 1996; Csuti et al., 1997), when the number of sites is large and the reservation goal is complex (as was the case in this study) heuristic algorithms can provide near-optimal solutions in realistic periods of time (Pressey *et al*., 1996, 1997). Two general classes of heuristic algorithm have been proposed (Csuti *et al*. 1997), and the outcome of either depends both on the decision-rules of the algorithm and the conservation target to which the algorithm is applied. Richness-based algorithms start with the site containing the most species and sequentially add sites with the most new species (e.g., Margules *et al*., 1988). A major disadvantage of richness-based algorithms is that a site containing a species not present in other sites may be ranked lower than a site containing several species more common among unreserved sites. In contrast, rarity-based algorithms select sites according to the rarity of species and thus tend to attain the conservation goal with fewer sites (e.g., Kershaw *et al*., 1994; Csuti et al., 1997). Our algorithms used summed irreplaceability values (see above), a form of rarity-based algorithm, and employed the following rule sequence. First, select the site with the highest summed irreplaceability. Second, in the event of a tie, select the site with the most additional taxa already represented. Third, if still a tie then select the first site in the list. After each selection summed irreplaceability was recalculated for the remaining sites (i.e., those not yet represented in the solution set) for the features (taxa or ecoregions) yet to be represented. This iteration was repeated until the target representation of taxa was achieved. Our target for both irreplaceability calculations and minimum set algorithms was to represent taxa and/or 12 % of the area of ecoregions once and to represent 12 % of the total area of each ecoregion.

Surrogacy

To investigate further the effects of focusing reservation efforts on a single focal group of taxa, we calculated how many taxa in the other focal groups were added at each iteration in the minimum set solutions for each focal group (see also Dobson et al., 1997; Howard et al., 1998). These data are presented as cumulative % of the taxa in each other focal group represented through the sequence of site selection. We then determined the number of additional sites required to achieve representation of the taxa in the other focal groups with further minimum set algorithms. This was achieved by including the minimum set solutions from other focal groups as mandatory reservations prior to initiating the new minimum set algorithm

RESULTS

National patterns of richness and irreplaceability

HAROLD TO MODIFY & INCORPORATE THE MAPS INTO THIS SECTION

Patterns in the national distribution of species richness and summed irreplaceability for the different focal groups are shown in Figure 1 (HAROLD TO SUPPLY FIGURE 1). There is a consistent trend toward greater species richness from north to south for all groups, with most species occurring near the United States border. The highest summed irreplaceabilities occurred in several nodes along the United States border. Summed irreplaceability declined with increasing latitude. For all groups there are fewer taxa in northern Canada (low species richness), and those taxa are widely distributed between sites (low summed irreplaceability). In contrast, near the United States border there are more species, many of which are found within only one or several sites.

There was high congruence in both species richness and summed irreplaceability between the focal groups, with significant ($P < 0.05$) Spearman rank correlations for all comparisons (Table 2). Patterns were similar for the focal groups (not shown). The strongest correlations were between Birds and Mammals, Reptiles, Amphibians, and COSEWICs. The weakest correlations were those with Ecoregions. Hence, sites containing the most species for one focal group tended to contain the most species for other focal groups. However, high species richness or summed irreplaceability for a site was not always a good predictor for other taxa (Figures 2-3).

Table 2. Summary of correlations between focal groups for species richness and summed irreplaceability. Values are Spearman rank correlation coefficients. $N = 1{,}275$ for all comparisons.

	Birds	Amphibians	Reptiles	Ecoregions
Species richness				
Mammals	0.96 $P < 0.001$	0.85 $P < 0.001$	0.75 $P < 0.001$	0.26 $P < 0.001$
Birds		0.84 $P < 0.001$	0.77 $P < 0.001$	0.26 $P < 0.001$
Amphibians			0.83 $P < 0.001$	0.13 $P < 0.001$
Reptiles				0.10 $P = 0.001$
Summed Irreplaceability				
Mammals	0.48 $P < 0.001$	0.52 $P < 0.001$	0.52 $P < 0.001$	0.30 $P < 0.001$
Birds		0.41 $P < 0.001$	0.51 $P < 0.001$	0.25 $P < 0.001$
Amphibians			0.81 $P < 0.001$	0.23 $P < 0.001$
Reptiles				

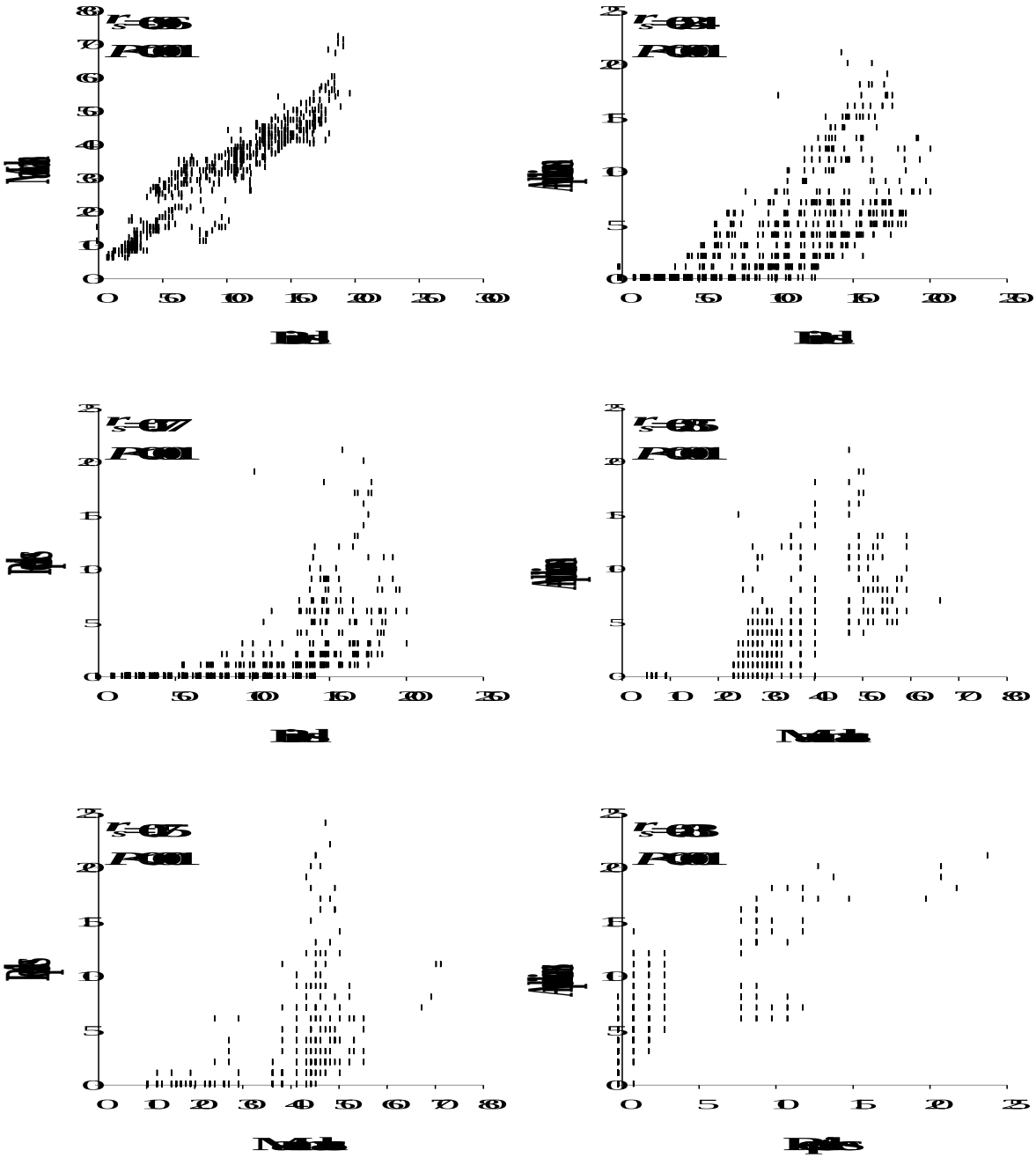

Figure 2. Focal group congruence in species richness between 1,275 10,000 km^2 equal-area sites.

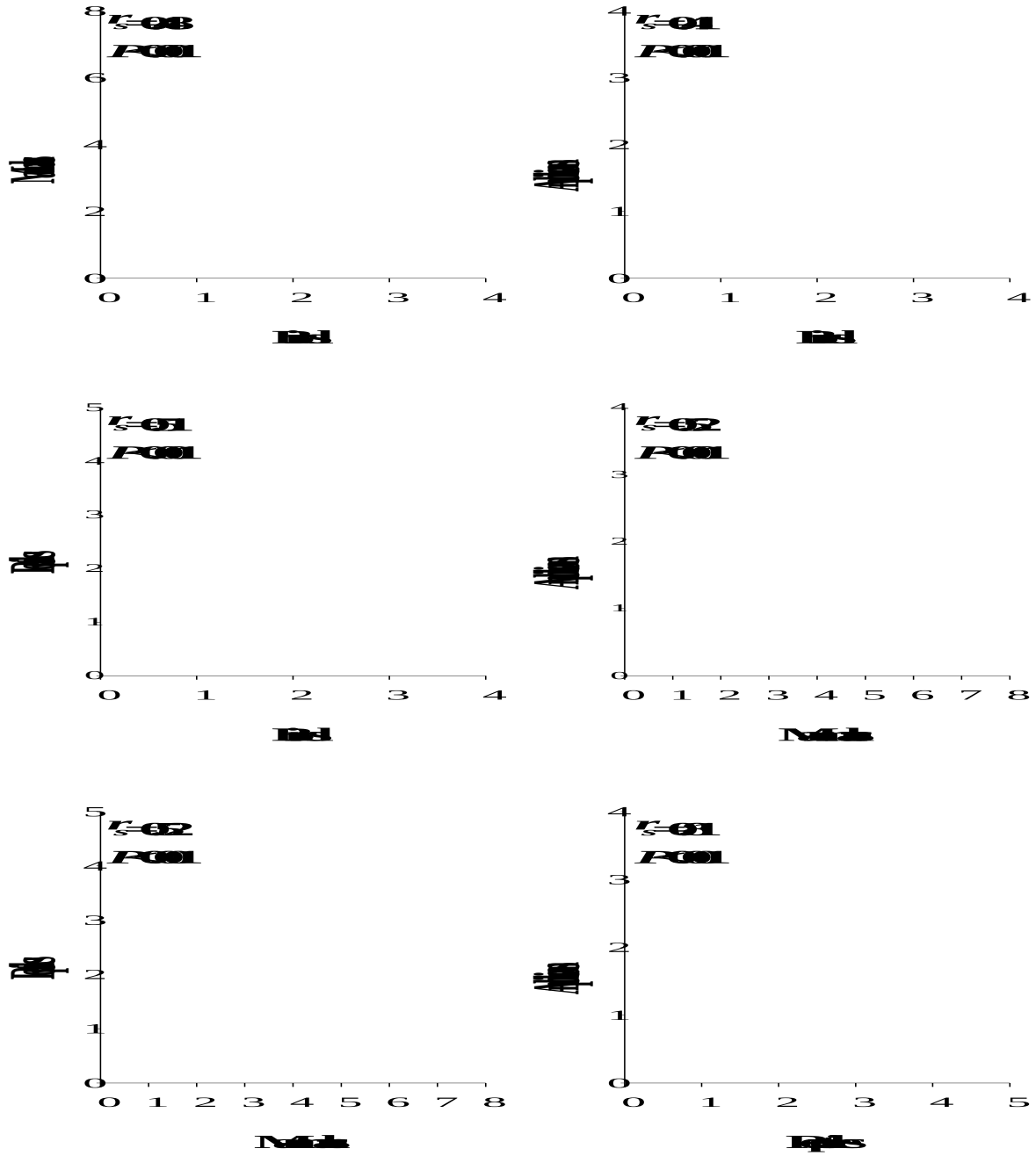

Figure 3. Focal group congruence in summed irreplaceability between 1,275 10,000 km^2 equal-area sites.

Minimum set representations

The implications of the above patterns for conservation strategies were explored with minimum set algorithms that selected sites according to their summed irreplaceability. Focal groups with strongly correlated summed irreplaceabilities would thus be expected to represent each other better than those with weak correlations. The location of sites required to represent each species at least once (Figure ? HAROLD TO SUPPLY) was congruent with the hotspots of summed irreplaceability shown in Figure ?. Remarkably few sites were required to represent taxa in each focal group at least once, indicating the effectiveness of using rarity-based measures like summed irreplaceability for identifying priority conservation areas (Table 3).

The number of taxa in a focal group was not necessarily a good predictor of how many sites were required to represent all taxa within that group. For example, to represent all 107 COSEWIC plants required 28 sites, but 628 Vertebrates were represented within just 33 sites. Similarly, 383 Birds were represented in 14 sites, but 153 Mammals required 16 sites. These differences arise from the spatial distribution of taxa that is specific to each focal group.

An interesting result was that the 9 sites were required to represent 46 taxa each of Amphibians and Reptiles. However, only one of the nine sites was common to both minimum sets, and this same site was also present in the minimum sets for Birds and Mammals.

Almost 15 % of the available 1,275 sites were required to represent Ecoregions. This was due to specifying an area-based target for Ecoregions, rather than mere representation. One less site was required to represent Vertebrates-Ecoregions; such a result occurs because of the different summed irreplaceabilities associated with the additional targets and because C-Plan does not identify optimal minimum sets.

Accumulation of taxa in minimum sets

Accumulation curves represent the cumulative number of features within the focal group that are represented at each site selection. The rate of accumulation of features was greatest in the first few site selections (Figure 4). This arises from the selection algorithm first choosing

Table 3. Approximate minimum number of 10,000 km^2 sites required to achieve representation of features within 10 focal groups. The algorithm used iteratively selected sites with the highest summed irreplaceability until all features within that focal group were represented.

Focal group	Number of taxa and/or Ecoregions	Number of sites
Mammals	153	16
Birds	383	14
Amphibians	46	9
Reptiles	46	9
Vertebrates	628	31
COSEWIC	264	55
COSEWIC Birds	41	9
COSEWIC plants	107	28
Ecoregions	217	188
Vertebrates-Ecoregions	845	187

sites with the highest summed irreplaceability. Since summed irreplaceability is primarily determined by the distribution of the rarest features, the initially rapid rate of accumulation indicates either that those sites also contained many common features. Differences in the rates of accumulation between focal groups were greatest in the initial two or three selections, but thereafter the rates of accumulation generally converged.

Surrogacy of focal groups

The relative effectiveness of using a focal group, or combinations of focal groups, as surrogates for representing other taxa is shown in Table 4 and Figures 5-7. We considered the extent of representation of Mammals, Birds, Reptiles, and Amphibians to be the critical test of surrogacy; only for these groups was data available for common species, and hence were most likely to approximate the actual distribution of unsampled taxa (see Gaston, 1994).

Mammals and Birds achieved better representation of other focal groups than did Reptiles or Amphibians (Figure 5). Although this result could partly be attributed to fewer sites being required for the latter groups (9 sites each compared to 16 and 14 for Mammals and Birds, respectively), Mammals (n = 153 taxa) achieved better representation of the other focal groups (all >80 %) than did Birds (n = 383). Hence, it is the spatial array of taxa that is more important in determining surrogacy. Mammals also achieved a high representation of COSEWICs (almost 60 %), whereas most other focal groups did poorer. Since Mammals, Birds, Reptiles and Amphibians included their respective COSEWIC taxa, the relatively poor surrogacy of these groups for COSEWICs must be due to low overlap with the COSEWICs not included in those groups (i.e., fish, plants, molluscs and Lepidoptera).

Given the small number of sites involved, the COSEWIC Birds and COSEWIC Plants achieved very good representation of other focal groups (Figure 6). COSEWIC Plants was better overall than COSEWIC Birds. This result further emphasises (i) the sensitivity of our minimum set algorithm to the distributions of the rarest taxa, and (ii) that there was considerable overlap in the distribution of these rare taxa.

Ecoregions as a focal group represented most (i.e., >90 %) Mammals and Birds (Figure 7), and also Amphibians and Reptiles (not shown for clarity). However, since the 188 sites were almost 15 % of total available sites, and relative to the equivalent number of sites selected by Mammals, Birds, Reptiles and Amphibians (i.e., ≤ 16) the 12 % area target for Ecoregions was an inefficient surrogate for the other taxa-based focal groups. Vertebrates-Ecoregions was a better surrogate for other focal-groups than Ecoregions, but still captured < 80 % of COSEWIC groups.

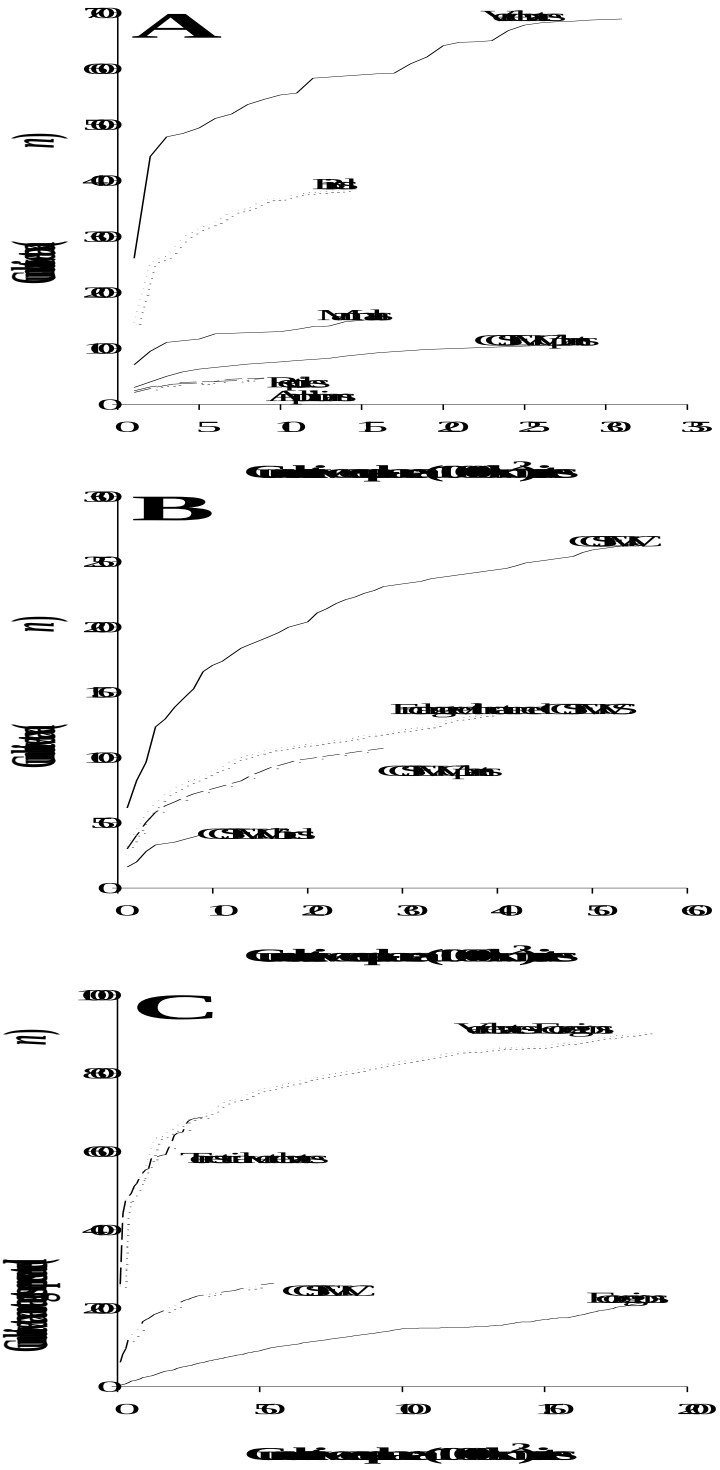

Figure 4. The relation between the cumulative number of sites sampled and the cumulative number of taxa represented for a variety of focal groups. Note that the scales differ between graphs. Sites were selected iteratively according to highest summed irreplaceability.

Table 4. Summary of representation achieved for the 10 focal groups by using another focal group as the selection group. To standardise for the different number of taxa in focal groups, representation is shown as per cent of taxa represented for a particular focal group. A dash indicates that the focal group was a subset of the target focal group and that representation, by definition, would be 100 %.

Focal group	Mammals	Birds	Reptiles	Amphibians	Vertebrates	COSEWIC	COSEWIC Birds	COSEWIC Plants	Ecoregions	Vertebrates-Ecoregions
Mammals	-	92	87	85	93	59	76	40	9	72
Birds	88	-	89	77	94	47	-	28	6	72
Reptiles	78	83	-	83	83	54	76	50	4	62
Amphibians	75	81	83	-	81	54	71	47	4	61
Vertebrates	-	-	-	-	-	75	-	55	13	78
COSEWIC	100	99	98	100	99	-	100	100	17	78
COSEWIC Birds	74	93	78	72	86	46	-	34	3	65
COSEWIC Plants	86	91	91	94	90	82	80	-	10	69
Ecoregions	93	99	87	85	96	60	98	43	-	97
Vertebrates-Ecoregions	-	-	-	-	-	78	-	61	-	-

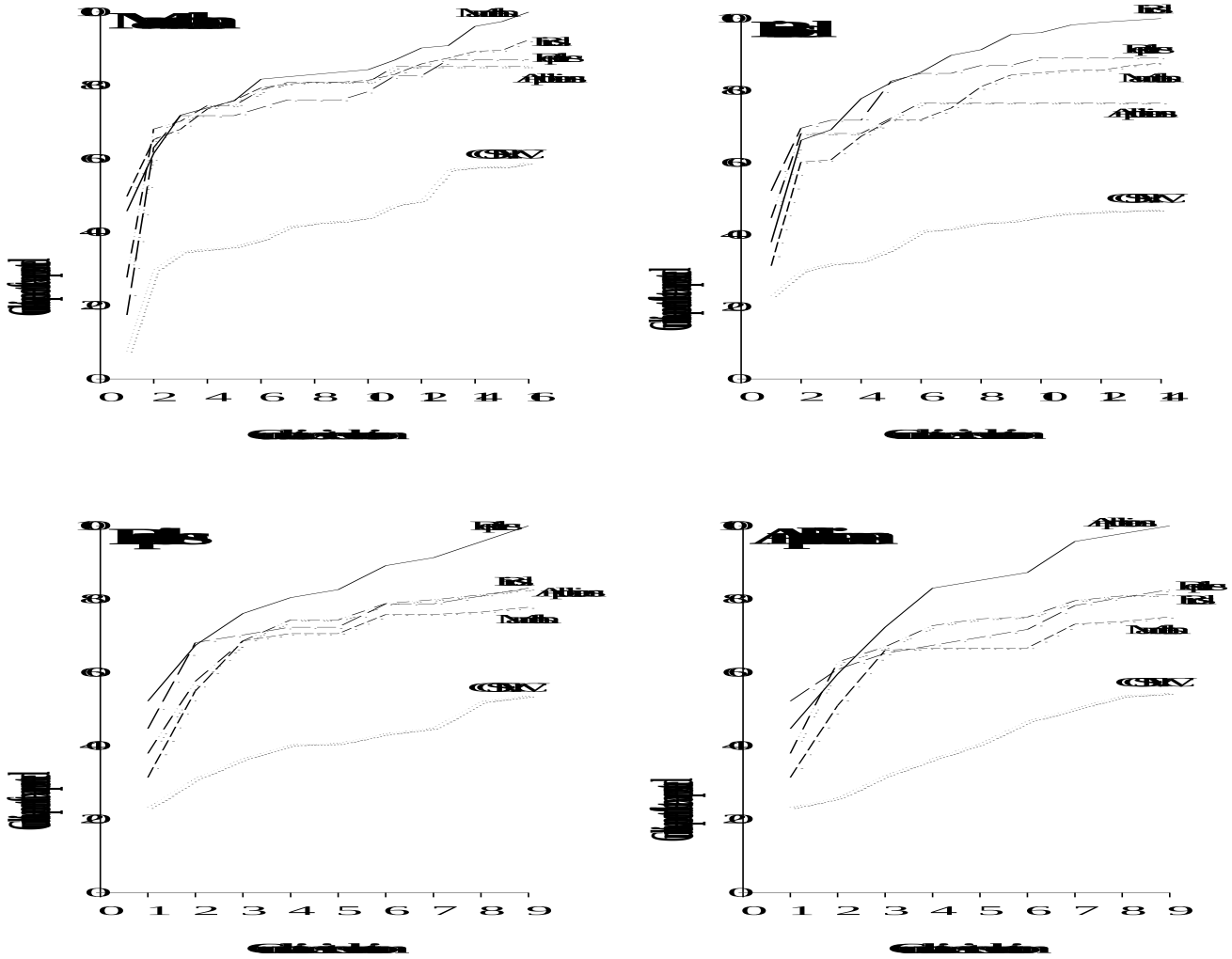

Figure 5. Cumulative representation of various focal groups achieved when using Mammals, Birds, Reptiles and Amphibians focal groups as the selection group. To standardise for the different number of taxa in focal groups, representation is shown as per cent of taxa represented for a particular focal group.

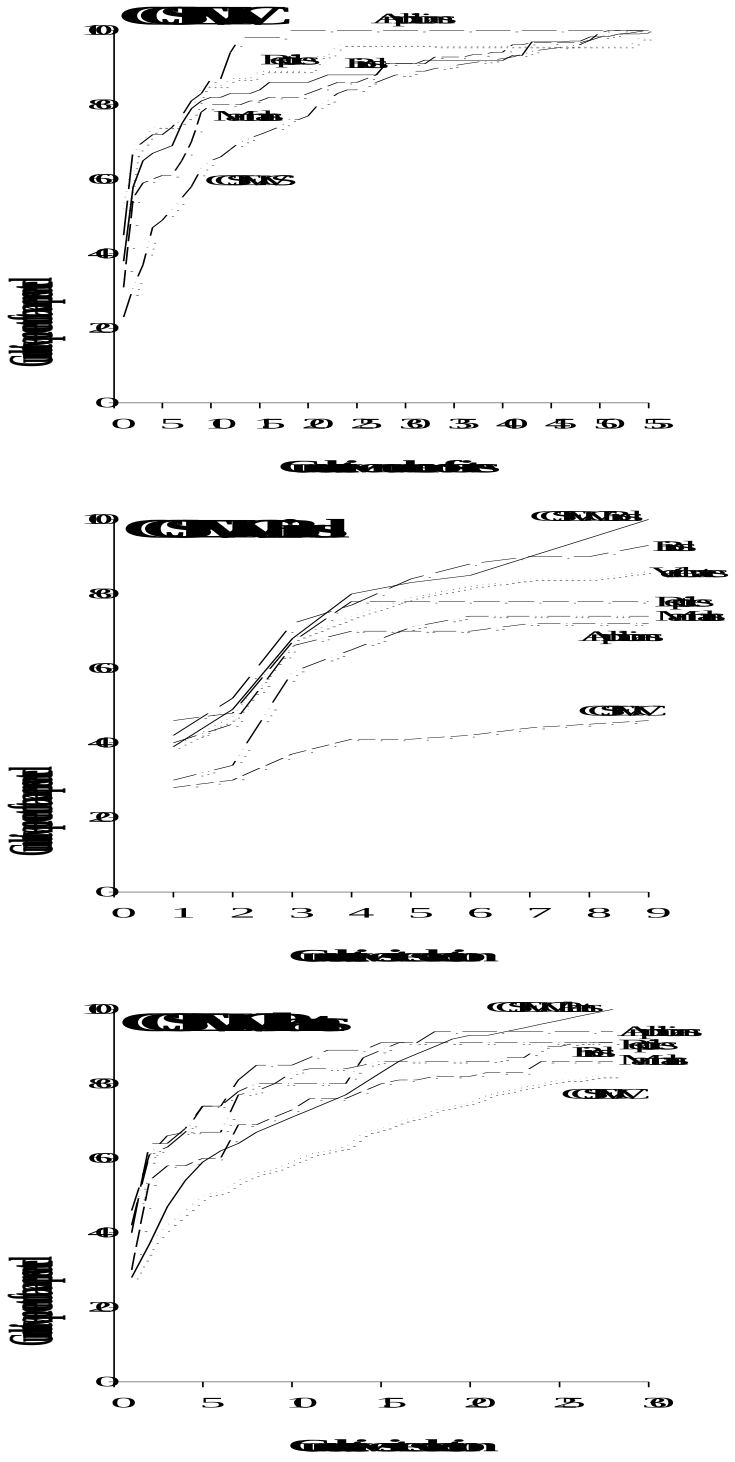

Figure 6. Cumulative representation of various focal groups achieved when using COSEWIC,

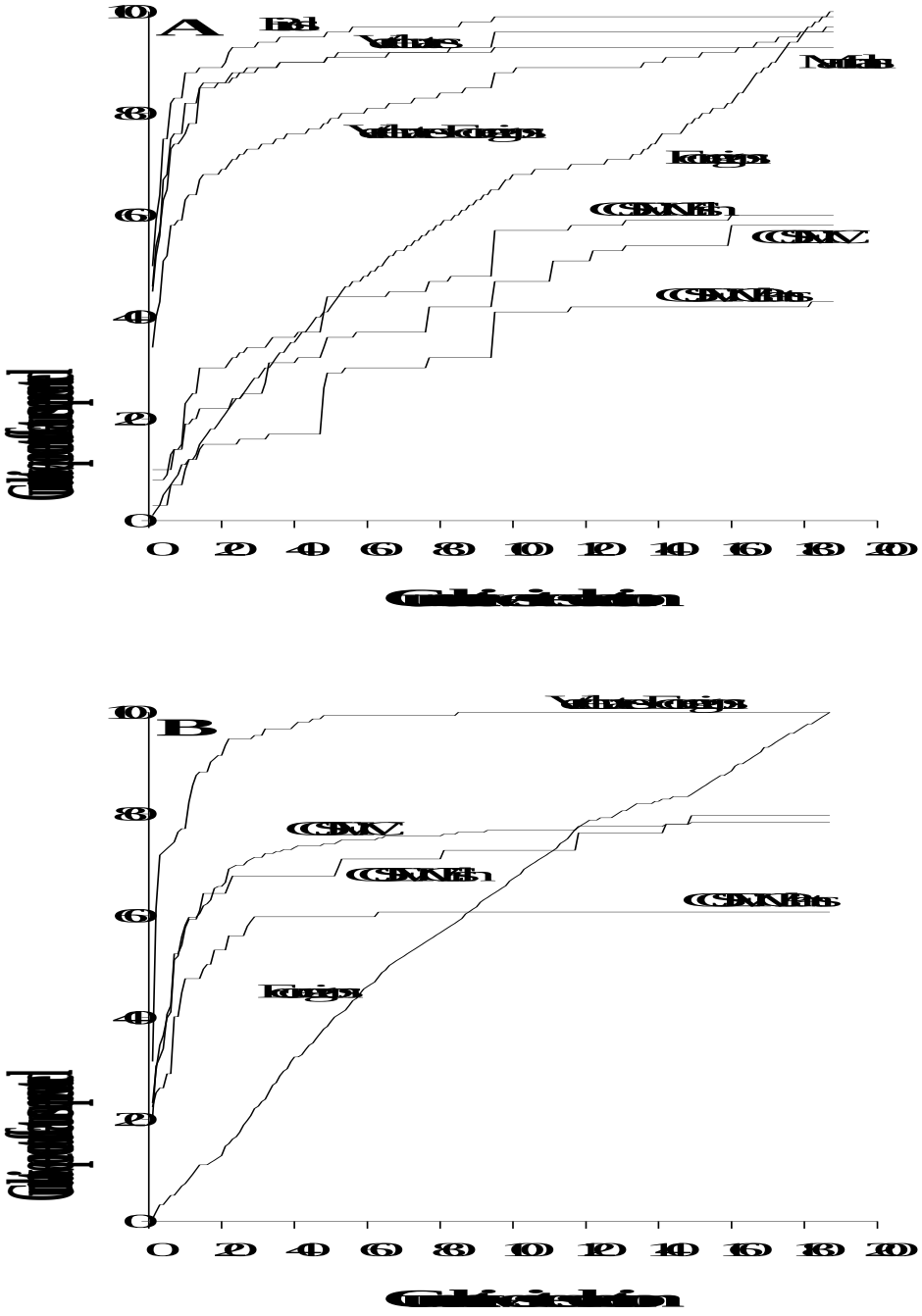

Figure 7. Cumulative representation of various other focal groups achieved when using **A**, Ecoregions, or **B**, Vertebrates-Ecoregions, as the selection group. To standardise for the different number of features in focal groups, representation is shown as per cent of taxa represented for a particular focal group.

DISCUSSION

Important sites for biodiversity conservation in Canada

Our analyses identified several general areas critical to the maintenance of biodiversity in Canada. For reasons discussed below, these areas are all located adjacent to the southern United States border; (i) Vancouver Island, British Columbia; (ii) Fraser Valley, British Columbia; (iii) Okanagan Valley, British Columbia; (iv) Niagara Peninsula, Ontario; (HAROLD TO COMPLETE)…

Some of these important conservation areas contained endemic taxa (e.g., Vancouver Island marmot on Vancouver Island), most were apparently determined by the presence of many edge-of-range taxa (e.g., for Mammals see Banfield, 1974; Birds, Peterson, 1990; Amphibians and Reptiles, Cook, 1984; fish, Scott and Crossman, 1973). That is, the southern political border of Canada has resulted in many species that are widespread in the United States being represented in only a few sites in southern Canada. Hence, all of the highly irreplaceable sites were contiguous with the southern United States border. Human activities potentially deleterious to some taxa are also concentrated along this border (H. Moore, unpublished data), possibly exacerbating the rarity of some taxa.

Implications for conservation management in Canada

We emphasise that our results do not indicate absolute priority locations for conservation activities, but rather identify locations deserving of further investigation at smaller scales appropriate to conservation activity. However, Erasmus et al. (1999) illustrate how prioritising conservation areas at smaller spatial scales leads to inefficiency, and that maximum efficiency is achieved by using largest-scale analysis; this is the approach we have adopted here. Hence, the question now becomes, given these apparently important sites, what should be done about them?

One answer is to identify potential threats to biodiversity in these sites. The appropriate analyses would require changes in scale, focusing on discrete areas at which quantifiable threats to individual taxa, or groups of taxa, might occur. Although such analyses are beyond the scope of this study, similar analyses could be conducted at finer scales within these sites. This would likely show that sites of high irreplaceability are themselves composed of sites of variable irreplaceability (i.e., it highlights the spatial heterogeneity of the larger sites). It would then be possible to measure and map priorities in terms of both irreplaceability and vulnerability, or risk of habitat loss. Such sites are most in danger of loss or degradation and will have the biggest negative impact on regional or national conservation goals if they are lost or degraded (Pressey, 1997). We note that finer-scale analyses would require data collected at a more appropriate scale than that used here. While this is available for some species (e.g., most COSEWICs), it is unavailable for many of the common species. However, given the relatively small number of highly irreplaceable sites, collecting such data would be a feasible project.

Since populations at the edge of a specie's range tend to have lower densities compared to centre of the range (Lawton, 1993), and contract (or expand) with changes in biotic and abiotic conditions, many of these edge-of-range species in Canada are presently classified as endangered, threatened or vulnerable. However, on a continental scale most of these species would not receive such a classification. Although these edge-of-range species have conservation value (Hunter and Hutchinson, 1994), most ecologists would agree that conservation budget would be better directed towards preserving truly endangered taxa. However, we recognise that most conservation decision-making occurs within geopolitical frameworks (Erasmus et al., 1999), and

that edge-of-range species will likley continue to be a high priority for conservation in Canada. However, a further possibility is to exclude locally-rare but globally-common taxa and repeat the analyses presented here and then compare results.

Surrogacy of focal groups

Because comprehensive surveys of biodiversity are prohibitively time-consuming and expensive (Lawton et al., 1998), a critical question in conservation planning is how well do sites selected on the basis of more easily surveyed taxa, such as Birds and mammals, reflect the distributions of other species? Given the rapid rate of habitat modification or loss in many parts of the world, the answer to this question has immediate application for locating protected areas (Lombard, 1995; Faith and Walker, 1996; Howard et al., 1998; Reid, 1998; Van Jaarsveld et al., 1998).

In Britain, species rich-areas (or 'hotspots') mapped at the 10 km^2 scale generally do not coincide for different taxa, and many rare species do not occur in the most species-rich sites (Prendergast et al., 1993; see also Williams et al., 1996). A similar finding was reported for the distributions of endangered species in the United States (Dobson et al., 1997). However, the application of complementarity-based reserve-selection procedures (Pressey et al., 1993) has shown that despite low spatial congruence in species richness between taxa, sets of priority areas selected using data on only one focal group can collectively also represent important sites for other taxa (Howard et al., 1998). Such a result is possible because the efficiency of a network of protected areas depends upon not only species richness, but also on how well they complement each other biologically. Furthermore, site-selection algorithms based on rarity rather than species richness consistently identify a lower number of sites required to achieve representation of all species (Williams et al., 1996; Csuti et al., 1997), suggesting that overlap in the distribution of rare species between taxa may be an important determinant of surrogacy.

Our results indicate that the same sites tended to be identified as highly irreplaceable when independently assessed for Mammals, Birds, Reptiles, Amphibians, and COSEWICs. In other words, the sites most important to each of these focal groups were identified independently. This result arose from a combination of overlap in the distributions of rare species (i.e., those of restricted distribution, both common and COSEWIC) and the properties of the predictor, summed irreplaceability, upon which our reserve selection procedure was based. Since the summed irreplaceability of a site is determined largely by the number of rare species within that site compared to other sites (S. Ferrier, R.L. Pressey and T.W. Barret, unpublished manuscript), the overlap in the distribution of edge-of-range species along the southern United States border between the focal groups (see above) meant that the same sites typically high summed irreplaceabilities for each group.

Hence, the four groups of taxa most likely to be used as surrogates in conservation planning provided similar representations of other focal groups. A practical implication of this finding is that conservation strategies based on these groups could also represent have considerable benefits for other taxa. However, we wish to emphasise that such an outcome would depend on the actual sites selected.

There is also no guarantee that area-based targets of ecosystems will protect all species. A key result of our analyses is that although the minimum-set solution to achieve 12 % of the area of ecoregions required 188 sites, a significant number of COSEWICs were not represented within these sites. This result emphasises that it is erroneous to assume that protecting very large areas

of land will protect all biodiversity. To achieve the best representation of biodiversity, all available information on species distributions needs to be incorporated into decision-making.

Future work

This study has developed and applied methodology for analysing the distributions of biotic and abiotic data in Canada. Our analyses were restricted to common vertebrates and COSEWICs by the availability of suitable range data. In the near future similar range maps are expected for vascular plants and Lepidoptera. When these data become available, we suggest that our analyses be repeated. While the priority sites identified in this study will not change, additional important areas may also be identified.

The framework developed in this study enables a comprehensive analysis of factors affecting the distribution of COSEWIC species (sensu Dobson et al., 1997) to be conducted. Such a study would use statistical methods to determine the relative impact of potentially deleterious human activities (or correlates thereof) on the distribution of these species. HAROLD TO COMPLETE…

BENEFITS

- Identification of priority locations for achieving national conservation goals in Canada. This project provides results for determining ecosystem representativeness and for identifying components of regional biodiversity that are poorly represented within existing conservation strategies.

- Extension of conservation planning beyond rescuing rare, threatened or endangered species and restoring or rehabilitating ecosystems. Extensive effort and sums have been spent on a small number of species and ecosystems. While there are strong conservation arguments for preserving these species, the effort expended can easily become out of proportion to the contribution that these species make to genetic diversity, and therefore to the fitness of the biota to adapt to environmental change. In a time when resources for environmental management are decreasing, managing for species before they become threatened or endangered in addition to prioritising effort so that resources are allocated in proportion to risk and value can optimise conservation effectiveness (Pressey et al., 1993; Pulliam & Babbitt, 1997).

- Improved knowledge and understanding of the distribution and co-occurrence of biodiversity (e.g. birds vs. mammals vs. endangered species) which can help to maximise protection of species at least cost and inconvenience to the public, provide a sounder scientific basis for ecosystem-based conservation planning, and provide a proactive mechanism for preventing future endangerment of more species (Dobson et al., 1997; Pulliam & Babbitt, 1997).

- Production of a novel equal-area sampling framework for Canada which is generalizable to both larger and smaller spatial scales. The framework can help decentralise resource management decision making to the community level, while maintaining the regional and national perspective necessary for integrated planning to ensure sustainable resource use.

- Multi-national, interagency co-operation in data sharing, knowledge integration, spatial analysis and technology transfer. This project has promoted collaboration among multiple

disciplines, agencies and jurisdictions in Canada, the USA and Australia. Technically, it has enhanced analysis capability within Canada through installation and use of non-commercial software developed and tested in Australia.

- Deployment of the equal-area sampling framework and C-Plan provides more quantitative and objective inputs to policy, planning and management at national, regional and ultimately international scales. For example, it enhances our knowledge regarding the importance of different sites in contributing to regional biodiversity of wildlife and other species at risk. For jurisdictions for which there are vegetation maps, similar analyses could be conducted to determine how conservation priorities based on habitat coverage compare to animal or plant species priorities.

DELIVERABLES

This technical report and digital outputs have been produced that can be used by Geomatics Canada and Canadian Wildlife Service to communicate in a format that is both useful as a reference to researchers and accessible to policy makers and managers. Products include:

- a digital hexagon sampling grid for Canada
- maps of priority sites for biodiversity conservation in Canada
- graphs of cumulative number of sites and cumulative number of species included in complementarity analyses
- graphs of cumulative number of other species groups included in cumulative number of sites selected for a given species group,
- documentation of data sources, methods, results, discussion, and significant limitations and conclusions.

MARKETING PLAN

The scientific nature of processes and analytical results produced through this work is of interest to the wildlife conservation disciplines and the geomatics discipline. Here one of the main marketing tools to be used to reach this group is scientific publications, both national and international, such as this technical report.

Also, results of this work as well as the new equal-area sample grid were provided to government web sites such as the Environment Canada Green Lane and the Natural Resources Canada CEONet.

The data and new grid have also been added to the EcoMAP database and GIS system and is being marketed as an integral part of the system.

INTELLECTUAL PROPERTY

Under the contract to Gregory Geosciences for this project, the ownership of the intellectual property has been defined as:

1. The intellectual property rights of any raw data supplied to the project by contributing agencies will remain with those agencies unless otherwise agreed upon.

2. The intellectual property rights of value-added data developed by the contractor such as the new comprehensive ecosystem framework or integrated data sets will belong to the contractor.

3. The intellectual property of the final summarized EcoMAP products will remain with the contractor. However, each contributing agency will be given access to copies for their own internal use.

4. The intellectual property rights of all products developed for the Internet will belong to any agency wishing to display it on the Internet.

PROJECT TEAM

GeoInsight Limited

Mr. Harold Moore was the principal project team member from GeoInsight (formerly Gregory Geoscience) Limited. He has 24 years of experience in applying remote sensing and GIS technologies to the study of the natural environment, human activity and the management of natural resource development. During that time he has managed many projects both large and small. Recently he has carried out projects that have updated the National Conservation Areas Database, modeled the threat to biodiversity, analyzed the level of human activity for the Canadian Ecosystems, and studied the effect of agricultural practices on bird nesting habitat diversity. Many of these projects involved a group of specialists in different fields and different agencies. He is a member of the GeoAccess advisory group looking at data visualization and infrastructure. Mr. Moore was assisted by Gregory Geoscience staff experienced in GIS development and database research.

Dr. Kathryn Freemark, Canadian Wildlife Service

Dr. Freemark has a strong research management and technical background in her work experience with Environment Canada and the EPA, her affiliations with Canadian and American universities, and her extensive scientific collaborations with academic, private sector and government scientists in Canada and the USA.

Mr. Moore and Dr. Freemark co-ordinated the efforts of the remaining team members who bring specialized expertise to the project. They belong to national and international agencies that are at the leading edge of this type of work. These team members are as follows:

Mr. Denis White	United states Environmental Protection Agency
Dr. Tony Sinclair	University of British Columbia, Vancouver
Dr. David Forsyth	University of British Columbia
Dr. Bob Pressey	New South Wales National Parks and Wildlife Service
Mr. Tom Barrett	New South Wales National Parks and Wildlife Service

FACILITIES

As a collaborative project, the facilities of a number of agencies were used including GIS and computer analysis labs at the University of British Columbia, the US-EPA in Corvallis, Oregon, the New South Wales National Parks Wildlife Service in Australia, the Canadian Wildlife Service and Gregory Geoscience Limited. The diversity of these facilities permitted parallel analysis and quick turn around of output products. Along with the hardware at these facilities a number of custom software packages and data sets.

ACKNOWLEDGEMENT

We thank Matthew Watts for programming C-Plan.

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Appendix 1. Summary of taxa used in analyses (number of taxa).

A. Reptiles (46)

(i) Common Reptiles (33)

Atlantic Ridley	*Lepidochelys kempi*
northern brown snake	*Storeria dekayi dekayi*
Butler's garter snake	*Thamnophis butleri*
common garter snake	*Thamnophis sirtalis*
common snapping turtle	*Chelydra serpentina*
eastern ribbon snake	*Thamnophis sauritus*
eastern box turtle	*Terrapene caolina*
fox snake	*Elaphe vulpina*
gopher snake	*Pituophis melanoleucus*
green turtle	*Chelonia mydas*
map turtle	*Graptemys geographica*
milk snake	*Lampropeltis triangulum*
night snake	*Hypsiglena torquata*
northern alligator lizard	*Gerrhonotus coeruleus*
northern water snake	*Nerodia sipedon*
northwestern garter snake	*Thamnophis elegans*
painted turtle	*Chrysemys picta*
plains garter snake	*Thamnophis radix*
queen snake	*Regina septemvitta*
racer	*Coluber constrictor*
redbelly snake	*Storeria occipitomaculata*
ringneck snake	*Diadophis punctatus*
rubber boa snake	*Charina bottae*
sharptail snake	*Contia tenuis*
short-horned lizard	*Phrynosoma douglassi*
smooth green snake	*Opheodrys vernalis*
stinkpot	*Sternotherus odoratus*
timber rattlesnake	*Crotalus horridus*
western skink	*Eumeces skiltonianus*
western rattlesnake	*Crotalus viridis*
western garter snake	*Thamnophis elegans*
western pond turtle	*Clemmys marmorata*
western hognose snake	*Heterodon nasicus*

(ii) Endangered Reptiles (2)

blue racer	*Coluber constrictor foxi*
Lake Erie water snake	*Nerodia sipedon insularum*

(iii) Threatened Reptiles (4)

Eastern massasauga rattlesnake	*Sistrurus catenatus*
Blanding's turtle (Nova Scotia)	*Emydoidea blandingi*
Spiny softshell turtle	*Trionyx spiniferus*
black rat snake	*Elaphe obsoleta obsoleta*

(iv) Vulnerable Reptiles (7)

eastern hognose snake	*Heterodon platyrhinos*
eastern short-horned lizard	*Phrynosoma douglassi*
eastern yellow-bellied racer	*Coluber constrictor flaviventris*
northern prairie skink	*Eumeces septentrionalis*
spotted turtle	*Clemmys guttata*
wood turtle	*Clemmys insculpta*
five-lined skink	*Eumeces fasciatus*

B. Amphibians (46)

(i) Common Amphibians (38)

American toad	*Bufo americanus*
blue spotted salamander	*Ambystoma laterale*
bullfrog	*Rana catesbeiana*
clouded salamander	*Aneides ferreus*
diploid grey treefrog	*Hyla chrysoscelis*
northern dusky salamander	*Desmognathus fuscus*
eastern newt	*Notophthalmus viridescens*
eschscholtz's salamander	*Ensatina eschscholtzii*
eastern redback salamander	*Plethodon cinereus*
four-toed salamander	*Hemidactylium scutatum*
green frog	*Rana clamitans*
great plains toad	*Bufo cognatus*
jefferson salamander	*Ambystoma jeffersonianum*
long-toe salamander	*Ambystoma macrodactylum*
mink frog	*Rana septentrionalis*
mudpuppy	*Necturus maculosus*
northern leopard frog	*Rana pipiens*
northern cricket frog	*Acris crepitans*
northwestern salamander	*Ambystoma gracile*
pacific tree frog	*Hyla regilla*
pickerel frog	*Rana palustris*
plains spadefoot toad	*Spea bombifrons*
red-legged frog	*Rana aurora*
roughskin newt	*Taricha granulosa*
spotted frog	*Rana pretiosa*
spring peeper	*Pseudacris crucifer*
spring salamander	*Gyrinophilus porphyriticus*
striped chorus frog	*Pseudacris maculata*
tailed frog	*Ascaphus truei*
tetraploid grey treefrog	*Hyla versicolor*
tiger salamander	*Ambystoma tigrinum*
northern two-lined salamander	*Eurycea bislineata*
western toad	*Bufo boreas*
wood frog	*Rana sylvatica*
Woodhouse's toad	*Bufo woodhousei*
western redback salamander	*Plethodon vehiculum*
yellow-spotted salamander	*Ambystoma aculatum*

(ii) Endangered Amphibians (2)

Blanchard's cricket frog	*Acris crepitans blanchardi*
northern leopard frog (B.C. pop.)	*Rana pipiens*

(iii) Threatened Amphibians (0)

(iv) Vulnerable Amphibians (7)

Fowler's Toad	*Bufo fowleri*
Pacific giant salamander	*Dicamptodon tenebrosus*
Smallmouth salamander	*Ambystoma texanum*
Northern leopard frog	*Rana pipiens*
coeurd'Alene salamander	*Plethodon idahoensis*
mountain dusky salamander	*Desmognathus orcophaeus*
great basin spadefoot toad	*Spea intermontanus*

C. Mammals (152)

(i) Common Mammals (123)

Virginia opossum	*Didelphis virginiana*
masked shrew	*Sorex cinereus*
dusky shrew	*Sorex obscurus*
vagrant shrew	*Sorex vagrans*
American water shrew	*Sorex palustris*
Bendire's shrew	*Sorex bindirii*
smokey shrew	*Sorex fumeus*
Arctic shrew	*Sorex arcticus*
Trowbridge's shrew	*Sorex trowbridgii*
pigmy shrew	*Microsorex hoyi*
short-tailed shrew	*Blarina brevicauda*
least shrew	*Cryptotis parva*
American shrew-mole	*Neürotrichus gibbsii*
Pacific coast mole	*Scapanus orarius*
hairy-tailed mole	*Parascalops breweri*
star-nosed mole	*Condylura cristata*
little brown bat	*Myotis lucifugus*
Yuma bat	*Myotis yumanensis*
Keen's bat	*Myotis keenii*
long-eared bat	*Myotis evotis*
long-legged bat	*Myotis volans*
California bat	*Myotis californicus*
small-footed bat	*Myotis leibii*
silver-haired bat	*Lasionycteris noctivagans*
Townsend's big-eared bat	*Plecotus townsendii*
eastern pipistrelle	*Pipistrellus subflavus*
big brown bat	*Eptesicus fuscus*
evening bat	*Nycticeius humeralis*
red bat	*Lasiurus borealis*
hoary bat	*Lasiurus cinerus*
big free-tailed bat	*Tadarida macrotis*
American pika	*Ochotona princeps*

eastern cottontail	*Sylvilagus floridanus*
snowshoe hare	*Lepus americanus*
Arctic hare	*Lepus arcticus*
white-tailed jack rabbit	*Lepus townsendii*
mountain beaver	*Aplodontia rufa*
eastern chipmunk	*Tamias striatus*
least chipmunk	*Eutamias minimus*
yellow pine chipmunk	*Eutamias amoenus*
Townsend's chipmunk	*Entamias townsendii*
red-tailed chipmunk	*Eutamias ruficaudus*
woodchuck	*Marmota monax*
yellow-bellied marmot	*Marmota flaviventris*
hoary marmots	*Marmota caligata*
Richardson's ground squirrel	*Spermophilus richardsonii*
Columbian ground squirrel	*Spermophilus columbianus*
Arctic ground squirrel	*Spermophilus parryii*
thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*
Franklin's ground squirrel	*Spermophilus franklinii*
golden-mantled ground squirrel	*Spermophilus lateralis*
grey or black squirrel	*Sciurus carolinensis*
fox squirrel	*Sciurus niger*
American red squirrel	*Tamiasciurus hudsonicus*
Douglas's squirrel	*Tamiasciurus douglasii*
northern flying squirrel	*Glaucomys sabrinus*
northern pocket gopher	*Thomomys talpoides*
olive-backed pocket mouse	*Perognathus fasciatus*
great basin pocket mouse	*Perognathus parvus*
American beaver	*Castor canadensis*
deer mouse	*Peromyscus maniculatus*
Sitka mouse	*Peromyscus sitkensis*
white-footed mouse	*Peromyscus leucopus*
Cascade deer mouse	*Peromyscus oreas*
northern grasshopper mouse	*Onychomys leucogaster*
bushy-tailed wood rat	*Neotoma cinerea*
red-backed vole	*Clethrionomys rutilus*
western red-backed vole	*Clethrionomys occidentalis*
Gapper's red-backed vole	*Clethrionomys gapperi*
brown lemming	*Lemmus lemmus*
southern bog lemming	*Synaptomys cooperi*
northern bog lemming	*Synaptomys borealis*
heather vole	*Phenacomys intermedius*
collared lemming	*Dicrostonyx torquatus*
Ungava lemming	*Dicrostonyx hudsonius*
Muskrat	*Ondrata zibethicus*
sagebush vole	*Lagurus curtatus*
Richardson's water vole	*Arvicola richardsoni*
prairie vole	*Microtus ochrogaster*
singing vole	*Microtus miurus*
meadow vole	*Microtus pennsylvanicus*
Monane vole	*Microtus montanus*
Townsend's vole	*Microtus townsendii*

tundra vole	*Microtus oeconomus*
long-tailed vole	*Microtus longicaudus*
rock vole	*Microtus chrotorrhinus*
chestnut-cheeked vole	*Microtus xanthognathus*
creeping vole	*Microtus oregoni*
Pacific jumping mouse	*Zapus trinotatus*
western jumping vole mouse	*Zapus princeps*
meadow jumping vole mouse	*Zapus hudsonius*
woodland jumping vole mouse	*Napaeozapus insignis*
American porcupine	*Erethizon dorsatum*
Coyote	*Canis latrans*
Wolf	*Canis lupus*
Arctic fox	*Alopex lagopus*
red fox	*Vulpes vulpes*
American black bear	*Ursus americanus*
Raccoon	*Procyon lotor*
American marten	*Martes americana*
Fisher	*Martes pennanti*
Ermine	*Mustela erminea*
long-tailed weasel	*Mustela frenata*
least weasel	*Mustela nivalis*
American mink	*Mustela vison*
Wolverine	*Gulo gulo*
American badger	*Taxidea taxus*
western spotted skunk	*Spilogale gracilis*
Striped skunk	*Mephitis mephitis*
river otter	*Lontra canadensis*
cougar	*Felis concolor*
lynx	*Lynx lynx*
bobcat	*Lynx rufus*
caribou	*Rangifer tarandus*
mule deer	*Odocoileus hemionus*
white-tailed deer	*Odocoileus virginianus*
moose	*Alces alces*
wapiti	*Cervus elaphus*
pronghorn	*Antilocapra americana*
mountain goat	*Oreamnos americanus*
muskox	*Ovibos moschatus*
bighorn sheep	*Ovis canadensis*
Dall's sheep	*Ovis dalli*

(ii) Endangered Mammals (5)

Peary Banks Island	*Rangifer tarandus pearyi*
Peary High Arctic	*Rangifer tarandus pearyi*
Vancouver Island marmot	*Marmota vancouverensis*
Marten (Newfoundland)	*Martes americana*
Wolverine (eastern population)	*Gulo gulo*

(iii) Threatened Mammals (5)

Wood bison	*Bison bison athabascae*
Caribou (Low Arctic Peary)	*Rangifer tarandus pearyi*

Woodland caribou	*Rangifer tarandus caribou*
Townsend's mole	*Scapanus townsendii*
Pacific water shrew	*Sorex bendirii*

(iv) Vulnerable Mammals (19)

Black Tailed Prairie Dog	*Cynomys ludovicianus*
Eastern Mole	*Scalopus aquaticus*
Fringed Bat	*Myotis thysanodes*
Gaspé Shrew	*Sorex gaspensis*
Grey fox	*Urocyon cinereoargenteus*
Grizzly bear	*Ursus arctos*
Keen's Long-eared bat	*Myotis keenii*
Nuttall's cottontail	*Sylvilagus nuttallii*
Ord's Kangaroo rat	*Dipodomys ordii*
Pallid bat	*Antrozous pallidus*
Plains pocket gopher	*Geomys bursarius*
Polar bear	*Ursus maritimus*
Southern flying squirrel	*Glaucomys volans*
Spotted bat	*Euderma maculata*
Western harvest mouse	*Reithrodontomys megalotis*
Woodland caribou	*Rangifer tarandus caribou*
Queen Charlotte's ermine	*Mustela erminea haidarum*
New Foundland wolverine	*Gulo gulo*
Woodland vole	*Microtus pinetorum*

D. Birds (383)

(i) Common Birds (342)

American Black Duck	*Anas rubripes*
Green-winged Teal	*Anas crecca*
Alder Flycatcher	*Empidonax alnorum*
American Avocet	*Recurvirostra americana*
American Bittern	*Botaurus lentiginosus*
American Coot	*Fulica americana*
American Crow	*Corvus brachyrhynchos*
American Dipper	*Cinclus mexicanus*
American Goldfinch	*Carduelis tristis*
American Kestrel	*Falco sparverius*
American Redstart	*Setophaga ruticilla*
American Robin	*Turdus migratorius*
American Wigeon	*Anas americana*
American Woodcock	*Scolopax minor*
Anna's Hummingbird	*Calypte anna*
Arctic Tern	*Sterna paradisea*
Atlantic Brant	*Branta bernicla*
American Tree Sparrow	*Spizella arborea*
American White Pelican	*Pelecanus erythrorhynchos*
Bald Eagle	*Haliaeetus leucocephalus*
Barrow's Goldeneye	*Becephala islandica*
Baird's Sparrow	*Ammodramus bairdii*

Bank Swallow	*Riparia riparia*
Barn Swallow	*Hirundo rustica*
Baird's Sandpiper	*Calidris bairdii*
Black-and-White Warbler	*Mniotilta varia*
Black-billed Cuckoo	*Coccyzus erythopthalmus*
Black-billed Magpie	*Pica pica*
Black-bellied Plover	*Pluvialis squatarola*
Buff-breasted Sandpiper	*Tryngites subruficollis*
Bay-breasted Warbler	*Dendoica castanea*
Black-backed Woodpecker	*Picoides arcticus*
Black-capped Chickadee	*Parus atricapillus*
Black-crowned Night Heron	*Nycticorax nycticorax*
Barred Owl	*Strix varia*
Belted Kingfisher	*Ceryle alcyon*
Bewick's Wren	*Thromanes bewickii*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Brown-headed Cowbird	*Molothrus ater*
Black-headed Grosbeak	*Pheuticus melanocephalus*
Blackburnian Warbler	*Dendroica fusca*
Blue Jay	*Cyanocitta cristata*
Blackpoll Warbler	*Dendroica striata*
Black Scoter	*Melanitta nigra*
Black Swift	*Cypseloides niger*
Black Tern	*Chlidonias niger*
Blue Grouse	*Dendragapus obscurus*
Bobolink	*Dolichonyx oryzivorus*
Boreal Chickadee	*Parus hudsonicus*
Bonaparte's Gull	*Larus philadelphia*
Boreal Owl	*Aegolius funereus*
Bohemian Waxwing	*Bombycilla garrulus*
Brandt's Cormorant	*Phalacrocorax penicillatus*
Brewer's Blackbird	*Euphagus cyanocephalus*
Brown Creeper	*Certhia americana*
Brewer's Sparrow	*Spizella breweri*
Brown Thrasher	*Toxostoma rufum*
Black-throated Blue Warbler	*Dendroica caerulescens*
Black-throated Green Warbler	*Dendroica virens*
Band-tailed Pigeon	*Columba fasciata*
Black-throated Gray Warbler	*Dendroica nigrescens*
Bufflehead	*Bucephala albeola*
Broad-winged Hawk	*Buteo platypterus*
Blue-winged Teal	*Anas discors*
Blue-winged Warbler	*Vermivora pinus*
Cassin's Finch	*Carpodacus cassinii*
Canada Goose	*Branta canadensis*
California Gull	*Larus californicus*
Calliope Hummingbird	*Stellula calliope*
Canvasback	*Aythya valisineria*
Canyon Wren	*Catherpes mexicanus*
Canada Warbler	*Wilsonia canadensis*
Carolina Wren	*Thryothorus ludovicianus*

Chestnut-backed Chickadee	*Parus rufescens*
Chestnut-collared Longspur	*Calcarius ornatus*
Clay-colored Sparrow	*Spizella pallida*
Cedar Waxwing	*Bombycilla cedrorum*
Chipping Sparrow	*Spizella passerina*
Chimney Swift	*Aeronautes saxatalis*
Cinnamon Teal	*Anas cyanoptera*
Clark's Grebe	*Aechmophorus clarkii*
Clark's Nutcracker	*Nucifraga columbiana*
Cliff Swallow	*Hirundo pyrrhonota*
Cape May Warbler	*Dendroica tigrina*
Common Bushtit	*Psaltriparus minimus*
Common Goldeneye	*Bucephala clangula*
Common Grackle	*Quiscalus quiscula*
Cooper's Hawk	*Accipiter cooperii*
Common Loon	*Gavia immer*
Common Merganser	*Mergus merganser*
Common Moorhen	*Gallinula chloropus*
Common Nighthawk	*Chordeiles minor*
Connecticut Warbler	*Oporornis agilis*
Common Poorwill	*Phalaenoptilus nuttalii*
Common Raven	*Corvus corax*
Common Redpoll	*Carduelis flammea*
Common Snipe	*Gallinago gallinago*
Common Tern	*Sterna hirundo*
Common Yellowthroat	*Geothlypis trichas*
Common Ringed Plover	*Charadrius hiaticula*
Chestnut-sided Warbler	*Dendroica pensylvanica*
Chuck-will's-widow	*Caprimulgus carolinensis*
Double-crested Cormorant	*Pelecanus erythorhynchos*
Dark-eyed Junco	*Junco hyemalis*
Dickcissel	*Spiza americana*
Downy Woodpecker	*Picoides pubescens*
Dusky Flycatcher	*Empidonax oberholseri*
Dunlin	*Calidris alpina*
Eastern Bluebird	*Sialia sialis*
Eared Grebe	*Podiceps nigricollis*
Eastern Kingbird	*Tyrannus tyrannus*
Eastern Meadowlark	*Sturnella magna*
Eastern Phoebe	*Sayornis phoebe*
Eastern Screech Owl	*Otus asio*
Eastern Wood-Pewee	*Contopus sordidulus*
Evening Grosbeak	*Coccothraustes vespertinus*
Field Sparrow	*Spizella pusilla*
Fox Sparrow	*Passerella iliaca*
Forster's Tern	*Sterna forsteri*
Franklin's Gull	*Larus pipixcan*
Gadwall	*Anas strepera*
Great Crested Flycatcher	*Myiarchus crinitus*
Golden-crowned Kinglet	*Regulus satrapa*
Golden-crowned Sparrow	*Zonotrichia atricapilla*

Gray-cheeked Thrush	*Catharus minimus*
Great Gray Owl	*Strix nebulosa*
Great Horned Owl	*Bubo virginianus*
Glaucous Gull	*Larus hyperboreus*
Green-backed Heron	*Butorides striatus*
Golden Eagle	*Aquila chrysaetos*
Gray Jay	*Perisoreus canadensis*
Gray Catbird	*Dumetella carolinensis*
Greater Scaup	*Aythya marila*
Grasshopper Sparrow	*Ammodramus savannarum*
Greater Yellowlegs	*Tringa melanoleuca*
Great Blue Heron	*Ardea herodias*
Greater White-fronted Goose	*Anser albifrons*
Golden-winged Warbler	*Vermivora chrysoptera*
Gyrfalcon	*Falco rusticolus*
Hammond's Flycatcher	*Empidonax hammondii*
Harlequin Duck	*Histrionicus histrionicus*
Harris' Sparrow	*Zonotrichia querula*
Hairy Woodpecker	*Picoides villosus*
Herring Gull	*Larus argentatus*
Hermit Thrush	*Catharus guttatus*
House Finch	*Carpodacus mexicanus*
Horned Grebe	*Podiceps auritus*
Horned Lark	*Eremophila alpestris*
Hooded Merganser	*Lophodytes cucullatus*
Hoary Redpoll	*Carduelis hornemanni*
House Wren	*Troglodytes troglodytes*
Hudsonian Godwit	*Limosa haemastica*
Hutton's Vireo	*Vireo huttoni*
Iceland Gull	*Larus glaucoides*
Indigo Bunting	*Passerina cyanea*
Killdeer	*Charadrius vociferus*
Lapland Longspur	*Calcarius lapponicus*
Lark Bunting	*Calamospiza melanocorys*
Lark Sparrow	*Chondestes grammacus*
Lazuli Bunting	*Passerina amoena*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Le Conte's Sparrow	*Ammodramus leconteii*
Least Flycatcher	*Empidonax minimus*
American Golden-Plover	*Pluvialis dominica*
Long-eared Owl	*Asio otus*
Least Sandpiper	*Calidris minutilla*
Lesser Scaup	*Aythya affinis*
Lewis' Woodpecker	*Melanerpes lewis*
Lesser Yellowlegs	*Tringa flavipes*
Lincoln's Sparrow	*Melospiza lincolnii*
Loggerhead Shrike	*Lanius ludovicianus*
Lesser Snow Goose	*Chen caerulescens*
Marbled Godwit	*Limosa fedoa*
Mallard	*Anas platyrhynchos*
Magnolia Warbler	*Dendroica magnolia*

Marsh Wren	*Cistothorus palustris*
McCown's Longspur	*Calcarius mccownii*
Mew Gull	*Larus canus*
Merlin	*Falco columbarius*
MacGillivray's Warbler	*Oporornis tolmiei*
Mountain Bluebird	*Sialia currucoides*
Mountain Chickadee	*Parus gambeli*
Mourning Dove	*Zenaida macroura*
Mourning Warbler	*Oporornis philadelphia*
Nashville Warbler	*Vermivora ruficapilla*
Northern Cardinal	*Cardinalis cardinalis*
Northwestern Crow	*Corvus caurinus*
Northern Flicker	*Colaptes auratus*
Northern Goshawk	*Accipiter gentilis*
Northern Harrier	*Circus cyaneus*
Northern Hawk Owl	*Surnia ulula*
Northern Mockingbird	*Mimus polyglottos*
Northern Oriole	*Icterus galbula*
Northern Parula	*Parula americana*
Northern Pintail	*Anas acuta*
Northern Pygmy-Owl	*Glaucidium gnoma*
Northern Waterthrush	*Seiurus noveboracensis*
Northern Wheatear	*Oenanthe oenanthe*
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
Northern Shoveler	*Anas clypeata*
Northern Shrike	*Lanius excubitor*
Northern Saw-whet Owl	*Aegolius acadicus*
Orange-crowned Warbler	*Vermivora celata*
Oldsquaw	*Clangula hyemalis*
Orchard Oriole	*Icterus spurius*
Olive-sided Flycatcher	*Contopus borealis*
Osprey	*Pandion haliaetus*
Ovenbird	*Seiurus aurocapillus*
Pacific Loon	*Gavia pacifica*
Pied-billed Grebe	*Podilymbus podiceps*
Peregrine Falcon	*Falco peregrinus*
Pectoral Sandpiper	*Calidris melanotos*
Philadelphia Vireo	*Vireo philadelphicus*
Pine Grosbeak	*Pinicola enucleator*
Pine Siskin	*Carduelis pinus*
Pine Warbler	*Dendroica pinus*
Pileated Woodpecker	*Dryocopus pileatus*
Palm Warbler	*Dendroica palmarum*
Prairie Falcon	*Falco mexicanus*
Purple Finch	*Carpodacus purpureus*
Purple Martin	*Progne subis*
Purple Sandpiper	*Calidris maritima*
Pygmy Nuthatch	*Sitta pygmaea*
Rose-breasted Grosbeak	*Pheuticus ludovicianus*
Ring-billed Gull	*Larus delawarensis*
Red-breasted Merganser	*Mergus serrator*

Red-breasted Nuthatch	*Sitta canadensis*
Red-breasted Sapsucker	*Sphyrapicus ruber*
Red-bellied Woodpecker	*Melanerpes carolinus*
Ruby-crowned Kinglet	*Regulus calendula*
Red Crossbill	*Loxia curvirostra*
Redhead	*Aythya americana*
Red Knot	*Calidris canutus*
Red Phalarope	*Phalaropus fulicaria*
Red-eyed Vireo	*Vireo olivaceus*
Rough-legged Hawk	*Buteo lagopus*
Ring-necked Duck	*Aythya collaris*
Red-necked Grebe	*Podiceps grisegena*
Red-necked Phalarope	*Phalaropus lobatus*
Red-naped Sapsucker	*Sphyrapicus nuchalis*
Rock Ptarmigan	*Lagopus mutus*
Rock Wren	*Salpinctes obsoletus*
Rufous-sided Towhee	*Pipilo erythrophthalmus*
Red-tailed Hawk	*Buteo jamaicensis*
Ruby-throated Hummingbird	*Archilochus colubris*
Red-throated Loon	*Gavia stellata*
Rusty Blackbird	*Euphagus carolinus*
Ruddy Duck	*Oxyura jamaicensis*
Ruffed Grouse	*Bonasa umbellus*
Rufous Hummingbird	*Selasphorus rufus*
Ruddy Turnstone	*Arenaria interpres*
Red-winged Blackbird	*Agelaius phoeniceus*
Sandhill Crane	*Grus canadensis*
Sage Grouse	*Centrocercus urophasianus*
Sabine's Gull	*Xema sabini*
Sanderling	*Calidris alba*
Say's Phoebe	*Sayornis saya*
Savannah Sparrow	*Passerculus sandwichensis*
Short-billed Dowitcher	*Limnodromus griseus*
Scarlet Tanager	*Piranga olivacea*
Semipalmated Plover	*Charadrius semipalmatus*
Semipalmated Sandpiper	*Calidris pusilla*
Sedge Wren	*Cistothorus platensis*
Sharp-tailed Grouse	*Tympanuchus phasianellus*
Siberian Tit	*Parus cinctus*
Smith's Longspur	*Calcarius pictus*
Snow Bunting	*Plectrophenax nivalis*
Snowy Owl	*Nyctea scandiaca*
Sora	*Porzana carolina*
Solitary Sandpiper	*Tringa solitaria*
Song Sparrow	*Melospiza melodia*
Solitary Vireo	*Vireo solitarius*
Spruce Grouse	*Dendragapus canadensis*
Sprague's Pipit	*Anthus spragueii*
Spotted Sandpiper	*Actitus macularia*
Sharp-shinned Hawk	*Accipiter striatus*
Stellar's Jay	*Cyanocitta stelleri*

Stilt Sandpiper	*Calidris himantopus*
Sharp-tailed Sparrow	*Ammodramus caudacutus*
Surfbird	*Aphriza virgata*
Surf Scoter	*Melanitta perspicillata*
Swainson's Hawk	*Buteo swainsoni*
Swamp Sparrow	*Melospiza georgiana*
Swainson's Thrush	*Catharus ustulatus*
Tennessee Warbler	*Vermivora peregrina*
Townsend's Solitaire	*Myadestes townsendi*
Townsend's Warbler	*Dendroica townsendi*
Tree Swallow	*Tachycineta bicolor*
Trumpeter Swan	*Cygnus buccinator*
Three-toed Woodpecker	*Picoides tridactylus*
Tufted Titmouse	*Parus bicolor*
Turkey Vulture	*Cathartes aura*
Upland Sandpiper	*Bartramia longicauda*
Vaux's Swift	*Chaetura vauxi*
Varied Thrush	*Ixoreus naevius*
Veery	*Catharus fuscescens*
Vesper Sparrow	*Pooecetes gramineus*
Violet-green Swallow	*Tachycineta thalassina*
Viginia Rail	*Rallus limicola*
American Pipit	*Anthus rubescens*
Wandering Tattler	*Heteroscelus incanus*
Warbling Vireo	*Vireo gilvus*
White-breasted Nuthatch	*Sitta carolinensis*
White-crowned Sparrow	*Zonotrichia leucophrys*
Western Bluebird	*Sialia mexicana*
Pacific-slope Flycatcher	*Empidonax difficilis*
Western Grebe	*Aechmophorus occidentalis*
Western Kingbird	*Tyrannus verticalis*
Western Meadowlark	*Sturnella neglecta*
Western Screech Owl	*Otus kennicottii*
Western Tanager	*Piranga ludoviciana*
White-eyed Vireo	*Vireo griseus*
Western Wood-Pewee	*Contopus sordidulus*
Whimbrel	*Numenius phaeopus*
Tundra Swan	*Cygnus columbianus*
White-headed Woodpecker	*Picoides albolarvatus*
Willow Flycatcher	*Empidonax trailii*
Willet	*Catoptrophorus semipalmatus*
Wilson's Phalarope	*Phalaropus tricolor*
Willow Ptarmigan	*Lagopus lagopus*
Williamson's Sapsucker	*Sphyrapicus thyroideus*
Wilson's Warbler	*Wilsonia pusilla*
Winter Wren	*Troglodytes troglodytes*
Wood Duck	*Aix sponsa*
Wood Thrush	*Hylocichla mustelina*
Whip-poor-will	*Caprimulgus vociferus*
White-rumped Sandpiper	*Calidris fuscicollis*
White-throated Sparrow	*Zonotrichia albicollis*

White-throated Swift	*Aeronautes saxatalis*
White-winged Crossbill	*Loxia leucoptera*
White-winged Scoter	*Melanitta fusca*
Yellow-breasted Chat	*Icteria virens*
Yellow-billed Cuckoo	*Coccyzus americanus*
Yellow-bellied Flycatcher	*Empidonax flaviventris*
Yellow-billed Loon	*Gavia adamsii*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Yellow Rail	*Coturnicops noveboracensis*
Yellow-headed Blackbird	*Xanthocephalus anthocephalus*
Yellow-rumped Warbler	*Dendroica coronata*
Yellow-throated Vireo	*Vireo flavifrons*
Yellow Wagtail	*Motacilla flava*
Yellow Warbler	*Dendroica petechia*

(iii) Endangered Birds (14)

whooping crane	*Grus americana*
northern bobwhite	*Colinus virginianus*
harlequin duck	*Histrionicus histrionicus*
anatum peregrine falcon	*Falco peregrinus anatum*
acadian flycatcher	*Empidonax virescens*
burrowing owl	*Athene cunicularia*
spotted owl	*Strix occidentalis*
mountain plover	*Charadrius montanus*
piping plover	*Charadrius wilsonia*
king rail	*Rallus elegans*
loggerhead shrike (Eastern)	*Lanius ludovicianus*
Henslow's sparrow	*Ammodramus henslowii*
sage thrasher	*Oreoscoptes montanus*
prothonotary warbler	*Protonotaria citrea*

(iv) Threatened Birds (7)

Yellow-breasted chat (B.C.)	*Icteria virens*
sage grouse (Prairie)	*Centrocercus urophasianus*
marbled murrelet	*Brachyramphus marmoratus*
loggerhead shrike (Prairie)	*Lanius ludovicianus*
roseate tern	*Sterna dougallii*
hooded warbler	*Wilsonia citrina*
white-headed woodpecker	*Picoides albolarvatus*

(iv) Vulnerable Birds (20)

Ancient Murrelet	*Synthliboramphus antiquus*
Barn Owl	*Tyto alba*
Caspian Tern	*Sterna caspia*
Cerulean Warbler	*Dendroica cerulea*
Ferruginous Hawk	*Buteo regalis*
Flammulated Owl	*Otus flammeolus*
Ivory Gull	*Pagophila eburnea*
Least Bittern	*Ixobrychus exilis*
Long-billed Curlew	*Numenius americanus*
Louisiana Waterthrush	*Seiurus motacilla*

Pacific Great Blue Heron	*Ardea herodias fannini*
Peale's Peregrine Falcon	*Falco peregrinus pealei*
Prairie Warbler	*Dendroica discolor*
Queen Charlotte Goshawk	*Accipiter gentilis laingi*
Red-headed Woodpecker	*Melanerpes erythrocephalus*
Red-shouldered Hawk	*Buteo lineatus*
Ross' Gull	*Rhodostethia rosea*
Short-eared Owl	*Asio flammeus*
Tundra Peregrine Falcon	*Falco peregrinus tundrius*
Yellow-breasted Chat	*Icteria virens*

E. Plants (107)

(i) Endangered Plants (33)

Gattinger's agalinis	*Agalinis gattingeri*
Skinner's agalinis	*Agalinis skinneriana*
deltoid balsamroot	*Balsamorhiza deltoidea*
water-plantain buttercup	*Ranunculus alismaefolius var. alismaefolius*
Long's braya	*Braya longii*
eastern prickly pear cactus	*Opuntia humifusa*
slender bush clover	*Lespedeza virginica*
pink coreopsis	*Coreopsis rosea*
southern maidenhair fern	*Adiantum capillus-veneris*
white prairie gentian	*Gentiana alba*
small white lady's-slipper	*Cypripedium candidum*
seaside birds-foot lotus	*Lotus formosissimus*
Furbish's lousewort	*Pedicularis furbishiae*
prairie lupine	*Lupinus lepidus var. lepidus*
pink wilkwort	*Polygala incarnata*
hoary mountain mint	*Pycnanthemum incanum*
eastern mountain avens	*Geum peckii*
slender mouse-ear-cress	*Halimolobos virgata*
Western prairie white fringed orchid	*Platanthera praeclara*
heart-leaved plantain	*Plantago cordata*
large whorled pogonia	*Isotria verticillata*
small whorled pogonia	*Isotria medeoloides*
wood poppy	*Stylophorum diphyllum*
Engelmann's quillwort	*Isoetes engelmannii*
thread-leaved sundew	*Drosera filiformis*
cucumber tree	*Magnolia acuminata*
drooping trillium	*Trillium flexipes*
water-pennywort	*Hydrocotyle umbellata*
spotted wintergreen	*Chimaphila maculata*
seaside centipede lichen	*Heterodermia stitchensis*
bearded owl-clover	*Triphysaria versicolor ssp versicolor*
tiny cryptanthe	*Cryptantha minima*
bluehearts	*Buchnera americana*

(ii) Threatened Plants (36)

Blue ash	*Fraxinus quadrangulata*

Anticosti aster	*Aster anticostensis*
White-top aster	*Aster curtus*
White wood aster	*Aster divaricatus*
american chestnut	*Castanea dentata*
colicroot	*Aletris farinosa*
deerberry	*Vaccinium stamineum*
mosquito fern	*Azolla mexicana*
Western blue flag	*Iris missouriensis*
Plymouth gentian	*Sabatia kennedyana*
American ginseng	*Panax quinquefolium*
Goat's-rue	*Tephrosia virginiana*
Golden crest	*Lophiola aurea*
Golden seal	*Hydrastis canadensis*
Round-leaved greenbrier	*Smilax rotundifolia*
Van Brunt's Jacob's ladder	*Polemonium van-bruntiae*
Small-flowered lipocarpha	*Lipocarpha micrantha*
Red mulberry	*Morus rubra*
Golden paintbrush	*Castilleja levisecta*
Sweet pepperbrush	*Clethra alnifolia*
Nodding pogonia	*Triphora trianthophora*
Redroot	*Lachnanthes caroliana*
False hop sedge	*Carex lupuliformis*
Western spiderwort	*Tradescantia occidentalis*
Pitcher's thistle	*Cirsium pitcheri*
Athabasca thrift	*Armeria maritima interior*
Kentucky coffee tree	*Gymnocladus dioica*
Purple twayblade	*Liparis liliifolia*
Sand verbena	*Abronia micrantha*
Bird's-foot violet	*Viola pedata*
Yellow montane violet	*Viola praemorsa praemorsa*
American water-willow	*Justicia americana*
Tyrrell's willow	*Salix planifolia tyrrellii*
Blunt-lobed woodsia	*Woodsia obtusa*
Apple moss	*Bartramia stricta*
hairy prairie-clover	*Dalea villosa var. villosa*

(iii) Vulnerable Plants (38)

Giant helleborine	*Epipactis gigantea*
Cryptic paw lichen	*Nephroma occultum*
Oldgrowth specklebelly lichen	*Pseudocyphellaria rainierensis*
Seaside bone lichen	*Hypogymnia heterophylla*
American columbo	*Frasera caroliniensis*
Bathurst aster	*Aster subulatus var. obtusifolius*
Bolander's quillwort	*Isoëtes bolanderi*
Branched bartonia	*Bartonia paniculata*
Broad beech fern	*Phegopteris hexagonoptera*
Climbing prairie rose	*Rosa setigera*
Dense blazing star	*Liatris spicata*
Dwarf hackberry	*Celtis tenuifolia*
Eastern prairie white fringed orchid	*Platanthera leucophaea*
False rue-anemone	*Isopyrum biternatum*

Few-flowered club-rush	*Scirpus verecundus*
Fernald's milk-vetch	*Astragalus robbinsii var. fernaldii*
Green dragon	*Arisaema dracontium*
Gulf of St. Lawrence aster	*Aster laurentianus*
Hare-footed locoweed	*Oxytropis lagopus*
Hill's pondweed	*Potamogeton hillii*
Hop tree	*Ptelea trifoliata*
Indian plantain	*Cacalia plantaginea*
Long's bulrush	*Scirpus longii*
Macoun's Meadowfoam	*Limnanthes macounii*
New Jersey rush	*Juncus caesariensis*
Phantom orchid	*Cephalanthera austinae*
Provancher's fleabane	*Erigeron philadelphicus provancheri*
Shumard oak	*Quercus shumardii*
Smooth goosefoot	*Chenopodium subglabrum*
Swamp rose mallow	*Hibiscus moscheutos*
Victorin's gentian	*Gentiana victorinii*
Victorin's water hemlock	*Cicuta maculata var. victorinii*
Western silver-leaf aster	*Virgulus sericeus*
Wild hyacinth	*Camassia scilloides*
Lilaeopsis	*Lilaeopsis chinensis*
Soapweed	*Yucca glauca*
Buffalograss	*Buchloë dacyloides*
Coastal wood fern	*Dryopteris arguta*

F. Fish (58)

(i) Endangered Fish (4)

Nooksack dace	*Rhinichthys* sp.
Salish sucker	*Catostomus* sp.
Aurora trout	*Salvelinus fontinalis timagamiensis*
Acadian whitefish	*Coregonus huntsmani*

(ii) Threatened Fish (15)

Blackfin cisco	*Coregonus nigripinnis*
Shortjaw cisco	*Coregonus zenithicus*
Shortnose cisco	*Coregonus reighardi*
Channel darter	*Percina copelandi*
Eastern sand darter	*Ammocrypta pellucida*
Margined madtom	*Noturus insignis*
Black redhorse	*Moxostoma duquesnei*
Copper redhorse	*Moxostoma hubbsi*
Great Lakes deepwater sculpin	*Myoxocephalus thompsoni*
Shorthead sculpin	*Cottus confusus*
Enos Lake stickleback	*Gasterosteus* sp.
Lake Simcoe whitefish	*Coregonus clupeaformis*
Lake Utopia dwarf smelt	*Osmerus* sp.
Texada (Benthic) stickleback	*Gasterosteus* sp.
Texada (Limnetic) stickleback	*Gasterosteus* sp.

(iii) Vulnerable Fish (39)

Banded killifish	*Fundulus diaphanus*
Bering wolffish	*Anarhichas orientalis*
Bigmouth buffalo	*Ictiobus cyprinellus*
Bigmouth shiner	*Notropis dorsalis*
Black buffalo	*Ictiobus niger*
Blackline prickleback	*Acantholumpenus mackayi*
Blackstripe topminnow	*Fundulus notatus*
Brindled madtom	*Noturus miurus*
Central stoneroller	*Campostoma anomalum*
Charlotte unarmoured stickleback	*Gasterosteus aculeatus*
Cultus pygmy sculpin	*Cottus* sp.
Chestnut lamprey	*Ichthyomyzon castaneus*
Fourhorn sculpin	*Myoxocephalus quadricornis*
Giant stickleback	*Gasterosteus* sp.
Green sturgeon	*Acipenser medirostris*
Greenside darter	*Etheostoma blennioides*
Lake chubsucker	*Erimyzon sucetta*
Lake lamprey	*Lampetra macrostoma*
Northern brook lamprey	*Ichthyomyzon fossor*
Orangespotted sunfish	*Lepomis humilis*
Pugnose minnow	*Opsopoeodus emilae*
Pugnose shiner	*Notropis anogenus*
Redbreast sunfish	*Lepomis auritus*
Redside dace	*Clinostomus elongatus*
River redhorse	*Moxostoma carinatum*
Rosyface shiner	*Notropis rubellus*
Shortnose sturgeon	*Acipenser brevirostrum*
Silver chub	*Macrhybopsis storeriana*
Silver shiner	*Notropis photogenis*
Speckled dace	*Rhinichthys osculus*
Spotted gar	*Lepisosteus oculatus*
Spotted sucker	*Minytrema melanops*
Spring cisco	*Coregonus* sp.
Squanga whitefish	*Coregonus* sp.
Umatilla dace	*Rhinichthys umatilla*
Western silvery minnow	*Hybognathus argyritis*
White sturgeon	*Acipenser transmontanus*
Kiyi	*Coregonus kiyi*
Warmouth	*Lepomis gulosus*

G. Molluscs (2)

(i) Endangered Mollusc (1)

Hotwater physa	*Physella wrighti*

(ii) Threatened Mollusc (1)

Banff Springs snail	*Physella johnsoni*

H. Lepidoptera (2)

(i) Endangered Lepidopteran (1)

Maritime ringlet butterfly	*Coenonympha tullia nipisiquit*

(ii) Vulnerable Lepidopteran (1)

Monarch butterfly	*Danaus plexippus*

Appendix 2. Summary of ecoregions used in analyses.

Name	Total area (km^2)
Ellesmere and Devon Island IceCaps	35261
Ellesmere and Devon Island IceCaps	24970
Ellesmere and Devon Island IceCaps	12852
Ellesmere and Devon Island IceCaps	51449
Baffin Mountains	97976
Baffin Islands Coastal lowlands	11113
Torngat Mountains	33661
Ellesmere Mountains	58170
Eureka Hills	94118
Ellesmere Mountains	15687
Sverdrup Islands Lowland	85456
Parry Islands Plateau	74073
Lancaster Plateau	113189
Banks Island Coastal Plain	12165
Banks Island Lowland	49864
Amundsen Gulf Lowlands	99652
Shaler Mountains	23453
Victoria Islands Lowland	193406
Prince of Wales Island Lowland	19894
Boothia Peninsula Plateau	38050
Gulf of Boothia Plateau	28902
Borden Peninsula Plateau	35078
Melville Peninsula Plateau	117169
Baffin Island Uplands	75871
Foxe Basin Plain	62976
Pangnirtung Upland	42061
Hall Peninsula Upland	33340
Meta Incognita Peninsula	85932
Baffin Upland	15275
Wager Bay Plateau	249338
Northern Ungava Peninsula	38051
Yukon Coastal Plain	6768
Tuktoyuktuk Coastal Plain	26135
Anderson River Plain	16327
Dease Arm Plain	54746
Coronation Hills	55885
Bluenose Lake Plain	21540
Bathurst Hills	13948
Queen Maud Gulf Lowland	65260
Chantrey Inlet Lowland	22548
Takijua Lake Upland	111497
Garry Lake Lowland	80717
Back River Plain	36267
Dubwant Lake Plain/Upland	51449
Maguse River Upland	76942
Southampton Island Plain	41696
Central Ungava Peninsula	153436
Ottawa islands	805

Belcher Islands	6670
Mackenzie Delta	8643
Peel River Plateau	57668
Great Bear Lake Plain	102579
Fort MacPherson Plain	28308
Colville Hills	18842
Norman Range	40198
Mackenzie River Plain	15283
Grandin Plains	9194
Franklin Mountains	6070
Keller Lake Plain	25482
Great Slave Lake Plain	36181
Nahani Plateau	11502
Sibbeston Lake Plain	12809
Horn Plateau	23271
Hay River Lowland	120134
Northern Alberta Uplands	58262
Muskwa Plateau	22888
Northern Alberta Uplands	12352
Coppermine River Upland	129017
Tazin Lake Upland	111718
Kazan River Upland	169910
Selwyn Lake Upland	185692
La Grande Hills	121693
Southern Ungava Peninsula	79339
New Quebec Central Plateau	180259
Ungava Bay Basin	85979
George Plateau	21878
Kingarutuk-Fraser River	64394
Smallwood Reservoir-Michikamau	84617
Coastal Barrens	11602
Mecatina River	6070
Kingarutuk-Fraser River	2848
Eagle Plateau	13142
Mecatina River	2496
Harp Lake	3094
Nipishish Lake	4961
Mecatina River	45874
Athabasca Plain	76241
Churchill River Upland	188196
Hayes River Upland	136520
Lac Seul Upland	143445
Lake of the Wooods	44768
Rainy River	3468
Thunder Bay-Quetico	26910
Lake Nipigon	92759
Big Trout Lake	108389
Abitibi Plains	186730
Lac Temiscaminque Lowland	90049
Algonquin-Lake Nipissing	76784
Southern Laurentians	170129

Riviere Rupert Plateau	90366
Central Laurentians	207537
Anticosti Island	9834
Mecatina Plateau	101482
Paradise River	19437
Lake Melville	20764
Strait of Belle Isle	3796
Northern Peninsula	10793
Long Range Mountains	6265
Southwestern Newfoundland	13355
Long Range Mountains	6403
Long Range Mountains	2972
Central Newfoundland	30640
Northeastern Newfoundland	9833
Maritime Barrens	43571
Avalon Forest	457
South Avalon-Burin Oceanic Barrens	3110
Appalachians	71801
Chaleur Uplands	25093
Northern New Brunswick Highlands	5076
Saint John River Valley	4617
Southern New Brunswick Uplands	14039
Maritime Lowlands	31647
Fundy Coast	9102
Southwest Nova Scotia Uplands	16692
Atlantic Coast	11342
Annapolis- Minas Lowlands	4802
South-central Nova Scotia Uplands	6403
Nova Scotia Highlands	18202
Cape Breton Highlands	2287
Prince Edward Island	8552
Iles-de-la-Madeleine	1189
St-Laurent Lowlands	46783
Frontenac Axis	1212
Manitoulin-Lake Simcoe	84218
Lake Erie Lowland	43600
Slave River Lowland	48662
Clear Hills Upland	42896
Peace Lowland	67182
Mid-Boreal Uplands	7729
Mid-Boreal Uplands	3201
Mid-Boreal Uplands	11578
Wabasca Lowland	49498
Western Boreal	10960
Mid-Boreal Uplands	24696
Western Alberta Upland	71819
Western Alberta Upland	1583
Mid-Boreal Uplands	118026
Mid-Boreal Lowland	90236
Boreal Transition	98170
Mid-Boreal Uplands	6724

Mid-Boreal Uplands	3162
Mid-Boreal Uplands	8458
Mid-Boreal Uplands	5207
Mid-Boreal Uplands	4619
Interlake Plain	39295
Aspen Parkland	170315
Moist Mixed Grassland	98430
Fescue Grassland	14824
Mixed Grassland	132170
Cypress Upland	8351
Aspen Parkland	2172
Lake Manitoba Plain	32497
Boreal Transition	1473
Boreal Transition	628
British-Richardson Mountains	25380
Old Crow Basin	14011
Old Crow Flats	5546
North Ogilvie Mountains	37239
Eagle plains	19322
Mackenzie Mountains	81664
Selwynn Mountains	68000
Klondike Plateau	36483
St.Elias Mountains	23320
Ruby Ranges	21636
Yukon Plateau -Central	25463
Yukon Plateau -North	54101
Yukon Southern Lakes	33668
Pelly Mountains	33553
Yukon-Stikine Highlands	23618
Boreal Mountains and Plateaus	100147
Liard Basin	32397
Hyland Highland	24629
Northern Canadian Rocky Mountains	35998
Mount Logan	3982
Northern Coastal Mountains	2724
Northern Coastal Mountains	24051
Nass Basin	5362
Queen Charlotte Ranges	6895
Queen Charlotte Lowland	2618
Mass Ranges	12269
Coastal Gap	46242
Pacific Ranges	58184
Western Vancouver Island	18910
Eastern Vancouver Island	13173
Georgia-Puget Basin	1401
Lower Mainland	4516
Cascade Ranges	285
Skeena Mountains	21942
Omineca Mountains	33523
Central Canadian Rocky Mountains	35525
Bulkley Ranges	2784

Fraser Plateau	88975
Fraser Basin	44677
Chilcotin Ranges	11617
Columbia Mountains and Highlands	87616
Western Continental Ranges	23291
Eastern Continental Ranges	38879
Interior Transition Ranges	14880
Thompson-Okanagan Plateau	37549
Okanagan Range	4446
Okanagan Highland	1149
Selkirk-Bitterroot Foothills	7806
Southern Rocky Mountain Trench	7619
Northern Continental Divide	15634
Coastal Hudson Bay Lowland	58492
Hudson Bay Lowland	128478
James Bay Lowlands	171019