

# **Guidance for the preparation of ESTR products – classifying threats to biodiversity**

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## PREFACE

The Canadian Councils of Resource Ministers developed a Biodiversity Outcomes Framework<sup>1</sup> in 2006 to focus conservation and restoration actions under the *Canadian Biodiversity Strategy*.<sup>2</sup> *Canadian Biodiversity: Ecosystem Status and Trends 2010*<sup>3</sup> was a first report under this framework. It assesses progress towards the framework's goal of "Healthy and Diverse Ecosystems" and the two desired conservation outcomes: i) productive, resilient, diverse ecosystems with the capacity to recover and adapt; and ii) damaged ecosystems restored.

The 22 recurring key findings that are presented in *Canadian Biodiversity: Ecosystem Status and Trends 2010* emerged from synthesis and analysis of technical reports prepared as part of this project. Over 500 experts participated in the writing and review of these foundation documents. This report, *Guidance for the preparation of ESTR products -- Classifying threats to biodiversity*, is one of three background papers prepared to assist the Ecosystem Status and Trends Report (ESTR) Steering Committee in developing a framework and providing guidance for the project. It is based on an analysis of literature and was compiled for the consideration of the ESTR Steering Committee.

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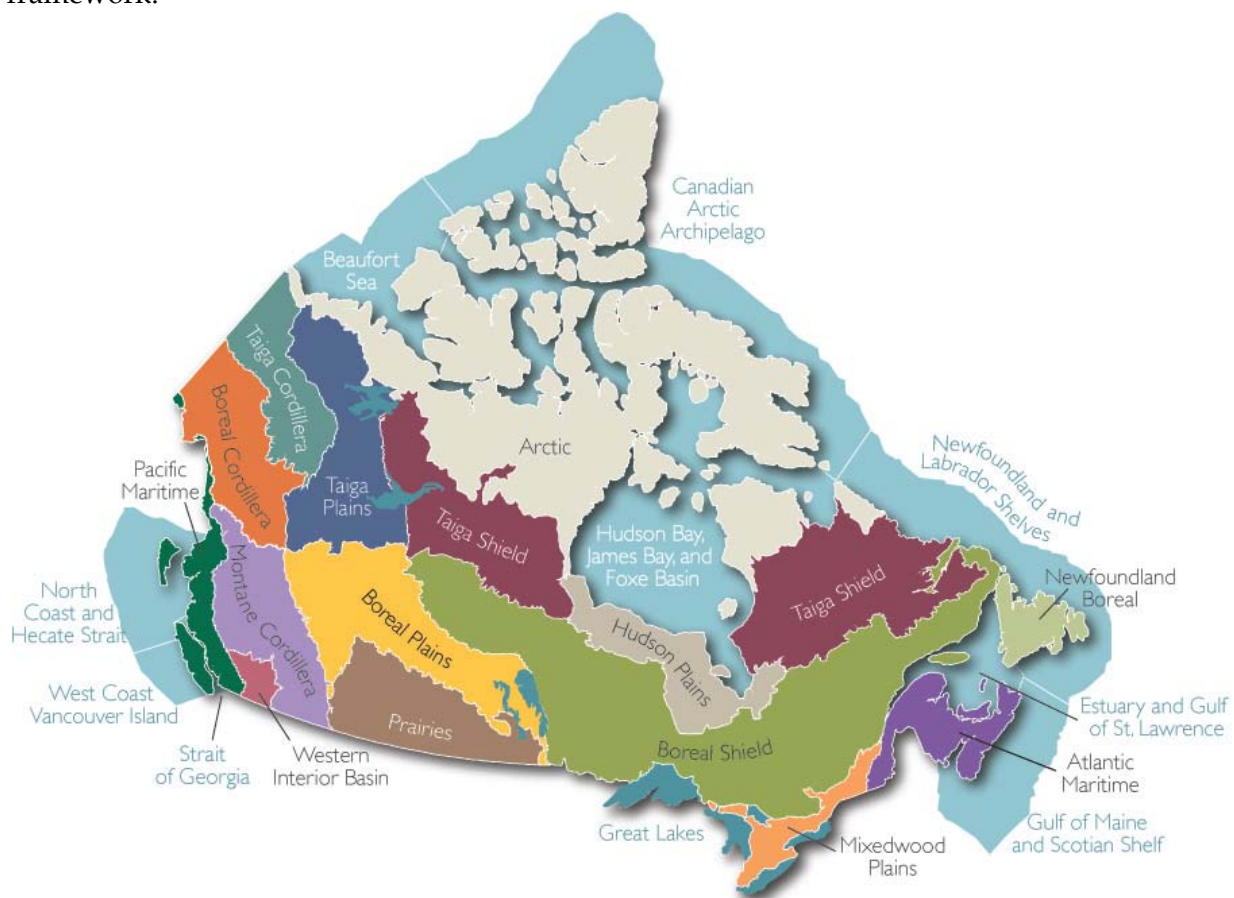
<sup>1</sup> Environment Canada. 2006. Biodiversity outcomes framework for Canada. Canadian Councils of Resource Ministers. Ottawa, ON. 8 p. <http://www.biodivcanada.ca/default.asp?lang=En&n=F14D37B9-1>

<sup>2</sup> Federal-Provincial-Territorial Biodiversity Working Group. 1995. Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity. Environment Canada, Biodiversity Convention Office. Ottawa, ON. 86 p. <http://www.biodivcanada.ca/default.asp?lang=En&n=560ED58E-1>

<sup>3</sup> Federal, Provincial and Territorial Governments of Canada. 2010. Canadian biodiversity: ecosystem status and trends 2010. Canadian Councils of Resource Ministers. Ottawa, ON. vi + 142 p. <http://www.biodivcanada.ca/default.asp?lang=En&n=83A35E06-1>

## Ecological Classification System – Ecozones<sup>+</sup>

A slightly modified version of the Terrestrial Ecozones of Canada, described in the *National Ecological Framework for Canada*,<sup>4</sup> provided the ecosystem-based units for all reports related to this project. Modifications from the original framework include: adjustments to terrestrial boundaries to reflect improvements from ground-truthing exercises; the combination of three Arctic ecozones into one; the use of two ecoprovinces – Western Interior Basin and Newfoundland Boreal; the addition of nine marine ecosystem-based units; and, the addition of the Great Lakes as a unit. This modified classification system is referred to as “ecozones” throughout these reports to avoid confusion with the more familiar “ecozones” of the original framework.<sup>5</sup>



<sup>4</sup> Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa/Hull, ON. 125 p. Report and national map at 1:7 500 000 scale.

<sup>5</sup> Rankin, R., Austin, M. and Rice, J. 2011. Ecological classification system for the ecosystem status and trends report. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 1. Canadian Councils of Resource Ministers. Ottawa, ON. <http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-1>

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# INTRODUCTION

During the preparation of Ecosystem Status and Trends (ESTR) ecozone+ reports it became clear that some guidance was required in naming and classifying threats to biodiversity in order to ensure consistency across reports. This paper provides that guidance by reviewing the relevant literature on the use of biodiversity or ecosystem threat classifications and presenting a classification to help identify threats, standardize nomenclature for similar issues in different ecozones+, and facilitate the comparison of information across ecozones+. As this guidance was provided part way through the preparation of ecozone+ reports, its use is not always evident.

## CLASSIFICATION OF THREATS

The concept of a threat is generally understood as a force with an actual or potential negative impact on biodiversity. However, synonymous terms exist for similar concepts and varying definitions exist for the same terminology (see Appendix 1). A paper by Salafsky et al.(2008) identified characteristics of a good threats classification scheme. These are described in Table 1 and are used later in this paper to compare potential classifications.

*Table 1. Description of characteristics of a good threats classification system.*

<b>Criterion</b>	<b>Definition</b>
Simple	Uses clear language and examples
Hierarchical	Creates a logical way of grouping threats that are related to one another to facilitate use of the classification and meaningful analyses at different levels, particularly the ecosystem level
Comprehensive	Contains all threats at least at higher levels of the hierarchy
Expandable	Enables new threats to be added to the classification if discovered
Exclusive	Allows a given threat to be placed in only one category within its hierarchy
Scalable	Permits the same terms to be used at all geographic scales

*Source: Salafsky et al., (2008)*

## Review of Existing Threats Classifications

### ***Primary literature***

Venter et al. (2006) quantified threats facing 488 terrestrial and aquatic species in Canada categorised by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as extinct, extirpated, endangered, threatened, or of special concern. They identified six broadscale threats, in order of prevalence, as: habitat loss; overexploitation; native species interactions; natural causes; pollution; and introduced species. Habitat loss was overwhelmingly the lead threat, contributing to the endangerment of 84% of all species. Each of the six threats was

further delineated (Appendix 2) to support finer analysis of how these threats contribute to biodiversity loss.

It is well recognized that threats interact synergistically, therefore semantic distinction of threats is nontrivial. While extensive, threat categories presented by Venter et al. (2006) are not exclusive with threats appearing in multiple categories. For example, pollution due to agricultural and urbanization activities were captured under the category of habitat loss in addition to under pollution. Numerous studies (Kerr and Cihlar, 2004; Kerr and Deguise, 2004) support the link between the conversion of habitat to agricultural and urban use as a threat to biodiversity and further recognize the increase in pollution threats associated with these conversions. The nature of the land use change has been found to be more strongly associated with species endangerment than the area of conversion (Kerr and Deguise, 2004; Brown and Laband, 2006).

A classification and quantification of threats was conducted by Wilcove et al. (1998) on 1,880 species listed as endangered or threatened under the U.S. *Endangered Species Act*. Five broadscale threats were examined: habitat degradation or loss; alien species; pollution; overexploitation; and disease. Despite minor differences in the broadscale threats assessed, Wilcove et al. (1998) also determined that the leading threat to species was habitat loss, contributing to the endangerment of 85% of all species. Finer scale analysis using 13 subcategories of habitat loss found agricultural activities and land conversion for commercial development to be the most significant causes of habitat change leading to species endangerment. Similar to Venter et al. (2006), the classification system by Wilcove et al. (1998) is extensive, however broad and fine scale categories are not exclusive, nor explicit enough to support consistent use of nomenclature.

Foin et al. (1998) examined recovery plans for 311 species listed under the U.S. *Endangered Species Act* and defined nine threat categories for quantification: habitat reduction; habitat modification; introduction of exotic species; population reduction by human harvest; specialized habitats; succession and disturbance; hybridization; biotic interaction; and coevolution. As expected, habitat reduction and modification were the leading threats referenced in recovery plans. This threat classification is not detailed enough to determine exclusivity, however summation of the percentage of recovery plans addressing each threat revealed no overlap among categories.

Lawler et al. (2002) also reviewed recovery plans for 181 species listed under the U.S. *Endangered Species Act*. Fifty-nine specific threats were identified and aggregated to nine categories: resource use; exotic species; construction; altered habitat dynamics; agriculture; native species interactions; pollution; water diversions; and other factors. The most prevalent threats were those associated with resource use, exotic species, construction, and changes in habitat dynamics, each of which accounted for 70 to 80% of all species examined. Not surprisingly, most species faced threats in multiple categories. While specific threats were extensive in scope and arranged hierarchically, the classification was similar to others in its lack of exclusivity.

Dextrase and Mandrak (2006) examined the specific impacts of alien invasive species on freshwater fauna based on information presented in COSEWIC status reports. In North America, extinction rates for freshwater fauna are five times higher than those for terrestrial groups (Ricciardi and Rasmussen, 1999). The introduction of alien invasive species was second to habitat loss as primary threats to imperilled fish. Most species introductions were deliberate efforts related to sport fishing, including the stocking of sport fish and stocking of forage fish as food for sport fish. Other pathways of introduction that have resulted in significant threats to native species included ballast water discharge, canals, movement of recreational boats, aquaculture and horticulture escapes, and aquarium fish releases. Habitat alteration such as flow modification, urbanization, and conversion to agricultural land served to support introduced species to the further detriment of native species (Light and Marchetti, 2007).

Smith et al. (2006) reviewed the role of disease in species extinction and endangerment and found that mostly anecdotal rather than experimental data support the view that disease is a primary threat to biodiversity. Examination of International Union for the Conservation of Nature (IUCN) Red List reports for extinct species found that in no case was infectious disease listed as the sole cause of extinction. Frequently, disease was identified as a threat in association with the introduction of alien species (Smith et al., 2006). For example, infectious disease can drive populations temporarily or permanently to low numbers or densities, predisposing them to extinction by other forces such as increased predation by alien species (Venter et al., 2006; Smith et al., 2006).

Chu et al. (2003) used census data from Statistics Canada to compare regional stresses on freshwater fish biodiversity in Canada. Stress indicators were indexed with species biodiversity and physical environmental data to establish conservation priority rankings among watersheds. The majority of stresses examined in this study were aspects of habitat conversion. A more recent paper by Chu et al. (2008) examined the synergistic influence of temperature, groundwater discharge, and climate change in freshwater biodiversity in southern Ontario watersheds.

Yiming and Wilcove (2005) compared threats to vertebrate species in China and the United States. Differences were observed in the relative significance of threats contributing to biodiversity loss, however the leading threats can be grouped into the same primary categories of overexploitation, habitat destruction, pollution, introduced species, and disease. Each category was delineated to a finer scale, however definitions of categories are not provided and categories are not exclusive. For example, food shortage appears as a subcategory under habitat destruction and food, raw materials, and incidental harvest each appear under overexploitation with no explanation of distinctions.

Flather et al. (1998) identified 63 threats to over 600 threatened and endangered species in the United States using published documents, such as, federal register listings, U.S. Fish and Wildlife Service technical bulletins, species recovery plans, environmental impact statements, and federal and state agency reports. Richter et al. (1997) similarly identified stressors and sources of stressors affecting such species through expert surveys. Neither Flather et al. (1998) nor Richter et al. (1997) classified these stressors systematically according to key drivers or threats.



## ***Applications of literature***

The IUCN has created standard classifications of direct threats, specifically to ensure a common nomenclature is used by conservationists to describe issues and facilitate cross-project learning as well as generalization of information across projects (Salafsky et al., 2008; IUCN, 2011) (see Appendix 3). The system is intuitive, comprehensive, and facilitates consistency with its definitions. The classification is unique in that it seeks exclusivity among categories. The system is also hierarchical with fine scale threats aggregating to the following broad categories of threats: residential and commercial development; agriculture; energy production and mining; transportation and service corridors; biological resource use; human intrusions and disturbance; natural system modifications; invasive and other problematic species and genes; pollution; geological events; and climate change and severe weather.

The reports of the Millennium Ecosystem Assessment (2005) supported information needs of the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species. Its objective was to report on global consequences of ecosystem changes to human well-being and identify management options for improving human well-being while conserving ecosystems. Thus direct and indirect drivers of change that were examined had an anthropocentric focus. While a hierarchical classification of drivers was not defined, anthropogenic direct drivers of changes to global diversity were discussed in the reports, including habitat change, invasive species and introduced pathogens, nutrient loading and pollution, overexploitation, and accelerated climate change. It was further recognized that interacting synergistically with these direct drivers are pervasive indirect global drivers that are demographic, economic, sociopolitical, scientific and technological, cultural or religious, and physical, biological, or chemical in nature.

*Global Biodiversity Outlook 2* was produced by the Secretariat of the Convention on Biological Diversity (2006) to report, through the use of indicators, global progress toward the 2010 Biodiversity Target of significant reductions to biodiversity loss. *Global Environmental Outlook 4* was a report produced by the United Nations Environment Programme (2007) to describe the current state of the global environment for human development and trends since 1987, and identify priorities for action. Similar to the reports of the Millennium Ecosystem Assessment (2005), whose results were integrated within the two global assessments, five key threats were identified but not systematically classified.

Natural Resources Canada (2004) mapped threats such as roads, industrial discharges, and sewage throughout Canada. Data on these threats were classified according to the density of road types (for example, highways, primary roads, all roads) in each ecozone, density of industrial discharges within 194 terrestrial ecoregions, and the percentage of the population served by primary, secondary, tertiary, or no sewage treatment.

The National Water Research Institute of Environment Canada recognizes 15 water related threats to aquatic ecosystem health and drinking water in Canada (Environment Canada, 2001). Status and trends, knowledge, and program needs to manage these threats were identified by

scientists and managers through workshops in 2001. While some threats were addressed as groupings of similar contaminants, for example pesticides, others were addressed as sources of a mixture of contaminants. Therefore threat categories are not exclusive of one another nor arranged hierarchically. The 15 threat categories are as follows: waterborne pathogens; algal toxins; taste and odour; pesticides; persistent organic pollutants and mercury; endocrine disrupting substances; nutrients – nitrogen and phosphorus; aquatic acidification; ecosystem effects of genetically modified organisms; municipal wastewater effluents; industrial point source discharges; urban runoff; landfills and waste disposal; agricultural and forestry land use impacts; natural sources of trace element contaminants; impacts of dams and diversions; and climate change.

The British Columbia Ministry of Environment produces a report on environmental trends every five years and an interim report on trends on a specific topic every two and a half years. The most recent publication (BC Ministry of Environment, 2007) reported on 44 indicators and over 25 supplementary measures grouped into seven topic areas, including species conservation. The topics and indicators are presented in Appendix 5. The threat classification published by Venter et al. (2006) was used to identify the primary threats to 179 species at risk in British Columbia. Overall, habitat loss to urbanization was found to be the greatest threat, followed by introduction of alien species. Differences among types of species did arise with marine mammals and marine fishes being affected by over exploitation and pollution more so than other species.

Alberta Environment commissioned a review of issues threatening aquatic ecosystems health throughout the province as well as monitoring programs and indicators tracking stressors associated with these issues (Stantec Consulting Ltd., 2005). Indicators were grouped with threats which are synonymous with stressors and specific concerns, however these are not exclusive and many indicators appear in a number of categories. The classification used is presented in Appendix 6. Key categories of stressors are: contaminant loading; landscape changes or habitat alterations; water use and water allocation; air emissions and acidification; recreational use; exotic species; transportation infrastructure; natural disturbances; and climate change.

The *State of Great Lakes 2007* (Environment Canada and US Environmental Protection Agency, 2007) is seventh in a series of reports by Environment Canada and U.S. Environmental Protection Agency to meet requirements of the Great Lakes Water Quality Agreement for regular reporting on binational goals and objectives specified in the Agreement. Ecosystem health is presented through indicators grouped into categories, some of which reflect threats, and others which reflect biophysical aspects of the Great Lakes (Appendix 4). While hierarchical and scalable, the groupings are not exclusive with various indicators (not threats) appearing in a number of categories: contamination; human health; biotic communities; invasive species; coastal zones and aquatic habitats; resource utilization; land use-land cover; and climate change.

## Comparing classifications

Table 2 compares the threats classifications reviewed in this paper against the criteria described in Table 1 on page 1. Among the threats classifications reviewed, only the IUCN (Salafsky et al., 2008; IUCN, 2011) classification was derived with the intention of standardizing nomenclature for threats, and facilitating comparisons and generalization of scalable data across ecosystems. As such, the IUCN threats classification meets most of the objectives for presenting information in the ESTR reports. The IUCN classification is simple in its use of clear language and illustrative examples, and facilitated consistent use of nomenclature by providing definitions. The classification is hierarchical in its grouping of related threats, expandable to accommodate new threats, and scalable to various geographic scales. Among classifications reviewed, only the IUCN's classification was designed to be exclusive, allowing a given threat to be placed in only one category within its hierarchy.

Table 2. Comparison of threats classifications.

Literature and initiatives with references to threats classifications (shading indicates studies focused on issues and species in Canada)	Simple	Hierarchical	Comprehensive	Expandable	Exclusive	Scalable
Venter <i>et al.</i> (2006)	√	√	*	√		√
Wilcove <i>et al.</i> (1998)	√	√	*	√		√
Foin <i>et al.</i> (1998)	√			√		√
Lawler <i>et al.</i> (2002)	**	√	*	√		√
Dextrase and Mandrak (2006)	√	√		√		√
Chu <i>et al.</i> (2003; 2008)	**			√		√
Yiming and Wilcove (2005)	**	√	*	√		√
Flather <i>et al.</i> (1998)	**			√		√
Richter <i>et al.</i> (1997)	**	√		√		√
IUCN (Salafsky et al., 2008; IUCN, 2011)	√	√	*	√	√	√
Millennium Ecosystem Assessment (2005)	√			√		√
Global Biodiversity Outlook 2 (Secretariat of the Convention on Biological Diversity, 2006)	√			√		√
Global Environmental Outlook 4 (United Nations Environmental Program, 2007)	√			√		√
Atlas of Canada – Map of Ecosystem Threats (Natural Resources Canada, 2004)				√		
National Water Research Institute (Environment Canada, 2001)	√			√		√
BC Ministry of Environment (BC Ministry of Environment, 2007)	√	√	*	√		√
Alberta Environment (Stantec Consulting Ltd., 2005)	√		*	√		
State of Great Lakes 2007 (Environment Canada and US Environmental Protection Agency, 2007)	√		*	√		

\*Extensive but not comprehensive. Some threats that may be important for a Canadian biodiversity report such as ESTR are not listed.

\*\*Clear language is used but no definitions or examples are provided.

The IUCN classification was derived to characterize common threats to biodiversity issues around the world. When compared to classifications and supporting studies derived specifically from data on Canadian species listed through COSEWIC (Chu et al., 2003; Kerr and Cihlar, 2004; Kerr and Deguise, 2004; Venter et al., 2006; Dextrase and Mandrak, 2006; Chu et al., 2008) the breadth of the IUCN classification was found to be more extensive than most Canadian classifications, particularly in relation to fine scale categories and definitions of habitat loss.

Differences were observed among classifications with respect to the approach to characterizing a threat. The IUCN classification characterizes threats from alien species according to the types of species introduced and further includes introduced genetic material (for example, pesticide resistant crops and genetically modified organisms) in the threat category of invasive and other problematic species and genes. In contrast, Dextrase and Mandrak (2006) distinguished threats among routes of introduction (for example, deliberate stocking of sport or forage fish, aquaculture escapes, ballast water discharge).

Native species interactions including competition, predation, symbiosis, and disease are grouped together as a category of threat by Venter et al. (2006). Richter (1997) further includes complications due to small population size (such as inbreeding or stochastic fluctuation) and genetic alteration (such as hybridization) among biotic interactions threatening species. Foin et al. (1998) define obligate coevolutionary relationships where species are dependent on one another as threats on species other than listed species. While disease is quantified as a threat to biodiversity in Wilcove et al. (1998), no definition is provided for this category of threat. Smith et al. (2006) documented concerns that mostly anecdotal rather than experimental data support the view of disease as a primary threat to biodiversity and that while infectious disease can drive populations to low densities, this predisposes rather than drives species to extinction. The IUCN classification places these native species interactions under the category of problematic native species, recognizing that “problems” occur when native species interactions become out of balance through direct or indirect human activities.

The threat of overexploitation includes intentional (for example, harvesting and persecution) and unintentional (for example, bycatch and road kill) human activities in the classification by Venter et al. (2006). While the IUCN classification neglects threats from unintentional activities, it distinguishes among harvesting activities under the category of biological resource use. Consumptive use of terrestrial animals, terrestrial plants, logging and wood harvesting activity, and fishing are distinguished in the IUCN classification.

The IUCN classification distinguishes among pollution threats according to primary activities (such as agricultural and forestry) generating pollutants and media (such as effluent) through which mixtures of pollutants are introduced to ecosystems. Venter et al. (2006) similarly distinguishes among pollutant generating activities -- agriculture, urbanization, extraction, infrastructure, and human disturbance. However no distinctions are made among media in which pollutants are found. In contrast, the National Water Research Institute (Environment Canada, 2001) and Stantec Consulting Ltd. (2005) grouped pollution threats according to the nature of pollutants (such as nutrients, organic pollutants, metals, pesticides). The *State of Great Lakes 2007* report (Environment Canada and US Environmental Protection Agency, 2007) presented pollution threats in relation to both sources (for example wastewater effluent) and

sinks (for example air, water, sediment, water, and biota), types of habitat (for example open lake, groundwater) and effects on human health (for example biomarkers of exposure and beach advisories). The B.C. Ministry of Environment (2007) coarsely grouped all pollution threats on biodiversity without any attempt to distinguish among chemical, physical (for example turbidity and sedimentation), thermal, or acoustic types of pollutants that define the category.

The IUCN classification makes the most explicit distinctions among abiotic threats to biodiversity, with separate categories for geological events (such as volcanic events, earthquakes and associated events such as tsunamis, and avalanches or landslides) and climate change and severe weather (for example, habitat shifting due to tundra thawing and sea level rise, droughts, temperature extremes, and storms and flooding). Numerous reports (Millennium Ecosystem Assessment, 2005; Secretariat of the Convention on Biological Diversity, 2006; United Nations Environmental Program, 2007) recognized accelerated climate change impacts as threats to biodiversity without definition of the range of impacts associated with the threats. Natural disasters, intrinsic factors, and natural causes are aggregated in the threat category of native species interactions by Venter et al. (2006) however abiotic interactions relating to these subcategories are not recognized or defined.

## **CLASSIFICATION OF THREATS FOR ESTR**

Recognizing the purpose of ESTR is to meet the interests of the Canadian Council of Resource Ministers and deliver, in part, on Canada's obligations under the *UN Convention on Biological Diversity*, the following threats classification is based on the analysis of COSEWIC listings by Venter et al. (2006) and expanded by the most recent IUCN classification of threats. Threats classifications and supporting studies that further detail or exemplify threats were also incorporated.

Forming the structure of the threats classification to be used as guidance for ESTR are five broadscale anthropogenic threats and a single category of natural threats:

### **Ecosystem change (ecosystem loss and ecosystem alteration)**

- threats from human activities that result in the reduction, conversion, fragmentation, alteration, or other modification of habitat and/or ecosystems which may lead to a loss ecosystem integrity or function

### **Pollution**

- threats from chemicals and mixtures of chemicals, nutrients and/or sediment loadings, thermal, acoustic or light pollution, or any other form of pollution that contaminates the environment

### **Invasive species (and the introduction of alien species and genetic material)**

- threats from invasive (alien and native) plants, animals, pathogens, microbes, or genetic material

### **Exploitation, harassment, or direct mortality of native species**

- threats from consumptive use of native biological resources including intentional and unintentional harvesting effects, by-catch, species control efforts, and other human activities that result in the direct mortality of individuals or populations

### **Accelerated climate change**

- threats from climatic changes that may be linked to global warming and severe weather events outside the natural range of variation that could eliminate a vulnerable species or habitat

### **Natural causes**

- threats resulting from any stochastic event or factor

The six threat categories have not been further delineated because as the literature suggests, fine scale threats are not mutually exclusive. Changes in biodiversity are almost always caused by multiple interacting threats and at the fine scale these threats are related through common stressors. Habitat loss or reduction and mortality, developmental, or reproductive impacts at the species level occur through stressors acting synergistically. A simplified classification of threats for ESTR is mapped to example stressors in Table 3. Use of this common classification in the preparation of ESTR products will help standardize nomenclature and facilitate comparison of biodiversity observations across ecosystems and consolidation results to a national scale.

Table 3. Classification of threats for ESTR.

Threat	Examples of Stressors	Impact
<b>Ecosystem Change</b> a) Ecosystem Alteration  b) Ecosystem Loss	<ul style="list-style-type: none"> <li>• Substrate alteration (e.g. impervious soils)</li> <li>• Alteration of vegetation cover (e.g. removal or change of riparian vegetation, reduced older forest, logging to the stream bank, overgrazing, replanting different species after logging, fire suppression, erosion)</li> <li>• Fragmentation of landscape (e.g. roads, seismic lines, linear infrastructure)</li> <li>• Alteration of hydrology (e.g. dams, channel changes, water withdrawals)</li> <li>• Complete ecosystem conversion (e.g. draining of wetlands; permanent land cover change, reservoir development, infrastructure development)</li> </ul>	<ul style="list-style-type: none"> <li>• Change or loss of a component of ecosystem structure, function, integrity, or composition</li> <li>• Complete loss of ecosystem function or structure</li> </ul>
<b>Pollution</b>	<ul style="list-style-type: none"> <li>• Change in nutrient loads (e.g. nitrogen and phosphorous additions)</li> <li>• Change in sediment loads</li> <li>• Contamination from pesticides (e.g. mortality, by-product loading in biota)</li> <li>• By-products from non-renewable resource development (e.g. tailing ponds, leachate)</li> <li>• Contamination of ecosystem, habitats, and species from industrial by-products (e.g. endocrine disruptors, pharmaceuticals, personal care products)</li> <li>• Acid precipitation</li> <li>• Air pollution (e.g. ground level ozone, particulate matter)</li> <li>• Light pollution</li> <li>• Temperature pollution</li> <li>• Contamination from long range transported contaminants</li> </ul>	<ul style="list-style-type: none"> <li>• Mortality, developmental, or reproductive impacts on individuals, populations, or species</li> <li>• Disruption of some ecosystem processes or change in ecosystem structure</li> </ul>
<b>Invasive Species</b>	<ul style="list-style-type: none"> <li>• Competition</li> <li>• Predation</li> <li>• Hybridization</li> <li>• Introduced Pathogens</li> <li>• Ecosystem modification</li> </ul>	<ul style="list-style-type: none"> <li>• Developmental or reproductive impacts on species or populations.</li> <li>• Change or loss of some component of ecosystem structure or composition</li> </ul>
<b>Exploitation, Harassment, or Direct Mortality of Native Species</b>	<ul style="list-style-type: none"> <li>• Regulated mortality (e.g. harvesting, hunting)</li> <li>• Accidental mortality (e.g. bycatch, road kills)</li> <li>• Purposeful or incidental harm (e.g. harassment, persecution)</li> <li>• Disease</li> </ul>	<ul style="list-style-type: none"> <li>• Decreased fitness or direct mortality of individuals which may result in decreases in population size and stability</li> </ul>
<b>Accelerated Climate Change</b>	<ul style="list-style-type: none"> <li>• Increased extreme weather patterns (e.g. storms, freezing rain)</li> <li>• Alteration of hydrological cycle (e.g. low stream flow, melting glaciers, melting permafrost, more variable stream flow, lake level changes)</li> <li>• Change in temperature (e.g. seasonal temperature changes)</li> <li>• Changes in precipitation (e.g. drought, flooding)</li> <li>• Changes in ice regimes (e.g. sea level rise)</li> </ul>	<ul style="list-style-type: none"> <li>• Change in some component of ecosystem function/processes, structure, or composition</li> <li>• Shifting or loss of ecosystems</li> </ul>
<b>Natural Causes</b>	<ul style="list-style-type: none"> <li>• Stochastic events (e.g. geologic events, wildfire, insect outbreaks)</li> </ul>	<ul style="list-style-type: none"> <li>• Change of some component of function, structure, or composition</li> <li>• Collapse of population</li> </ul>

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# APPENDICES

## Appendix 1. Terminology used for classifying and describing biodiversity threats

Terminology	Definition	Source
Direct threats, sources of stress, proximate pressures	Proximate human activities or processes that have caused, are causing or may cause the destruction, degradation, and/or impairment of biodiversity targets and natural processes.	(Salafsky et al., 2008) (IUCN, 2011)
Indirect threats, drivers, root causes	Negative factors, including social, economic, political, institutional, or cultural factors, that contribute to the occurrence or persistence of direct threats.	(IUCN, 2011)
Drivers	Any natural or human-induced factors that directly or indirectly cause a change in an ecosystem.	(Millennium Ecosystem Assessment, 2005) (Secretariat of the Convention on Biological Diversity, 2006)
Drivers, indirect drivers, underlying drivers, driving forces	Fundamental processes in society which drive activities with a direct impact on the environment. These processes include demographics, economic processes, scientific and technological innovation, distribution pattern processes and cultural, social, political, and institutional processes.	(United Nations Environmental Program, 2007)
Pressures, human interventions in the environment	Human activities which may be directed toward causing a desired environmental change or by-products of other human activities. Key pressures include substance emissions which may take the form of pollution or waste, external inputs such as fertilizers, chemicals and irrigation, land use, resource extraction, and modification and movement of organisms.	(United Nations Environmental Program, 2007)
Direct drivers	Factors, primarily physical, chemical, and biological, such as land cover change, climate change, air and water pollution, irrigation, use of fertilizers, harvesting, and the introduction of alien invasive species. A direct driver unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy.	(Millennium Ecosystem Assessment, 2005) (Secretariat of the Convention on Biological Diversity, 2006)
Indirect drivers	Factors, primarily demographic, economic, sociopolitical, scientific and technological, and cultural and religious, that operate diffusely, often by altering one or more direct drivers. The influence of indirect drivers is established by understanding their effect on direct drivers.	(Millennium Ecosystem Assessment, 2005) (Secretariat of the Convention on Biological Diversity, 2006)
Stressor	Physical, chemical, and biological factors that are either unnatural events or activities, or natural to the system but applied at an excessive or deficient level, which adversely affect the ecosystem through significant changes in the ecological components, patterns, and processes in natural systems (eg. water withdrawal, pesticide use, timber harvesting, acidification, and land-use change)	(BC Ministry of Environment, 2007)

## Appendix 2. Delineation of broadscale biodiversity threats by Venter et al. (2006)

Broadscale Threat	Fine Scale Threat	Definition
Habitat loss		Reduction or degradation of required habitat
	Urbanization	Development of human settlements (urban, suburban, and rural) and industrial and commercial buildings
	Agriculture	Crops, wood plantations, non-timber plantations, livestock (including ranching), and aquaculture
	Human disturbance	Recreation, tourism, military activities, research, transport, vehicle and vessel traffic
	Extraction	Logging, mining, fishing, groundwater, oil and gas, aquifer depletion
	Infrastructure	Transportation, telecommunications, power lines, dams, impoundments, water diversions, pipeline construction
Introduced species		Competition, predation, hybridization, infection, or habitat modification by introduced species
	Competitors	
	Predators	
	Hybridizers	
	Pathogens	
Overexploitation		Intentional or unintentional harvest or persecution
	Harvesting	
	Bycatch	
	Road kill	
	Persecution	
	Collisions	
Pollution		Chemical, thermal or acoustic pollution, turbidity and sedimentation
	Agriculture	
	Urbanization	
	Extraction	
	Infrastructure	
Native species interactions		Any increase or decrease in a species' native competitors, predators, pathogens, prey, symbionts, or other organisms with which it interacts
	Natural causes	
	Intrinsic factors	
	Natural disasters	
Natural causes		Any stochastic event (eg. storm, drought, or fire) or factor inherent to the species (eg. limited dispersal, narrow niche)

## Appendix 3. Classifications of direct threats by the IUCN (Salafsky et al., 2008; IUCN, 2011)

Threats By Level of Classification <sup>a</sup>			Definition <sup>b</sup>
1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> Level (examples only)	
<b>1. Residential &amp; commercial development</b>			<b>human settlements or other non-agricultural land uses with a substantial footprint</b>
	1.1	housing & urban areas <i>urban areas, suburbs, villages, vacation homes, shopping areas, offices, schools, hospitals</i>	human cities, towns, and settlements including non-housing development typically integrated with housing
	1.2	commercial & industrial areas <i>manufacturing plants, shopping centers, office parks, military bases, power plants, train &amp; ship yards, airports</i>	factories and other commercial centers
	1.3	tourism & recreation areas <i>ski areas, golf courses, beach resorts, cricket fields, county parks, campgrounds</i>	tourism and recreation sites with a substantial footprint
<b>2. Agriculture &amp; aquaculture</b>			<b>threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture</b>
	2.1	annual & perennial non-timber crops <i>farms, household swidden plots, plantations, orchards, vineyards, mixed agroforestry systems</i>	crops planted for food, fodder, fibre, fuel, or other uses
	2.2	wood & pulp plantations <i>teak or eucalyptus plantations, silviculture, Christmas tree farms</i>	stands of trees planted for timber or fibre outside of natural forests, often with non-native species
	2.3	livestock farming & ranching <i>cattle feed lots, dairy farms, cattle ranching, chicken farms, goat, camel, or yak herding</i>	domestic terrestrial animals raised in one location on farmed or non-local resources (farming); also domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (ranching)
	2.4	marine & freshwater aquaculture <i>shrimp or fin fish aquaculture, fish ponds on farms, hatchery salmon, seeded shellfish beds, artificial algal beds</i>	aquatic animals raised in one location on farmed or non-local resources; also hatchery fish allowed to roam in the wild
<b>3. Energy production &amp; mining</b>			<b>threats from production of non-biological resources</b>
	3.1	oil & gas drilling <i>oil wells, deep sea natural gas drilling</i>	exploring for, developing, and producing petroleum and other liquid hydrocarbons
	3.2	mining & quarrying <i>coal mines, alluvial gold panning, gold mines, rock quarries, coral mining, deep sea nodules, guano harvesting</i>	exploring for, developing, and producing minerals and rocks
	3.3	renewable energy <i>geothermal power production, solar farms, wind farms (including birds flying into windmills), tidal farms</i>	exploring, developing, and producing renewable energy

Threats By Level of Classification <sup>a</sup>			Definition <sup>b</sup>
1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> Level (examples only)	
<b>4. Transportation &amp; service corridors</b>			<b>threats from long, narrow transport corridors and the vehicles that use them including associated wildlife mortality</b>
	4.1	roads & railroads <i>highways, secondary roads, logging roads, bridges &amp; causeways, road kill, fencing associated with roads, railroads</i>	surface transport on roadways and dedicated tracks
	4.2	utility & service lines <i>electrical &amp; phone wires, aqueducts, oil &amp; gas pipelines, electrocution of wildlife</i>	transport of energy & resources
	4.3	shipping lanes <i>dredging, canals, shipping lanes, ships running into whales, wakes from cargo ships</i>	transport on and in freshwater and ocean waterways
	4.4	flight paths <i>flight paths, jets impacting birds</i>	air and space transport
<b>5. Biological resource use</b>			<b>threats from consumptive use of "wild" biological resources including deliberate and unintentional harvesting effects; also persecution or control of specific species</b>
	5.1	hunting & collecting terrestrial animals <i>bushmeat hunting, trophy hunting, fur trapping, insect collecting, honey or bird nest hunting, predator control, pest control, persecution</i>	killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch
	5.2	gathering terrestrial plants <i>wild mushrooms, forage for stall fed animals, orchids, rattan, control of host plants to combat timber diseases</i>	harvesting plants, fungi, and other non-timber/non-animal products for commercial, recreation, subsistence, research or cultural purposes, or for control reasons
	5.3	logging & wood harvesting <i>clear cutting of hardwoods, selective commercial logging of ironwood, pulp operations, fuel wood collection, charcoal production</i>	harvesting trees and other woody vegetation for timber, fibre, or fuel
	5.4	fishing & harvesting aquatic resources <i>trawling, blast fishing, spear fishing, shellfish harvesting, whaling, seal hunting, turtle egg collection, live coral collection, seaweed collection</i>	harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch

Threats By Level of Classification <sup>a</sup>			Definition <sup>b</sup>
1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> Level (examples only)	
<b>6. Human intrusions &amp; disturbance</b>			<b>threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources</b>
	6.1 recreational activities	<i>off-road vehicles, motorboats, jet-skis, snowmobiles, ultralight planes, dive boats, whale watching, mountain bikes, hikers, birdwatchers, skiers, pets in rec areas, temporary campsites, caving, rock-climbing</i>	people spending time in nature or traveling in vehicles outside of established transport corridors, usually for recreational reasons
	6.2 war, civil unrest & military exercises	<i>armed conflict, mine fields, tanks &amp; other military vehicles, training exercises &amp; ranges, defoliation, munitions testing</i>	Actions by formal or paramilitary forces without a permanent footprint
	6.3 work & other activities	<i>law enforcement, drug smugglers, illegal immigrants, species research, vandalism</i>	People spending time in or traveling in natural environments for reasons other than recreation or military activities
<b>7. Natural system modifications</b>			<b>threats from actions that convert or degrade habitat in service of “managing” natural or semi-natural systems, often to improve human welfare</b>
	7.1 fire & fire suppression	<i>fire suppression to protect homes, inappropriate fire management, escaped agricultural fires, arson, campfires, fires for hunting</i>	suppression or increase in fire frequency and/or intensity outside of its natural range of variation
	7.2 dams & water management/use	<i>dam construction, dam operations, sediment control, change in salt regime, wetland filling for mosquito control, levees and dikes, surface water diversion, groundwater pumping, channelization, artificial lakes</i>	changing water flow patterns from their natural range of variation either deliberately or as a result of other activities
	7.3 other ecosystem modifications	<i>land reclamation projects, abandonment of managed lands, rip-rap along shoreline, mowing grass, tree thinning in parks, beach construction, removal of snags from streams</i>	other actions that convert or degrade habitat in service of “managing” natural systems to improve human welfare
<b>8. Invasive &amp; other problematic species &amp; genes</b>			<b>threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance</b>
	8.1 invasive non-native/alien species	<i>feral cattle, household pets, zebra mussels, Dutch elm disease or chestnut blight, Miconia tree, introduction of species for biocontrol, Chytrid fungus affecting amphibians outside of Africa</i>	harmful plants, animals, pathogens and other microbes not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities

Threats By Level of Classification <sup>a</sup>			Definition <sup>b</sup>
1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> Level (examples only)	
	8.2	problematic native species <i>overabundant native deer, overabundant algae due to loss of native grazing fish, native plants that hybridize with other plants, plague affecting rodents</i>	harmful plants, animals, or pathogens and other microbes that are originally found within the ecosystem(s) in question, but have become “out-of-balance” or “released” directly or indirectly due to human activities
	8.3	introduced genetic material <i>pesticide resistant crops, hatchery salmon, restoration projects using non-local seed stock, genetically modified insects for biocontrol, genetically modified trees, genetically modified salmon</i>	human altered or transported organisms or genes
<b>9. Pollution</b>			<b>Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources</b>
	9.1	household sewage & urban waste water <i>discharge from municipal waste treatment plants, leaking septic systems, untreated sewage, outhouses, oil or sediment from roads, fertilizers and pesticides from lawns and golf-courses, road salt</i>	water-borne sewage and non-point runoff from housing and urban areas that include nutrients, toxic chemicals and/or sediments
	9.2	industrial & military effluents <i>toxic chemicals from factories, illegal dumping of chemicals, mine tailings, arsenic from gold mining, leakage from fuel tanks, PCBs in river sediments</i>	water-borne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries that include nutrients, toxic chemicals and/or sediments
	9.3	agricultural & forestry effluents <i>nutrient loading from fertilizer run-off, herbicide run-off, manure from feedlots, nutrients from aquaculture, soil erosion</i>	water-borne pollutants from agricultural, silvicultural, and aquaculture systems that include nutrients, toxic chemicals and/or sediments including the effects of these pollutants on the site where they are applied
	9.4	garbage & solid waste <i>municipal waste, litter from cars, flotsam &amp; jetsam from recreational boats, waste that entangles wildlife, construction debris</i>	rubbish and other solid materials including those that entangle wildlife
	9.5	air-borne pollutants <i>acid rain, smog from vehicle emissions, excess nitrogen deposition, radioactive fallout, wind dispersion of pollutants or sediments, smoke from forest fires or wood stoves</i>	atmospheric pollutants from point and nonpoint sources
	9.6	excess energy <i>noise from highways or airplanes, sonar from submarines that disturbs whales, heated water from power plants, lamps attracting insects, beach lights disorienting turtles, atmospheric radiation from ozone holes</i>	inputs of heat, sound, or light that disturb wildlife or ecosystems

Threats By Level of Classification <sup>a</sup>			Definition <sup>b</sup>
1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> Level (examples only)	
<b>10. Geological events</b>			<b>threats from catastrophic geological events</b>
	10.1	volcanoes <i>eruptions, emissions of volcanic gasses</i>	volcanic events
	10.2	earthquakes/tsunamis <i>earthquakes, tsunamis</i>	earthquakes and associated events
	10.3	avalanches/landslides <i>avalanches, landslides, mudslides</i>	avalanches or landslides
<b>11. Climate change &amp; severe weather</b>			<b>long-term climatic changes that may be linked to global warming and other severe climatic or weather events outside the natural range of variation that could wipe out a vulnerable species or habitat</b>
	11.1	habitat shifting & alteration <i>sea-level rise, desertification, tundra thawing, coral bleaching</i>	major changes in habitat composition and location
	11.2	droughts <i>severe lack of rain, loss of surface water sources</i>	periods in which rainfall falls below the normal range of variation
	11.3	temperature extremes <i>heat waves, cold spells, oceanic temperature changes, disappearance of glaciers/sea ice</i>	periods in which temperatures exceed or go below the normal range of variation
	11.4	storms & flooding <i>thunderstorms, tropical storms, hurricanes, cyclones, tornados, hailstorms, ice storms or blizzards, dust storms, erosion of beaches during storms</i>	extreme precipitation and/or wind events or major shifts in seasonality of storms

<sup>a</sup> The classification is composed of 3 levels of direct threats, analogous to families, genera, and species in the Linnaean system. The 1<sup>st</sup> level is denoted by whole numbers and bold text (**1. Residential and commercial development**). The 2<sup>nd</sup> level is denoted by decimal numbers and plain text (1.2 commercial and industrial areas). The 3<sup>rd</sup> level is denoted by italic text (*manufacturing plants*). The classifications are designed to be comprehensive, consistent, and exclusive for the 1<sup>st</sup> and 2<sup>nd</sup> levels. The 3<sup>rd</sup> level, by contrast, currently only contains some illustrative examples rather than comprehensive listings of threats at this level.

<sup>b</sup> Definitions are only given for 1<sup>st</sup> and 2<sup>nd</sup> level threat classifications.



## Appendix 4. Categories and indicators used in the *State of Great Lakes 2007* report (Environment Canada and US Environmental Protection Agency, 2007)

Category	Subcategory	Indicator Name
Contamination	Nutrients	<ul style="list-style-type: none"> <li>• Phosphorus concentrations and loadings</li> <li>• Phosphorus and nitrogen levels (coastal wetlands)</li> <li>• Nutrient management plans</li> </ul>
	Toxics in Biota	<ul style="list-style-type: none"> <li>• Contaminants in young-of-the-year spottail shiners</li> <li>• Contaminants in colonial nesting waterbirds</li> <li>• Contaminants in whole fish</li> <li>• External anomaly prevalence index for nearshore fish</li> <li>• Biologic markers of human exposure to persistent chemicals</li> <li>• Contaminants in sport fish</li> <li>• Contaminants in snapping turtle eggs</li> <li>• Contaminants affecting productivity of bald eagles</li> <li>• Population of American otters and contaminants affecting American otters</li> </ul>
	Toxics in Media	<ul style="list-style-type: none"> <li>• Atmospheric deposition of toxic chemicals</li> <li>• Toxic chemical concentrations in offshore waters</li> <li>• Concentrations of contaminants in sediment cores</li> <li>• Drinking water quality</li> <li>• Air quality</li> <li>• Acid rain</li> </ul>
	Sources and Loadings	<ul style="list-style-type: none"> <li>• Atmospheric deposition of toxic chemicals</li> <li>• Air quality</li> <li>• Wastewater treatment and pollution</li> <li>• Acid rain</li> </ul>
Biotic Communities	Fish	<ul style="list-style-type: none"> <li>• Salmon and trout</li> <li>• Walleye</li> <li>• Preyfish populations</li> <li>• Lake trout</li> <li>• Status of lake sturgeon in the Great Lakes</li> <li>• Coastal wetland fish community health</li> </ul>
	Birds	<ul style="list-style-type: none"> <li>• Contaminants in colonial nesting waterbirds</li> <li>• Wetland dependent bird diversity and abundance</li> <li>• Contaminants affecting productivity of bald eagles</li> <li>• Breeding bird diversity and abundance</li> </ul>
	Mammals	<ul style="list-style-type: none"> <li>• Population of American otter and contaminants affecting American otter</li> </ul>
	Amphibians	<ul style="list-style-type: none"> <li>• Coastal wetland amphibian diversity and abundance</li> <li>• Groundwater dependent plant and animal communities</li> </ul>

Category	Subcategory	Indicator Name
	Invertebrates	<ul style="list-style-type: none"> <li>• Native freshwater mussels</li> <li>• Benthos diversity and abundance – aquatic oligochaete communities</li> <li>• Zooplankton populations</li> <li>• Hexagenia</li> <li>• Abundances of the benthic amphipod <i>Diporeia</i> spp.</li> <li>• Coastal wetland invertebrate community health</li> </ul>
	Plants	<ul style="list-style-type: none"> <li>• Phytoplankton populations</li> <li>• Coastal wetland plant community health</li> <li>• Health of terrestrial plant communities</li> <li>• Forest lands – conservation of biological diversity</li> </ul>
	General	<ul style="list-style-type: none"> <li>• Habitat fragmentation</li> <li>• Nearshore species diversity and stability</li> <li>• Threatened species</li> <li>• Status and protection of special places and species</li> </ul>
Invasive species	Aquatic	<ul style="list-style-type: none"> <li>• Sea lamprey</li> <li>• Non-native aquatic species</li> </ul>
	Terrestrial	<ul style="list-style-type: none"> <li>• Non-native terrestrial species</li> </ul>
Coastal zones	Nearshore aquatic	<ul style="list-style-type: none"> <li>• Fish habitat</li> <li>• Phosphorus and nitrogen levels (coastal wetlands)</li> <li>• Effects of water level fluctuations</li> <li>• Human impact measures (coastal wetlands)</li> <li>• Extent of hardened shoreline</li> <li>• Sediment available for coastal nourishment</li> <li>• Artificial coastal structures</li> </ul>
	Coastal wetlands	<ul style="list-style-type: none"> <li>• Coastal wetland invertebrate community health</li> <li>• Coastal wetland fish community health</li> <li>• Coastal wetland amphibian diversity and abundance</li> <li>• Contaminants in snapping turtle eggs</li> <li>• Wetland dependent bird diversity and abundance</li> <li>• Coastal wetland area by type</li> <li>• Coastal wetland restored area by type</li> <li>• Sediment flowing into coastal wetlands</li> <li>• Phosphorus and nitrogen levels</li> <li>• Effects of water level fluctuations</li> <li>• Coastal wetland plant community health</li> <li>• Land cover adjacent to coastal wetlands</li> <li>• Human impact measures</li> <li>• Sediment available for coastal nourishment</li> </ul>

Category	Subcategory	Indicator Name
	Terrestrial	<ul style="list-style-type: none"> <li>• Effects of water level fluctuations</li> <li>• Human impact measures (coastal wetlands)</li> <li>• Area, quality and protection of special lakeshore communities – Alvars</li> <li>• Area, quality and protection of special lakeshore communities – islands</li> <li>• Area, quality and protection of special lakeshore communities – cobble beaches</li> <li>• Area, quality and protection of special lakeshore communities – sand dunes</li> <li>• Extent of hardened shoreline</li> <li>• Nearshore land use</li> <li>• Extent and quality of nearshore natural land cover</li> <li>• Nearshore species diversity and stability</li> <li>• Sediment available for coastal nourishment</li> <li>• Protected nearshore areas</li> </ul>
Aquatic habitats	Open lake	<ul style="list-style-type: none"> <li>• Fish habitat</li> <li>• Phosphorus concentrations and loadings</li> <li>• Toxic chemical concentrations in offshore waters</li> <li>• Concentrations of contaminants in sediment cores</li> <li>• Extent of hardened shoreline</li> <li>• Sediment available for coastal nourishment</li> <li>• Artificial coastal structures</li> </ul>
	Groundwater	<ul style="list-style-type: none"> <li>• Natural groundwater quality and human induced changes</li> <li>• Groundwater and land: use and intensity</li> <li>• Base flow due to groundwater discharge</li> <li>• Groundwater dependent plant and animal communities</li> </ul>
Human health		<ul style="list-style-type: none"> <li>• Drinking water quality</li> <li>• Biologic markers of human exposure to persistent chemicals</li> <li>• Geographic patterns and trends in disease incidence</li> <li>• Beach advisories, postings and closures</li> <li>• Contaminants in sport fish</li> <li>• Air quality</li> </ul>
Land use and land cover	General	<ul style="list-style-type: none"> <li>• Land cover adjacent to coastal wetlands</li> <li>• Land cover and land conversion</li> <li>• Groundwater and land: use and intensity</li> <li>• Habitat fragmentation</li> <li>• Nearshore land use</li> <li>• Extent and quality of nearshore natural land cover</li> </ul>
	Forest lands	<ul style="list-style-type: none"> <li>• Conservation of biological diversity on forest lands</li> <li>• Maintenance and productive capacity of forest ecosystems</li> <li>• Maintenance of forest ecosystem health</li> <li>• Conservation and maintenance of soil and water resources on forest lands</li> </ul>
	Agricultural lands	<ul style="list-style-type: none"> <li>• Sustainable agriculture practices</li> <li>• Nutrient management plans</li> <li>• Integrated pest management</li> </ul>

Category	Subcategory	Indicator Name
	Urban/suburban lands	<ul style="list-style-type: none"> <li>• Urban density</li> <li>• Brownfields redevelopment</li> <li>• Ground surface hardening</li> </ul>
	Protected Areas	<ul style="list-style-type: none"> <li>• Area, quality and protection of special lakeshore communities – Alvars</li> <li>• Area, quality and protection of special lakeshore communities – islands</li> <li>• Area, quality and protection of special lakeshore communities – cobble beaches</li> <li>• Area, quality and protection of special lakeshore communities – sand dunes</li> <li>• Protected nearshore areas</li> <li>• Status and protection of special places and species</li> </ul>
Resource utilization		<ul style="list-style-type: none"> <li>• Commercial/industrial eco-efficiency measures</li> <li>• Household stormwater recycling</li> <li>• Economic prosperity</li> <li>• Water withdrawals</li> <li>• Energy consumption</li> <li>• Solid waste disposal</li> <li>• Vehicle use</li> <li>• Wastewater treatment and pollution</li> </ul>
Climate change		<ul style="list-style-type: none"> <li>• Ice duration on the Great Lakes</li> <li>• Effect on crop heat units</li> </ul>

## Appendix 5. Categories and indicators used for reporting on environmental trends in British Columbia in 2007 (BC Ministry of Environment, 2007)

Category	Indicator Name
Population and Economic Activity	<ul style="list-style-type: none"> <li>• Rate of change of selected land uses in Metro Vancouver, 1986 to 2002</li> <li>• Changes in areas of the Agricultural Land Reserve in BC since 1974</li> <li>• Level of municipal wastewater treatment in BC</li> <li>• Trends in shellfish closures due to sewage contamination</li> <li>• Municipal solid waste disposed and recycled per person in regional districts in BC</li> <li>• Trends in waste diversion through industry-led product stewardship programs</li> <li>• Intensity of conventional energy use in economic activity in BC</li> <li>• Trends in greenhouse gas intensity in BC</li> </ul>
Air Quality	<ul style="list-style-type: none"> <li>• Percentage of monitored communities that are achieving the Canada-wide standard for fine particulate matter (PM<sub>2.5</sub>) in BC</li> <li>• Percentage of monitored communities in BC that are achieving the Canada-wide standard for ground level ozone</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• Water quality index for surface water bodies in BC 2002-2004</li> <li>• Trends in surface water quality in BC</li> <li>• Percentage of observation wells that show declining water levels due primarily to human activity</li> <li>• Number of heavily developed aquifers in BC</li> <li>• Daily municipal water use per capita in BC</li> </ul>
Climate Change	<ul style="list-style-type: none"> <li>• Long term trends in air temperature in BC</li> <li>• Coastal sea surface temperature</li> <li>• Precipitation changes in BC</li> <li>• Changes in the spring snowpack in BC</li> <li>• Mean sea level</li> <li>• Trends in greenhouse gas emissions in BC</li> <li>• Trends in fossil fuel use in the transportation sector in BC</li> </ul>

Category	Indicator Name
Contaminants	<ul style="list-style-type: none"> <li>• Total on-site discharge of toxic substances in BC, 2002-2005</li> <li>• Trends in dioxin and furan levels in pulp and paper mill effluent, sediments and Dungeness crab tissues</li> <li>• Cleanup of contaminated sites in BC</li> <li>• Long-term trends in persistent organic pollutants in bird eggs in BC (Great Blue Heron, Cormorant, Osprey)</li> <li>• Persistent organic pollutants in tissues of marine mammals on the BC coast</li> <li>• Trends in pesticide use by professional landscape services in the Lower Mainland of BC. Status of grassland habitats in southern interior BC</li> </ul>
Ecosystems	<ul style="list-style-type: none"> <li>• Area of protected grasslands in BC</li> <li>• Status of BC forests</li> <li>• Trend in the number of road crossings of streams in BC, 2000 to 2005</li> <li>• Economic and conservation tenures in the intertidal areas of BC estuaries</li> <li>• Protected area in BC</li> <li>• Proportion of ecologically intact land within protected areas in BC</li> <li>• Changes in road density and road length in BC</li> </ul>
Species Conservation	<ul style="list-style-type: none"> <li>• Changes in the conservation status of fauna and flora in BC</li> <li>• Percentage of known species and ecological communities on the BC Red list</li> <li>• Threats to species at risk in BC</li> <li>• Progress toward completing recovery strategies for species at risk in BC</li> <li>• Number of alien species by group in BC</li> </ul>

## Appendix 6. Alberta Environment review of issues and indicators (Stantec Consulting Ltd., 2005)

Stressor	Specific Concern	Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health
Contaminant Loading	Pathogens	<ul style="list-style-type: none"> <li>• Identification of pathogens in water and affected humans (such as giardiasis, botulism) (CWQG)</li> <li>• Identification of pathogens in water and waterfowl (based on mortalities in wetlands) (botulism)</li> <li>• Identification of pathogens in water and amphibians (based on mortalities) (viral &amp; fungal)</li> </ul>
	Organic Pollutants/Oxygen Depleting Substances	<ul style="list-style-type: none"> <li>• Water quality monitoring for organics (CWQG/ASWQG)</li> <li>• Dissolved oxygen monitoring (CWQG/ASWQG)</li> </ul>
	Nutrients	<ul style="list-style-type: none"> <li>• Water quality monitoring of nutrients (balance of N, P, DOC, ions)</li> <li>• Organic Influx (concentration of particulate organic matter)</li> <li>• Dissolved oxygen monitoring (CWQG/ASWQG)</li> <li>• Algal blooms in lakes (phytoplankton chlorophyll a)</li> <li>• Algal blooms in lakes (phytoplankton identification for toxic species or monitoring of toxins of cyanobacteria)</li> <li>• Periphytic algae in streams (chlorophyll a and ash free dry mass)</li> <li>• Macrophytes (% coverage)</li> <li>• Zooplankton monitoring in lakes (biomass, composition, abundance and dominance)</li> <li>• Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> <li>• Fish (condition factor, weight-at-age)</li> </ul>
	Sediments	<ul style="list-style-type: none"> <li>• Water quality monitoring for suspended sediments (turbidity, secchi depth)</li> <li>• Sediment quality monitoring of sediment bound contaminants such as metals (CSQG)</li> <li>• Sediment deposition (particle size, rate of accumulation)</li> <li>• Physical habitat assessment (depth of pools)</li> <li>• Zooplankton monitoring in lakes (biomass, composition, abundance and dominance)</li> <li>• Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> </ul>
	Pesticides (includes insecticides, herbicides and fungicides) (acute or chronic toxicity, endocrine disruption)	<ul style="list-style-type: none"> <li>• Water quality monitoring for pesticides (CWQG)</li> <li>• Sediment quality monitoring for pesticides (CSQG)</li> <li>• Monitoring of aquatic vegetation loss from herbicides (% coverage)</li> <li>• Chronic toxicity testing</li> </ul>

Stressor	Specific Concern	Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health
		<ul style="list-style-type: none"> <li>• Benthic macroinvertebrates (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> <li>• Fish for endocrine disruption.</li> </ul>
	Metals (chronic and acute toxicity, bioaccumulation)	<ul style="list-style-type: none"> <li>• Water quality monitoring for metals (CWQG/ASWQG)</li> <li>• Sediment quality monitoring for metals (GSQG)</li> <li>• Acute and chronic toxicity testing</li> <li>• Fish tissue monitoring for metals (bioaccumulation)</li> </ul>
	Petroleum Hydrocarbons	<ul style="list-style-type: none"> <li>• Water quality monitoring for hydrocarbons (CWQG)</li> </ul>
Landscape Changes/Habitat Alterations	Endocrine Disrupting Substances	<ul style="list-style-type: none"> <li>• Monitoring for the presence of EDS</li> <li>• Laboratory bioassays to detect presence of EDS</li> <li>• Monitoring of abnormalities in fish growth, development and reproduction (deformities, inhibited growth, decreased gonad weight, depressed thyroid and immune functions, sex ratios)</li> </ul>
	Wood Preservatives	<ul style="list-style-type: none"> <li>• Water quality monitoring for wood preservatives (CWQG)</li> </ul>
	Pharmaceuticals and Personal Care Products	<ul style="list-style-type: none"> <li>• Water quality monitoring for pharmaceuticals and PCPs</li> <li>• Sediment quality monitoring for pharmaceuticals and PCPs</li> </ul>
	Brominated Flame Retardants	<ul style="list-style-type: none"> <li>• Water quality monitoring for BFRs</li> <li>• Sediment quality monitoring for BFRs</li> <li>• Air quality monitoring for BFRs</li> </ul>
	Biosolids/Sludges	<ul style="list-style-type: none"> <li>• Water quality monitoring for contaminants associated with biosolids/sludges in nearby surface waters (nutrients, metals, volatile organics)</li> <li>• Monitoring of contaminants (nutrients, metals and volatile organics) in biosolids/sludges</li> </ul>
	Construction of Dams and Other Impoundments	<ul style="list-style-type: none"> <li>• Hydrological assessment (effects on discharge)</li> <li>• Physical habitat assessment (habitat fragmentation, altered flows, dewatering, flooding of areas)</li> <li>• Restricted passage or movement of fish assessment</li> <li>• Water quality monitoring (nutrients, metals, temperature, dissolved oxygen)</li> </ul>
	Disruption of Riparian Habitat	<ul style="list-style-type: none"> <li>• Riparian habitat monitoring (vegetation species composition, structure in terms of ground cover, shrubs and overstory, width of riparian zone, proportion of native to “weed” species, extent of riparian clearing)</li> <li>• Physical habitat assessment of waterbody due to streamside vegetation removal (bank stability, % shade lost, sedimentation)</li> </ul>
	Waterbody Habitat Alteration or Loss	<ul style="list-style-type: none"> <li>• Physical habitat assessment (velocity, depth, morphological types, bank stability, % instream cover, substrate)</li> </ul>



<b>Stressor</b>	<b>Specific Concern</b>	<b>Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health</b>
	Draining of Wetlands	<ul style="list-style-type: none"> <li>• Loss or fragmentation of wetland area (% wetland lost) Species at risk of habitat loss (% decrease in waterfowl, amphibians)</li> </ul>
	Disturbance of Hydrologic Regime	<ul style="list-style-type: none"> <li>• Instream flow needs assessment</li> <li>• Physical habitat assessment (loss of wetted area, widening of channel, discharge)</li> </ul>
	Vegetation Removal (agriculture, forestry, cut lines)	<ul style="list-style-type: none"> <li>• % Cover and fragmentation of vegetation</li> <li>• Sediment deposition into waterbodies from erosion (particle size)</li> </ul>
	Changes in Chemical and Physical Process	<ul style="list-style-type: none"> <li>• Water quality monitoring</li> </ul>
	Intensification of Urbanization of Watersheds	<ul style="list-style-type: none"> <li>• Water quality monitoring (various contaminants)</li> <li>• Physical habitat assessment (sedimentation, loss of wetlands) Landuse (type and extent of landuse)</li> </ul>
Water Use/Water Allocation	Population Growth - Increased Consumption (urban and agriculture)	<ul style="list-style-type: none"> <li>• Instream flow needs assessment</li> <li>• Monitoring of water quality, riparian habitat and fish if instream flow needs are not met</li> <li>• Monitoring discharge levels</li> </ul>
	Population Growth – Increased Stormwater Runoff	<ul style="list-style-type: none"> <li>• Water quality monitoring (various contaminants)</li> </ul>
	Change in Flow Regime (withdrawals)	<ul style="list-style-type: none"> <li>• Instream flow needs assessment</li> <li>• Monitoring of water quality, riparian habitat and fish if instream flow needs are not met</li> <li>• Monitoring discharge levels</li> </ul>
Air Emissions and Acidification	Industrial Air Pollution (dust and contaminants)	<ul style="list-style-type: none"> <li>• Air quality monitoring (carbon dioxide, carbon monoxide, nitrogen oxide, ammonia, methane)</li> </ul>
	Acid Inputs and Acid Rain	<ul style="list-style-type: none"> <li>• Water chemistry (pH and alkalinity of lakes and ponds)</li> <li>• Precipitation (acid rain)</li> <li>• Zooplankton in lakes (biomass, composition, abundance and dominance)</li> <li>• Monitor sensitive aquatic systems especially if there is a risk of exceeding threshold levels of acidifying emissions</li> </ul>
	Vehicle Emissions (greenhouse gases)	<ul style="list-style-type: none"> <li>• Air quality monitoring (carbon dioxide, methane)</li> </ul>
	Atmospheric Deposition of Contaminants	<ul style="list-style-type: none"> <li>• Monitor contaminants in wet and dry atmospheric deposition</li> </ul>
Recreational Use	Water-Based Activities (swimming, boating, water skiing, camping)	<ul style="list-style-type: none"> <li>• Water quality monitoring (pathogens, nutrients, hydrocarbons)</li> </ul>

<b>Stressor</b>	<b>Specific Concern</b>	<b>Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health</b>
	Habitat Alterations (beach modifications, marinas, docks, piers)	<ul style="list-style-type: none"> <li>• Physical habitat assessment (substrate, shoreline erosion)</li> </ul>
	Fishing Pressure	<ul style="list-style-type: none"> <li>• Creel surveys</li> <li>• Fish population surveys</li> <li>• Population genetic structure using DNA (determine genetic variability to protect endangered species)</li> </ul>
	Access Management	<ul style="list-style-type: none"> <li>• Monitoring road density (length of roads and trails)</li> <li>• Monitoring use of roads and trails (number of vehicles)</li> </ul>
Exotic Species	Exotic Species Introduction	<ul style="list-style-type: none"> <li>• Presence/absence of exotic species</li> <li>• Ratio of exotics to natural species</li> </ul>
Transportation Infrastructure	Infrastructure Development (roads, bridges, culverts)	<ul style="list-style-type: none"> <li>• Physical habitat assessment (sedimentation, fish habitat, spawning grounds)</li> <li>• Fish presence/absence survey</li> </ul>
	Wetland Loss	<ul style="list-style-type: none"> <li>• Loss or fragmentation of wetland area (% wetland lost)</li> <li>• Species at risk of habitat loss (% decrease in waterfowl, amphibians)</li> </ul>
	Salinity (road salting)	<ul style="list-style-type: none"> <li>• Water quality monitoring for salinity</li> </ul>
Natural Disturbances	Drought	<ul style="list-style-type: none"> <li>• Precipitation, temperature and discharge monitoring</li> <li>• Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> <li>• Riparian habitat assessment</li> <li>• Some aspects of water quality (dissolved oxygen, temperature, conductivity, nutrients)</li> </ul>
	Flooding	<ul style="list-style-type: none"> <li>• Precipitation monitoring and discharge monitoring</li> <li>• Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> <li>• Riparian habitat assessment</li> <li>• Some aspects of water quality (dissolved oxygen, temperature, conductivity, nutrients)</li> </ul>
	Wildfire	<ul style="list-style-type: none"> <li>• Temperature and precipitation monitoring</li> <li>• Weather monitoring (lightning)</li> <li>• Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices)</li> <li>• Some aspects of water quality (suspended solids, nutrients)</li> </ul>
Climate Change	Streamflow and Lake Levels	<ul style="list-style-type: none"> <li>• Instream flow needs survey</li> <li>• Monitoring lake levels</li> </ul>

Stressor	Specific Concern	• Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health
		• Zooplankton in lakes (biomass, composition, abundance and dominance)
	Extreme Weather Events	• Monitoring extent and duration of extreme weather events (heavy rain causing flooding, dry conditions causing drought )
	Changes in Chemical and Physical Process (temperature, precipitation, greenhouse gases)	<ul style="list-style-type: none"> <li>• Ice phenology (lake ice duration, glaciers)</li> <li>• Temperature and precipitation monitoring</li> <li>• Air quality monitoring (carbon dioxide, methane)</li> </ul>