Threats to Canadian species at risk: An analysis of finalized recovery strategies

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ABSTRACT

In order to reverse the decline of imperilled species, we need to know what is threatening their survival. Canada's Species at Risk Act (SARA) is intended to provide for the protection and recovery of species listed under the Act. Threats to SARA-listed species must be documented in recovery strategies, which also define recovery goals and critical habitat. We reviewed finalized recovery strategies for 146 species to determine the major threats to these species and whether designation of critical habitat or the relative ambition of recovery goals is associated with the nature of threats. We then compared our findings to the threats described in reports prepared by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), the independent body which prepares status reports for all imperilled species (including those not listed under SARA). Human disturbance, in particular due to recreation, was the most frequently listed threat in recovery strategies, followed by invasive species and residential and commercial development. Threats differed among taxonomic groups and broad habitat types, but there was no evidence that low ambition of recovery goals or failure to designate critical habitat were correlated with particular threats. However, species with certain threats, including biological resource use, were less likely either to be listed under SARA and/or to have a finalized recovery strategy once listed. Documenting threat-based differences in the recovery process is an important first step toward ensuring that SARA results in timely and effective measures to recover all listed species.

1. Introduction

In order to implement actions that can halt and reverse the continuing decline of species at risk, managers need to understand the threats to those species (Hayward 2009; Lawler et al., 2002; Wilcove et al., 1998). For this reason, the description of threats is a key part of recovery planning under legislation designed to improve the status of imperilled species. For example, the Endangered Species Act (ESA) of the USA (1973), the Environmental Protection and Biological Conservation Act of Australia (1999),

and the Species at Risk Act of Canada (2002) all require that recovery planning documents include a description of the threats to each listed species (Foin et al., 1998; Clark et al., 2002; Mooers et al., 2010; Walsh et al., 2012).

Many analyses have characterized the threats to groups of imperilled species with the aim of determining the primary causes of species endangerment and how these differ by taxonomic group, geographic region, or habitat type. Habitat loss and degradation, exotic invasive species, overexploitation, and pollution are generally the top threats to imperilled species (e.g. Croxall et al., 2012; Czech et al., 2000; Foin et al., 1998; Hayward 2009; Kappel, 2005; Li and Wilcove, 2005; Schipper et al., 2008; Venter et al., 2006; Wilcove et al., 1998). However, these categories are too

broad to indicate which activities are responsible for declining biodiversity. For example, habitat loss and degradation can result from multiple activities including residential or commercial development, agricultural operations, oil or mineral extraction, road construction, logging, or recreational activities. Because the activities that cause habitat loss or degradation are likely to affect the choice of approaches to abate or reverse threat impacts, a classification that parses the causes can help promote the development of effective conservation strategies (Prugh et al., 2010; Salafsky et al., 2008).

We have undertaken an analysis of threats based on recovery strategies written for species listed under Canada's Species at Risk Act (hereafter 'SARA'; SARA, 2002). Species that are candidates for listing under SARA are assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an independent scientific advisory body that has assessed the status of Canadian wildlife species since 1977, long before SARA was enacted (Government of Canada, 2009). COSEWIC produces a status report for each candidate species that outlines the evidence for its designation as at-risk. Risk categories under SARA include extirpated, endangered (equivalent to the IUCN category Critically Endangered), threatened (IUCN Endangered), or special concern (IUCN Vulnerable). Wildlife species designated at-risk by COSEWIC are candidates for formal listing under SARA, but the Government of Canada has the option of listing or not listing the species under SARA, and may incorporate economic analyses and consultation with stakeholders and the public in its decision (Mooers et al., 2010).

All species listed under SARA as extirpated, endangered or threatened must receive a recovery strategy which outlines the major threats to the species, identifies critical habitat (to the extent possible), and defines population and distribution objectives for species recovery (SARA, 2002). Critical habitat is defined as the habitat necessary for the survival or recovery of the species (SARA, 2002), and destruction of designated critical habitat is prohibited. Under SARA, recovery strategies must be finalized within 1–2 years of a species being listed (depending on the species' status). Following this, an action plan must be written that specifies actions that will be carried out to promote species recovery.

Previous studies have documented biases in government decisions to list or not list a species under SARA, including a tendency for harvested species and species from the north not to be listed (Findlay et al., 2009; Mooers et al., 2007). In addition, there have been long delays in the production and finalization of recovery strategies (Mooers et al., 2010). In spite of the requirement to designate critical habitat in recovery strategies, to the extent possible, many recovery strategies produced before 2010 did not include critical habitat designation, and legal action has been taken to challenge the government to do so (Mooers et al., 2010). To date, action plans have been finalized for only seven species (5% of species with finalized recovery strategies).

As SARA passes the 10 year anniversary of its enactment and faces potential revisions by the Canadian government, it is timely to assess patterns and potential biases in the completion and content of recovery strategies. In the US, analyses of recovery plans produced under the ESA have provided key insights into how the process of recovery planning can be improved (e.g. Clark et al., 2002). Recovery strategies are arguably the most important step in the implementation of SARA as they establish objectives for on-the-ground recovery actions. They also provide an as-yet untapped resource for determining which human activities are the primary threats to species listed under SARA. This knowledge could enable the prioritization of threat-abatement strategies that will benefit the greatest number of species.

In particular, it is important to reveal whether the recovery process under SARA is working for certain species, but not others. For example, Metrick and Weitzman (1996) found that listing and spending decisions under the ESA were biased towards larger species. In Australia there is a bias in listing and recovery planning favouring amphibians and birds over other groups (Walsh et al., 2012). Similarly, Laycock et al. (2009) found spending on recovery in the UK to be highly biased towards vertebrates. In Canada, harvested species are already known to be less likely than non-harvested species to be listed under SARA (Findlay et al., 2009; Mooers et al., 2007), but whether or not this pattern extends to the recovery planning process has not been explored.

We compiled information on threats and related features from the finalized recovery strategies of 146 wildlife species listed under SARA. We used these data to ask three main questions:

(1) What are the most common threats to Canada's SARA-listed species as described in finalized recovery strategies, and how do threats differ by taxonomic group and broad habitat type? We use the IUCN standardized threat classification system (Salafsky et al., 2008) to identify the particular activities or industries causing the threat (e.g. residential and commercial development) rather than broadly described threats (e.g. habitat loss).

(2) Does the presence of particular threats correlate with the identification of critical habitat (or not), or with the relative ambition of recovery goals? Given the biases detected in the SARA listing process (Findlay et al., 2009; Mooers et al., 2007), such correlations might indicate similar biases in recovery planning. For example, species with threats related to economically important industries might be less likely to have critical habitat designated or they might have less ambitious population and distribution objectives. Such associations could have consequences in terms of species recovery. For example, there is evidence from the US that species with designated critical habitat are more likely to show improving population trends (Taylor et al., 2005), and are more likely to see implementation of recovery actions (Lundquist et al., 2002).

(3) Finally, are the most common threats reported in recovery strategies the same as the most common threats reported by COSEWIC? To answer this question, we used data previously compiled from COSEWIC status reports using the same threat classification system we used for analyzing recovery strategies (Prugh et al., 2010). Here we are testing whether certain threats are associated with the likelihood of recovery strategies being finalized. Because SARA has only been in force since 2003, it may be too early to judge the role of recovery strategy production in improving the actual status of imperilled species. However, there is evidence from the US that the production of a recovery strategy itself is correlated with improved species status (Kerkvliet and Langpap, 2007; Taylor et al., 2005). Therefore, delays in the production of recovery strategies for imperilled species may contribute to their continued decline.

2. Methods

2.1. Data collection

We obtained finalized recovery strategies from the Species at Risk Public Registry website (www.sararegistry.gc.ca, Government of Canada, 2011). We divided the 146 species with finalized recovery strategies (as of December 2011) randomly among 14 participants in a graduate student seminar at the University of British Columbia, with each participant scoring between 4 and 13 species. We assessed each wildlife species (these may comprise species, subspecies, or populations) independently even if it was part of a multi-species recovery strategy. Before individual data compilation

began, all participants scored the same set of three species in order to calibrate our responses, revise our list of variables, and resolve ambiguities in the scoring process.

We scored each species for a set of attributes divided into four categories, as follows:

(1) *Species information* including higher taxonomic group and broad habitat type (marine, terrestrial or freshwater). We categorized species into six broad taxonomic or functional groups: arthropods ($n = 8$), birds ($n = 16$), fishes (marine and freshwater; $n = 22$), molluscs ($n = 13$), plants and lichens (including vascular plants, lichens and mosses, but abbreviated as plants because only two lichens have recovery strategies; $n = 64$), and non-avian tetrapods (abbreviated as tetrapods, including mammals, reptiles and amphibians but excluding birds; $n = 23$). We chose these categories to avoid having taxonomic groups with very few (<8) species.

(2) *Characteristics of the recovery strategy* including the year the strategy was finalized, whether or not the recovery strategy identifies critical habitat, and an index of the relative ambition of the population and distribution objectives outlined in the strategy. To characterize the ambition level, we recorded the stated goals in each recovery strategy regarding targets for the total number of individuals, the number of populations, and the extent of the distribution of the species. For each of these categories, we assigned a score from 0 (no objective set) through 4 (restore to historic levels, interpreted as most ambitious) as outlined in Table 1. We then averaged the scores across all categories with non-zero values for each species to indicate the relative ambition score out of a maximum of 4. Recovery strategies with zeroes in all three categories received an ambition score of zero. Thus a total score of zero means there were no explicit goals for population or distribution, while a score of 4 indicates that the stated goal was to increase the abundance and/or extent of the species back to historical levels.

(3) *The nature of the threats to the species.* We compiled threat descriptions for each threat in order of rank, if threats were ranked, or else in the order in which threats were listed in the recovery strategy. Some recovery strategies explicitly ranked threats in order of importance, while others did not. For each species, we recorded whether or not threats were explicitly ranked. We also noted whether or not the severity or extent of threats was specified. We recorded threat descriptions word for word from the recovery strategy.

Following this, a smaller working group reviewed the threat descriptions for each of the 146 species and classified these according to the International Union for Conservation of Nature (IUCN) classification system (Table 2; Salafsky et al., 2008). This is a hierarchical system in which threats are first classified into broader, first-level threat types. Within each first-level type, there are three to eight second-level entries that specify the cause of the threat with more precision. For example, threats due to first-level type 4, "transportation and service corridors", are broken down into second-level types 4.1 "roads and railroads", 4.2 "utility and

service lines", 4.3 "shipping lanes", or 4.4 "flight paths" (Table 2). We selected this system because it attempts to identify the direct threats to species persistence and recovery and it is increasingly widely used, thus increasing the utility of our analysis for assessing recovery priorities, and allowing comparison with past (e.g. Prugh et al., 2010) and future analyses of threats. Where possible we coded each threat description to IUCN second-level threat type, but if we could not determine which second-level threat applied, we designated the threat by first-level IUCN type only (e.g. 4.0 = transportation and service corridors, unspecified). We added a first-level threat type 12 to designate "natural events" that generally affect small populations, and type 13 to designate threats listed as "unknown" in recovery strategies (Table 2).

Whether the threats were explicitly ranked or not, we kept track of the order of reporting of threats for each species, because the description of importance often suggested that ranking was implicit in the order of presentation. If a single threat type appeared more than once in the list of threats, the rank of the first listed occurrence was maintained. For example, if the first and third listed threat were both classified as IUCN type 1.3, then type 1.3 received a score of "1" for that species. For cases in which a threat description could be classified as more than one IUCN threat type, those types each received the same rank score for a given species. For example, the first listed threat to the endangered Whooping Crane (*Grus americana*) is described as habitat loss and degradation due to conversion of wetlands for hay and grain production (IUCN Threat 2.1) and drainage of wetlands (IUCN Threat 7.2). Therefore, Whooping Crane received a rank score of "1" for both. The IUCN threat type or types of the second listed threat as described in the recovery strategy received a rank score of "2", and so on.

2.2. Data analyses

2.2.1. What are the most commonly listed threats in recovery strategies?

We determined the percentage of all species affected by each first-level threat type. We included three subsets of the data for this analysis: (1) only the highest ranked (or first listed) threat, (2) only the three highest ranked (or first three listed) threats, and (3) all threats mentioned. This allowed us to compare results when threats of lesser importance (or later listing) were or were not included. We also determined the percentage of all species affected by each second-level IUCN threat type.

2.2.2. Are threats reported in recovery strategies correlated with taxonomic group, habitat type, identification of critical habitat, year of recovery strategy completion, or ambition of recovery goals?

We used both multivariate and univariate approaches to address this question. We used distance-based redundancy analysis (Anderson, 2001; McArdle and Anderson, 2001) to test for relationships between the multivariate threat distribution of species, and the explanatory variables: (i) taxonomic group, (ii) broad habitat type (marine, freshwater, or terrestrial), (iii) presence/absence of designated critical habitat, (iv) the year the recovery strategy was finalized, and (v) the ambition score for population and distribution objectives. We created a species by threat matrix, in which

Table 1
The scoring of the ambition of population and distribution objectives.

Description of objective	Score
No goals included/no information	0
Maintain at levels less than current levels	1
Maintain at levels equal to current levels, or vague (e.g. "maintain self-sustaining population", or "maintain at levels equal to or greater than current")	2
Restore to levels greater than current levels but less than historic levels, or restore to levels greater than current levels with historic levels unknown	3
Restore to levels equal to historic levels	4

Table 2
IUCN threat types used to define threats described in finalized recovery strategies for 146 species listed under SARA. Abbreviations for each level 1 threat type are given in brackets.

IUCN level 1 type	IUCN level 2 type
1. Residential and commercial development (Res/Com Dev't)	1.1. Housing and urban areas 1.2. Commercial and industrial areas 1.3. Tourism and recreation areas
2. Agriculture and aquaculture (Agriculture)	2.1. Annual and perennial non-timber crops 2.2. Wood and pulp plantations 2.3. Livestock farming and ranching 2.4. Marine and freshwater aquaculture
3. Energy production and mining (Oil/Mining)	3.1. Oil and gas drilling 3.2. Mining and quarrying 3.3. Renewable energy
4. Transportation and service corridors (Transport)	4.1. Roads and railroads 4.2. Utility and service lines 4.3. Shipping lanes 4.4. Flight paths
5. Biological resource use (Bio Res Use)	5.1. Hunting and trapping terrestrial animals 5.2. Gathering terrestrial plants 5.3. Logging and wood harvesting 5.4. Fishing and harvesting aquatic resources 5.5. Historical harvest/fishing 5.6. Bycatch
6. Human intrusions and disturbance (Human Disturb)	6.1. Recreational activities 6.2. War, civil unrest and military exercises 6.3. Work and other activities and multiple causes
7. Natural system modifications (Nat Sys Mod)	7.1. Fire and fire suppression 7.2. Dams and water management/use 7.3. Other ecosystem modifications
8. Invasive and other problematic species and genes (Invasive spp.)	8.1. Invasive, non-native species 8.2. Problematic native species 8.3. Introduced genetic material 8.4. Persecution of unpopular species
9. Pollution	9.1. Domestic and urban waste water 9.2. Industrial and military effluents 9.3. Agriculture and forestry effluents 9.4. Garbage and solid waste 9.5. Air-borne pollutants 9.6. Excess energy 9.7. Oil and gas pollution
10. Geological events (Geo Events)	10.1. Volcanoes 10.2. Earthquakes/tsunamis 10.3. Avalanches/landslides
11. Climate change and severe weather (Clim Change)	11.1. Habitat shifting and alteration 11.2. Droughts 11.3. Temperature extremes 11.4. Storms and flooding 11.5. Other impacts
12. Natural events (Nat Events)	12.1. Environmental stochasticity 12.2. Demographic failure 12.3. Loss of genetic diversity 12.4. Low recruitment 12.5. Natural mortality 12.6. Low population size 12.7. Geographically limited range 12.8. Low connectivity
13. Uncertain/not listed (Unknown)	None

we assigned each first-level IUCN threat type a number for each species ranging from 0 (threat type not present in the recovery strategy), to 7 (threat type is highest ranked or first listed threat in the recovery strategy). Accordingly, if a threat type was the seventh listed threat for a species, we coded it as "1". This assigned greater weight to threat types of higher rank or earlier listing in a recovery strategy. We used the Bray–Curtis dissimilarity measure on the log-transformed threat values to compute dissimilarities between all possible pairs of species based on their threat type distribution (the use of different dissimilarity measures and transformations resulted in qualitatively identical results). We then used

distance-based redundancy analysis to assess whether each of the five explanatory variables alone was significantly correlated with the multivariate threat distribution as represented by the dissimilarity matrix. Some of our explanatory variables are highly correlated (for example, taxonomic group and broad-scale habitat), so we also did sequential tests assessing whether each variable that was significant on its own retained significance after accounting for all other variables, starting with the variable that individually explained the most variation.

In order to visualize the data, we used a Canonical Analysis of Principal Coordinates (CAP) to ordinate species in multivariate

threat space (Anderson and Willis, 2003). CAP finds the axis in multivariate space that best distinguishes groups; in our case, different higher taxonomic groups (Anderson et al., 2008). We carried out multivariate analyses using the DISTLM function in PRIMER version 6 with PERMANOVA+ (Clarke and Gorley, 2006). We then analyzed contingency tables for the relationships between individual threat types and individual categorical explanatory variables using Fisher's exact test. We used R 2.7.0 (R Development Core Team, 2008) to perform univariate analyses.

2.2.3. Are the key threats reported in recovery strategies the same as those reported in COSEWIC status reports?

We compared our assessment of threats based on finalized recovery strategies to a dataset of threats reported in COSEWIC status reports (Prugh et al., 2010). The COSEWIC dataset includes threats described in 339 COSEWIC reports, categorized by Prugh et al. (2010) using the IUCN classification system (Salafsky et al., 2008). We compared the percentage of species with threats reported for each IUCN first-level threat type in recovery strategies versus COSEWIC reports to see if the most frequently listed threat types are the same in the two sets of documents. We excluded the 40 species in the COSEWIC dataset that are not SARA-listed, and therefore do not require a recovery strategy. This resulted in 299 COSEWIC reports and 146 recovery strategies.

One potential source of differences in threats between these two sources is that the recovery strategy dataset and the COSEWIC dataset had only 83 species in common. Therefore, to examine whether certain threat types are associated with decisions not to list species under SARA, or with the probability of having a finalized recovery strategy, we focused on the threats described in COSEWIC reports only and divided these reports into subsets: (1) species listed under SARA versus those recommended by COSEWIC, but not listed under SARA, and (2) species listed under SARA with finalized recovery strategies versus species listed under SARA without finalized recovery strategies (as of December, 2011). We used Fisher's exact test to determine whether any of the first-level threat types was significantly associated with species being SARA listed versus not, or having a finalized recovery strategy versus not having one.

3. Results

3.1. What are the most common threats described in recovery strategies?

Finalized recovery strategies were available for only 146 species of the 374 due by the end of December, 2011. It is important to note that the majority of these species (64) are plants. Of our 146 species, 129 (88%) had known threats documented in their recovery strategies. The 17 species without known threats included six extirpated species for which recovery was deemed not feasible (for example, the Paddlefish, *Polyodon spathula*), and 11 endangered species for which threats are not known due to a lack of information. In all cases where threats were not known, potential or hypothesized threats were nonetheless listed in the recovery strategy (for example, the Hoary Mountain-mint, *Pycnanthemum incanum* had five well described potential threats listed in order of significance), and we recorded these in our scoring, maintaining all 146 species in the analysis. Approximately half of the recovery strategies had explicitly ranked threats (75 out of 146, or 51%), and also about half described the severity or extent of each threat (76 out of 146, or 52%). Species with explicitly ranked threats did not always have severity or extent defined, and vice versa. Although only half of the recovery strategies explicitly noted the severity or extent of each threat, this proportion appears to be increasing over time: 34% of recovery strategies finalized in 2007 explicitly noted the severity or extent of each threat, whereas 71% of recovery strategies finalized in 2011 did so.

The average number of first-level threat types per species was 4.7. The top five first-level threat types in terms of frequency in recovery strategies always included residential and commercial development, human intrusions and disturbance, natural system modifications, and invasive and other problematic species and genes (Table 3). This result was independent of the number of threats examined per species. Climate change and severe weather, geological events, and threats unknown or not listed were always in the bottom three in terms of frequency. These patterns were the same when we included only the 75 species with threats explicitly ranked (results not shown).

The importance of two threat types changed depending on how many threats were counted. Natural events, which includes natural mortality and demographic failure, tended to be listed later in recovery strategies, as shown by its occurrence in a higher percentage of species when all listed threats were considered (47.3%; Table 3), than when only the top three threats were considered (31.5% of species). Natural events was listed as the first (and/or highest ranked) threat type for only eight species of 146 (5.5%), all of which are plants. Biological resource use was in the top five threat types when only the first listed threat was considered, but fell to seventh when all listed threats were considered. Fig. 1 shows the average rank of each threat type (when present in a recovery strategy) versus the percent of species with that threat type listed. Human intrusions and disturbance, for example, was the most common threat type, listed as a threat for 58% of all species with

Table 3
Percent of species with each first-level IUCN threat type listed in their recovery strategies. Note that the sum of the percentages adds up to more than 100% because each species has more than one threat type listed. The four threat types in bold are always found in the top 5 threats; italicized threat types change in importance depending on how many listed threats are included.

| All listed threats	% Of species	First 3 listed only	% Of species	First listed threat only	% Of species
Human disturbance	58.2	**Residential/commercial development**	48.6	**Residential/commercial development**	32.9
Invasive species	55.5	**Natural systems modification**	37.7	**Natural systems modification**	20.5
Residential/commercial development	54.1	**Human disturbance**	36.3	**Human disturbance**	17.8
Natural events	47.3	**Invasive species**	34.2	**Invasive species**	16.4
Natural systems modification	45.9	*Natural events*	31.5	*Biological resource use*	15.1
Pollution	41.1	*Biological resource use*	29.5	Pollution	11.0
Biological resource use	39.0	Pollution	28.8	Transportation	9.6
Energy/mining	30.8	Energy/mining	24.7	Agriculture/aquaculture	6.8
Transportation	30.8	Transportation	22.6	Energy/mining	5.5
Agriculture/aquaculture	28.8	Agriculture/aquaculture	19.9	*Natural events*	5.5
Climate change	26.7	Unknown	8.2	Climate change	3.4
Unknown	13.7	Climate change	6.8	Unknown	2.1
Geological events	0.7	Geological events	0.7	Geological events	0
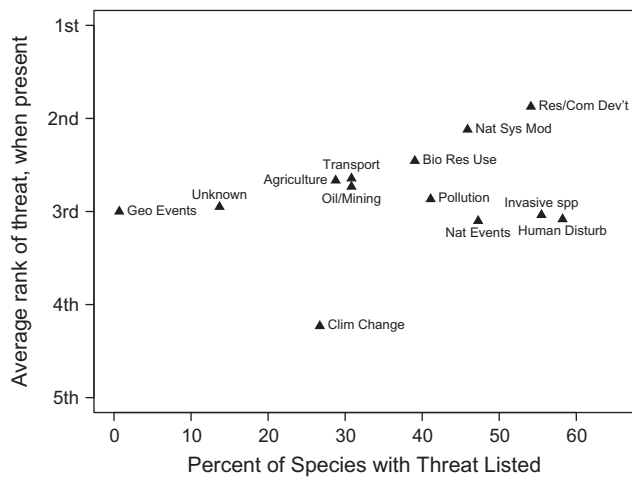
Fig. 1. Percentage of species with each IUCN first-level threat type reported versus the average rank of each threat type, as described in finalized recovery strategies for 146 species. See Table 2 for full names of abbreviated threat types.

finalized recovery strategies, but on average it was mentioned third or later. Residential and commercial development was the third most commonly mentioned threat, and was listed the earliest, on average (Fig. 1).

When all listed threats were classified by IUCN second-level threat type, the most-listed threat was recreational activities (IUCN 6.1–47% of species), followed by invasive non-native species (IUCN 8.1–43% of species) and commercial and industrial areas (IUCN 1.2–33% of all species, Table 4). Most IUCN first-level threat types were dominated by one or two second-level types. Type 1 (residential and commercial development) was most often due to commercial and industrial areas (38%); threats that were categorized as agriculture and aquaculture were dominated by annual and perennial non-timber crops (41%); transportation and service corridor threats were most often due to roads and railroads (53%); and biological resource use was dominated by logging and wood harvest

(40%) and fishing and harvesting aquatic resources (31%; see Fig. A.1 in Appendix A in Supplementary materials).

3.2. Are threats correlated with taxonomic group, habitat type, or recovery strategy features?

Taxonomic group ($R^2 = 20.5\%$), broad habitat type (marine, terrestrial or freshwater; $R^2 = 15.9\%$), and ambition level were each significantly related to the multivariate distribution of threat types, although the amount of variation explained by the ambition level was very low ($R^2 = 2.2\%$; Table 5). There was no significant relationship between the threat distribution and the year a recovery strategy was completed or whether or not critical habitat was identified in the recovery strategy (Table 5). In addition, all univariate tests of the relationship between individual first-level threat types and the designation of critical habitat were not significant (results not shown). Broad habitat type explained a significant amount of variation in the multivariate threat distribution even after taxonomic group was accounted for, and ambition level remained significant even after taxonomic group and broad habitat type were both accounted for (Table 5). Once taxonomic group, habitat type, ambition score and year of recovery strategy finalization were accounted for, the designation of critical habitat had a significant but very small relationship to the multivariate threat distribution ($R^2 = 1.9\%$, Table 5).

Clusters of species by taxonomic group are evident in the ordination of species in threat space (Fig. 2). Tetrapods (excluding birds) mainly clustered in the direction of threats from transportation and service corridors. Plants and lichens were more likely to have threats listed under natural events, residential and commercial development, and human intrusions and disturbance. These patterns were supported by the univariate analyses of each threat type separately. Fisher's exact tests indicated that the frequency of threat types differed depending on taxonomic groups for all threat types except climate change and unknown/uncertain threats (Fig. 3).

Table 4
Percentage of species with each IUCN second-level type listed, and the average rank order (avg. rank) in recovery strategies. Only threat types listed for 10% or more of species are shown.

Type	Description	% Species	Avg. rank	# Species
6.1	Recreational activities	47	3.00	69
8.1	Invasive non-native species	43	3.11	63
1.2	Commercial and industrial areas	33	1.85	48
1.1	Housing and urban areas	32	2.57	46
7.2	Dams and water management/use	27	2.13	39
9.3	Agriculture and forestry effluents	23	2.82	34
7.1	Fire and fire suppression	23	2.76	33
1.0	Residential and commercial development, unspecified	19	1.04	28
3.1	Oil and gas drilling	18	2.54	26
5.3	Logging and wood harvesting	18	2.77	26
4.1	Roads and railroads	17	2.84	25
3.2	Mining and quarrying	16	2.79	24
12.0	Natural events, unspecified	15	3.50	22
5.4	Fishing and harvesting aquatic resources	14	2.35	20
2.1	Annual/perennial non-timber crops	14	2.80	20
13.0	Uncertain/not listed	14	2.95	20
12.5	Natural mortality	14	3.20	20
6.3	Work and other activities and multiple causes	13	4.47	19
9.1	Domestic and urban waste water	12	2.71	17
12.2	Demographic failure	12	3.29	17
8.2	Problematic native species	11	2.38	16
12.1	Stochasticity	11	3.06	16
4.3	Shipping lanes	10	2.33	15
2.0	Agriculture and aquaculture, unspecified	10	3.36	14
9.2	Industrial and military effluents	10	3.79	14

Table 5
Distance-based redundancy analysis results for tests of explanatory factors on the multivariate threat distribution.

| Factor	Number of groups	R^2	p-Value (based on 9999 permutations)
Individual tests			
Taxonomic group	6	0.20481	**0.0001**
Broad habitat	3	0.1586	**0.0001**
Critical habitat defined vs. not	2	0.00477	0.6142
Year RS finalized	6	0.00932	0.2578
Ambition score	Continuous	0.02235	**0.0084**
Sequential tests			
Taxonomic group	6	0.20481	**0.0001**
+Broad habitat	3	0.04607	**0.0001**
+Ambition score	Continuous	0.01815	**0.007**
+Year RS finalized	6	0.00984	0.1312
+Critical habitat defined vs. not	2	0.01936	**0.0041**
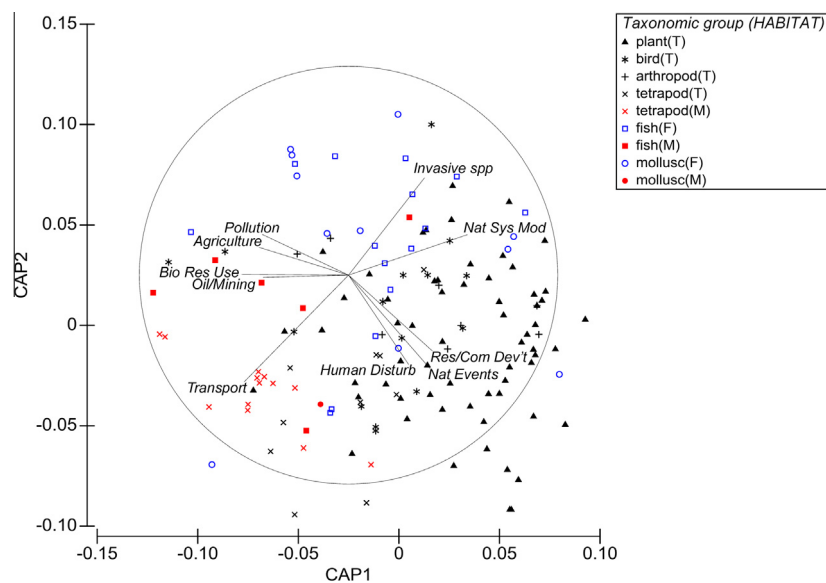
Fig. 2. Canonical Analysis of Principal Coordinates (CAP) ordination of species in multivariate threat space by taxonomic group and broad habitat type. Habitat types are terrestrial (T), freshwater (F) and marine (M). Each symbol represents one species; species closer together in the ordination have similar combinations of threat types. The vectors represent the strength (a longer vector means a stronger correlation) and direction of the correlation between the ordination axes and individual IUCN threat types. The circle is a unit circle (radius = 1.0).

Marine species, most of which (13 of 20) are marine tetrapods, were proportionally more often threatened by transportation, pollution, biological resource use and energy production/mining (Figs. 2 and 4), while terrestrial species were most likely to be threatened by natural events and residential/commercial development, and freshwater species by pollution, invasive species, and natural systems modification (Figs. 2 and 4). Marine and non-marine species were about equally likely to be threatened by agriculture (which includes aquaculture) and climate change (Fig. 4).

Although our analysis indicated a relationship between the ambition level of recovery goals and the threat distribution, the amount of variation explained was low, and subsequent Fisher's exact tests relating the presence or absence of individual threat types to a categorical representation of ambition level were not significant (results not shown).

3.3. Threats from recovery strategies versus COSEWIC reports

The order of importance of IUCN threat types was different in recovery strategies than it was in COSEWIC status reports (Fig. 5). In particular, human intrusions and disturbance was found to be the most common threat in finalized recovery strategies, but

was only the eighth most common in COSEWIC reports. Biological resource use was the most common threat in COSEWIC reports, but was the seventh most common threat listed in recovery strategies.

Using only the threats tallied from COSEWIC reports, species not listed under SARA were significantly more likely to be threatened by biological resource use than those listed under SARA (based on Fisher's exact test; Fig. 6a). SARA-listed species were significantly more likely to be threatened by residential and commercial development, agriculture, and transportation and service corridors. Among SARA-listed species, those with finalized recovery strategies were less likely to be threatened by agriculture and residential and commercial development (Fig. 6b). Biological resource use was also less frequent among species with finalized recovery strategies, but the association was not significant ($p = 0.16$).

4. Discussion

To our knowledge, our study is the first to analyze threats and associated patterns in recovery strategies produced under Canada's SARA. Analyses of recovery plans produced under the ESA of the United States have suggested that increased focus on addressing
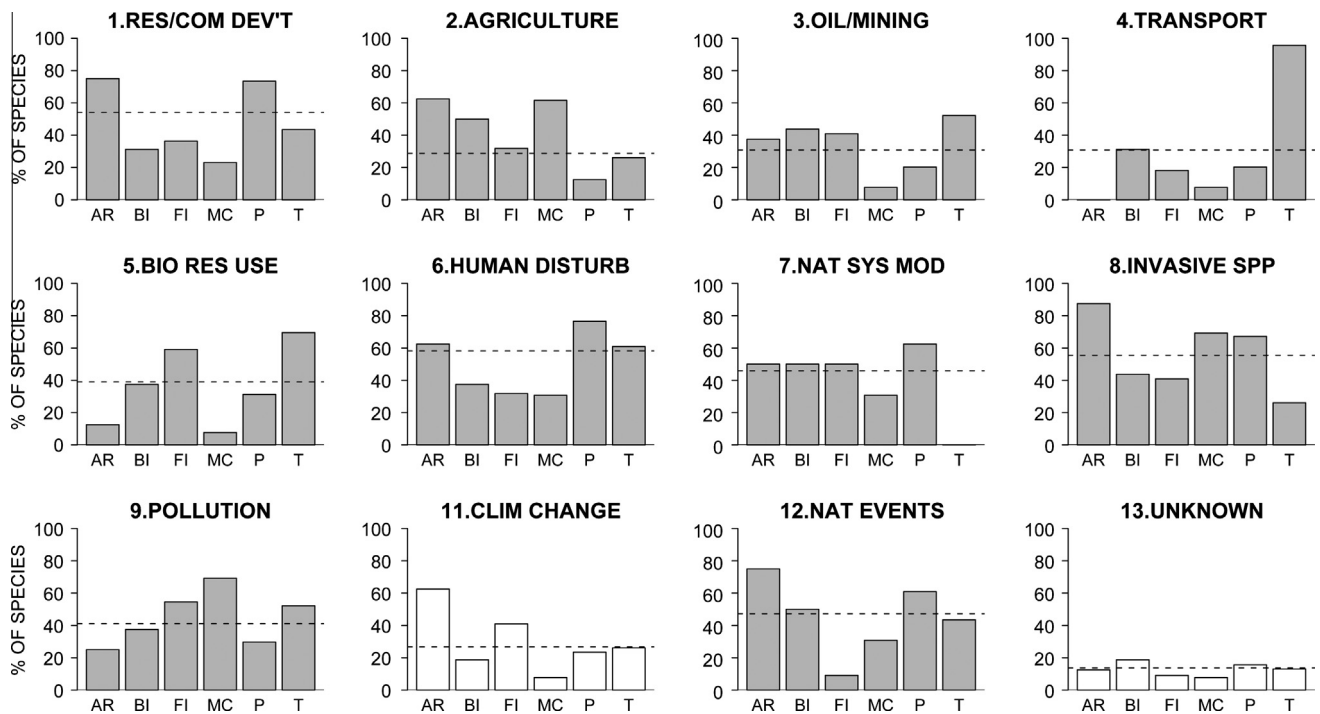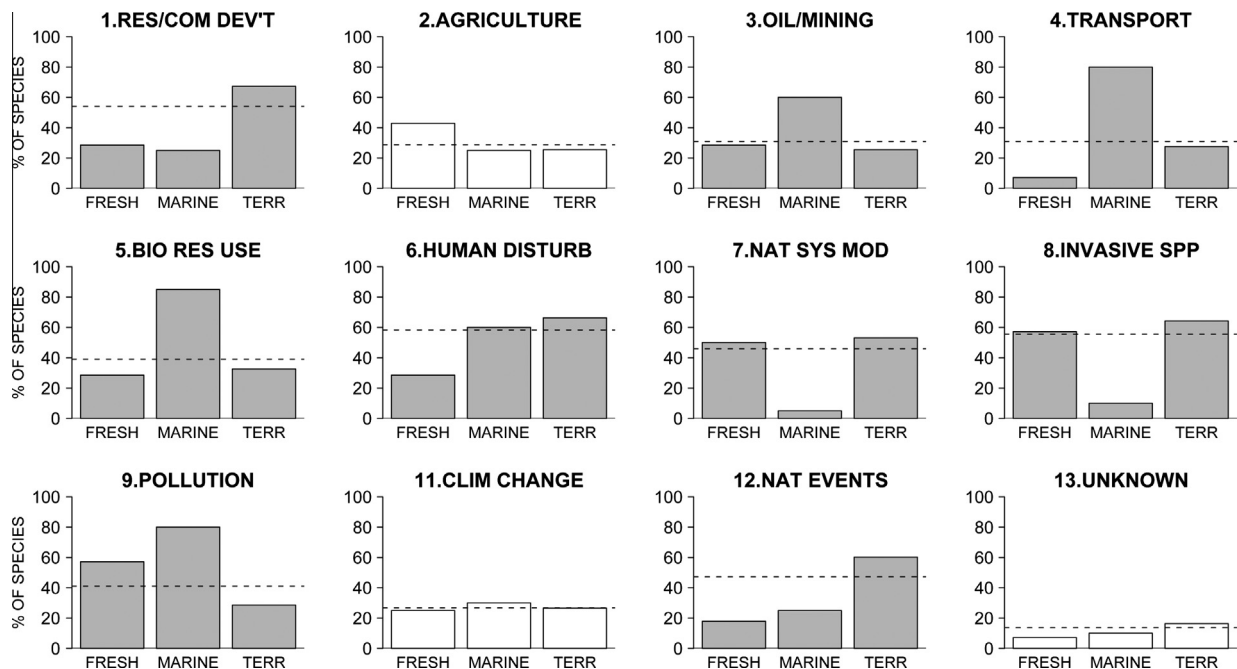
Fig. 3. The percentage of species in each taxonomic group threatened by each IUCN first-level threat type. Fisher's exact tests indicated that there is a significant association ($p < 0.05$) between taxonomic group and the presence/absence of all threat types except for climate change and unknown/uncertain threats (unshaded graphs). Dashed lines show the percentage of all species pooled. (AR = arthropods, BI = birds, FI = fish, MC = molluscs, P = plants (including lichens and mosses), and T = tetrapods (including mammals, amphibians and reptiles).

Fig. 4. The percentage of species in each broad habitat type threatened by each IUCN first-level threat type. Fisher's exact tests indicated that there is a significant association ($p < 0.05$) between broad habitat type and the presence/absence of all threat types except for agriculture and aquaculture, climate change, and unknown/uncertain threats (unshaded graphs). Dashed lines show the percentage of all species pooled (Freshwater = "FRESH", marine = "MARINE" and terrestrial = "TERR").

threats would enhance the success of recovery actions (Clark et al., 2002). In Canada, recovery strategies include only a general description of the broad strategy to address threats; the description of specific actions is reserved for the action plan (SARA, 2002). Our analysis is limited to the information available within

recovery strategies, and does not allow us to determine the root cause of any observed patterns in threats or the recovery process. Nonetheless, under SARA, action plans are meant to address the threats and meet the population and distribution objectives defined in recovery strategies. Thus, our analysis can provide
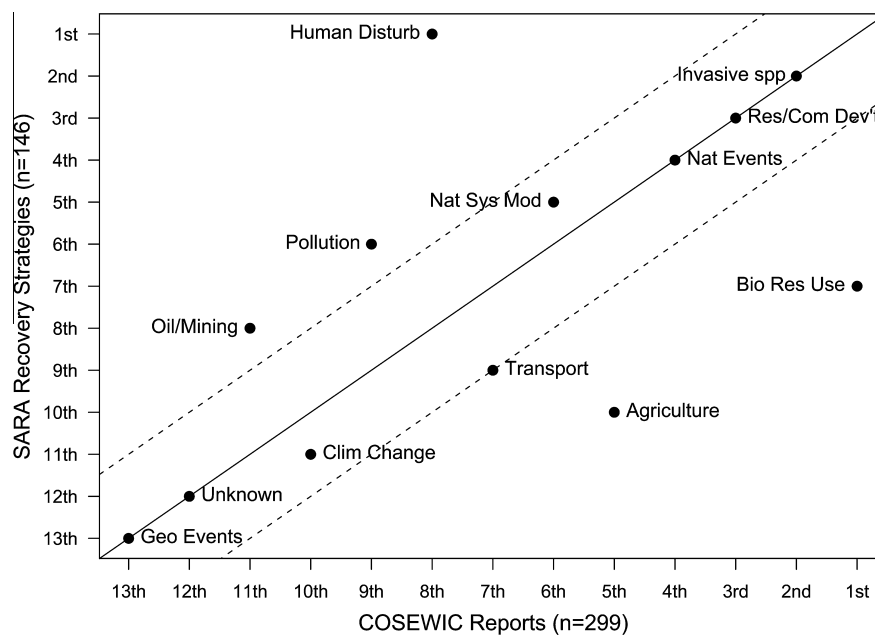
Fig. 5. Rank order of IUCN first-level threat types for 299 SARA-listed species as reported in COSEWIC reports (x-axis), versus rank order as reported in 146 finalized recovery strategies (y-axis). The solid line is the 1:1 line. Points beyond the dotted lines are threat types that differ by more than 2 ranks.
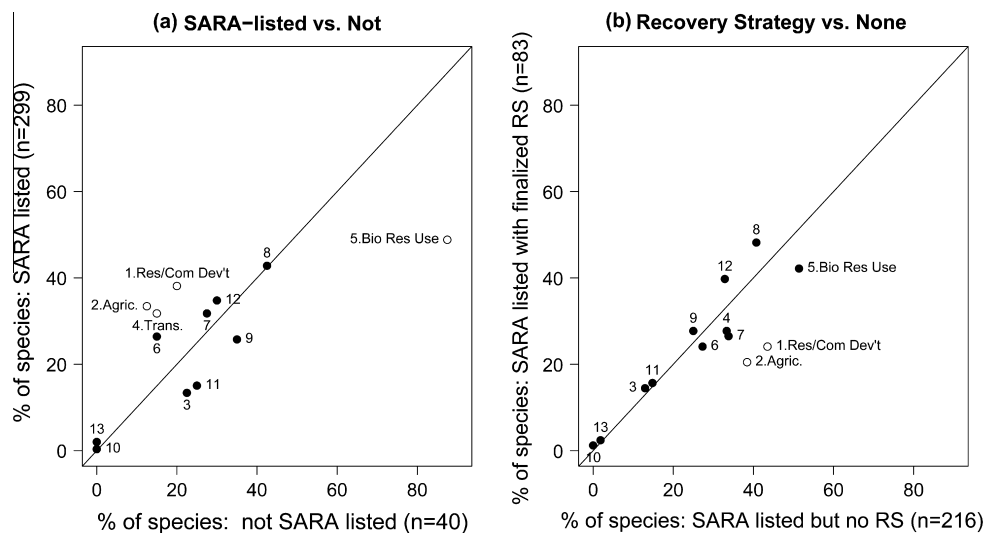

Fig. 6. Proportion of species with threats listed under each of the 13 IUCN first-level threat types according COSEWIC reports: (a) comparing SARA-listed species to species not listed by SARA, and (b) comparing listed species with a finalized recovery strategy to those without a finalized recovery strategy. Significant associations between individual threat types and being listed or not and having a finalized recovery strategy or not are indicated by open symbols (Fisher's exact test $p < 0.05$). Threat types not labeled by name are labeled by number, see Table 2. In both graphs the line is the 1:1 line.

important insights for improving recovery strategies and for developing action plans, therefore contributing to better outcomes of recovery efforts for Canada's species at risk.

4.1. The nature of threats listed in recovery strategies

Our findings point to habitat destruction and degradation via direct human disturbance as the dominant threat to imperilled species listed under Canada's Species at Risk Act. Human intrusions and disturbance, invasive species, and residential and commercial development are the most frequent threats listed in recovery strategies (Table 3 and Fig. 1). However, some less frequently listed threats are ranked higher or listed earlier. For example, biological

resource use is listed for only 57 out of our 146 species, but for 43 (75%) of those species, it is among the top three threats. On the other hand, climate change was in the top three threats of only ten species. We found that climate change was usually listed as a "potential" threat at the very end of the list of threats in a recovery strategy. Kappel (2005) also found climate change to be less important than many other threat types for marine, estuarine and diadromous species. Climate change is also a less common threat in recovery plans under the ESA in the USA, although its importance has increased in plans drafted since 2004 (Polvilitis and Suckling, 2010). Climate change is projected to lead to the extinction of up to 37% of terrestrial species by 2050 (Thomas et al., 2004), but it can be difficult to document the direct deleterious effects of

climate change on individual species. This along with the uncertainty associated with projecting these effects into the future are likely the reasons why climate change is almost always listed as a "potential" threat later in recovery strategies.

The presence and impact of invasive species was listed as a threat for 43% of species in our analysis. This contrasts with the results of Venter et al. (2006), who found that only 22% of Canada's species at risk were threatened by invasive species. While their analysis was based on COSEWIC status reports, we believe the discrepancy in our findings is not primarily attributable to different data sources. A more likely explanation for the difference is that Venter et al. excluded from their analysis threats described as "potential" whereas we included these. In support of this explanation, Prugh et al.'s (2010) analysis of threats in COSEWIC reports also finds that invasive species are listed as a threat for more than 40% of species.

Although we need more information on the potential threat of global processes like climate change, our analysis suggests that in the short-term, if our focus is on the most imminent threats to individual species, the priority should be to minimize the threats caused by localized human disturbance. Sixty-nine species in total (47%) had recreational activities (threat type 6.1) listed as a threat in their recovery strategy (Table 4). Forty-five of these are plants, many of which have few, small populations found along shorelines and other areas attractive for recreation. A typical example is the endangered contorted-pod evening primrose (*Camissonia contorta*), which is primarily threatened by the destruction of its sandy backshore habitat due to hiking, dog walking, sunbathing, picnicking, and ATV traffic (Parks Canada Agency, 2011). In Canada, biodiversity is highest in the south, which is also where most of our human population resides, and where the greatest losses and degradation of habitat have already occurred (Kerr and Cihlar, 2004). As the human population continues to increase, we can expect threats due to localized human impacts like recreation and residential and commercial development to increase. However, we must keep in mind that this conclusion is based on a subset of species that is (1) dominated by plants, and (2) the result of a process of listing and recovery with potential threat-related biases (discussed below).

4.2. Threats differ between taxonomic groups and broad habitat types

As many other studies have shown, we found differences in the dominant threats to imperilled species based on taxonomic group and broad habitat type (Figs. 2–4). The dominant threat to plant species is human intrusions and disturbance, followed closely by residential and commercial development and invasive species. Most of the plant species included in our sample (53 of 64 species) are described as range edge species, reaching their northern limits in southern Canada. As a result, many of these species occur in habitats that are both rare in Canada and highly influenced by human populations (Kerr and Cihlar, 2004; Coristine and Kerr, 2011). Venter et al. (2006) also found human disturbance via recreation to be the most common cause of habitat destruction for imperilled plants in Canada, and Burgman et al. (2007) found threats from localized human activities to be "emerging issues" in the preservation of endangered plants in Australia. Our analysis indicates that imperilled plants will benefit the most from the regulation of recreational activities in sensitive areas.

In contrast, 95% of the tetrapods (mammals, reptiles and amphibians) are threatened by transportation and service corridors, while the most common threat to arthropods is invasive species. Although our analysis includes just eight species of arthropods (all insects), we note that invasive species, along with development, were also identified as the most frequent threats to insects in an analysis of 57 insect species listed as threatened or

endangered in the United States (Wagner and Van Driesche, 2010). Biological resource use, pollution, and transportation each threaten over three quarters of the marine species in our dataset (see Fig. 4, also Fig. A.2 in Appendix A). Most of the twenty species of marine habitats with finalized recovery strategies are marine tetrapods (13 total, including 11 mammals and two turtles). Few marine fish species are listed under SARA, apparently because many of them are commercially harvested (Findlay et al., 2009; Hutchings and Festa-Bianchet, 2009; Mooers et al., 2007). Therefore, it is not surprising that none of the six marine fishes with finalized recovery strategies is subject to commercial exploitation.

4.3. Threat-based patterns and potential biases in the SARA process

Our analysis found no strong relationship between threats and whether or not critical habitat was identified. Although the designation of critical habitat was significantly related to the multivariate threat distribution after accounting for the other explanatory factors, the association was very low relative to the other factors (Table 5). This along with the lack of any significant univariate relationships with identification of critical habitat suggests no support for the idea that the presence of particular threats (e.g. economically important industries like oil development or agriculture) is influencing the identification of critical habitat. However, we emphasize that fewer than half of finalized recovery strategies include critical habitat designation, and that many species do not yet have a finalized recovery strategy.

Similarly, we found no evidence of threat-associated differences in the ambition of recovery goals. The relationship of ambition level to the multivariate threat distribution was negligible compared to taxonomic group and habitat type (Fig. 5), and univariate tests showed no significant association with particular threat types. Therefore, the average ambition of recovery goals, which ranged between maintaining the population at current levels and restoring the population to historical levels, was statistically indistinguishable regardless of which threats were listed. However, recovery goals on the whole were relatively modest, in most cases aiming for maintenance of the population or distribution at current levels, rather than increasing it beyond current levels. The reasons for this modest ambition level and low rate of designation of critical habitat need to be determined. If it is a result of political controversy associated with designating critical habitat and providing ambitious recovery goals for species that are economically important, this does not seem to link directly with any particular threat type.

The striking differences between threat frequencies and their rankings in finalized recovery strategies compared to COSEWIC status reports highlight potential biases based on threats (or correlates of threats) not only during the SARA listing process, but also in receiving a finalized recovery strategy. COSEWIC status reports contain a much higher proportion of species with identified threats from biological resource use and agriculture than reported in recovery strategies, in which human intrusions and disturbance was significantly higher ranked (Fig. 5). When we compare the frequency of threats to SARA-listed versus non-listed species, it is clear that non-listed species are much more likely to be threatened by biological resource use. A full 87.5% of the species that the government decided not to list under SARA are threatened by biological resource use, while only 49% of listed species are (Fig. 6a). The majority of these non-listed species are harvested marine fishes already known to be far less likely than other groups of species to receive SARA listing (Findlay et al., 2009; Hutchings and Festa-Bianchet 2009; Mooers et al., 2007). Examples include porbeagle shark (*Lamna nasus*), and populations of Atlantic cod (*Gadus morhua*), Sockeye (*Onchorhyncus nerka*), Chinook (*O. tshawytscha*), and Coho (*O. kisutch*) Salmon.

We also found differences in the frequencies of threat types for species listed under SARA with and without finalized recovery strategies. SARA-listed species threatened by agriculture and residential and commercial development are significantly *less* likely to have a finalized recovery strategy (Fig. 6b). Biological resource use was also less frequently a threat to species with recovery strategies, but not significantly so. We cannot be sure if this correlation occurs because there is more controversy associated with writing recovery strategies for species threatened by these industries due to socio-economic concerns, or if some other unmeasured variable correlated with these threats is leading to delays in recovery strategy production. Species threatened by activities that have less economic importance, or species that are found primarily in protected areas like national parks, may be less controversial. A cursory examination of the seven action plans completed to date reveals that these seven species occur primarily on federal or provincial public lands, and/or fall directly under federal responsibility (e.g. 3 of the 7 occur only in national parks or national wildlife areas). If species that occur primarily in protected areas are also more likely to have finalized recovery strategies, this could produce a negative association with threats from commercial development and agriculture, but we lack the data to examine this further in this study. A useful follow-up to our study would be to elucidate the cause of these observed correlations, whether due to socio-economic factors, knowledge deficiencies, or other factors. Ensuring the efficacy of SARA, or of any legislation that attempts to promote recovery of imperilled species, will require continued review and oversight to ensure that efforts are focused on the most effective actions for the recovery of species at risk.

5. Conclusions and recommendations

In addition to confronting the impacts of large industries like oil and mineral extraction, agriculture, and logging, our analysis of recovery strategies highlights the importance of mitigating local human disturbances, in particular those due to recreation and commercial and industrial development. Regional and local efforts to protect relatively small parcels of habitat will continue to be a vital part of maintaining and improving the status of Canada's imperilled species.

In order to improve recovery strategies produced under SARA, we recommend the use of a standardized threats classification. An understanding of common threats is desirable, and thus a common set of terms and guidelines for applying these would be beneficial. We join the growing numbers of analyses that make use of the IUCN Threats Classification, but we note that this system is not universally favoured (e.g. Balmford et al., 2009). In our view, a key criterion in selecting a threat classification for recovery strategies is to allow the identification of types of human activities that are contributing to declines, thus helping efforts to identify measures to abate or reverse the impacts of these threats. In addition, we encourage recovery strategy authors to explicitly rank threats, and to note the frequency and severity of each threat in as much detail as possible, for example, as described in Master et al. (2009). The increase over time in the number of recovery strategies that quantify the frequency and severity of threats is encouraging because this information will aid in prioritization of actions for species' recovery. These recommendations are also applicable to recovery planning in other jurisdictions.

Finally, our analysis provides an example of the role that academic scientists can play in summarizing the outcomes of conservation initiatives led by government, and providing guidance for future improvements to implementation. The goal of species at risk legislation is the effective protection and recovery of imperilled species. When potential biases in the recovery process are re-vealed, legislators can be challenged to reduce them, or at least to make the reasons clear and public. Just ten years into the implementation of Canada's *Species at Risk Act*, it may be too early to measure progress on the ground and in the water, but it is vital at this stage to invest in effective, well informed, and scientifically sound practices and policies that improve the outlook for recovery of species at risk.

Acknowledgements

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.07.006.

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