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REPORT

Habitat loss and the limits to endangered species recovery

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Abstract

Canada is one of the last places on earth with extensive wilderness areas, yet the number of Canadian species threatened with extinction continues to rise every year. Using satellite-derived land use data, we find that habitat loss explains most of the variation in numbers of endangered species across Canada. Habitat loss within species ranges is, therefore, likely to be the leading factor inhibiting their recovery. We measured habitat loss individually within the known ranges of 243 terrestrial species at risk of extinction across Canada. Recovery potential, as measured by extent of natural habitat within each species' range, is bimodally distributed, but less than 50% of the range of the majority of Canada's species at risk is natural habitat and there is no detectable habitat remaining for 16 of the 243 species at risk. There were no differences in the recovery potential of species categorized either by threat level (special concern, threatened, or endangered) or taxon. Despite having extensive wilderness areas, Canada has similar rates of endangerment to other countries in the Americas, underlining the effect of severe habitat loss to intensive agriculture that has occurred in Canada's most biologically diverse regions. Improvements to protected areas networks and especially cooperative conservation activities with private landowners will do the most to improve the recovery prospects of species at risk in Canada.

Keywords

Endangered species recovery, habitat loss, land use, remote sensing.

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INTRODUCTION

The number of species at risk of extinction continues to increase every year (Hughes *et al.* 1997; Chapin *et al.* 2000). About 83% of the Earth's land surface has been influenced by human activity (Sanderson *et al.* 2002), which has increased extinction rates to mass extinction proportions (May & Tregonning 1998). Even in countries where relatively extensive wilderness areas persist, such as Canada (Sanderson *et al.* 2002), the number of species at risk of extinction is increasing rapidly (e.g. Kerr & Cihlar 2004).

There has been considerable research to elucidate the causes of species endangerment (e.g. Dobson *et al.* 1997; Wilcove *et al.* 1998). Introduced species, pollution, overexploitation, and habitat loss can endanger species or reduce their populations to levels at which they contribute little to ecosystem function (Czech & Krausman 1997; Daily 1997; Hughes *et al.* 1997; Wilcove *et al.* 1998; Blackburn & Duncan 2001). In Canada, the conversion of natural areas into agricultural land is likely responsible for the decline of most species (Kerr & Cihlar 2004).

Canada's new endangered species legislation has two goals: to prevent extinctions and facilitate recovery of species at risk. 'Species at risk' are designated by the Committee on the Status of Endangered Wildlife in Canada (http://www.cosewic.gc.ca) based on extinction risk, extent of range outside Canada, among other criteria; e.g. the species must be native to Canada. Naturally rare species that are not in decline would be unlikely to be listed. The recovery potential for Canada's species at risk is unknown. One key obstacle to measuring recovery potential has been the lack of synoptic, high resolution land use data throughout Canada. Land use change is the subject of considerable research (e.g. DeFries *et al.* 2004) because of its serious influences on species' extinction risk (e.g. May & Tregonning 1998; Sanderson *et al.* 2002). Despite its importance to conservation research, high resolution land use data covering all of Canada have only recently been developed (Kerr & Cihlar 2003).

Here, we investigate recovery potential among species at risk in Canada by examining the extent of remaining natural habitat within their ranges. There are greater numbers of species at risk in agricultural lands (Kerr & Cihlar 2004) but the extent to which the lack of natural areas prevents endangered species recovery remains unexplored. Furthermore, we compare rates of species endangerment in Canada to those observed in other parts of the world that are generally considered to be particularly threatened and test whether wildlife in Canada is proportionally less threatened than in other countries in the Americas, most of which have far more extensive habitat loss than Canada. Finally, we examine patterns of habitat loss and species endangerment among Canada's ecozones, which is the scale at which much of Canada's conservation planning takes place.

METHODS

All distribution data for species at risk were obtained from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; http://www.cosewic.gc.ca). By May 2003, COSEWIC listed 431 species, 243 of which were predominantly terrestrial. These species included birds (n = 46), mammals (n = 34), lepidopterans (n = 7), reptiles (n = 15), amphibians (n = 13), and plants, lichens and fungi (n = 128). We converted the digital range maps for all species at risk to raster geographic information system files and projected them to Lambert Conformal Conic projection (chosen because this is the standard used by Government of Canada for remote sensing applications).

We measured the extent of human-dominated land uses within each ecozone according to new land use data (Kerr & Cihlar 2003). These data are derived from SPOT4/Vegetation satellite data (see Kerr & Ostrovsky 2003) and include a thematically and spatially detailed (1 km resolution) representation of known land uses within areas of human activity and land cover outside areas of permanent land conversions. This land use/land cover dataset identifies spatially extensive agricultural land uses and natural land covers. The data were converted to a binary raster differentiating human-modified (such as agricultural or urban lands) from natural areas (Fig. 1). Although these satellite land use data are the most comprehensive and spatially detailed yet published for Canada, they are subject to some biases. First, some forest clearcuts cannot be reliably distinguished from burned areas using 1 km resolution satellite data, although clearcuts are usually much smaller than burned areas, which extended across almost

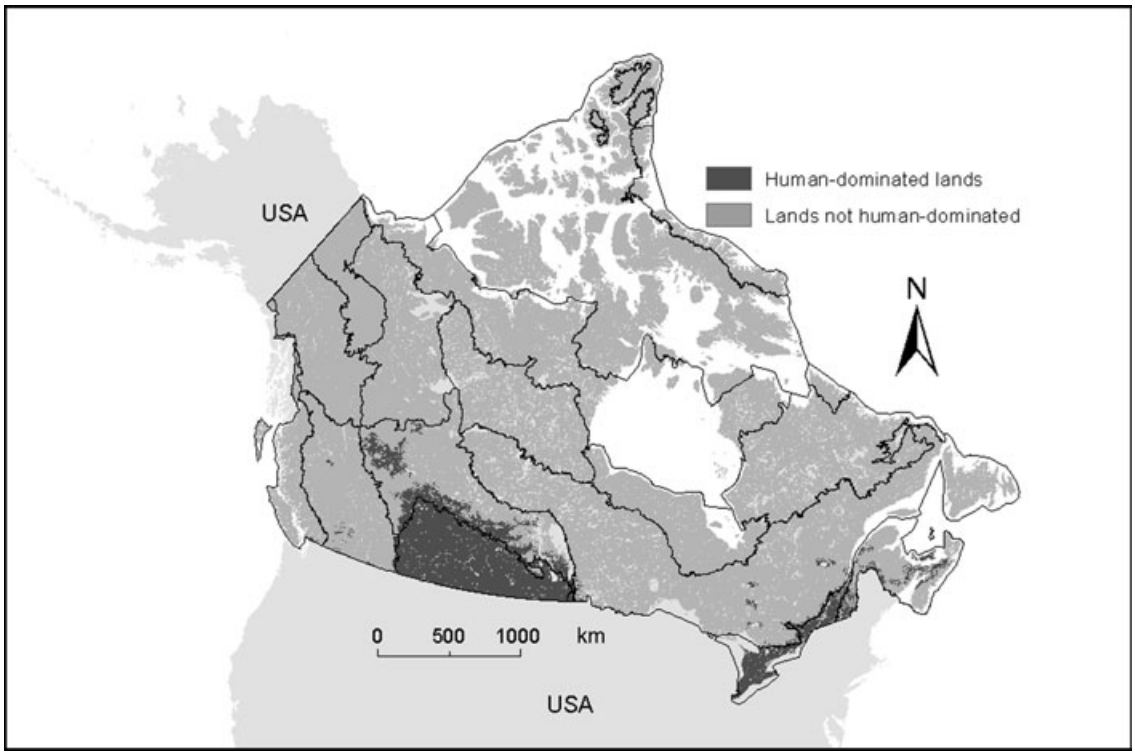

Figure 1 Human land use (natural lands are lighter grey, human-modified lands are dark grey) overlaid with Canada's 15 terrestrial ecozones. Data are derived from SPOT4/Vegetation 1 km resolution multispectral data (Kerr & Cihlar 2003). The Prairie ecozone of central Canada and the Mixedwood Plains ecozone of southeastern Canada are most completely dominated by human land uses.

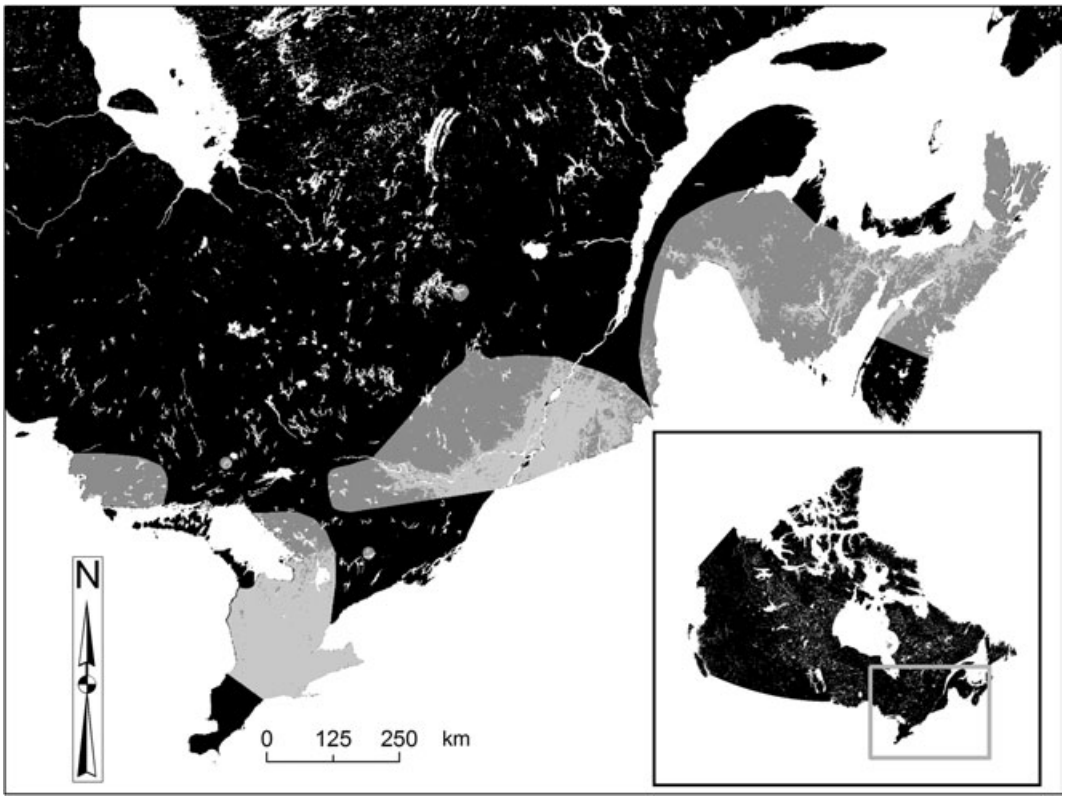

Figure 2 Depiction of the natural area and modified area within the distribution range of the Wood Turtle, *Glyptemys insculpta*. The darker grey areas represent natural habitat, the lighter grey represents area that has been permanently modified by human activity, and black represents areas of Canada that are outside the range of the Wood Turtle. For all 243 species used in this study, the extent of natural area within their range was estimated by filtering each distribution map through the land use map.

50 000 km^2 in 1998 (Canadian Council of Forest Ministers 1999). Selectively logged areas, which account for very little forestry activity in Canada (*c.* 7.4% or *c.* 720 km^2 in 2002; National Forestry Database: http://nfdp.ccfm.org), are not detectable at this resolution. Second, modified areas also include grazing lands that may retain semi-natural characteristics in some regions. In the absence of high resolution land cover data for Canada (e.g. based on Landsat TM data at 30 m resolution, Cihlar *et al.* 2003), we cannot measure the impact of these errors on accuracy of estimates of natural land area within species' ranges. The extent of natural areas within each species' range was estimated by filtering each range map through the binary land use (natural vs. modified) map (Fig. 2). The area of unmodified habitat within the range for each species was measured in Arc/Info Grid and sorted by taxon and COSEWIC status category (special concern, threatened, and endangered). We also counted the number of species at risk in each of Canada's 15 terrestrial ecozones. Many species ranges extend across more than one ecozone: these species have been counted once for each ecozone into which their ranges extend. Because of ensuing pseudoreplication among our data, probability tests should be interpreted with caution, although we provide them for information purposes.

Moran's I for spatial autocorrelation of endangered species numbers per ecozone was calculated using Rook's Case (Sawada 1999). Spatial autocorrelation, if present, can cause probability tests to be unreliable or bias regression coefficients (see Diniz-Filho *et al.* 2003). Moran's I was not statistically significant in these data ($I = 0.036$, $P = 0.43$), so ordinary least squares regression analysis results were retained. We do not consider spatial autocorrelation further.

Analysis of variance was used to determine if there were differences between the extent of unmodified habitat among the six terrestrial taxa included in the COSEWIC database and among status categories (endangered, threatened, species concern) within each taxon (i.e. do endangered species have less natural land cover within their ranges than threatened or special concern species). A linear regression was performed to test for a relationship between numbers of species at risk and habitat loss per ecozone after inspecting a scatterplot of these two variables. Ecozones are of different areas (Table 1), so ecozone area was included in regression models to ensure that habitat loss effects were

Table 1 Area of each of Canada's ecozones with extent of human-modified and natural land areas

Ecozone	Total area of ecozone (km^2)	Unmodified area (km^2)	Modified area (km^2)
Northern Arctic	1 420 878	1 420 878	0
Arctic Cordillera	240 688	240 688	0
Southern Arctic	741 197	741 197	0
Taiga Cordillera	250 777	250 777	0
Taiga Plains	547 617	547 616	1
Boreal Cordillera	425 335	425 322	13
Taiga Shield	1 148 426	1 148 415	11
Pacific Maritime	188 004	185 783	2221
Boreal Plains	655 544	485 387	170 157
Montane Cordillera	465 545	457 617	7928
Boreal Shield	1 704 434	1 681 513	22 921
Hudson Plains	354 272	354 272	0
Prairies	451 596	14 081	437 515
Mixed Wood Plains	114 809	13 803	101 006
Atlantic Maritime	200 948	162 722	38 226

Modified areas are for permanent human land uses that were detected using SPOT4/Vegetation data (at 1 km resolution).

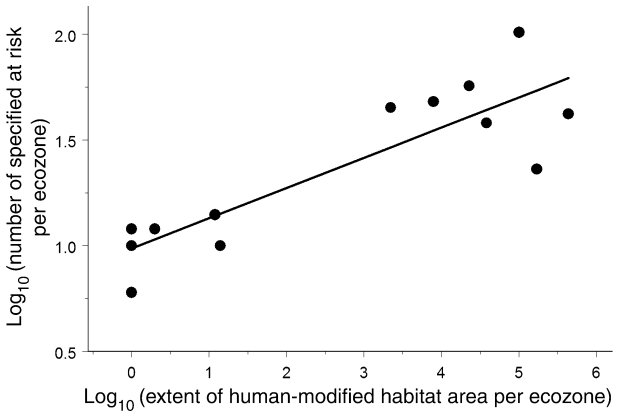

Figure 3 The relationship between the numbers of species at risk and the extent of human-modified area per ecozone. Data were Log_{10} transformed.

not conflated with area effects. Log_{10} transformations were used to stabilize residual variation in the regression.

Finally, we compared rates of endangerment in all other mainland countries in the Americas ($n = 21$; e.g. including Brazil and Guatemala but excluding Cuba and Jamaica), measured as the number of IUCN listed mammal and bird species divided by the total species richness per country for those taxa (World Conservation Monitoring Centre 2002), against rates observed in Canada. Canada has the largest absolute wilderness area (*c.* 6.4×10^6 km^2) but also proportionally greater (*c.* 65%, as measured in Sanderson *et al.* 2002) wilderness extent than most countries in North or South America. For example, wilderness areas extend across *c.* 49% of Brazil, *c.* 12% of the USA, *c.* 46% of Venezuela, *c.* 44% of Colombia; only Suriname (74%), French Guiana (85%), and Guyana (78%) have greater proportions of wilderness areas than Canada.

All geographic data were processed using ArcInfo Grid 8.3 [Environmental Systems Research Institute (ESRI) 2002]. Statistical analyses were conducted using SPLUS Version 6.2 (Insightful Corporation 2002).

RESULTS

Numbers of species at risk increase with the extent of human-modifed area ($R^2 = 0.78$, $P < 10^{-4}$, Fig. 3). Ecozone area is not significantly related to numbers of species at risk per ecozone singly ($F = 0.79$, $P = 0.39$) or in multiple regression models with extent of human-modified area (variable $P = 0.58$). Almost all of this habitat loss is to agricultural land uses, although urban areas are also extensive in parts of Canada (Kerr & Cihlar 2003). The extent of natural habitat remaining within the ranges of endangered species is highly variable across Canada but is particularly limited in the prairie and mixed wood plains ecozones, where the majority of endangered species are found (142 of the 243 species considered in this study). We considered the extent of natural land covers remaining within the ranges of COSEWIC-listed species to be an estimate of their maximum recovery potential.

Species in different threat categories (special concern, threatened, endangered) do not differ in the proportions of their ranges that consist of natural habitat ($F_{2,239} = 2.1$, d.f. = 2, $P = 0.13$). Furthermore, there were no differences in the amount of habitat remaining in the ranges of species in different threat categories within particular taxa (Table 2), including amphibians ($F_{2,10} = 0.210$, d.f. = 12, $P = 0.814$), birds ($F_{2,43} = 1.912$, d.f. = 45, $P = 0.160$), lepidopterans ($F_{2,4} = 4.553$, d.f. = 6, $P = 0.093$), mammals ($F_{2,30} = 0.324$, d.f. = 32, $P = 0.726$), plants ($F_{2,125} = 2.845$, d.f. = 127, $P = 0.062$) and reptiles ($F_{2,12} = 3.15$, d.f. = 14, $P = 0.079$).

Because habitat losses in Canada are concentrated in a relatively small proportion of the country, we predicted that Canada should have proportionately fewer species at risk than countries where habitat losses are more severe. There are 193 mammalian species in Canada (World Conservation Monitoring Centre 2002), of which 16 distinct species are listed as being at risk and there are 30 bird species at risk of extinction of 310 species total (World Conservation Monitoring Centre 2002). Rates of species endangerment among other countries in the Americas, including those with tropical forests that are considered to be experiencing rapid losses of species, are similar to those in Canada (mean

Table 2 Means and standard deviations of proportions of natural land cover area remaining within the ranges of each taxon by threat level

Taxon	Threat level (mean ± SD)		
	Endangered (*n*)	Threatened (*n*)	Special concern (*n*)
Amphibians	0.46 ± 0.34 (3)	0.45 ± 0.45 (5)	0.61 ± 0.39 (5)
Birds	0.40 ± 0.39 (16)	0.50 ± 0.39 (9)	0.65 ± 0.37 (21)
Lepidopterans	0.91 ± 0.15 (3)	0.71 ± 0.11 (2)	0.38 ± 0.31 (2)
Mammals	0.71 ± 0.45 (10)	0.75 ± 0.33 (8)	0.62 ± 0.40 (15)
Plants	0.47 ± 0.38 (54)	0.48 ± 0.39 (36)	0.64 ± 0.40 (38)
Reptiles	0.78 ± 0.38 (3)	0.31 ± 0.27 (6)	0.28 ± 0.28 (6)

Threat level is determined by COSEWIC assessments. There are no significant differences in the extent of remaining natural area between threat levels.

proportion of threatened mammals among other countries ± SD = 8.7 ± 5.6%; mean proportion of threatened birds among other countries ± SD = 7.0 ± 4.9%).

DISCUSSION

Habitat loss relates very strongly to the number of species at risk per ecozone (Fig. 3) and is a severe obstacle to endangered species recovery in the most biologically imperilled regions of Canada. Most permanent habitat losses are to agriculture (Kerr & Cihlar 2003), which is, by far, the most extensive human land use in Canada. That habitat loss is a primary cause of species declines and extinctions (Wilcove *et al.* 1998; Pimm & Raven 2000; Ceballos & Ehrlich 2002; Kerr & Cihlar 2004) is rarely disputed but to the extent that this factor causes species declines, it also inhibits their recovery. Although land cover modification is also collinear with overall species richness patterns and the predominantly climatic factors that likely cause those patterns (Currie 1991; Kerr and Packer 1997; Kerr *et al.* 2001; Hawkins *et al.* 2003), previous work has shown that the strong trend of increasing endangerment in southern Canada does not arise because species richness is higher there (see Kerr & Cihlar 2004).

Among the 243 species at risk considered in this study, 16 have no detectable habitat remaining based on satellite-based land use data for Canada, 58 have less than 10% natural habitat remaining within their potential ranges, and 113 species have less than a third natural habitat remaining in their potential ranges (Fig. 4). Most of these species were once found in the mixed wood plains or prairie ecozones, both of which are predominantly (and, for the most part, permanently) agricultural and have very little protected area (Kerr & Cihlar 2004). Recovery potential and viability for these species will remain relatively low in Canada. However, the distribution of remaining habitat available to endangered wildlife in Canada is bimodal: some species in predominantly wilderness areas are nevertheless considered at risk of extinction. Habitat loss is far less dramatic in such areas but temporary habitat conversions because of forestry activities

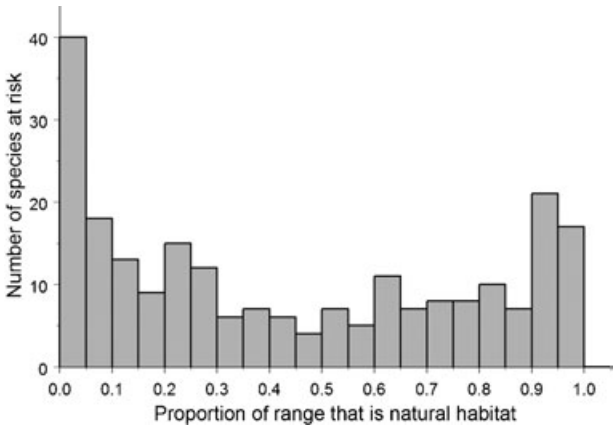

Figure 4 A histogram showing the numbers of species at risk (total = 243) relative to proportion of remaining natural habitat within their total ranges.

are not detectable in the current generation of SPOT4/Vegetation land cover/land use maps. It is possible that such factors threaten some species. Other forms of human disturbances, such as fire suppression or hunting, may also threaten some species in apparently intact wilderness areas. Because of the difficulty of detecting such effects using either satellite or ancillary GIS data sources, it is possible that the wilderness extent in Canada has not been estimated accurately.

The ranges of many of Canada's species at risk extend into the USA (where they are often also threatened), both in the north (into Alaska) and the south (into the lower 48 states), so extirpation of such species from Canada will not lead to their immediate extinction. However, peripheral populations of declining species are particularly important to their conservation (Channel & Lomolino 2000), so stemming the loss of endangered wildlife from Canada will improve the outlook for many species in the USA.

What are the recovery prospects for species whose potential ranges consist mostly of agricultural lands? A substantial minority of COSEWIC-listed species probably

cannot be restored to non-threatened status because of extreme habitat losses within their potential ranges, although it may be possible to increase some species' population sizes even in the absence of substantial expansions to their current distributions. There is some potential for protected areas to provide refugia for populations of some species at risk, but this role is severely limited because of land use conflict. Protected areas in the most threatened regions of Canada are extremely small (among the 11 watersheds with 25 or more species at risk, protected areas cover *c.* 0.14% of the 32 500 km^2 area; Kerr & Cihlar 2004; also Warman *et al.* 2004). Alleviating the substantial gaps in Canada's protected areas network is probably the most valuable contribution that could be made to endangered species conservation. However, progress toward this objective is possible without requiring the designation of formal protected areas – cooperative habitat conservation measures taken with private landowners, which is advocated in Canada's endangered species legislation, would be extremely helpful in agricultural landscapes. Anecdotal evidence, such as the recent protection of > 100 km^2 of range lands adjacent to Waterton National Park in southwestern Alberta (see Nature Conservancy of Canada; http://www.natureconservancy.ca), suggest that this approach can yield practical benefits for conservation.

We expected that rates of species endangerment in Canada would be lower than in other countries in the Americas. Patterns of habitat loss in Canada, like the distribution of endangered species (Kerr & Cihlar 2004) and, more generally, species richness (Currie 1991; Kerr *et al.* 2001), are highly asymmetrical. Areas with the highest species richness tend also to be particularly well suited to agriculture, with the result that habitat loss in Canada is most severe in biodiversity hotspots. As a result, simple calculations of rates of habitat loss may fail to project extinction rates accurately (cf. Seabloom *et al.* 2002).

Although we have used the most detailed remote sensing and species databases available for Canada, our analyses cannot exclude biases because of data resolution. First, we have taken the natural habitat area within each species' range map to represent that species' maximum recovery potential. This method overestimates recovery potential for most species because they are often restricted to particular habitats that may only extend across a small proportion of the actual natural habitat within the total range map for the species. Our land use/land cover data are derived from 1 km resolution SPOT4/Vegetation data (see Kerr & Cihlar 2003) and cannot detect very small habitat remnants. Thus, some species have no measurable habitat area remaining within their ranges, which obviously underestimates the actual amount available. An intriguing possibility is that some of the species (e.g. Golden paintbrush, *Castilleja levisecta*) with no detectable natural land covers remaining within their ranges might have adapted to entirely human-dominated landscapes. However, examination of the COSEWIC database that describes the natural history characteristics of each species (http://www.cosewic.gc.ca) demonstrates that this is not the case. We detected no differences between taxa in the extent of natural land covers within species' ranges, nor indeed between different threat classes (i.e. endangered mammals do not tend to have less remaining natural habitat than threatened mammals) – had there been systematic differences in mapping quality between taxa (e.g. plants versus mammals), it is more likely we would have detected them. Because, we measured habitat extent proportionally in this analysis, however, mapping resolution differences between taxa, if they exist at all, are unlikely to qualitatively change our observations. Instead, it is possible that differences in threat levels to species reflects the degree to which they are unable to use resources found in human modified landscapes or how seriously they are affected by human activities that occur secondarily to habitat loss (e.g. increased pesticide use). Finally, population size is unknown for most species at risk, so we have taken the extent of natural habitat within their entire ranges to represent the limits to their recovery.

The extent of human-modified lands predict the number of species at risk among Canada's ecozones. When each species' range is reconsidered in light of a spatially and thematically detailed map describing the extent of remaining natural habitat in that area, it is clear that recovery potential for many of Canada's species at risk is severely limited. Of the 243 species at risk considered in this study, the ranges of 219 overlap southern ecozones that include some intensive human land uses and 69 overlap northern ecozones. Preventing the rapid extinction of Canada's endangered species may be possible by securing cooperation with private landowners or by improving reserve networks, but habitat restoration across broad areas of southern Canada will be necessary for the recovery of most of Canada's endangered species. Because habitat loss is especially extensive in the most biological diverse areas of Canada (see Kerr & Cihlar 2004), rates of species endangerment in Canada are comparable with those observed among other countries in the Americas with far more extensive habitat loss.

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