Correlates of Vertebrate Extinction Risk in Canada

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Species status assessments are often hindered by a paucity of demographic, abundance, or distributional data. Although extinction-risk correlates have been identified, their wide applicability may be compromised by differences in the variables examined, modeling technique, and phylogenetic or distributional scale. Here, we apply a common analytical approach to examine 14 possible extinction-risk correlates for mammals, fishes, and birds throughout Canada. Among mammals, risk is positively and strongly correlated with road density and age at maturity for land animals and weakly with body size for sea dwellers. Delayed maturity is of primary importance to predicting risk status in fishes, with small body size of secondary importance in freshwater environments. For birds, road density is the dominant correlate of risk. Logistic regression in a multimodel framework offers an instructive means of identifying risk correlates and of applying them in a practicable, empirically defensible manner, thus enhancing support for species-independent risk criteria.

Keywords: life history, mammals, fishes, birds, human impact, COSEWIC

International concerns about global and regional reductions in the abundance of plants and animals have hastened efforts to identify correlates of extinction risk in a wide variety of species (Purvis et al. 2000a, 2000b). Such correlates are particularly important in that they can enable the rapid assessment of poorly understood species groups on the basis of their similarities to more heavily studied taxonomic or geographic neighbors. Concomitant with this work is the question of whether extinction-risk correlates are likely to differ among species groups or whether the correlates are sufficiently similar that one might be justified in applying risk-assessment criteria and associated thresholds to assessments of species status that are independent of taxonomic affiliation (Mace et al. 2008).

The study of extinction-risk correlates has, to date, been focused primarily on vertebrates. Body size, for example, is positively associated with extinction risk in many groups—for instance, birds (Bennett and Owens 1997); terrestrial mammals (Cardillo et al. 2005); marine mammals (Dulvy et al. 2003); and marine fishes (Jennings et al. 1998), although both small- and large-bodied freshwater fishes may be at greater risk (Olden et al. 2007). Age at maturity is also linked to extinction probability—for example, in freshwater fishes (Parent and Schriml 1995), terrestrial mammals (Purvis et al. 2000b), and marine fishes (Denney et al. 2002)—almost certainly because of its negative association with maximum population growth rate (Cole 1954). Litter or clutch size (fecundity in fishes) has divergent associations with extinction probability in some groups—negative correlation in land mammals (Purvis et al. 2000b), positive association in birds (Jiguet et al. 2007)—or none at all in others, such as marine fishes (Hutchings 2001). Unsurprisingly, narrow distributional range (e.g., Purvis et al. 2000b, Long et al. 2007) and low abundance (e.g., Purvis et al. 2000b, O'Grady et al. 2004) have also been associated with greater risk of extinction. We present a summary of these and additional life-history, ecological, and behavioral correlates in table 1.

Prominent among anthropogenic correlates of risk are those that affect habitat (Dulvy et al. 2003, Venter et al. 2006, Schipper et al. 2008), one generic (albeit indirect) metric of which is road density within a species' range (Chu et al. 2003). For some taxonomic groups, such as freshwater fishes, physical alterations to habitat may make it difficult to reliably distinguish the biological correlates of extinction risk from those associated with habitat degradation (Duncan and Lockwood 2001, Reynolds et al. 2005a, Olden et al. 2007). A second dominant correlate is exploitation pressure effected by unsustainable rates of fishing or hunting (Dulvy et al. 2003, Hutchings and Reynolds 2004, Schipper et al. 2008).

Notwithstanding the considerable strengths of the analyses undertaken to date, because most have been restricted to a single taxonomic class or subclass (table 1), it is unclear how broadly applicable the results might be across different taxonomic groups within a specific conservation or management region in which species status assessments are often undertaken. Generality may also be compromised by an inconsistency in analytical techniques, by inconsistent choices of potential extinction-risk correlates (and differing units of measurement), and by differences in the habitats or distributional scales of the species of interest (e.g., temperate, tropical, marine, freshwater, terrestrial, coral reef environments). There is also the question of how

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Table 1. Life-history, ecological, and behavioral correlates of extinction risk in vertebrates.

Positive correlate of extinction risk	Taxonomic group	Sources
Large body size	Terrestrial mammals	Cardillo and Bromham 2001, Cardillo 2003, Cardillo et al. 2005, Davidson et al. 2009
	Marine mammals	Dulvy et al. 2003
	Freshwater fishes	Olden et al. 2007
	Marine fishes	Jennings et al. 1998, Denney et al. 2002, Dulvy et al. 2003, Reynolds et al. 2005b, Field et al. 2009
	Birds	Bennett and Owens 1997, Norris and Harper 2004
Small body size	Freshwater fishes	Reynolds et al. 2005a, Olden et al. 2007
Age at maturity	Terrestrial mammals	Purvis et al. 2000b
	Freshwater fishes	Parent and Schriml 1995
	Marine fishes	Denney et al. 2002, Myers and Worm 2005, Reynolds et al. 2005b
Small litter or clutch size	Terrestrial mammals	Purvis et al. 2000b
	Birds	Bennett and Owens 1997, Krüger and Radford 2008
Small distributional range	Terrestrial mammals	Purvis et al. 2000b
	Freshwater fishes	Reynolds et al. 2005a
	Birds	Long et al. 2007, Manne et al. 1999
Low latitudinal midpoint	Freshwater fishes	Reynolds et al. 2005a
Low density or population size	Terrestrial mammals	Purvis et al. 2000b, Davidson et al. 2009
	Birds	O'Grady et al. 2004
Trophic position	Terrestrial mammals	Purvis et al. 2000b
Low natal dispersal/migration	Birds	Jiguet et al. 2007

different scales of examination (e.g., spatial, taxonomic) might affect the influence of extinction-risk correlates. Differences in ecology or life history also predispose species to respond differently to various threats. With birds, for example, habitat specialists appear to be particularly vulnerable to habitat loss (Owens and Bennett 2000).

In light of the limitations to achieving generality associated with performing multiple analyses on different traits across scales, we adopted a common analytical and statistical approach in order to examine a common suite of potential extinction-risk correlates across a wide range of vertebrates, including terrestrial and marine mammals, freshwater and marine fishes, and birds. We constructed predictive models of risk status that accounted for the influence of life history (e.g., age at maturity, clutch or brood size, body size), distribution (e.g., latitude, aquatic depth), and anthropogenic disturbance (e.g., road density, fishing; table 2). Spatially, our analysis was restricted to species in Canadian aquatic and terrestrial environments. The primary reason for focusing on Canadian ecosystems lies in the breadth and wealth of available data on more than 600 species at risk. The information is published by COSEWIC (Committee on the Status of Endangered Wildlife in Canada; *www.cosewic.gc.ca*), the national independent body legally responsible, under the Species at Risk Act, for advising the federal minister of the environment on species that warrant inclusion on the national list of species at risk. Our work builds on that undertaken by Venter and colleagues (2006), who characterized threats across taxonomic groups within Canada by directly comparing at-risk and not-at-risk species.

Data sources and analysis

The vertebrate species included in our study were those assessed by COSEWIC as being at risk as of March 2008. For the purposes of our analysis, we combined species assessed as extinct, extirpated, endangered, threatened, or of special concern into a single "at-risk" category. To form a comparison data set of sufficient but similar size, we used lists of species in Canada (e.g., *www.wildspecies.ca*) to randomly select 50 "not-at-risk" species for each of the five vertebrate groups. Taxonomic affiliation is unlikely to have a significant effect on our results, given that the species assessed as being at risk and not at risk were not generally taxonomically biased (see tables S1–S5 in the supplementary online materials at *dx.doi.org/10.1525/bio.2011.61.7.8*). We used online databases (table 2) to collate data on candidate extinction-risk correlates for the not-at-risk species; for the at-risk species, we consulted COSEWIC status reports and recovery strategies (*www.sararegistry.gc.ca*) and supplemented these data using online databases. Where multiple values were present, we recorded the mean. Where values for both male and female members of a species were available, we recorded the values for the female members. Data on amphibians and reptiles were excluded because of either a paucity of life-history information or an insufficient number of species with which to compare the at-risk and

Table 2. Ranks assigned to potential correlates of extinction risk.

Potential correlates	Terrestrial mammals	Marine mammals	Freshwater fishes	Marine fishes	Birds	Description
Age at maturity	1	2	1	1	2	Age at maturity (in years)
Life span	c	c	c	c	d	Maximum reported age (in years)
Size at maturity	c	c	c	c	2	Length or height at maturity (in millimeters)
Maximum size	2	1	2	2	d	Maximum length or height (in millimeters)
Gestation time	2	2				Gestation average (in months)
Number of eggs or litter size	2	d	d	d	2	Number of eggs or offspring
Size of eggs or offspring	c	c	d	d	c	Egg diameter (fish, in millimeters), egg length × height (birds, in millimeters squared), or offspring mass (mammals, in grams)
Altricial or precocial					2	Altricial or precocial young
Latitude midpoint			3	3		Midpoint between the maximum and minimum latitudes (in degrees)
Depth midpoint			d	2		Midpoint between the maximum and minimum depths (in meters)
Road density	1		d		1	Median road length in range (in meters per square kilometer)
Fishing intensity				3		Commercial fishing intensity (from FishBase: 1, no interest; 2, subsistence or minor commercial; 3, commercial; 4, highly commercial)
Data sources	AnAge database (*www.genomics.senescence.info/species*), Animal Diversity Web (*www.animaldiversity.ummz.umich.edu*)	AnAge database (*www.genomics.senescence.info/species*), Animal Diversity Web (*www.animaldiversity.ummz.umich.edu*)	FishBase (*www.fishbase.org*), Scott and Crossman 1973	FishBase (*www.fishbase.org*), Scott and Crossman 1973	Birds of North America Online (*www.bna.birds.cornell.edu/bna*), Patuxent Bird Identification InfoCenter (*www.mbr-pwrc.usgs.gov/infocenter*), Natureserve (*www.natureserve.org*)	

Note: Data-deficient variables (d) and collinear variables (c; variance inflation factor ≥ 5 or $r \geq .7$) are shown here but were not included in candidate model sets. Numbers indicate relative importance ranking for each variable, according to summed Akaike weights of models containing that variable (a rank of 1 identifies the variables of greatest importance; values within a relative importance of 0.1 of the next most important variable are denoted with the same rank). In the case of the collinear variables, we chose those that had the most support in the literature and were the easiest to collect reliably.

not-at-risk groups. Frequency distributions of the candidate extinction-risk correlates, which we illustrate as beanplots for visual-comparative purposes (figure 1; Kampstra 2008), show all the data, including those deemed to be either excessively collinear (see below) or of insufficient sample size or data quality to include in the modeling process (table 2). We did not include range size in our models, given that it is frequently used in classifying species as at risk (figure S1), and we were concerned that our results might then be confounded by the listing criteria.

As a proxy for human disturbance of terrestrial habitat, we calculated road density as the median length of roads, in meters per square kilometer, from road network coverage maps available from GeoGratis (Government of Canada; *www.geogratis.ca*) within the species' Canadian terrestrial ranges. For the marine fishes, we used a discrete metric of human impact reported in FishBase (*www.fishbase.org*), called *commercial fishing intensity*, which we grouped into four classes: (1) no interest, (2) subsistence fishery or minor commercial interest, (3) commercial interest, and (4) high commercial interest. The lack of range maps for 55% of the freshwater fish species in our data set (Scott and Crossman 1973) prevented us from including nearby road density as a potential correlate for

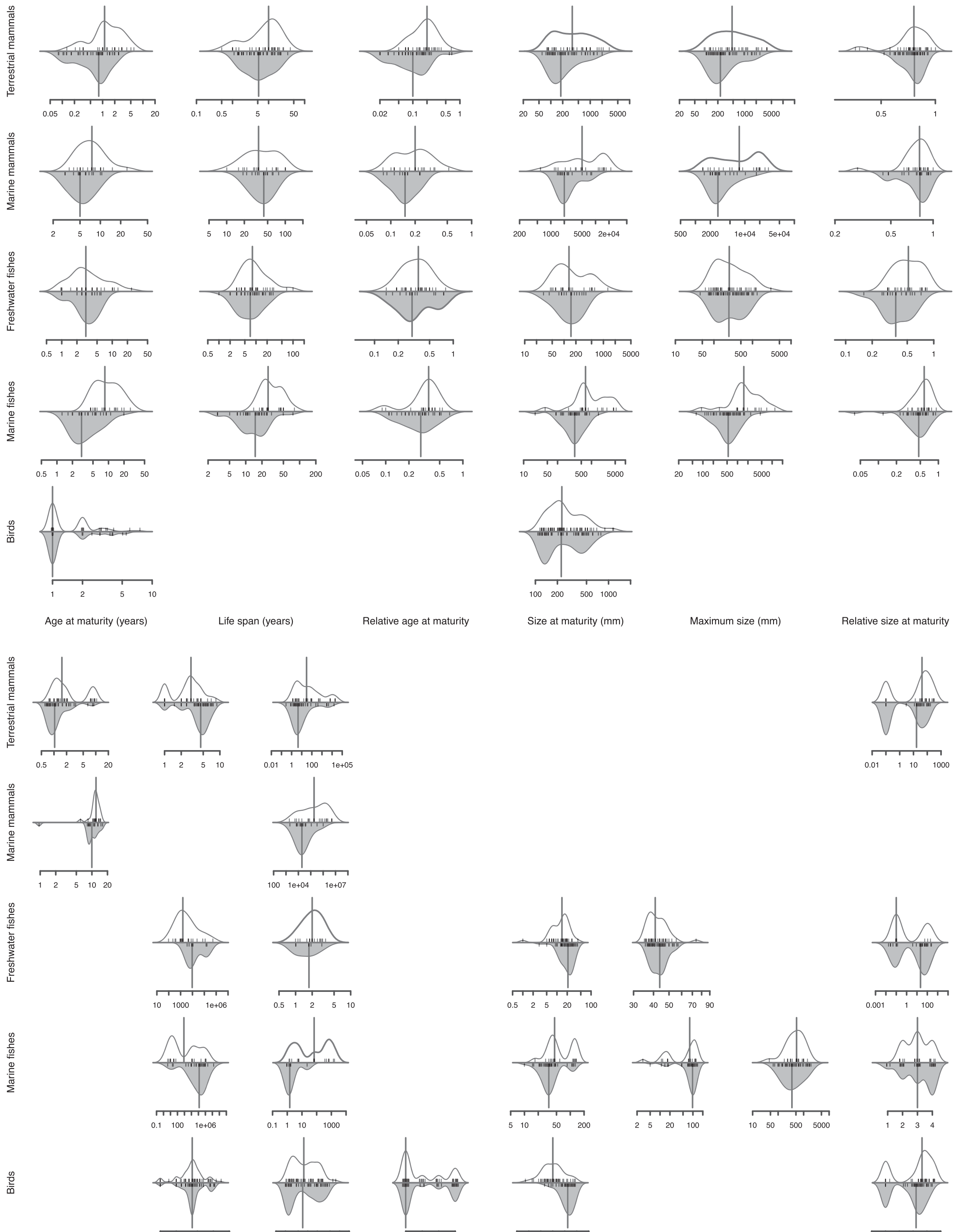

Figure 1. Beanplots of potential correlates of extinction risk for five groups of vertebrate species in Canada. The short vertical lines indicate species for which data are available. The estimated density of the distribution of values is shown for at-risk (white) and not-at-risk (gray) species in the form of curved polygons (beans). The median of each distribution is shown with a long vertical black line. Note the log-distributed horizontal axes. Missing plots were either data deficient (depth midpoint for freshwater fishes, range area for terrestrial and marine mammals, life span and maximum size for birds) or not applicable (all others). Relative age at maturity is the age at maturity divided by life span. Relative size at maturity is the size at maturity divided by maximum size. Abbreviations: g, grams; m, meters; mm, millimeters; m × km^{-2}, meters per square kilometer; °, degrees.

freshwater fishes in the predictive modeling portion of our analysis. The few existing data on metrics of past harvest intensities for Canadian marine mammals prevented us from including a metric of human-associated extinction risk for this taxonomic group.

We constructed predictive models of species risk status (at risk versus not at risk) using generalized linear models with a binomial family and a logit link in a multimodel framework. The resulting logistic regression can be expressed as

$$\text{logit}(p_i) = \log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 x_{1,i} + \ldots + \beta_k x_{k,i},$$

where p_i is the estimated probability of being at risk for a given species i, β_0 is an intercept, and β_1 through β_k are the coefficients of independent variables $x_{1,i}$ through $x_{k,i}$. The k covariates used to fit the models were selected on the basis of their potential importance as extinction-risk predictors, as it was determined by previous research (see table 1), and the ease with which they could be measured reliably. We excluded collinear variables (for which the variance inflation factor was greater than five; Menard 1995) and variables that were highly correlated ($r \geq .7$) with one another (table 2). Finally, we used variables for which values were available for at least 50% of both the at-risk and the not-at-risk species. We fit all candidate models with the k covariates as main effects and generated averaged predictive models by ranking the models by their Akaike information criterion with a correction for small sample sizes (AIC_c; Sugiura 1978, Burnham and Anderson 2002) and averaging the coefficients on the basis of their Akaike weights (see the supplementary online materials for full details of the multimodel analysis).

Model evaluation

We evaluated the predictive performance of the models by carrying out 10-fold cross-validations (Stone 1974, Kohavi 1995). For each taxonomic group, we divided the data into 10 subsets, retaining 1 subset for validation while fitting each candidate model to the remainder of the data. We repeated the process for each subset before repeating the entire 10-fold cross-validation procedure 1000 times to obtain an average misclassification rate (MR) for each candidate model. Ten-fold cross-validation is commonly used in this sort of investigation because lower-fold (two- or five-fold) validations often introduce greater variation because of the limited size of the training data and because higher-fold validations (e.g., the leave-one-out method) can introduce increased bias (Kohavi 1995). Receiver operating characteristic curves provide a measure of model performance at different prediction cutoffs. The area under such curves (AUC) represents the probability that a given species will be categorized correctly. We report the MR and AUC values both for comparison with the AIC_c ranking and as a method for comparing model performance across taxonomic groups.

Given that the International Union for Conservation of Nature (IUCN) Red List criteria are used as a starting point for discussion of a species' status in COSEWIC assessments, that the Red List criteria indirectly use generation time as a method to scale time-based life-history parameters, and that generation time is related to age at maturity (Cole 1954), we conducted two additional analyses to ensure that any correlates identified here were not purely a consequence of their having been used to assess species status. First, we tested whether generation time was positively related to scaled population decline for at-risk species within one taxonomic group (marine fishes), the taxonomic group for which magnitude of population decline is most often used as a basis for assessing status (figure S1). Second, given that the IUCN Red List criteria are not used to assess whether species are of special concern, we tested the sensitivity of our results by comparing special-concern species with not-at-risk species (i.e., excluding extinct, extirpated, endangered, and threatened species).

Analysis of relative life-history traits

As an additional exploratory analysis, we also tested for differences in relative age at maturity (age at maturity divided by life span) and relative size at maturity (size at maturity divided by maximum size) between the at-risk and the not-at-risk species. We reasoned that the differences in somatic and reproductive investment indicated by these variables could affect risk status. For example, those species that mature late relative to their life spans might not readily be able to depend on a lengthy reproductive period of life to offset greater mortality. We did not include these relative measures at our predictive modeling stage for two reasons. First, we lacked strong prior empirical support for doing so (these measures had not been examined previously). Second, their inclusion would have generated an excessive number of candidate models, given our data set sizes, and would have reduced our capacity to make valid predictive inferences (Burnham and Anderson 2002). We excluded birds from this part of the analysis because of uncertain and imprecise determinations of maximum natural life spans (which can exceed 50 years in pelagic seabirds; Holmes and Austad 1995) and maximum body sizes for all but a small number of species. We fit logistic regressions modeling risk status as a function of relative life-history traits within each taxonomic group.

Results of the analysis

The candidate extinction-risk correlates in our analyses were generally—although not always—characterized by unimodal distributions (figure 1). In addition to allowing for a visual comparison of median and modal values between the at-risk and not-at-risk species, the beanplots illustrate the breadth of data that were typically available for each of the 14 potential correlates within each vertebrate group. After removing the species with incomplete data for all investigated variables in our models, our sample sizes ranged from 14 to 40 for the not-at-risk species and from 16 to 29 for the at-risk species (table S6).

Based on the values of the Akaike weights (w_i) and Δ_i ($AIC_{c(i)} - AIC_{c(min)}$, where $AIC_{c(i)}$ is the AIC_c value for model i and $AIC_{c(min)}$ is the smallest AIC_c value in the set of models, our analyses revealed support for more than one model within each of the five taxonomic groups (largest $w_i = 0.44$, between two and four models with $\Delta_i < 2$; table 3). As a consequence, we incorporated all of the candidate models (including those with $\Delta_i \geq 2$) into the averaged model for each group of species (figures 2 and 3; table S7). The resultant models for terrestrial mammals and marine fishes performed well (AUC = 0.80–0.93, MR = 0.22–0.34, for models with $\Delta_i < 2$; table 3), whereas the predictive models were less accurate for the marine mammals (best two models, AUC = 0.67–0.74, MR = 0.34–0.35), freshwater fishes (AUC = 0.55–0.77, MR = 0.36–0.42), and birds (best two models, AUC = 0.66–0.70, MR = 0.39–0.43; table 3). The misclassification rate based on the averaged predictive models was lowest for the marine fishes (MR = 0.18) and highest for the marine mammals (MR = 0.39; figure 2).

Among all of the variables examined, age at maturity was the most consistently important (and positive) correlate of risk status, ranking among the most important variables for the terrestrial mammals, freshwater fishes, and marine fishes (figures 2a, 2e, 2g, and 3; table 2; table S7). Although there was some evidence that risk declined with maximum size in the freshwater fishes, there was less evidence of a link between maximum size and status for the marine fishes, for which the data suggested a weakly positive association

Table 3. Summary of the logistic regression models having the greatest support for each of the five vertebrate groups under study.

Model	$l(\theta)$	K	AIC_c	Δ_i	w_i	MR	AUC
Terrestrial mammals							
am, rd	–31.39	3	69.18	0.00	0.32	0.32	0.80
am, gt, rd	–30.94	4	70.58	1.40	0.16	0.34	0.82
ms, am, gt, rd	–29.93	5	70.91	1.73	0.13	0.33	0.83
ms, am, rd	–31.22	4	71.13	1.95	0.12	0.33	0.80
Marine mammals							
ms	–19.29	2	42.98	0.00	0.44	0.35	0.67
ms, gt	–19.03	3	44.88	1.91	0.17	0.34	0.74
Freshwater fishes							
ms, am, lm	–20.51	4	50.23	0.00	0.41	0.37	0.77
ms, am	–22.52	3	51.75	1.51	0.19	0.36	0.66
am	–23.89	2	52.11	1.88	0.16	0.42	0.55
Marine fishes							
ms, am	–12.54	3	31.87	0.00	0.15	0.28	0.90
am	–13.78	2	31.95	0.08	0.14	0.30	0.90
ms, am, dm	–11.31	4	32.00	0.13	0.14	0.23	0.93
am, dm	–12.74	3	32.27	0.40	0.12	0.22	0.91
Birds							
rd	–41.85	2	87.88	0.00	0.22	0.40	0.66
en, rd	–41.37	3	89.12	1.23	0.12	0.40	0.70
ap, rd	–41.44	3	89.26	1.37	0.11	0.41	0.68
am, rd	–41.53	3	89.44	1.56	0.10	0.43	0.66
sm, rd	–41.59	3	89.57	1.68	0.09	0.39	0.67

am, age at maturity; ap, altricial or precocial young; dm, depth midpoint; en, egg number; fi, fishing pressure; gt, gestation time; lm, latitude midpoint; lr, latitude range; ls, litter size; ms, maximum size; ra, range area; rd, road density; sm, size at maturity. AIC_c, Akaike's information criterion with a correction for finite sample sizes; AUC, area under the receiver operating characteristic curves; K, the number of parameters; $l(\theta)$ the value of the maximized log-likelihood function; MR, 10-fold cross-validated misclassification rates averaged over 1000 runs; w_i, Akaike weight; Δ_i, $AIC_{c(i)} - AIC_{c(min)}$, where $AIC_{c(i)}$ is the AIC_c value for model i and $AIC_{c(min)}$ is the smallest AIC_c value in the set of models. The models are ordered by decreasing w_i, and only those with $\Delta_i < 2$ are shown.

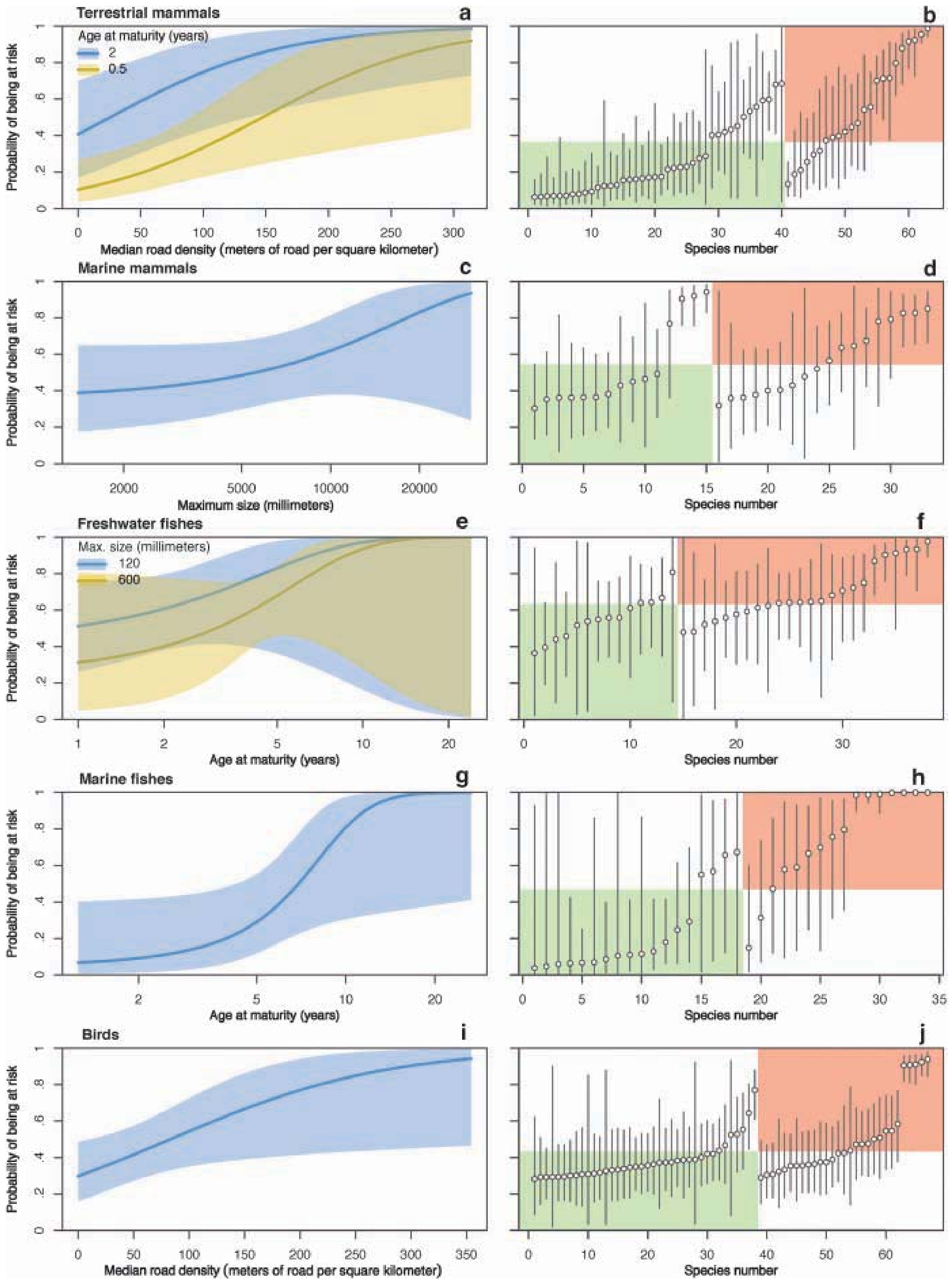

Figure 2. Panels (a), (c), (e), (g), and (i) show the predicted risk status for five groups of vertebrate species calculated from averaged logistic models. Estimates (dark blue and yellow lines) and 95% unconditional confidence intervals (shaded areas) are shown. The variable with the greatest relative importance (according to the sum of the Akaike weights of the models containing each variable) is shown across its range of values on the horizontal axis (note the log-distributed horizontal axes). Other variables were set to their median values. Where two variables were of similar relative importance (within .1 on a scale of 0 to 1), the second most important variable is shown with separate lines set at approximately the first and third quartile values. Panels (b), (d), (f), (h), and (j) show the classification of the five data sets based on the averaged model. Estimates (circles) and unconditional confidence intervals (lines) are shown. The bottom left green panel indicates correctly classified not-at-risk species. The top right red panel indicates correctly classified at-risk species. Species are ordered by increasing predicted probability of being classified as at risk.

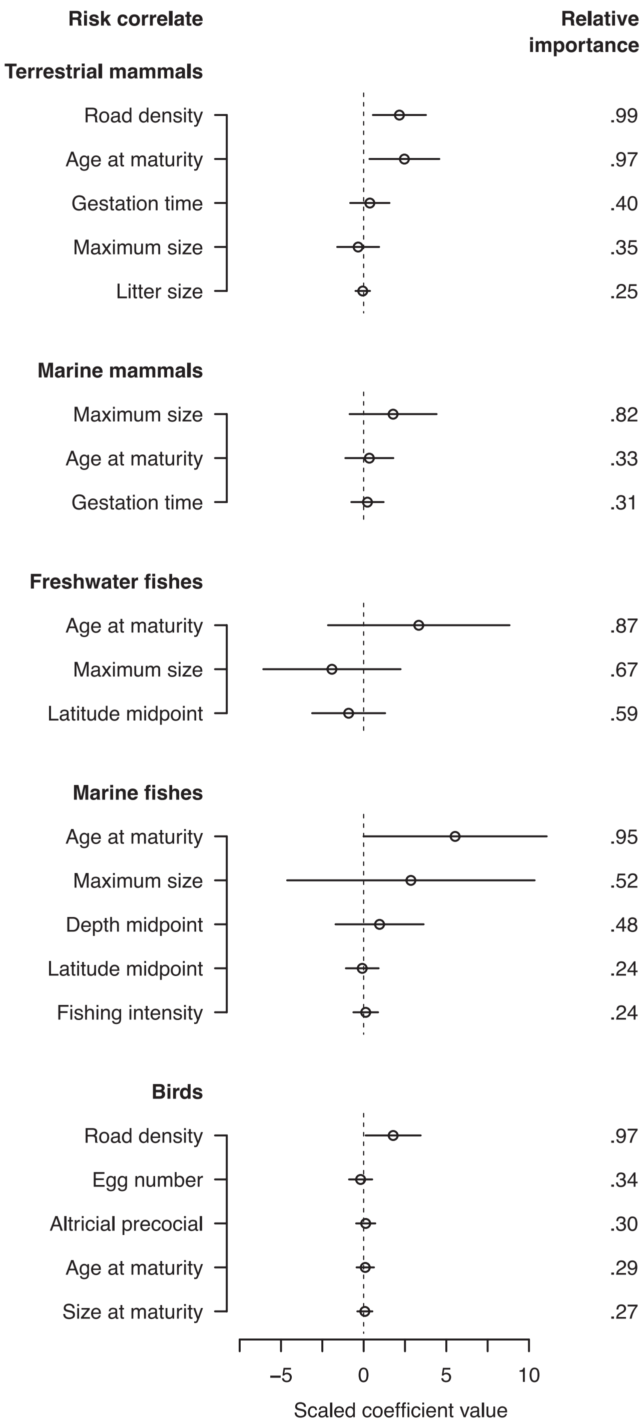

Figure 3. Scaled model parameter estimates (circles) with 95% unconditional confidence intervals (lines) from averaged predictive logistic models of risk status for the five taxonomic vertebrate groups under study. The parameters are ordered within each vertebrate group by their relative importance (indicated on the right) to the averaged model on a scale of 0 to 1. In this figure, the data were scaled within each vertebrate group by subtracting the mean and dividing by two standard deviations (Gelman 2008) to allow for comparison among parameters and across groups.

(relative importance = .83 and .52, respectively). For the marine mammals, maximum body size was the most important (and positive) predictor of risk status (figures 2c and 3), although there was relatively low confidence in this assessment and the performance of the averaged model was relatively poor (figure 2d).

Among the distribution-related variables, there was weak evidence that the marine fishes inhabiting deeper waters and the freshwater fishes in lower latitudes were more likely to be at risk (figure 3). In the taxonomic groups for which metrics of anthropogenic impact were readily available (terrestrial mammals, marine fishes, and birds), road density was associated with increased risk of extinction in the terrestrial mammals and birds (figures 2a and 3).

Our data did not support the hypothesis that generation time was directly related to the reported magnitude of population decline (figure S2). Our main conclusions for the terrestrial mammals, freshwater fishes, and marine fishes were not altered when we compared only the species of special concern with the not-at-risk species (figures S3, S4, and S5). For the marine mammals, maximum size (the most important correlate within the taxonomic group) changed from being a weakly positive correlate to being a weakly negative correlate, but the revised confidence interval was wide and included the original estimate (figure S5). The positive road density coefficient for birds became weaker (figure S5).

Our additional exploratory analyses testing for the influence of two relative life-history traits identified patterns consistent with the results obtained from the averaged predictive models. Controlling for differences in life span, (relative) age at maturity was greater for the at-risk species than for the not-at-risk species in the terrestrial mammals (coefficient estimate = 4.66, 95% confidence interval = 0.27–9.05; figures 4a and 5). Controlling for differences in maximum size, (relative) size at maturity was greater for the at-risk species than for the not-at-risk species in the freshwater fishes (coefficient estimate = 5.50, 95% confidence interval = 0.71–10.28) and the difference was nearly significant for the marine fishes (figures 4b and 5).

Correlates of risk status

The present study is both exploratory and confirmatory in nature. It is exploratory in the sense that one objective was to determine which correlates of risk status would emerge from a large data set on a previously unexamined group of species within a spatially delimited region across a wide range of vertebrates (figure 1). Furthermore, we explored possible links between risk status and two relative life-history metrics that—to our knowledge—had not been previously examined in this context. It is confirmatory in the sense that we tested a subset of previously hypothesized correlates of risk and confirmed many as being of primary importance for predicting risk status of vertebrates in Canada (figures 2 and 3).

The relative importance of the extinction-risk correlates of species at risk in Canada differed among our five groups of terrestrial and aquatic vertebrates. Road density and age at maturity were the most important (and positively

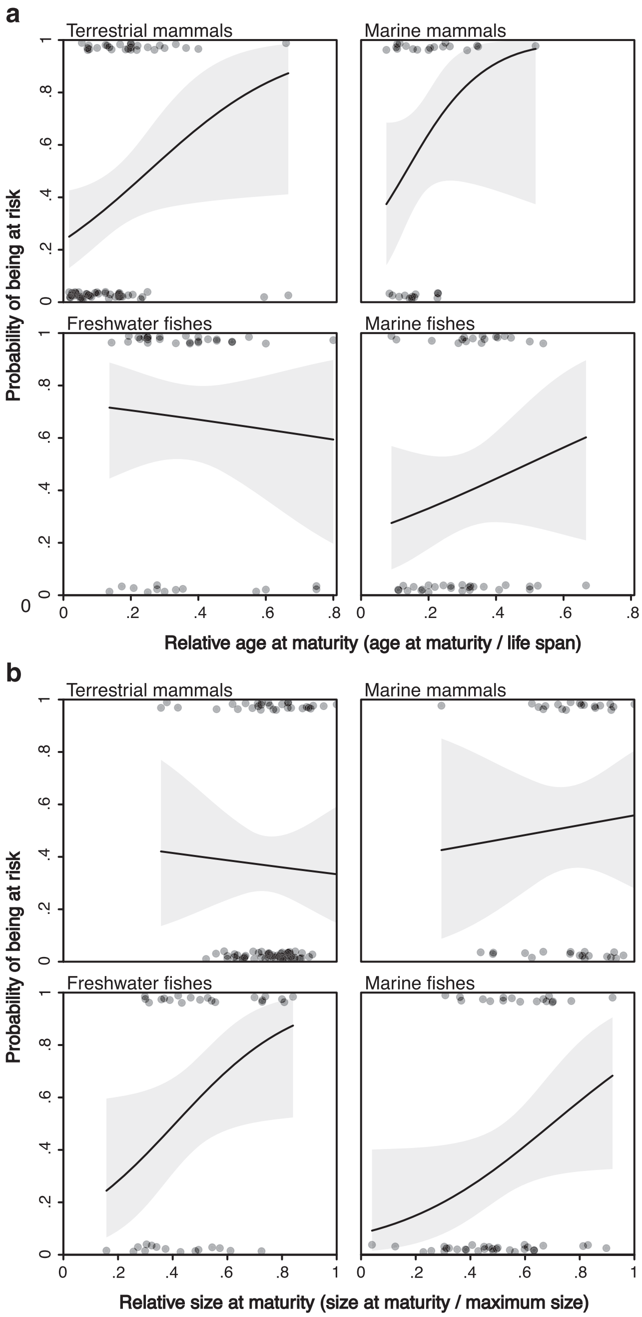

Figure 4. Estimates and uncertainty for the effect of relative age (a) and size (b) at maturity on the probability of a species being classified as at risk. The black lines represent fitted logistic regressions, the shaded areas represent 95% confidence intervals, and the dots represent the individual species represented by the data to which the models were fit (a small amount of vertical jittering was added for clarity).

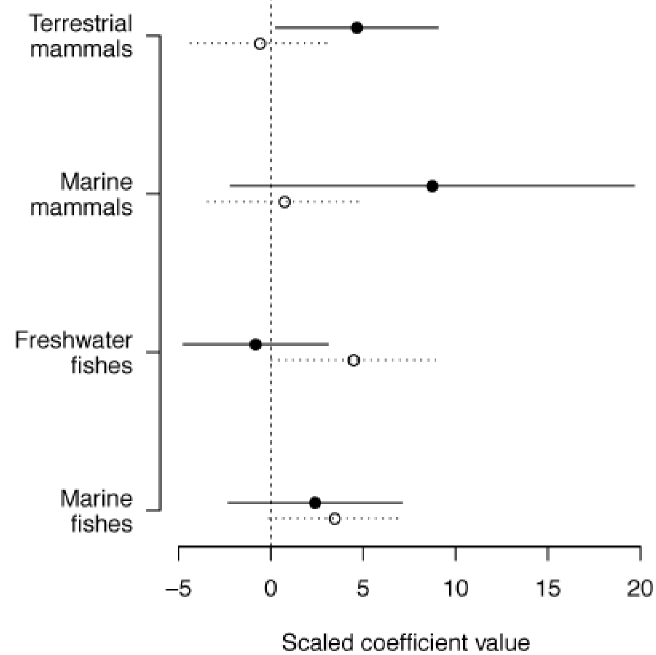

Figure 5. Scaled coefficients of relative age at maturity (solid symbols) and relative size at maturity (open symbols) with 95% confidence intervals from logistic regressions predicting probability of a species being at risk. The data were scaled within each vertebrate group by subtracting the mean and dividing by two standard deviations to allow for comparison among parameters and across groups.

associated) determinants of at-risk status in the terrestrial mammals. For the freshwater and marine fishes, age at maturity (positive correlate) was of primary importance and maximum size (negative correlate) was of secondary importance. For the marine mammals, larger individuals may bear a greater risk than smaller individuals. In the birds, the primary determinant of at-risk status was greater road density. Although some of these correlates are consistent with previous work (table 1), others are not, and we discuss these similarities and dissimilarities in greater detail below.

We found strong evidence for high road density and late age at maturity as predictors of terrestrial mammal risk status. Road density, our metric of terrestrial anthropogenic impact, has frequently been correlated with risk in terrestrial mammals (Cardillo et al. 2004, 2005, 2008, Benítez-López et al. 2010). The finding that late age at maturity correlates with risk concurs with Purvis and colleagues' (2000b) work. However, in contrast to some studies (Purvis et al. 2000b, Cardillo et al. 2005, Davidson et al. 2009), we found less evidence in Canadian terrestrial mammals that risk status increases with body size. Although the beanplot for maximum size (figure 1) suggests that at-risk terrestrial mammals tend to be larger and maximum size was correlated with age at maturity (r = .64), there was less evidence for its importance when it was compared with other correlates in the multimodel analysis (figure 3). Although we used maximum length in our analysis rather than mass (to ensure that we had consistent units across taxa in our analyses), it is unlikely that our results can be explained by a different unit of measure, given the high correlation (r = .96) that exists between the logarithm of maximum length and the logarithm of maximum mass in our data set. Substituting body mass for body length in our multimodel-averaged analysis did not affect our conclusions.

For the marine mammals, there was little evidence that any of the variables in our data set were associated with risk status, other than the limited effect that we documented for body size. The lack of dominant extinction-risk correlates at the taxonomic scale considered here would, however, justify efforts to explore the existence of such correlates at a finer taxonomic scale. Analyses that distinguish pinnipeds and cetaceans from one another, for example, may well yield further insights into the identification of factors affecting risk. We would also note that the low classification success in our model for marine mammals might be attributable to a comparative lack of information on past and present anthropogenic factors that might affect risk status (e.g., historically intensive exploitation rates, current levels of incidental catch).

Our analyses provided some evidence that older age at maturity and smaller maximum body size are positive correlates of extinction risk in freshwater fishes. In contrast to the (weak) positive correlation of larger maximum body size with risk status for marine fishes, the opposite effect may be evident for freshwater fishes because of higher levels of habitat loss and degradation (Olden et al. 2007). Although we detected some evidence that smaller maximum body size was associated with greater risk, this pattern was only evident after removing incomplete rows of data (such as those used in the multimodel analysis; figure S6) and not with the complete data set (figure 1). Although the distribution of the data (figure 1; figure S6) does not rule out Olden and colleagues' (2007) hypothesis that both large and small freshwater fishes are at greatest risk, the form of the predictive logistic regression model did not allow us to investigate the hypothesis explicitly (figure 2e). There was little evidence of the effect of latitude midpoint that Reynolds and colleagues (2005a) had documented for freshwater fishes in Europe. This may be attributable to the relatively narrow latitudinal range occupied by Canadian freshwater fishes at risk, most of which are located adjacent to the US border in the west and in southwestern Ontario and to southeastern Quebec in the east (Hutchings and Festa-Bianchet 2009).

The capability of our models to predict risk status in marine fishes was better than that in any other taxonomic group. Age at maturity was the most important correlate of risk, a finding concordant with the results of previous studies (Denney et al. 2002, Reynolds et al. 2005b). Commercial fishing interest was of minimal influence as a risk correlate, an observation contrary to expectations that fishing mortality affects extinction probability in marine fishes (e.g., Hutchings 2001, Hutchings and Reynolds 2004). This discrepancy can almost certainly be attributed to the imperfect degree to which present or past fishing mortality is reflected by the four-point measure of current fishing interest analyzed here. A more comprehensive analysis of the extinction risks posed by fishing would include an examination of the degree to which magnitude of population decline and current population status relative to some conservation-based target were correlated with temporal changes in levels of fishing mortality.

Our data suggested a pronounced association between small range area and bird species endangerment consistent with the findings of previous studies (Manne et al. 1999; Long et al. 2007). However, range area may be confounded with the explicit determinants of the COSEWIC decisionmaking process (figure S1), and so it was not included as a predictor in our formal analysis. Accordingly, we found that road density was the most influential (positive) correlate of bird risk status. Elevated road densities seem to have negative effects on the local population densities of many bird species (Fahrig and Rytwinski 2009, Benítez-López et al. 2010). For many birds that are already at low numbers—in particular, ecological specialists adapted to narrow habitat niches (Owens and Bennett 2000)—the progression to endangerment is therefore more likely as road density and its associated habitat disruption increase. Collectively, the precedence of road density in predicting bird species' endangerment over other intrinsic life-history parameters (large body size, Norris and Harper 2004; small clutch size, Krüger and Radford 2008) suggests that in Canada, habitat loss (i.e., a reduction in niche availability) is the most important process driving bird endangerment.

Implications for species status assessment

Our study of the biological and anthropogenic correlates of extinction risk in Canadian vertebrates represents a logical taxonomic and analytical extension of previous research. To achieve an arguably greater degree of spatial and taxonomic generality, we undertook analyses across five large and diverse groups of vertebrates that were consistent in the variables considered, the models applied, and the spatial scale examined. Although one might argue that with such an approach, the importance of some extinction-risk correlates for certain species might not be detected, our intent was to attain a level of generality across taxonomic groups able to inform national (e.g., COSEWIC) and international (e.g., IUCN) efforts to apply consistent methodologies and criteria to assess extinction risk across widely diverse taxa. In this regard, age at maturity was the most important correlate of at-risk status among the 14 life-history, distribution, and anthropogenic variables examined here, a finding supportive of the scaling of the IUCN's various decline-related criteria and thresholds to species and population generation times.

One unavoidable caveat associated with our work is that the correlates of risk that we have identified are based on past rather than future conditions. This means that changes to extinction risks posed by climate change (which has been identified as a threat to an increasing number of species in Canada, such as Peary caribou, *Rangifer tarandus pearyi*; polar bear, *Ursus maritimus*; and beach pinweed, *Lechea maritima*; *www.sararegistry.gc.ca*) will not have been accounted for in our analyses. Although some of the correlates of risk evaluated here may be relatively robust to climate change (e.g., road density), others (such as geographical range) may be more susceptible to climate-related influences, particularly in a country such as Canada, in which significant changes in terrestrial biodiversity attributable to global warming are anticipated (Lawler et al. 2009).

From an assessment perspective, we suggest that there may be considerable promise in the logistic modeling approach adopted here. First, functions such as those depicted in figure 2 serve to illustrate qualitatively, for different groups of species, how different variables are related to the probability of those species being at risk. Second, one could use the values associated with the risk-status functions (defined by the forward or backward S-shaped part of the curves in figure 2) to define trait thresholds in species status assessments. For example, for marine fishes inhabiting Canadian waters, using the data accumulated to date, one could apply a threshold age at maturity of 5 to 10 years to distinguish species that may be at heightened extinction risk. The extent to which one would adhere strictly to such thresholds would depend on the slope of the curve (the shallower the slope, the broader the range of values encompassing the threshold) and on the width of the 95% unconditional confidence intervals associated with the model (the greater the width, the greater the uncertainty in the threshold).

In summary, we draw three primary conclusions from our analyses. From a methodological perspective, there is utility in applying consistent analytical techniques (and consistent units of measurement) to studies of extinction-risk correlates across multiple taxonomic groups within a single spatially discrete region. Second, the correlates identified here may prove helpful in undertaking assessments for data-limited species within the context of a precautionary approach to assessing extinction risk. That is, all else being equal, species of concern for which a correlate of risk suggests heightened extinction probability might be afforded a higher protection status than those for which a correlate does not. Third, we suggest that logistic regression offers an instructive means of identifying correlates of extinction risk and of applying them in a practicable, readily understandable, and empirically defensible manner in species status assessments. Broadscale examinations such as the one we have undertaken here may also serve to enhance empirical support for the broadly articulated and widely applied extinction-risk criteria often used by international and national assessment organizations.

Acknowledgments

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References cited

Benítez-López A, Alkemade R, Verweij PA. 2010. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biological Conservation 143: 1307–1316.

Bennett PM, Owens IPF. 1997. Variation in extinction risk among birds: Chance or evolutionary predisposition? Proceedings of the Royal Society B 264: 401–408.

Burnham KP, Anderson DR. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd ed. Springer.

Cardillo M. 2003. Biological determinants of extinction risk: Why are smaller species less vulnerable? Animal Conservation 6: 63–69.

Cardillo M, Bromham L. 2001. Body size and risk of extinction in Australian mammals. Conservation Biology 15: 1435–1440.

Cardillo M, Purvis A, Sechrest W, Gittleman JL, Bielby J, Mace GM. 2004. Human population density and extinction risk in the world's carnivores. PLoS Biology 2: e197.

Cardillo M, Mace GM, Jones KE, Bielby J, Bininda-Emonds ORP, Sechrest W, Orme CDL, Purvis A. 2005. Multiple causes of high extinction risk in large mammal species. Science 309: 1239–1241.

Cardillo M, Mace GM, Gittleman JL, Jones KE, Bielby J, Purvis A. 2008. The predictability of extinction: Biological and external correlates of decline in mammals. Proceedings of the Royal Society B 275: 1441–1448.

Chu C, Minns CK, Mandrak NE. 2003. Comparative regional assessment of factors impacting freshwater fish biodiversity in Canada. Canadian Journal of Fisheries and Aquatic Sciences 60: 624–634.

Cole LC. 1954. The population consequences of life history phenomena. Quarterly Review of Biology 29: 103–137.

Davidson AD, Hamilton MJ, Boyer AG, Brown JH, Ceballos G. 2009. Multiple ecological pathways to extinction in mammals. Proceedings of the National Academy of Sciences 106: 10702–10705.

Denney NH, Jennings S, Reynolds JD. 2002. Life-history correlates of maximum population growth rates in marine fishes. Proceedings of the Royal Society B 269: 2229–2237.

Dulvy NK, Sadovy Y, Reynolds JD. 2003. Extinction vulnerability in marine populations. Fish and Fisheries 4: 25–64.

Duncan JR, Lockwood JL. 2001. Extinction in a field of bullets: A search for causes in the decline of the world's freshwater fishes. Biological Conservation 102: 97–105.

Fahrig L, Rytwinski T. 2009. Effects of roads on animal abundance: An empirical review and synthesis. Ecology and Society 14: 21.

Field IC, Meekan MG, Buckworth RC, Bradshaw CJA. 2009. Susceptibility of sharks, rays and chimaeras to global extinction. Advances in Marine Biology 56: 275–363.

Gelman A. 2008. Scaling regression inputs by dividing by two standard deviations. Statistics in Medicine 27: 2865–2873.

Holmes DJ, Austad SN. 1995. The evolution of avian senescence patterns: Implications for understanding primary aging processes. American Zoologist 35: 307–317.

Hutchings JA. 2001. Conservation biology of marine fishes: Perceptions and caveats regarding assignment of extinction risk. Canadian Journal of Fisheries and Aquatic Sciences 58: 108–121.

Hutchings JA, Festa-Bianchet M. 2009. Scientific advice on species at risk: A comparative analysis of status assessments of polar bear, *Ursus maritimus*. Environmental Reviews 17: 45–51.

Hutchings JA, Reynolds JD. 2004. Marine fish population collapses: Consequences for recovery and extinction risk. BioScience 54: 297–309.

Jennings S, Reynolds JD, Mills SC. 1998. Life history correlates of responses to fisheries exploitation. Proceedings of the Royal Society B 265: 333–339.

Jiguet F, Gadot A-S, Julliard R, Newson SE, Couvet D. 2007. Climate envelope, life history traits and the resilience of birds facing global change. Global Change Biology 13: 1672–1684.

Kampstra P. 2008. Beanplot: A boxplot alternative for visual comparison of distributions. Journal of Statistical Software 28: 1–9.

Kohavi R. 1995. A study of cross-validation and bootstrap for accuracy estimation and model selection. Proceedings of the 14th International Joint Conference on Artificial Intelligence 2: 1137–1143.

Krüger O, Radford AN. 2008. Doomed to die? Predicting extinction risk in the true hawks Accipitridae. Animal Conservation 11: 83–91.

Lawler JL, Shafer SL, White D, Kareiva P, Maurer EP, Blaustein AR, Bartlein PJ. 2009. Projected climate-induced faunal change in the Western Hemisphere. Ecology 90: 588–597.

Long PR, Székely T, Kershaw M, O'Connell M. 2007. Ecological factors and human threats both drive wildfowl population declines. Animal Conservation 10: 183–191.

Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akçakaya HR, Leader-Williams N, Milner-Gulland EJ, Stuart SN. 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. Conservation Biology 22: 1424–1442.

Manne, LL, Brooks, TM, Pimm, SL. 1999. Relative risk of extinction of passerine birds on continents and islands. Nature 399: 258–261.

Menard S. 1995. Applied Logistic Regression Analysis. Sage.

Myers RA, Worm B. 2005. Extinction, survival or recovery of large predatory fishes. Philosophical Transactions of the Royal Society B 360: 13–20.

Norris K, Harper N. 2004. Extinction processes in hot spots of avian biodiversity and the targeting of pre-emptive conservation action. Proceedings of the Royal Society B 271: 123–130.

O'Grady JJ, Reed DH, Brook BW, Frankham R. 2004. What are the best correlates of predicted extinction risk? Biological Conservation 118: 513–520.

Olden JD, Hogan ZS, Zanden MJV. 2007. Small fish, big fish, red fish, blue fish: Size-biased extinction risk of the world's freshwater and marine fishes. Global Ecology and Biogeography 16: 694–701.

Owens IPF, Bennett PM. 2000. Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. Proceedings of the National Academy of Sciences 97: 12144–12148.

Parent S, Schriml LM. 1995. A model for the determination of fish species at risk-based upon life-history traits and ecological data. Canadian Journal of Fisheries and Aquatic Sciences 52: 1768–1781.

Patterson BD, Ceballos G, Sechrest W, Tognelli MF, Brooks T, Luna L, Ortega P, Salazar I, Young BE. 2003. Digital Distribution Maps of the Mammals of the Western Hemisphere. Version 1.0. NatureServe.

Purvis A, Gittleman JL, Cowlishaw G, Mace GM. 2000a. Predicting extinction risk in declining species. Proceedings of the Royal Society B 267: 1947–1952.

Purvis A, Jones K, Mace GM. 2000b. Extinction. Bioessays 22: 1123–1133.

Reynolds JD, Dulvy NK, Goodwin NB, Hutchings JA. 2005a. Biology of extinction risk in marine fishes. Proceedings of the Royal Society B 272: 2337–2344.

Reynolds JD, Webb TJ, Hawkins LA. 2005b. Life history and ecological correlates of extinction risk in European freshwater fishes. Canadian Journal of Fisheries and Aquatic Sciences 62: 854–862.

Ridgely RS, Allnutt TF, Brooks T, McNicol DK, Mehlman DW, Young BE, Zook JR. 2003. Digital Distribution Maps of the Birds of the Western Hemisphere. Version 1.0. NatureServe.

Schipper J, et al. 2008. The status of the world's land and marine mammals: Diversity, threat, and knowledge. Science 322: 225–230.

Scott WB, Crossman EJ. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada Bulletin. Bulletin no. 184.

Stone M. 1974. Cross-validatory choice and assessment of statistical predictions. Journal of the Royal Statistical Society B 36: 111–147.

Sugiura N. 1978. Further analysis of the data by Akaike's information criterion and the finite corrections. Communications in Statistics – Theory and Methods 7: 13–26.

Venter O, Brodeur NN, Nemiroff L, Belland B, Dolinsek IJ, Grant JWA. 2006. Threats to endangered species in Canada. BioScience 56: 903–910.

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Supplementary Online Materials for Correlates of Vertebrate Extinction Risk in Canada

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Aimee Lee S. Houde, and Jeffrey A. Hutchings

Contents

Details of the multimodel analysis

The selection of a limited set of well-supported candidate models is an important step in conducting valid multimodel inference (Burnham and Anderson 2002). Among other attributes, it lessens the likelihood of obtaining spurious results by model over-fitting (Freedman 1983, Lukacs et al. 2009), which can result in overestimation of precision at best or, at worst, the obtaining of results that are tailored only to the dataset under study (Burnham and Anderson 2002). Given a limited number of life-history variables, the *a priori* absence of biological reasons to exclude certain models, and the need for balance among the frequency with which the parameters were represented in the candidate models (to evaluate the relative importance of the model variables), we examined candidate models with all combinations of the k covariates as main effects. We excluded covariate interactions because of the small size of our datasets after row-wise deletion of missing values ($n = 33$ to 67 per taxonomic group, see table S6). The second-order corrected Akaike Information Criterion (AIC_c) is more appropriate than the AIC (Akaike 1973) when the number of observations n does not greatly exceed the number of explanatory variables K (usually $n/K < 40$) (Sugiura 1978, Hurvich and Tsai 1989):

$$AIC_c = AIC + \frac{2K(K+1)}{n-K-1}.$$

To generate an averaged predictive model, we ranked the models by their AIC_c and averaged the coefficients by their Akaike weights w_i (Akaike 1978, Buckland et al. 1997):

$$w_i = \frac{exp(-\Delta_i/2)}{\sum_{r=1}^{R} exp(-\Delta_r/2)}$$

where $\Delta_i = AIC_{c[i]} - AIC_{c[min]}$ (the smallest AIC_c value in the set of models) and R is the number of models. The weighted-average model coefficients $\hat{\bar{\theta}}$ were then calculated as:

$$\hat{\bar{\theta}} = \sum_{i=1}^{R} w_i \hat{\theta}_i$$

where R represents the number of candidate models and $\hat{\theta}_i$ the estimated coefficient of the i^{th} model. Models additional to the "best model" often contain valuable information. Averaging the coefficients across all candidate models tends to reduce bias, increase precision, and stabilize estimates across data sets (Burnham and Anderson 2002).

Except for those circumstances where overwhelming evidence supports the best model, standard error estimates of the parameters in the selected models tend to overestimate precision because of model selection uncertainty (Breiman 1992, Hjorth 1994, Burnham and Anderson 2002). To address model selection uncertainty, we calculated the unconditional standard error of the averaged parameters $\widehat{se}(\hat{\bar{\theta}})$ as:

$$\widehat{se}(\hat{\bar{\theta}}) = \sum_{i=1}^{R} w_i \sqrt{\widehat{var}(\hat{\theta}_i|g_i) + (\hat{\theta}_i - \hat{\bar{\theta}})^2}$$

where $\widehat{var}(\hat{\theta}_i|g_i)$ represents the parameter variance given each model g_i (Burnham and Anderson 2002). We used the same calculation to derive the unconditional standard error of the estimate. We assessed the relative importance of each variable by calculating the sum of the w_i across all of the models in which the variable occurred, given that each variable appears in an equal number of models (Burnham and Anderson 2002). We report the relative importance of the life-history parameters for all taxonomic groups. To allow a graphical comparison of the effect sizes between parameters (including categorical and continuous variables) and across taxonomic groups, we refit our averaged predictive models using data that had been scaled by subtracting their mean and dividing by two standard deviations (Gelman 2008). This linear transformation does not affect the relative importance of the parameters or the predicted risk status; it only standardizes the scale of the coefficients. We include the unscaled parameter estimates for prediction purposes as an appendix (table S7).

Supplementary references

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. Second International Symposium on Information Theory. Budapest: Akademiai Kiado, 267–281.

Akaike H. 1978. A Bayesian analysis of the minimum AIC procedure. Annals of the Institute of Statistical Mathematics 30:9–14.

Breiman L. 1992. The little bootstrap and other methods for dimensionality selection in regression: X-fixed prediction error. Journal of the American Statistical Association 87:738–754.

Buckland S, Burnham K, Augustin N. 1997. Model selection: An integral part of inference. Biometrics 53:603–618.

Burnham KP, Anderson DR. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer.

Freedman D. 1983. A note on screening regression equations. The American Statistician 37:152–155.

Gelman A. 2008. Scaling regression inputs by dividing by two standard deviations. Statistics in Medicine 27:2865–2873.

Hjorth JSU. 1994. Computer intensive statistical methods: validation, model selection and bootstrap. Chapman and Hall.

Hurvich CM, Tsai CL. 1989. Regression and time-series model selection in small samples. Biometrika 76:297–307.

Lukacs P, Burnham K, Anderson D. 2009. Model selection bias and Freedman's paradox. Annals of the Institute of Statistical Mathematics 62:117–125.

Sugiura N. 1978. Further analysis of the data by Akaike's information criterion and the finite corrections. Communications in Statistics — Theory and Methods 7:13–26.

Supplementary figures

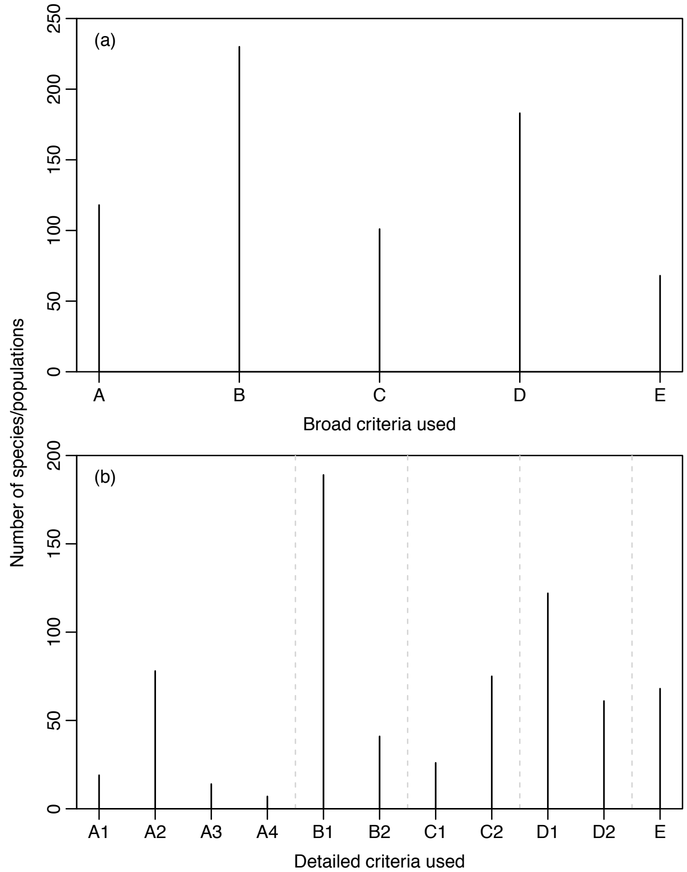

Figure S1: Criteria used to classify species or populations as at-risk by COSEWIC. Shown for (a) criteria groups and (b) criteria subgroups. Letters in (a) refer to: A. Decline in total number of mature individuals B. Small distribution range and decline or fluctuation C. Small and declining number of mature individuals D. Very small or restricted total population E. Quantitative analysis (population projections). See COSEWIC's *Assessment Process and Criteria* available at: http://www.cosewic.gc.ca/ for descriptions of the detailed criteria used in (b).

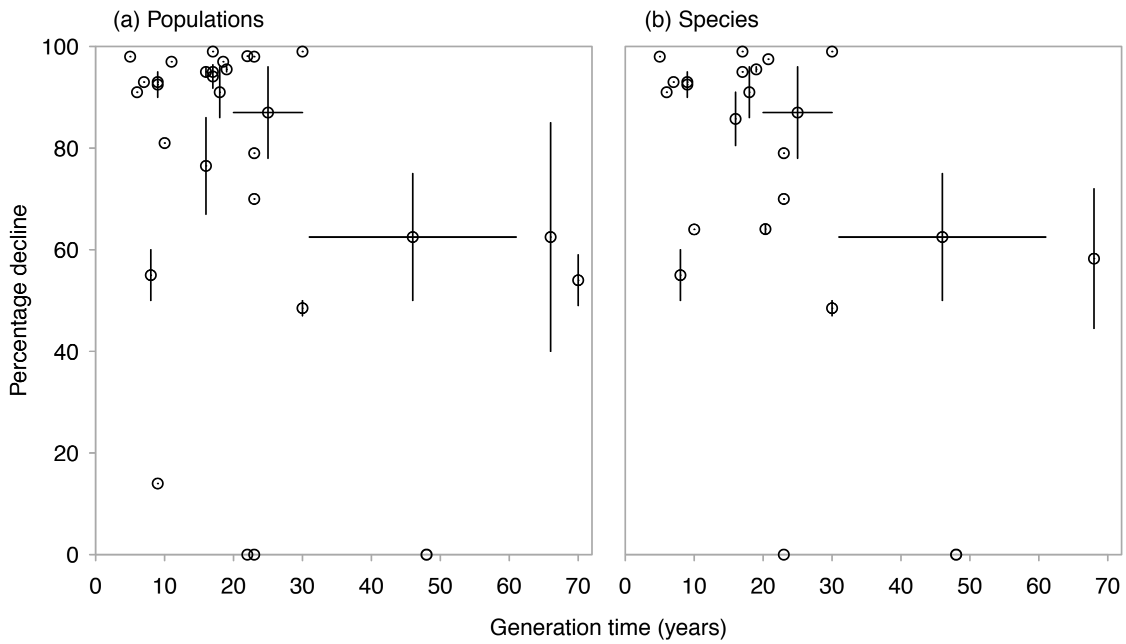

Figure S2: Relationship between reported magnitude of population decline and reported generation time within marine fish (a) populations and (b) species that were classified as at risk by COSEWIC. Horizontal and vertical lines indicate ranges of reported values. Circles indicate midpoint of upper and lower values (where a range of values was given) or point values (where a single value was given). In (b), average upper and lower values are shown where there were multiple populations for a given species.

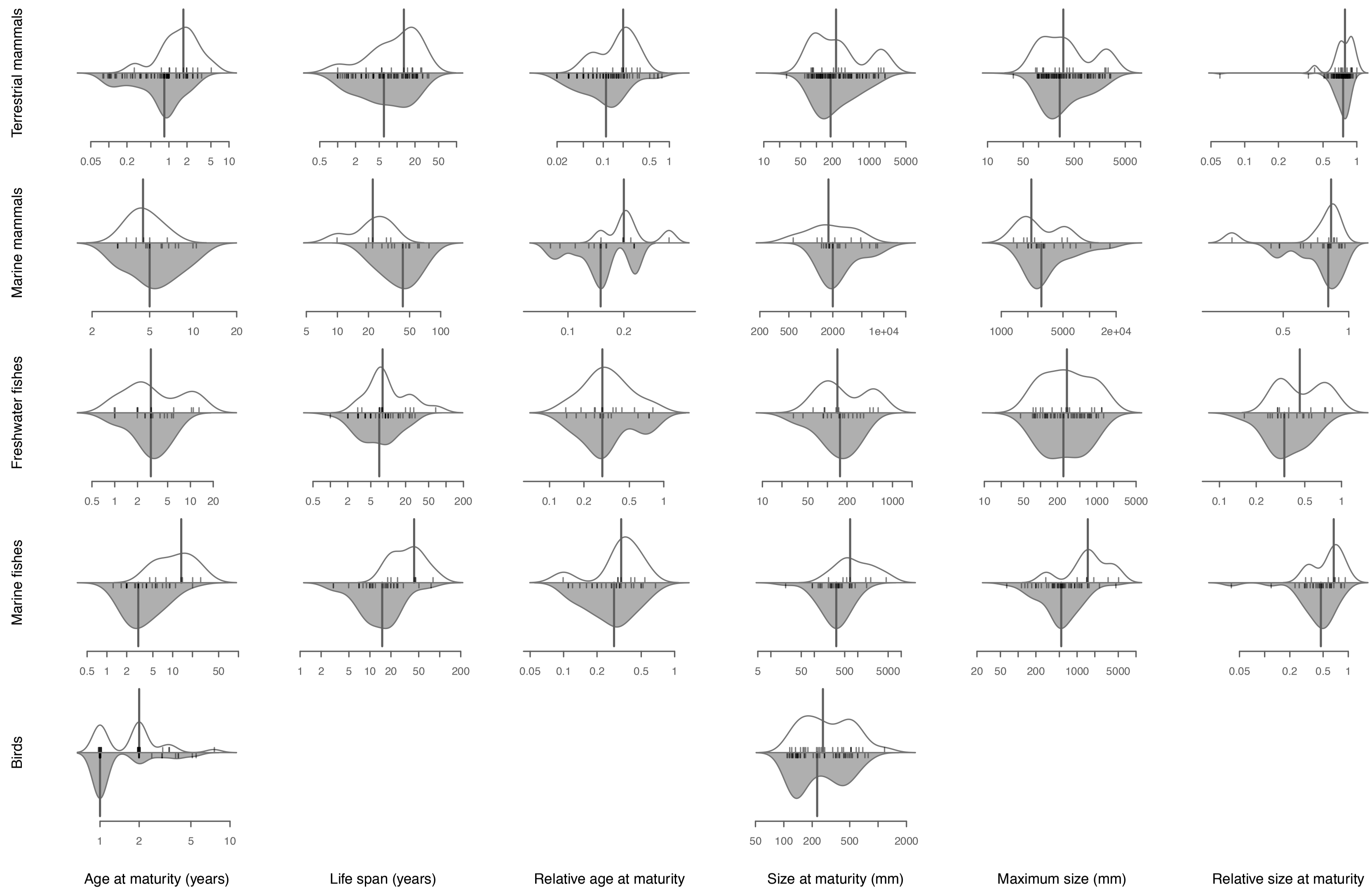

Figure S3: Potential life-history correlates of extinction risk for species listed as special concern (white) and not-at-risk (grey). **Species listed as extinct, extirpated, endangered, or threatened were excluded.** See Figure 1a in the main manuscript for a detailed description and comparison.

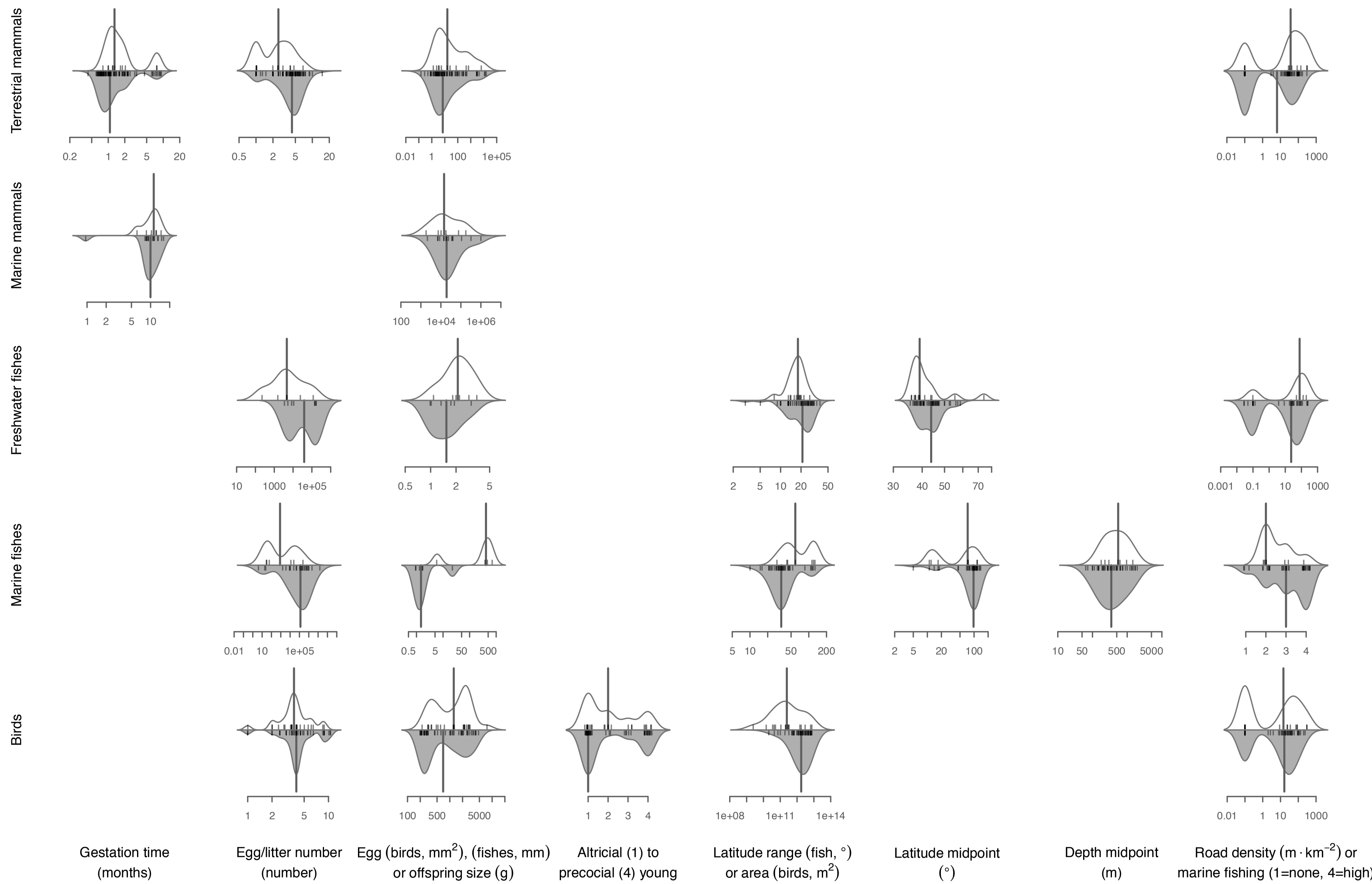

Figure S4: Potential correlates of extinction risk for species listed as special concern (white) and not-at-risk (grey). **Species listed as extinct, extirpated, endangered, or threatened were excluded.** See Figure 1b in the main manuscript for a detailed description and comparison.

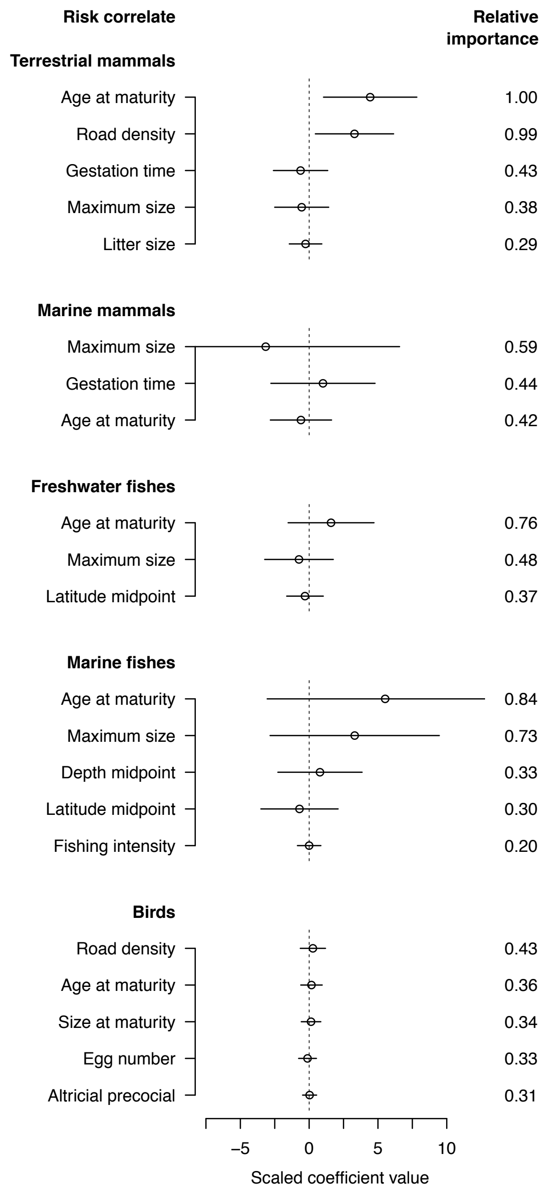

Figure S5: Scaled model parameter estimates (circles) with 95% unconditional confidence intervals (lines) from averaged predictive logistic models of risk status for the five taxonomic vertebrate groups under study **for special concern and not-at-risk species only** (i.e. excluding extinct, extirpated, endangered, and threatened species). Parameters are ordered within each vertebrate group by their relative importance (indicated on right) to the averaged model on a scale of 0 to 1. In this figure, the data were scaled within each vertebrate group by subtracting the mean and dividing by two standard deviations (Gelman 2008) to allow for comparison between parameters and across groups.

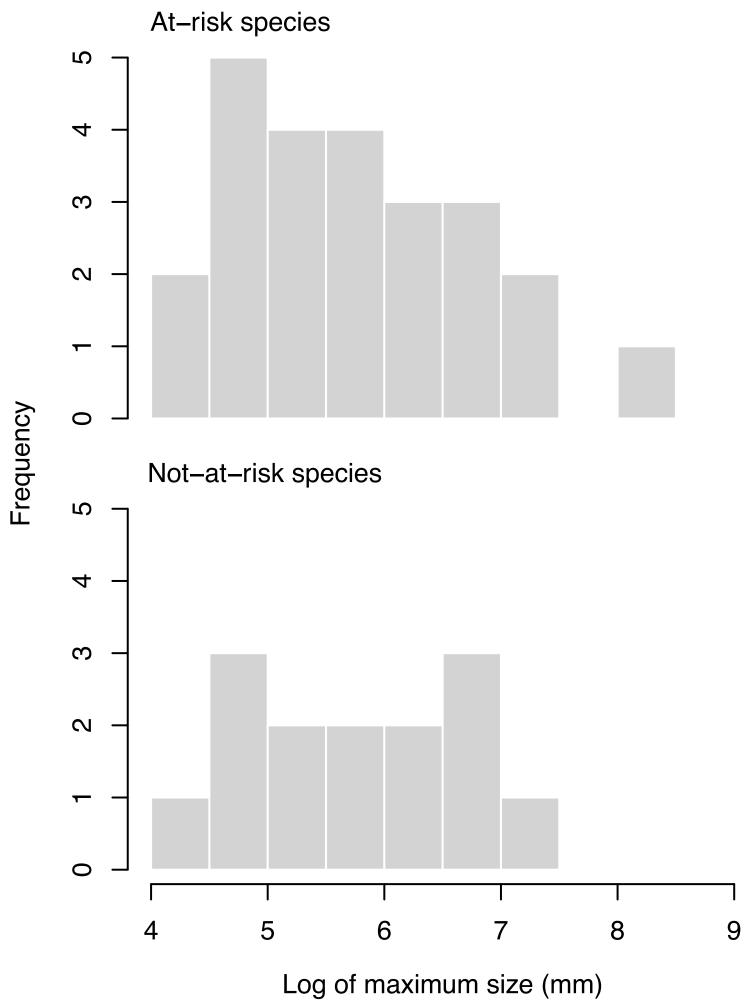

Figure S6: Distribution of maximum size for at-risk and not-at-risk Canadian freshwater fish species after deleting rows with incomplete data for the modelling portion of the analysis.

Supplementary tables

Table S1: Terrestrial mammal species evaluated.

Scientific name	Common name	Status
Antilocapra americana	Pronghorn	Not at risk
Antrozous pallidus	Pallid Bat	At risk
Aplodontia rufa	Mountain Beaver	At risk
Bison bison athabascae	Wood Bison	At risk
Bison bison bison	Plains Bison	At risk
Blarina brevicauda	Northern Short-tailed Shrew	Not at risk
Canis latrans	Coyote	Not at risk
Canis lupus lycaon	Eastern Wolf	At risk
Cervus canadensis	Wapiti	Not at risk
Clethrionomys rutilus	Northern Red-backed Vole	Not at risk
Cynomys ludovicianus	Black-tailed Prairie Dog	At risk
Dicrostonyx groenlandicus	Northern Collared Lemming	Not at risk
Dicrostonyx richardsoni	Richardson's Collared Lemming	Not at risk
Dipodomys ordii	Ord's Kangaroo Rat	At risk
Eptesicus fuscus	Big Brown Bat	Not at risk
Euderma maculatum	Spotted Bat	At risk
Glaucomys volans	Southern Flying Squirrel	At risk
Gulo gulo	Wolverine	At risk
Lasionycteris noctivagans	Silver-haired Bat	Not at risk
Lasiurus borealis	Eastern Red Bat	Not at risk
Marmota caligata	Hoary Marmot	Not at risk
Marmota vancouverensis	Vancouver Island Marmot	At risk
Martes americana atrata	American Marten	At risk
Martes pennanti	Fisher	Not at risk
Microtus longicaudus	Long-tailed Vole	Not at risk
Microtus ochrogaster	Prairie Vole	Not at risk
Microtus oeconomus	Tundra Vole	Not at risk
Microtus oregoni	Creeping Vole	Not at risk
Microtus pennsylvanicus	Meadow Vole	Not at risk
Microtus pinetorum	Woodland Vole	At risk
Microtus richardsoni	Water Vole	Not at risk
Microtus xanthognathus	Taiga Vole	Not at risk
Mustela erminea haidarum	Ermine haidarum subspecies	At risk
Mustela nigripes	Black-footed Ferret	At risk
Mustela nivalis	Least Weasel	Not at risk
Myotis keenii	Keen's Long-eared Bat	At risk
Myotis lucifugus	Little Brown Myotis	Not at risk
Myotis thysanodes	Fringed Bat	At risk
Myotis volans	Long-legged Myotis	Not at risk
Myotis yumanensis	Yuma Myotis	Not at risk

Napaeozapus insignis	Woodland Jumping Mouse	Not at risk
Neotamias amoenus	Yellow-pine Chipmunk	Not at risk
Neotamias townsendii	Townsend's Chipmunk	Not at risk
Neotoma cinerea	Bushy-tailed Woodrat	Not at risk
Ochotona collaris	Collared Pika	Not at risk
Odocoileus hemionus	Mule Deer	Not at risk
Ondatra zibethicus	Common Muskrat	Not at risk
Onychomys leucogaster	Northern Grasshopper Mouse	Not at risk
Ovis canadensis	Mountain Sheep	Not at risk
Parascalops breweri	Hairy-tailed Mole	Not at risk
Phenacomys ungava	Eastern Heather Vole	Not at risk
Procyon lotor	Northern Raccoon	Not at risk
Puma concolor	Mountain Lion	Not at risk
Rangifer tarandus caribou	Woodland Caribou	At risk
Rangifer tarandus groenlandicus	Barren-ground Caribou	At risk
Scalopus aquaticus	Eastern Mole	At risk
Scapanus townsendii	Townsend's Mole	At risk
Sciurus carolinensis	Eastern Grey Squirrel	Not at risk
Sorex bendirii	Pacific Water Shrew	At risk
Sorex cinereus	Masked Shrew	Not at risk
Sorex fumeus	Smoky Shrew	Not at risk
Sorex monticolus	Dusky Shrew	Not at risk
Sorex palustris	American Water Shrew	Not at risk
Spermophilus franklinii	Franklin's Ground Squirrel	Not at risk
Spermophilus lateralis	Golden-mantled Ground Squirrel	Not at risk
Spermophilus parryii	Arctic Ground Squirrel	Not at risk
Spermophilus saturatus	Cascade-mantled Ground Squirrel	Not at risk
Sylvilagus floridanus	Eastern Cottontail	Not at risk
Sylvilagus nuttallii nuttallii	Nuttall's Cottontail nuttallii subspecies	At risk
Synaptomys borealis	Northern Bog Lemming	Not at risk
Tamias striatus	Eastern Chipmunk	Not at risk
Taxidea taxus	American Badger	At risk
Urocyon cinereoargenteus	Grey Fox	At risk
Ursus americanus	American Black Bear	Not at risk
Ursus arctos	Grizzly Bear	At risk
Ursus maritimus	Polar Bear	At risk
Vulpes velox	Swift Fox	At risk
Western Harvest Mouse	Western Harvest Mouse	At risk
Zapus hudsonius	Meadow Jumping Mouse	Not at risk

Table S2: Marine mammal species evaluated.

Scientific name	Common name	Status
Balaena mysticetus	Bowhead Whale	At risk
Balaenoptera acutorostrata	Minke Whale	Not at risk
Balaenoptera borealis	Sei Whale	At risk
Balaenoptera musculus	Blue Whale	At risk
Balaenoptera physalus	Fin Whale	At risk
Callorhinus ursinus	Northern Fur Seal	At risk
Cystophora cristata	Hooded Seal	Not at risk
Delphinapterus leucas	Beluga Whale	At risk
Delphinus delphis	Short-Beaked Common Dolphin	Not at risk
Enhydra lutris	Sea Otter	At risk
Erignathus barbatus	Bearded Seal	Not at risk
Eschrichtius robustus	Grey Whale	At risk
Eubalaena glacialis	North Atlantic Right Whale	At risk
Eubalaena japonica	North Pacific Right Whale	At risk
Eumetopias jubatus	Steller Sea Lion	At risk
Globicephala melas	Long-finned Pilot Whale	Not at risk
Halichoerus grypus	Gray Seal	Not at risk
Hyperoodon ampullatus	Northern Bottlenose Whale	At risk
Lagenorhynchus acutus	Atlantic White-sided Dolphin	Not at risk
Lagenorhynchus albirostris	White-Beaked Dolphin	Not at risk
Lagenorhynchus obliquidens	Pacific White-sided Dolphin	Not at risk
Lissodelphis borealis	Northern Right-whale Dolphin	Not at risk
Megaptera novaeangliae	Humpback Whale	At risk
Mesoplodon bidens	Sowerby's Beaked Whale	At risk
Mirounga angustirostris	Northern Elephant Seal	Not at risk
Monodon monoceros	Narwhal	At risk
Odobenus rosmarus rosmarus	Atlantic Walrus	At risk
Orcinus orca	Killer Whale	At risk
Pagophilus groenlandica	Harp Seal	Not at risk
Phoca vitulina mellonae	Harbour Seal Lacs des Loups Marins subsp.	At risk
Phocoena phocoena	Harbour Porpoise	At risk
Phocoenoides dalli	Dall's Porpoise	Not at risk
Physeter macrocephalus	Sperm Whale	Not at risk
Pusa hispida	Ringed Seal	Not at risk
Tursiops truncatus	Bottle-Nosed Dolphin	Not at risk
Zalophus californianus	California Sea Lion	Not at risk
Ziphius cavirostris	Cuvier's Beaked Whale	Not at risk

Table S3: Freshwater fish species evaluated.

Scientific name	Common name	Status
Acipenser brevirostrum	Shortnose Sturgeon	At risk
Acipenser fulvescens	Lake Sturgeon	At risk
Ambloplites rupestris	Rock Bass	Not at risk
Ameiurus nebulosus	Brown bullhead	Not at risk
Campostoma anomalum	Central stoneroller	Not at risk
Catostomus catostomus ssp	Salish Sucker	At risk
Catostomus macrocheilus	Largescale sucker	Not at risk
Clinostomus elongatus	Redside Dace	At risk
Coregonus hoyi	Bloater	Not at risk
Coregonus kiyi orientalis	Lake Ontario Kiyi	At risk
Coregonus nigripinnis	Blackfin cisco	At risk
Coregonus reighardi	Shortnose Cisco	At risk
Coregonus zenithicus	Shortjaw Cisco	At risk
Cottus bairdii	Mottled sculpin	Not at risk
Cottus cognatus	Slimy sculpin	Not at risk
Cottus confusus	Shorthead sculpin	At risk
Cottus rhotheus	Torrent sculpin	Not at risk
Cottus ricei	Spoonhead Sculpin	Not at risk
Cottus sp.	Eastslope Sculpin	At risk
Couesius plumbeus	Lake Chub	Not at risk
Cyprinella spiloptera	Spotfin Shiner	Not at risk
Erimystax x-punctatus	Gravel Chub	At risk
Esox americanus vermiculatus	Grass Pickerel	At risk
Esox niger	Chain pickerel	Not at risk
Etheostoma blennioides	Greenside darter	Not at risk
Etheostoma caeruleum	Rainbow Darter	Not at risk
Etheostoma microperca	Least darter	Not at risk
Etheostoma nigrum	Johnny darter	Not at risk
Fundulus diaphanus	Banded Killifish	At risk
Fundulus notatus	Blackstripe Topminnow	At risk
Hybognathus argyritis	Western Silvery Minnow	At risk
Hybognathus regius	Eastern Silvery Minnow	Not at risk
Ichthyomyzon fossor	Northern Brook Lamprey	At risk
Ichthyomyzon unicuspis	Silver lamprey	Not at risk
Ictalurus punctatus	Channel catfish	Not at risk
Ictiobus cyprinellus	Bigmouth buffalo	At risk
Ictiobus niger	Black buffalo	At risk
Lampetra appendix	American brook lamprey	Not at risk
Lampetra macrostoma	Vancouver lamprey	At risk
Lampetra richardsoni	Morrison Creek Lamprey	At risk
Lepisosteus oculatus	Spotted Gar	At risk
Lepomis auritus	Redbreast Sunfish	At risk

Lepomis cyanellus	Green sunfish	Not at risk
Lepomis gibbosus	Pumpkinseed	Not at risk
Lepomis gulosus	Warmouth	At risk
Lepomis humilis	Orangespotted Sunfish	At risk
Lythrurus umbratilis	Redfin shiner	Not at risk
Micropterus dolomieu	Smallmouth bass	Not at risk
Micropterus salmoides	Largemouth Bass	Not at risk
Minytrema melanops	Spotted Sucker	At risk
Morone chrysops	White bass	Not at risk
Moxostoma anisurum	Silver redhorse	Not at risk
Moxostoma carinatum	River Redhorse	At risk
Moxostoma duquesnei	Black Redhorse	At risk
Moxostoma erythrurum	Golden Redhorse	Not at risk
Moxostoma hubbsi	Copper Redhorse	At risk
Moxostoma macrolepidotum	Shorthead redhorse	Not at risk
Moxostoma valenciennesi	Greater Redhorse	Not at risk
Myoxocephalus thompsonii	Deepwater Sculpin (Ontario, Quebec)	At risk
Nocomis biguttatus	Hornyhead chub	Not at risk
Notropis anogenus	Pugnose Shiner	At risk
Notropis atherinoides	Emerald shiner	Not at risk
Notropis dorsalis	Bigmouth shiner	Not at risk
Notropis heterolepis	Blacknose shiner	Not at risk
Notropis percobromus	Carmine Shiner	At risk
Notropis photogenis	Silver shiner	At risk
Notropis stramineus	Sand shiner	Not at risk
Notropis volucellus	Mimic Shiner	Not at risk
Noturus flavus	Stonecat	Not at risk
Noturus miurus	Brindled Madtom	Not at risk
Noturus stigmosus	Northern Madtom	At risk
Oncorhynchus clarkii lewisi	Westslope Cutthroat Trout	At risk
Percina caprodes	Logperch	Not at risk
Percopsis omiscomaycus	Trout-Perch	Not at risk
Pimephales notatus	Bluntnose Minnow	Not at risk
Platygobio gracilis	Flathead chub	Not at risk
Pomoxis annularis	White crappie	Not at risk
Pomoxis nigromaculatus	Black Crappie	Not at risk
Prosopium cylindraceum	Round whitefish	Not at risk
Rhinichthys atratulus	Eastern Blacknose Dace	Not at risk
Rhinichthys cataractae ssp	Nooksack Dace	At risk
Rhinichthys falcatus	Leopard dace	Not at risk
Rhinichthys osculus	Speckled Dace	At risk
Richardsonius balteatus	Redside shiner	Not at risk
Sander vitreus	Walleye	Not at risk
Semotilus corporalis	Fallfish	Not at risk

Table S4: Marine fish species evaluated.

Scientific name	Common name	Status
Anarhichas denticulatus	Northern Wolffish	At risk
Anarhichas lupus	Atlantic Wolffish	At risk
Anarhichas minor	Spotted Wolffish	At risk
Anarrhichthys ocellatus	Wolf-eel	Not at risk
Anguilla rostrata	American eel	At risk
Apeltes quadracus	Fourspine stickleback	Not at risk
Boreogadus saida	Polar cod	Not at risk
Bothrocara brunneum	Twoline eelpout	Not at risk
Bothrocara molle	Soft eelpout	Not at risk
Bothrocara pusillum	Alaska eelpout	Not at risk
Brosme brosme	Cusk	At risk
Carcharodon carcharias	White Shark	At risk
Centroscyllium fabricii	Black dogfish	Not at risk
Cetorhinus maximus	Basking Shark	At risk
Citharichthys stigmaeus	Speckled sanddab	Not at risk
Coregonus clupeaformis	Lake whitefish	Not at risk
Cyclopterus lumpus	Lumpsucker	Not at risk
Diaphus theta	California headlightfish	Not at risk
Dorosoma cepedianum	American gizzard shad	Not at risk
Embiotoca lateralis	Striped seaperch	Not at risk
Enchelyopus cimbrius	Fourbeard rockling	Not at risk
Engraulis mordax	Californian anchovy	Not at risk
Eopsetta jordani	Petrale sole	Not at risk
Eptatretus stoutii	Pacific hagfish	Not at risk
Eumesogrammus praecisus	Fourline snakeblenny	Not at risk
Gadus macrocephalus	Pacific cod	Not at risk
Gadus morhua	Atlantic Cod	At risk
Galeorhinus galeus	Tope	At risk
Hexagrammos stelleri	Whitespotted greenling	Not at risk
Hexanchus griseus	Bluntnose Sixgill Shark	At risk
Hippoglossoides elassodon	Flathead sole	Not at risk
Isopsetta isolepis	Butter sole	Not at risk
Isurus oxyrinchus	Shortfin Mako	At risk
Lamna nasus	Porbeagle	At risk
Lepidopsetta bilineata	Rock sole	Not at risk
Leucoraja ocellata	Winter Skate	At risk
Lycenchelys crotalinus	Snakehead eelpout	Not at risk
Lycenchelys jordani	Shortjaw eelpout	Not at risk
Lycodes pacificus	Blackbelly eelpout	Not at risk
Macrourus berglax	Roughhead Grenadier	At risk
Mallotus villosus	Capelin	Not at risk
Melanogrammus aeglefinus	Haddock	Not at risk

Merluccius bilinearis	Silver hake	Not at risk
Merluccius productus	North Pacific hake	Not at risk
Microgadus proximus	Pacific tomcod	Not at risk
Myxine glutinosa	Hagfish	Not at risk
Oncorhynchus mykiss	Rainbow trout	Not at risk
Ophiodon elongatus	Lingcod	Not at risk
Parophrys vetulus	English sole	Not at risk
Platichthys stellatus	Starry flounder	Not at risk
Porichthys notatus	Plainfin midshipman	Not at risk
Prionace glauca	Blue Shark	At risk
Protomyctophum thompsoni	Bigeye lanternfish	Not at risk
Reinhardtius hippoglossoides	Greenland halibut	Not at risk
Sardinops sagax	Pacific Sardine	Not at risk
Scomber japonicus	Chub mackerel	Not at risk
Scomber scombrus	Atlantic mackerel	Not at risk
Scophthalmus aquosus	Windowpane	Not at risk
Sebastes paucispinis	Bocaccio	At risk
Sebastolobus altivelis	Longspine Thornyhead	At risk
Spirinchus thaleichthys	Longfin smelt	Not at risk
Squalus acanthias	Picked dogfish	Not at risk
Stenobrachius leucopsarus	Northern lampfish	Not at risk
Stenodus leucichthys	Inconnu	Not at risk
Theragra chalcogramma	Alaska pollack	Not at risk
Triglops murrayi	Moustache sculpin	Not at risk
Xiphias gladius	Swordfish	Not at risk

Table S5: Bird species evaluated.

Scientific name	Common name	Status
Accipiter gentilis laingi	Northern Goshawk laingi subspecies	At risk
Aegolius acadicus brooksi	Northern Saw-whet Owl brooksi subspecies	At risk
Aeronautes saxatalis	White-throated Swift	Not at risk
Aix sponsa	Wood Duck	Not at risk
Alca torda	Razorbill	Not at risk
Ammodramus henslowii	Henslow's Sparrow	At risk
Anas clypeata	Northern Shoveler	Not at risk
Anthus spragueii	Sprague's Pipit	At risk
Ardea herodias fannini	Great Blue Heron fannini subspecies	At risk
Asio flammeus	Short-eared Owl	At risk
Athene cunicularia	Burrowing Owl	At risk
Aythya americana	Redhead	Not at risk
Brachyramphus marmoratus	Marbled Murrelet	At risk
Bucephala albeola	Bufflehead	Not at risk
Bucephala clangula	Common Goldeneye	Not at risk
Bucephala islandica	Barrow's Goldeneye	At risk
Buteo platypterus	Broad-winged Hawk	Not at risk
Buteo regalis	Ferruginous Hawk	At risk
Buteo swainsoni	Swainson's Hawk	Not at risk
Butorides virescens	Green Heron	Not at risk
Calcarius mccownii	McCown's Longspur	At risk
Calidris canutus islandica	Red Knot islandica subspecies	At risk
Calidris canutus roselaari	Red Knot roselaari type	At risk
Calidris canutus rufa	Red Knot rufa subspecies	At risk
Cathartes aura	Turkey Vulture	Not at risk
Catharus bicknelli	Bicknell's Thrush	At risk
Centrocercus urophasianus phaios	Greater Sage-Grouse phaios subspecies	At risk
Chaetura pelagica	Chimney Swift	At risk
Charadrius melodus circumcinctus	Piping Plover circumcinctus subspecies	At risk
Charadrius montanus	Mountain Plover	At risk
Charadrius vociferus	Killdeer	Not at risk
Chordeiles minor	Common Nighthawk	At risk
Colinus virginianus	Northern Bobwhite	At risk
Contopus virens	Eastern Wood-Pewee	Not at risk
Coturnicops noveboracensis	Yellow Rail	At risk
Dendragapus obscurus	Dusky/Blue Grouse	Not at risk
Dendroica cerulea	Cerulean Warbler	At risk
Dendroica fusca	Blackburnian Warbler	Not at risk
Dendroica kirtlandii	Kirtland's Warbler	At risk
Dendroica palmarum	Palm Warbler	Not at risk
Dendroica pensylvanica	Chestnut-sided Warbler	Not at risk
Dendroica striata	Blackpoll Warbler	Not at risk

Dendroica virens	Black-throated Green Warbler	Not at risk
Empidonax virescens	Acadian Flycatcher	At risk
Eremophila alpestris strigata	Horned Lark strigata subspecies	At risk
Euphagus carolinus	Rusty Blackbird	At risk
Falco peregrinus anatum	Peregrine Falcon anatum subspecies	At risk
Falco peregrinus pealei	Peregrine Falcon pealei subspecies	At risk
Falco peregrinus tundrius	Peregrine Falcon tundrius subspecies	At risk
Falco sparverius	American Kestrel	Not at risk
Fulica americana	American Coot	Not at risk
Gavia immer	Common Loon	Not at risk
Glaucidium gnoma	Northern Pygmy-Owl	Not at risk
Grus americana	Whooping Crane	At risk
Histrionicus histrionicus	Harlequin Duck	At risk
Icteria virens auricollis	Yellow-breasted Chat auricollis subspecies	At risk
Icteria virens virens	Yellow-breasted Chat virens subspecies	At risk
Icterus spurius	Orchard Oriole	Not at risk
Ixobrychus exilis	Least Bittern	At risk
Lagopus muta	Rock Ptarmigan	Not at risk
Lanius ludovicianus excubitorides	Loggerhead Shrike excubitorides subspecies	At risk
Lanius ludovicianus migrans	Loggerhead Shrike migrans subspecies	At risk
Larus californicus	California Gull	Not at risk
Larus hyperboreus	Glaucous Gull	Not at risk
Leucosticte tephrocotis	Gray-crowned Rosy-Finch	Not at risk
Limnodromus griseus	Short-billed Dowitcher	Not at risk
Limosa haemastica	Hudsonian Godwit	Not at risk
Loxia curvirostra percna	Red Crossbill percna subspecies	At risk
Megascops asio	Eastern Screech-Owl	Not at risk
Megascops kennicottii kennicottii	Western Screech-Owl kennicottii subspecies	At risk
Megascops kennicottii macfarlanei	Western Screech-Owl macfarlanei subspecies	At risk
Melanerpes erythrocephalus	Red-headed Woodpecker	At risk
Melanerpes lewis	Lewis's Woodpecker	At risk
Melanitta fusca	White-winged Scoter	Not at risk
Melospiza lincolnii	Lincoln's Sparrow	Not at risk
Melospiza melodia	Song Sparrow	Not at risk
Mimus polyglottos	Northern Mockingbird	Not at risk
Numenius americanus	Long-billed Curlew	At risk
Numenius borealis	Eskimo Curlew	At risk
Oporornis philadelphia	Mourning Warbler	Not at risk
Oreoscoptes montanus	Sage Thrasher	At risk
Otus flammeolus	Flammulated Owl	At risk
Pagophila eburnea	Ivory Gull	At risk
Passerculus sandwichensis princeps	Savannah Sparrow princeps subspecies	At risk
Passerina cyanea	Indigo Bunting	Not at risk
Phalaropus tricolor	Wilson's Phalarope	Not at risk
Phoebastria albatrus	Short-tailed Albatross	At risk

Phoebastria nigripes	Black-footed Albatross	At risk
Picoides albolarvatus	White-headed Woodpecker	At risk
Poecile gambeli	Mountain Chickadee	Not at risk
Pooecetes gramineus affinis	Vesper Sparrow affinis subspecies	At risk
Protonotaria citrea	Prothonotary Warbler	At risk
Puffinus creatopus	Pink-footed Shearwater	At risk
Rallus elegans	King Rail	At risk
Rhodostethia rosea	Ross's Gull	At risk
Seiurus motacilla	Louisiana Waterthrush	At risk
Setophaga ruticilla	American Redstart	Not at risk
Somateria mollissima	Common Eider	Not at risk
Sphyrapicus thyroideus	Williamson's Sapsucker	At risk
Spizella arborea	American Tree Sparrow	Not at risk
Spizella pallida	Clay-colored Sparrow	Not at risk
Stelgidopteryx serripennis	Northern Rough-winged Swallow	Not at risk
Sterna dougallii	Roseate Tern	At risk
Strix occidentalis caurina	Northern Spotted Owl caurina subspecies	At risk
Synthliboramphus antiquus	Ancient Murrelet	At risk
Tachycineta bicolor	Tree Swallow	Not at risk
Toxostoma rufum	Brown Thrasher	Not at risk
Tympanuchus cupido	Greater Prairie-Chicken	At risk
Tyto alba	Barn Owl	At risk
Uria lomvia	Thick-billed Murre	Not at risk
Vermivora chrysoptera	Golden-winged Warbler	At risk
Vireo olivaceus	Red-eyed Vireo	Not at risk
Vireo solitarius	Blue-headed Vireo	Not at risk
Wilsonia citrina	Hooded Warbler	At risk
Wilsonia pusilla	Wilson's Warbler	Not at risk

Table S6: Sample sizes for taxonomic groups analyzed. For the data used in the models, we deleted all rows in which the data were incomplete for the variables evaluated.

Taxon	All data		Data used in models	
	Not at risk	At risk	Not at risk	At risk
Terrestrial mammals	50	29	40	23
Marine mammals	18	19	15	18
Freshwater fishes	50	36	14	24
Marine fishes	50	17	18	16
Birds	50	65	38	29

Table S7: Model parameter estimates, 95% unconditional confidence intervals (CI), and relative importance (Rel. imp.) of the averaged predictive logistic models of risk status for the five vertebrate species groups under study.

Variable	Coefficient	Lower CI	Upper CI	Rel. imp.
Terrestrial mammals				
Intercept	-2.705	-4.483	-0.927	
Road dens. ($m \cdot km^{-2}$)	0.015	0.004	0.025	0.99
Age mat. (yr)	1.186	0.168	2.203	0.97
Gest. time (months)	0.075	-0.164	0.314	0.40
Max. size (mm)	-0.001	-0.001	0.001	0.35
Lit. size (number)	-0.015	-0.140	0.109	0.25
Marine mammals				
Intercept	-1.313	-3.568	0.942	
Max. size (mm)	0.001	-0.001	0.001	0.82
Age mat. (yr)	0.041	-0.132	0.213	0.33
Gest. time (months)	0.040	-0.130	0.210	0.31
Freshwater fishes				
Intercept	0.719	-0.157	1.596	
Age mat. (yr)	3.335	-2.156	8.826	0.87
Max. size (mm)	-1.918	-6.072	2.236	0.67
Lat. mid. (deg)	-0.908	-3.116	1.301	0.59
Marine fishes				
Intercept	-4.347	-8.391	-0.303	
Age mat. (yr)	0.465	-0.001	0.931	0.95
Max. size (mm)	0.001	-0.001	0.002	0.52
Depth mid. (m)	0.001	-0.003	0.006	0.48
Lat. mid. (°)	-0.001	-0.013	0.011	0.24
Fishing intensity (1–4)	0.067	-0.332	0.466	0.24
Birds				
Intercept	-0.805	-2.005	0.396	
Road dens. ($m \cdot km^{-2}$)	0.010	0.001	0.020	0.97
Egg num. (number)	-0.034	-0.164	0.096	0.34
Age mat. (yr)	0.125	-0.455	0.704	0.30
Alt. (0) or prec. (1)	0.037	-0.163	0.237	0.29
Size mat. (mm)	0.001	-0.001	0.001	0.27