LETTER

Reducing threats to species: threat reversibility and links to industry

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Abstract

Threats to species' persistence are typically mitigated via lengthy and costly recovery planning processes that are implemented only after species are at risk of extinction. To reduce overall threats and minimize risks to species not yet imperiled, a proactive and broad-scale framework is needed. Using data on threats to imperiled species in Canada to illustrate our approach, we link threats to industries causing the harm, thus providing regulators with quantitative data that can be used directly in cost-benefit and risk analyses to broadly reduce threat levels. We then show how ranking the ease of threat abatement and reversal assists prioritization by identifying threats that are easiest to mitigate as well as threats that are possible to abate but nearly impossible to reverse. This new framework increases the usefulness of widely available threat data for preventative conservation and species recovery.

Introduction

Identifying and mitigating threats to endangered species is critical to the success of recovery efforts. In North America and several other regions, threats are addressed via recovery plans that are mandated by endangered species legislation such as the Endangered Species Act in the United States and the Species at Risk Act in Canada. Because of funding limitations and political constraints, it is not possible to mitigate all threats to species that require government-mandated recovery actions, let alone species that are threatened, yet not legally protected (Wilcove & Master 2005). Even with improved prioritization schemes to obtain the highest conservation return-on-investment (Goldstein *et al.* 2008; Briggs 2009; Joseph *et al.* 2009), the recovery planning process is a necessary but highly inefficient safety net. Recovery plans can be effective at reducing threats for individual species in particular locations, but they are not designed to reduce widespread threats from industries. Additionally, plans often take years to be developed and implemented, and these lengthy delays can result in continued species declines, leading to increased costs and decreased likelihood of successful recovery (Lundquist *et al.* 2002). Proactive, broad-scale measures to reduce threats across multiple species outside of the recovery planning framework are therefore needed to lower financial costs and halt species declines (Bloomgarden 1995; Scott *et al.* 2005).

As a first step, quantifying the number of imperiled species facing specific threats can reveal conservation actions and policies that will benefit the greatest number of imperiled species (and likely, the greatest number of species not yet imperiled) in a given region (Flather *et al.* 1998). Most analyses have indicated that habitat loss and

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Table 1 Previously published summaries of threats to imperiled species

Study	Geographic scope	Taxonomic scope	Major threat(s)
Baille *et al.* (2004)	Global	Birds, mammals, amphibians	Habitat destruction and fragmentation; invasive alien species; overutilization
Burgman *et al.* (2007)	Australia	Plants	Land clearing; grazing
Collar *et al.* (1994)	Global	Birds	Habitat loss; small range or population; overhunting
Czech & Krausman (1997), Czech *et al.* (2000)	USA	Plants, vertebrates, invertebrates	Interactions with nonnative species; urbanization; agriculture
Dextrase & Mandrak (2006)	Canada	Freshwater fish and molluscs	Habitat loss and degradation; introduced alien species; pollution
Flather *et al.* (1998)	USA	Plants, vertebrates, invertebrates	Agricultural development; residential/industrial development; introduction of exotic species
Hayward (2009)	Global	Mammals (carnivores, primates, ungulates)	Habitat loss and degradation; harvesting; persecution
Kappel (2005)	Global	Marine, estuarine, diadromous species	Overexploitation; habitat loss; pollution
Lawler *et al.* (2002)	USA	Plants, vertebrates, invertebrates	Resource use; exotic species; construction
Li & Wilcove (2005)	China	Vertebrates	Overexploitation
Richter *et al.* (1997)	USA	Aquatic vertebrates and invertebrates	Agricultural nonpoint pollution; alien species; altered hydrologic regimes
Schemske *et al.* (1994)	USA	Plants	Development; grazing; collecting
Venter *et al.* (2006)	Canada	Plants, vertebrates, invertebrates	Habitat loss; overexploitation; native species interactions
Wilcove *et al.* (1998)	USA	Plants, vertebrates, invertebrates	Habitat destruction and degradation; alien species
Williams *et al.* (1989)	North America	Fishes	Habitat destruction and degradation

degradation, invasive species, and overexploitation are the primary threats to imperiled species (Table 1) and drivers of extinction (Diamond 1989). These threat summaries have revealed interesting regional and taxonomic differences in threat syndromes (Li & Wilcove 2005; Venter *et al.* 2006), but several problems have limited the usefulness of threat data for preventative conservation and species recovery. First, the categories used in threat summaries have been highly variable and often preclude identification of the industry or specific activity that is ultimately responsible for the damage (e.g., "pollution," Table 1), rendering identification of those responsible for species declines as well as cost-benefit analyses of conservation actions difficult or impossible. Second, some threats are much easier to address than others, but the ease of threat abatement and/or reversibility is an important component of mitigation that is often overlooked (but see Marsh *et al.* 2007; Joseph *et al.* 2009).

In this article, we propose a broad-scale threat mitigation framework that supplements the recovery planning process. This framework has two components: (1) linking threats to specific industrial sectors to identify those entities responsible for the threats, and (2) ranking the ease of threat abatement and reversibility to facilitate prioritization. We highlight the distinction between threat abatement (halting the threat and preventing its further spread) and threat reversal (restoring damaged habitat for the reestablishment of extirpated populations). We use data on threats to species in Canada to illustrate our framework.

Among developed countries, Canada has an especially strong dependence on its natural resources. Natural resource products accounted for 65% of Canada's exports in 2008 (Statistics Canada 2008). Although only 6.4% of species in Canada are of global conservation concern (Cannings *et al.* 2005), most of Canada's species occur along its southern border, as does 90% of its growing human population (CIA 2007), where few protected areas exist (Kerr & Cihlar 2004; Warman *et al.* 2004). As climate change shifts species distributions northward (Parmesan & Yohe 2003; Hitch & Leberg 2007), Canada's role in preserving North American biodiversity may become increasingly important.

We link threats to industries by mapping the IUCN unified threats classification system (Salafsky *et al.* 2008) onto the North American Industry Classification System. Knowing which sectors are responsible for endangering which species is a crucial first step in determining where new regulations, incentives, and outreach efforts will be most beneficial. We then rank the political ease of threat abatement and reversal for a subset of threats to species in Canada. Although many factors affect threat abatement

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and reversal (e.g., economic, social, and ecological), we focus primarily on political ease because it is critical in determining the likelihood of mitigation. This combined framework increases the practical application of widely available threat data.

Methods

Threats to Canadian species were extracted from species status reports. The Committee on the Status of Endangered Wildlife in Canada assigned each designatable unit (species, subspecies, or population; Green 2005) to one of the following categories: extinct, extirpated, endangered, threatened, special concern (the five "at-risk" categories, $n = 529$), not-at-risk ($n = 157$), or data-deficient ($n = 41$). We were able to obtain reports for 339 at-risk designatable units (Table 2; hereafter "imperiled species") from the Species at Risk Act Public Registry (www.sararegistry.gc.ca).

Each report contains a section detailing threats to the species. We recorded the threats for each species using the IUCN classification system (Table 3, Salafsky *et al.* 2008). Although other systems have been proposed (Balmford *et al.* 2009), the IUCN system is the most widely used classification scheme. We added several subcategories to enable differentiation of some threats that the IUCN system grouped together (e.g., we separated pollution by agriculture and forestry). When more than one specific threat within a threat category was cited for a species (e.g., hunting [5.1] and bycatch [5.1.1]), the threat category or industry ("biological resource use" or "hunting/fishing") was counted only once. All data were entered by one researcher (ALJ) to maintain consistency of data interpretation from the reports.

We used the North American Industry Classification System (Office of Management and Budget 2007) to classify each IUCN threat category according to its associated industrial economic sector (Table 3). Threats that were not readily associated with particular sectors (e.g., invasive species) were excluded from analyses of threats from industries. We obtained economic data from Statistics Canada to estimate the economic contribution of industries that posed a "significant" threat to species in Canada (defined as threatening $\geq$10% of the species). The contributions of each industry to Canada's Gross Domestic Product (GDP) and employment (number of persons employed) were obtained for calendar year 2008. Jobs were classified slightly differently than GDP and did not match our threat classification as closely; we therefore used the contribution to GDP in 2008 as the measure of economic contribution. GDP and jobs were highly correlated ($r = 0.95$, $n = 6$ matching categories). GDP estimates were seasonally adjusted at annual rates in chained (2002) Canadian dollars (Statistics Canada 2009).

To illustrate the ranking of threats according to ease of abatement and reversibility, five imperiled species in each of the 10 taxonomic categories (Table 2) were randomly chosen ($n = 50$ species), and threats to those species ($n = 101$ threats) were rated by the four authors with Canadian species-at-risk expertise (all but DW). Each threat was rated on a scale of 1–5 in terms of the political ease of abating and reversing each threat, with "1" being nearly impossible and "5" being relatively easy (Table 4). This scale was established by consensus among the authors. Threats that involved direct exploitation rather than habitat destruction were ranked in terms of abatement only, because it is not possible to "reverse" the threat of exploitation; it can only be halted (abated). Life history traits were obtained from each species' status report to develop an index of biological recovery potential, calculated as fecundity (number of young per female per year) divided by generation time (years). Although several combinations of life history parameters could be used to create an index of biological recovery potential, our index accounts for key life history traits and is relatively simple.

We chose to rate political rather than economic ease because the political axis is more important in cases where industries contribute little economically but have powerful lobbies. Because conducting a detailed assessment of the political ease of abatement and reversibility for each threat was beyond the scope of this study, we present our rankings as an illustration of the concept rather than as a rigorous quantitative analysis. The authors were knowledgeable about Canadian species at risk, but it is impossible to avoid subjectivity in assessing the political climate surrounding particular issues. Despite the inherent subjectivity, our rankings are likely fair approximations of the relative ease of reversing threats, and we

Table 2 Status of imperiled Canadian species included in this study

Taxon	Extinct/ extirpated	Endangered	Threatened	Special concern	Total
Amphibians	0	3	1	5	9
Birds	2	21	8	13	44
Freshwater fish	4	20	12	12	48
Lepidopterans	0	11	4	1	16
Marine fish	0	7	6	4	17
Marine mammals	0	9	10	12	31
Mollusks	1	9	2	2	14
Plants	1	53	30	20	104
Reptiles	2	8	8	7	25
Terrestrial mammals	2	11	7	11	31
Total	12	152	88	87	339

Table 3 Threat categorizations, showing modified IUCN categories and corresponding industries. North American Industry Classification System (NAICS) codes corresponding to each specific threat are given

IUCN threat code	IUCN category	Specific threat	Industry classification	NAICS code
1.1	Residential/commercial development	Housing and Urban areas	Construction	2361
1.2		Commercial and Industrial areas	Construction	2362
1.3		Tourism and recreation areas	Recreation	7139
2.1	Agriculture and aquaculture	Annual and perennial nontimber crops	Agriculture	111
2.2		Wood and pulp plantations	Agriculture	1132
2.3		Livestock farming and ranching	Agriculture	1121
2.4		Marine and freshwater aquaculture	Agriculture	1125
3.1	Energy production and mining	Oil and gas drilling	Oil/gas/mining	211
3.2		Mining and Quarrying	Oil/gas/mining	212
3.3		Renewable energy[a]	–	–
4.1.1	Transportation and service corridors	Roads and railroads–mortality from collisions	Transportation	482, 484, 485
4.1.2		Road construction	Construction	2371
4.2		Utility and service lines	Utilities	221
4.3		Shipping lanes	Transportation	483
4.4		Flight paths	Transportation	481
5.1	Biological resource use	Hunting and collecting terrestrial animals	Hunting/fishing	1141
5.1.1		Incidental take (bycatch) of terrestrial animals	Hunting/fishing	1141
5.1.2		Persecution of terrestrial animals	–	–
5.2		Gathering terrestrial plants	Agriculture	1132
5.3		Logging and Wood harvesting	Forestry	113
5.4		Fishing and harvesting aquatic resources	Hunting/fishing	1142
5.4.1		Incidental take (bycatch) of aquatic resources	Hunting/fishing	1142
5.4.2		Persecution of aquatic resources	Hunting/fishing	1142
6.1	Human intrusions and disturbance	Recreational activities	Recreation	71219
6.2		War, civil unrest, and military exercises	National security	928
6.3		Work and other activities (research)	Conservation programs	92412
7.1	Natural systems modification	Fire suppression	Forestry	11531
7.1.1		Fire (controlled burns)	Conservation programs	92412
7.1.2		Fire (accidental wildfires)	Recreation	71219
7.2		Dams and water management/use (function unspecified)	Utilities	221111
7.2.1		Dams (hydroelectric)	Utilities	221111
7.2.2		Dams and water diversion for sawmills	Manufacturing	321
7.2.3		Dams and water diversion for agriculture	Agriculture	111
7.2.4		Dykes and water management for flood control	Water control	92411
7.3.1		Other ecosystem modifications–conservation action/inaction	Conservation programs	92412
7.3.2		Other ecosystem modifications–maintenance activities	Landscaping services	56173
8.1	Invasive/problematic species	Invasive nonnative/Alien species	–	–
8.1.1		Invasive nonnative/Alien diseases	–	–
8.2		Problematic native species	–	–
8.2.1		Problematic native diseases	–	–
8.3		Introduced genetic material	Agriculture	111
9.1	Pollution	Household sewage and urban waste water	Residential construction	2361
9.2		Industrial and military effluents	Manufacturing	31–33
9.3.1		Water-borne pollutants from agriculture and aquaculture	Agriculture	111
9.3.2		Water-borne pollutants from forestry	Forestry	113
9.4.1		Garbage and solid waste	Manufacturing	31–33
9.4.2		Fishing debris (discarded nets)	Hunting/fishing	1142
9.5		Air-Borne Pollutants	Manufacturing	31–33

Continued.

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Table 3 Continued

IUCN threat code	IUCN category	Specific threat	Industry classification	NAICS code
9.6		Excess energy	Manufacturing	31–33
10.1	Geological events	Volcanoes	–	–
10.2		Earthquakes/Tsunamis	–	–
10.3		Avalanches/landslides	–	–
11.1	Climate change and severe weather	Habitat shifting and alteration	–	–
11.2		Droughts	–	–
11.3		Temperature extremes	–	–
11.4		Storms and Flooding	–	–

[a]The IUCN category "renewable energy" does not currently have a corresponding NAICS classification. No threats in our analysis fell into this category.

use the average rank of each threat-species combination solely to point out broad patterns. Concordance among authors was moderate (Kendall's coefficient of concordance $W = 0.55$, $\chi^2_{180} = 392$, $P < 0.0001$).

Results

Industry accountability

Using IUCN classifications, "biological resource use" (hunting, fishing, and logging) was the most frequently cited threat to imperiled species in Canada, followed by invasive species and development (Figure 1A). Reclassifying threats according to responsible industrial sectors resulted in a substantially different ranking of threat importance. For example, agriculture was the fifth-highest ranking threat using the IUCN classification, whereas it was the primary threat using the North American Industry Classification System (Figure 1). The matrix summarizing the specific threats posed by each industry (Table S1) can inform risk assessment processes and the development of new regulations by providing regulatory agencies with quantitative data on species threatened by the industrial activities they oversee.

Agriculture, construction, and hunting/fishing were the industries that threatened the most species, each threatening 34–42% of imperiled species in Canada (Figure 1B). When separated, fishing threatened more species than hunting did (23% vs. 14%). We excluded the specific threat "persecution of terrestrial animals" (5.1.2), which is not directly tied to the hunting industry; including this category would raise the proportion of species threatened by hunting to 18%. These cases involved shooting and poisoning of snakes, rodents, and predators. "Persecution of aquatic resources" (5.4.2) was directly tied to the fishing industry; four species of marine mammals and sharks are threatened by illegal shooting due to interference with fishing operations.

The hunting/fishing industry (combined because it was not possible to obtain separate economic data) contributed the least to Canada's GDP and had by far the highest threat-to-contribution ratio, threatening 95 species per million Canadian dollars contributed to the economy (Table 5). Although agriculture and construction threatened similar numbers of species, agriculture's threat-to-contribution ratio was nearly four times higher due to its lower contribution to GDP.

Table 4 Ranking scale of the political ease of threat abatement and reversibility. Threats to imperiled species in Canada were ranked independently according to the political ease of abatement (halting and preventing further spread) and reversal (restoring damaged habitat for the reestablishment of extirpated populations), on a scale of 1–5

Ranking	Political ease of threat abatement/reversal
1	Nearly impossible Major public outcry likely and/or prohibitively expensive, no political support
2	Major barriers Large constituency opposed to action and few in favor, political support highly unlikely
3	Significant barriers Small but vocal/influential constituency opposed to action, political support unlikely
4	Mildly difficult Small constituency opposed to action but majority of public in favor, political support likely if supporters are vocal
5	Easy No vocal opposition to action, political support likely with mild pressure

Threat abatement and reversibility

Threats from construction, agriculture, and fishing were judged to be the most politically difficult ones to abate.

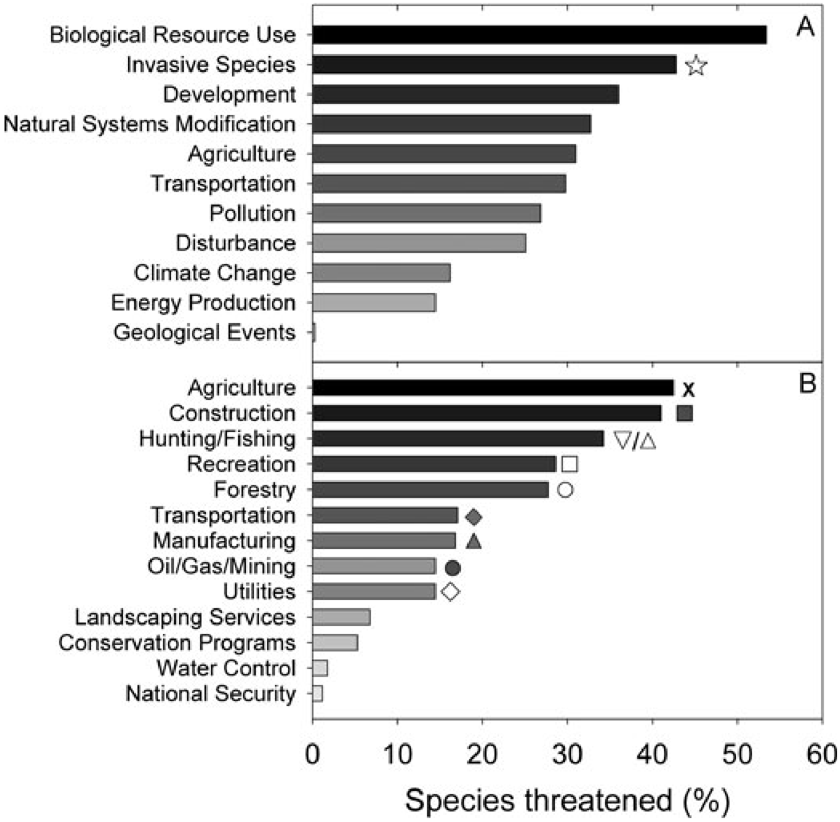

Figure 1 Threats to imperiled species in Canada according to (A) the IUCN classification system and (B) our reclassification assigning threats to specific industries (see Table 3 for cross-classifications). Symbols next to bars correspond to threats shown in Figure 2 (bars without symbols do not occur in Figure 2). Darker shading indicates higher threat frequency.

Moreover, the species threatened by construction tended to have relatively low biological recovery potential (Figure 2A; e.g., night snake *Hypsiglena torquata deserticola*, cerulean warbler *Dendroica cerulea*, mountain beaver *Aplodontia rufa*). Threats caused by invasive species were judged to be the politically easiest to abate (although inadequate scientific knowledge, technology, or resources make many invasive species difficult to control in practice; see "Discussion" section). Threats from fishing were judged to be politically difficult to abate but the affected species had high recovery potential; conversely, threats from hunting were judged to be politically easier to abate but the affected species had lower recovery potential (Figure 2A).

Table 5 Number of species threatened by industrial sectors in relation to their economic contribution in Canada. Threat-to-contribution ratio was measured as the number of species threatened divided by the contribution of the industry to Canada's GDP in 2008 (millions of Canadian dollars)

Industry	# Species threatened	GDP Contribution in 2008 ($million)	Threat-per-contribution ratio
Fishing/hunting	116	1,213	95.6
Recreation	97	3,827	25.3
Forestry	94	4,994	18.8
Agriculture	144	20,260	7.1
Construction	139	74,852	1.9
Utilities	49	31,139	1.6
Transportation	58	56,756	1.0
Oil/gas/mining	49	55,304	0.9
Manufacturing	57	175,636	0.3

The authors generally judged threats to be more difficult to reverse than to abate, especially construction (Figure 2B). In contrast, threats from mining/oil/gas were judged to be politically easier to reverse than to abate (Figure 2B). That is, restoring habitat that has been destroyed by these activities, a step that is generally mandated by law, was seen as politically easier than preventing these industries from exploring and developing new areas.

Discussion

We have developed a new framework that links threats to the responsible industries and evaluates the reversibility of those threats. This approach allows widely available threat data to be used in cost-benefit and risk analyses

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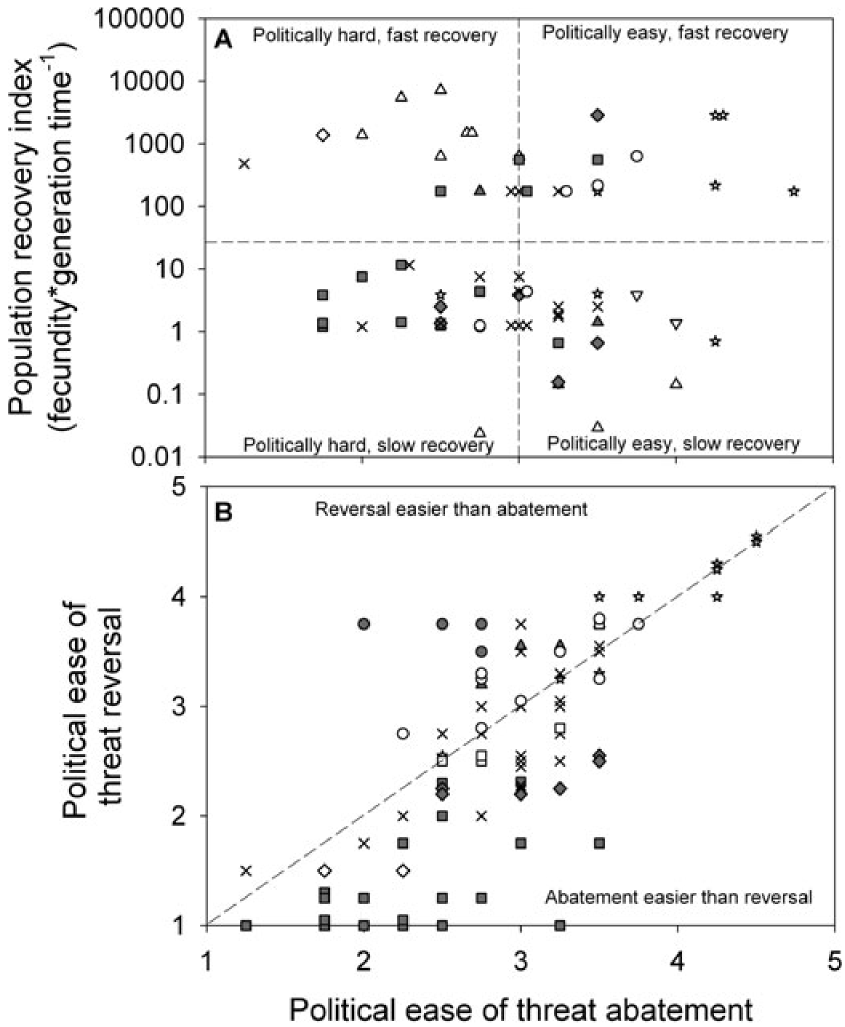

Figure 2 Political ease of threat abatement (halting and preventing further spread of the threat) versus (A) population recovery potential and (B) political ease of threat reversal (restoring populations to areas adversely affected by a threat) for a sample of threats to species in Canada ($n = 101$ threat-species combinations). Table 4 describes the reversibility/abatement scale. Fecundity (number of young per female per year) divided by generation time was used as an index of the recovery potential for each species. Symbols correspond to threat categories in Figure 1. Dashed lines divide panel (A) into quadrants and panel (B) into two triangles to facilitate interpretation.

by industry regulators and policy makers, thereby allowing threats to imperiled species to be explicitly considered by regulators for the first time. Although industries are currently held accountable for environmental harm that directly targets humans, such as mercury contamination, harm to biodiversity has been treated as an externality, with costs largely born by taxpayers to recover species after they become imperiled. Additionally, the method of allocating these taxpayer funds among imperiled species has not been science-based (Restani & Marzluff 2002). Our framework provides a science-based tool that regulators and planners can use to develop new regulations and allocate funding to mitigation efforts where they will be most effective for conservation.

The industries that threatened the greatest numbers of species were construction, agriculture, and hunting/fishing. Regulatory agencies that oversee the activities of these industries can use these data to explicitly include the risk to species posed by various activities and thereby develop sensible regulations to limit risks and fund recovery efforts. For example, incidental take (by-catch) by fisheries threatened nearly as many aquatic species as direct harvesting (Table S1). The Department of Fisheries and Oceans can use these data when developing new incentives, fines, or regulations to reduce the risks posed by the fishing industry. Similarly, regulators such as provincial land use ministries, federal transportation agencies, and agencies that regulate pollutants (e.g., the Pest Management Regulatory Agency) can use the data on threats to inform their risk management processes.

Consistent with Canada's economic dependence on and heavy subsidization of the natural resources sector (Schrank 2005; Gale & Gale 2006; Sumaila & Pauly 2006), biological resource use (hunting, fishing, and logging) was the most frequently cited threat to species in Canada. Although the combined hunting/fishing industry threatened fewer species than agriculture or construction, hunting and fishing threatened far more species relative to their economic contribution than any other industry. Threats from resource overexploitation are technically the easiest to mitigate, because no habitat restoration is required for recovery after abatement. Canada does not stand alone as a nation that would strongly benefit from policies aimed at reducing the threat of overexploitation: it has been identified as a threat to approximately one third of the world's imperiled species (Groombridge 1992) and is the top threat to imperiled vertebrates in China (Li & Wilcove 2005).

The primary impediment to abating threats from the fishing industry appears to be political rather than biological or economic; most fish populations have a high recovery potential, and the fishing industry employs few people and contributes relatively little to the economy (Figure 2, Table 5). In fact, some fisheries are a net drain on the economy when government subsidies are taken into account (Schwindt *et al.* 2000). Despite these facts, harvested fish and mammals at risk of extinction in Canada are routinely denied legal protection (Mooers *et al.* 2007), indicating a lack of political will to reduce threats from exploitation. In contrast, some of the first endangered species to be fully recovered in the United States were ones that had been threatened by exploitation, such as the American alligator, *Alligator mississippiensis* (Abbitt & Scott 2001). Thus, the political clout of certain industries is not solely a reflection of their economic importance, and this clout varies among regions and countries.

The biological and political reversibility of a threat can differ markedly. For example, controlling an invasive species such as scotch broom (*Cytisus scoparius*), which has been implicated in the extirpation of the Pacific northwestern gophersnake (*Pituophis catenifer catenifer*) in Canada (COSEWIC 2002), faces little political resistance but is difficult to accomplish. Other threats, such as overgrazing and fishing, are biologically easy to reverse or abate (remove cows, stop fishing) but strong resistance from political lobbies can impede mitigation efforts. Considering both biological and political axes (Figure 2A) allows one to identify species that are easy to protect politically and likely to recover quickly. For example, the badly timed controlled burns that threaten the Dakota skipper butterfly (*Hesperia dacotae*) and the trampling by picnic-goers that threatens the short-rayed alkali aster (*Symphyotrichum frondosum*) are threats identified as all-around easy to mitigate; once these threats are reduced, the affected species are likely to respond quickly. Similarly, our analysis identifies threats that will be difficult to address for both biological and political reasons, such as the housing construction that threatens the uncharismatic blue-grey taildropper slug (*Prophysaon coeruleum*) in Ontario and Quebec. Species such as these are among the most difficult cases facing conservationists.

In addition to identifying easy and difficult conservation cases, ranking the ease of threat abatement and reversibility highlights activities that are essentially irreversible and therefore pose a permanent threat to imperiled species. For example, our analysis suggests that mitigation of agricultural threats would face less political resistance than mitigation of threats from construction. This finding could be used to justify prioritization of policies that target harmful agricultural practices. However, unlike the case with agriculture, the damage from construction is nearly impossible to reverse. This permanence would argue for emphasizing policies aimed at protecting the remaining habitats of species threatened by construction. Our approach thus makes some of the difficult choices inherent to conservation more transparent.

Despite the importance of threat mitigation to species conservation, the recording of threats to species in Canada and elsewhere has proceeded without the benefit of standardized guidelines (Hayward 2009). Most importantly, it is hard to separate common but low-level threats from those that are more severe. The recent development of a standard threat data form by the IUCN should greatly improve the quality of data used in frameworks such as ours (Master *et al.* 2009).

In summary, we have laid out a protocol for categorizing threats from industries and for prioritizing these in terms of their reversibility. This protocol has advantages for conservation first by identifying industries with high threat footprints, secondly by facilitating the explicit consideration of threats to species by industry regulators and policy makers, and thirdly by providing rankings of the reversibility of threats to help prioritize mitigation efforts and funding allocations. The explicit linking of threats to industries and consideration of threat reversibility should substantially increase the efficacy of threat mitigation efforts.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Numbers of imperiled species threatened by specific activities of each industry in Canada ($n = 339$ imperiled species; each species could be threatened by multiple activities).

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References

Abbitt, R.J.F., Scott J.M. (2001) Examining differences between recovered and declining endangered species. *Conserv Biol* **15**, 1274–1284.

Baille, J., Hilton-Taylor C., Stuart S.N. (2004)) *2004 IUCN Red List of threatened species: A global assessment*, IUCN, Cambridge, UK.

Balmford, A., Carey P., Kapos V., *et al*. (2009) Capturing the many dimensions of threat: comment on Salafsky et al. *Conserv Biol* **23**, 482–487.

Bloomgarden, C.A. (1995) Protecting endangered species under future climate change: from single-species preservation to an anticipatory approach. *Environ Manag* **19**, 641–648.

Briggs, S.V. (2009) Priorities and paradigms: directions in threatened species recovery. *Conserv Lett* **2**, 101–108.

Burgman, M.A., Keith D., Hopper S.D., Widyatmoko D., Drill C. (2007) Threat syndromes and conservation of the Australian flora. *Biol Conserv* **134**, 73–82.

Cannings, S., Anions M., Rainer R., Stein B. (2005) *Our home and native land: Canadian species of global conservation concern*. NatureServe Canada, Ottawa.

CIA (2007) The world factbook. Central Intelligence Agency. Available at: www.cia.gov/cia/publications/factbook/index.html. Accessed 29 June 2007.

Collar, N.J., Crosby M.J., Stattersfield A.J. (1994) *Birds to watch 2: The world list of threatened birds*. BirdLife International, Cambridge, UK.

COSEWIC (2002) *COSEWIC assessment and status report on the Gophersnake Pituophis catenifer in Canada*. Committee on the Status of Endangered Wildlife in Canada, Ottawa.

Czech, B., Krausman P.R. (1997) Distribution and causation of species endangerment in the United States. *Science* **277**, 1116–1117.

Czech, B., Krausman P.R., Devers P.K. (2000) Economic associations among causes of species endangerment in the United States. *BioScience* **50**, 593–601.

Dextrase, A.J., Mandrak N.E. (2006) Impacts of alien invasive species on freshwater fauna at risk in Canada. *Biol Invasions* **8**, 13–24.

Diamond, J.M. (1989) Overview of recent extinctions. Pages 37–41 in D. Western & M.C. Pearl, editors. *Conservation for the twenty-first century*. Oxford University Press, Oxford, UK.

Flather, C.H., Knowles M.S., Kendall I.A. (1998) Threatened and endangered species geography. *BioScience* **48**, 365–376.

Gale, R., Gale F. (2006) Accounting for social impacts and costs in the forest industry, British Columbia. *Environ Impact Assess Rev* **26**, 139–155.

Goldstein, J.H., Pejchar L., Daily G.C. (2008) Using return-on-investment to guide restoration: a case study from Hawaii. *Conserv Lett* **1**, 236–243.

Green, D.M. (2005) Designatable units for status assessment of endangered species. *Conserv Biol* **19**, 1813–1820.

Groombridge, B. (1992) *Global biodiversity: status of the Earth's living resources*. Chapman and Hall, New York.

Hayward, M.W. (2009) The need to rationalize and prioritize threatening processes used to determine threat status in the IUCN Red List. *Conserv Biol* **23**, 1568–1576.

Hitch, A.T., Leberg P.L. (2007) Breeding distributions of North American bird species moving north as a result of climate change. *Conserv Biol* **21**, 534–539.

Joseph, L.N., Maloney R.F., Possingham H.P. (2009) Optimal allocation of resources among threatened species: a project prioritization protocol. *Conserv Biol* **23**, 328–338.

Kappel, C.V. (2005) Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species. *Front Ecol Environ* **3**, 275–282.

Kerr, J.T., Cihlar J. (2004) Patterns and causes of species endangerment in Canada. *Ecol Appl* **14**, 743–753.

Lawler, J.J., Campbell S.P., Guerry A.D., Kolozsvary M.B., O'Connor R.J., Seward L.C.N. (2002) The scope and treatment of threats in endangered species recovery plans. *Ecol Appl* **12**, 663–667.

Li, Y.M., Wilcove D.S. (2005) Threats to vertebrate species in China and the United States. *BioScience* **55**, 147–153.

Lundquist, C.J., Diehl J.M., Harvey E., Botsford L.W. (2002) Factors affecting implementation of recovery plans. *Ecol Appl* **12**, 713–718.

Marsh, H., Dennis A., Hines H., *et al*. (2007) Optimizing allocation of management resources for wildlife. *Conserv Biol* **21**, 387–399.

Master, L.L., Faber-Langendoen D., Bittman R., *et al*. (2009) *NatureServe conservation status assessments: Factors for assessing extinction risk*. NatureServe report (April 2009), Available at: natureserve.org/publications/ConsStatusAssess_StatusFactors.pdf. Accessed 27 August 2009.

Mooers, A.O., Prugh L.R., Festa-Bianchet M., Hutchings J.A. (2007) Biases in legal listing under Canadian endangered species legislation. *Conserv Biol* **21**, 572–575.

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Office of Management and Budget (2007) *North American Industry Classification System (NAICS)*. Office of Management and Budget, Economic Classification Policy Committee, Springfield, VA.

Parmesan, C., Yohe G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421**, 37–42.

Restani, M., Marzluff J.M. (2002) Funding extinction? Biological needs and political realities in the allocation of resources to endangered species recovery. *BioScience* **52**, 169–177.

Richter, B.D., Braun D.P., Mendelson M.A., Master L.L. (1997) Threats to imperiled freshwater fauna. *Conserv Biol* **11**, 1081–1093.

Salafsky, N., Salzer D., Stattersfield A.J., *et al*. (2008) A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. *Conserv Biol* **22**, 897–911.

Schemske, D.W., Husband B.C., Ruckelshaus M.H., Goodwillie C., Parker I.M., Bishop J.G. (1994) Evaluating approaches to the conservation of rare and endangered plants. *Ecology* **75**, 584–606.

Schrank, W.E. (2005) The Newfoundland fishery: ten years after the moratorium. *Marine Policy* **29**, 407–420.

Schwindt, R., Vining A., Globerman S. (2000) Net loss: A cost-benefit analysis of the Canadian Pacific salmon fishery. *J Policy Anal Manag* **19**, 23–45.

Scott, J.M., Goble D.D., Wiens J.A., Wilcove D.S., Bean M., Male T. (2005) Recovery of imperiled species under the Endangered Species Act: the need for a new approach. *Front Ecol Environ* **3**, 383–389.

Statistics Canada (2008) The role of natural resources in Canada's economy. *Canadian Economic Observer* **21**, Available at: www.statcan.gc.ca/pub/11-010-x/11-010-x2008011-eng.htm. Accessed 15 June 2009.

Statistics Canada (2009) Table 379-0027 – Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS). http://www40.statcan.gc.ca/l01/cst01/econ41-eng.htm. Accessed 30 June 2009.

Sumaila, U., Pauly D. (2006) *Catching more bait: A bottom-up re-estimation of global fisheries subsidies*. Fisheries Centre, University of British Columbia, Vancouver, Canada.

Venter, O., Brodeur N.N., Nemiroff L., Belland B., Dolinsek I.J., Grant J.W.A. (2006) Threats to endangered species in Canada. *BioScience* **56**, 903–910.

Warman, L.D., Forsyth D.M., Sinclair A.R.E., *et al*. (2004) Species distributions, surrogacy, and important conservation regions in Canada. *Ecol Lett* **7**, 374–379.

Wilcove, D.S., Master L.L. (2005) How many endangered species are there in the United States? *Front Ecol Environ* **3**, 414–420.

Wilcove, D.S., Rothstein D., Dubow J., Phillips A., Losos E. (1998) Quantifying threats to imperiled species in the United States. *BioScience* **48**, 607–615.

Williams, J.E., Johnson J.E., Hendrickson D.A., *et al*. (1989) Fishes of North America endangered, threatened, or of special concern: 1989. *Fisheries* **14**, 2–20.

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