Evaluating the (Mis) Application of the Indicator Species Concept in Canadian Environmental Impact Assessment

by

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Abstract

Environmental Impact Assessment (EIA) is a land use planning process that is meant to characterize and mitigate potential impacts of proposed development projects to valued components (VC), including a large array of species. Indicator species are often used to represent broader assemblages of species in environmental management and conservation. However, there is a danger of making false inferences in the absence of a transparent and rigorous framework for selecting and applying indicator species. By reviewing ten recent Canadian federal EIAs, I investigated whether and how terrestrial wildlife indicator species were used to evaluate potential impacts on wildlife VCs. Indicators were used ubiquitously, though variably, across EIAs. The variation can be attributed to a lack of rigorous indicator frameworks and absent or vague regulatory guidance. The findings of this study provide evidence for a systemic failure to uphold minimum standards of evidence in Canadian federal EIA. This has important implications for the scientific integrity of information used in government decision-making. Regulatory guidance should be adapted to promote the appropriate use of indicator species in EIA.

Keywords: wildlife management; species conservation; terrestrial ecosystem; environmental planning; systematic review; policy analysis
Acknowledgements

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<tr>
<td>BC</td>
<td>British Columbia</td>
</tr>
<tr>
<td>BC EAO</td>
<td>British Columbia Environmental Assessment Office</td>
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<tr>
<td>CEA Agency</td>
<td>Canadian Environmental Assessment Agency</td>
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<tr>
<td>CEA Act</td>
<td>Canadian Environmental Assessment Act</td>
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<td>CWS</td>
<td>Canadian Wildlife Service</td>
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<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EIS</td>
<td>Environmental Impact Statement</td>
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<td>EIS Guidelines</td>
<td>Environmental Impact Statement Guidelines</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>MB</td>
<td>Manitoba</td>
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<td>MBCCA</td>
<td>Migratory Birds Convention Act</td>
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<tr>
<td>NFL</td>
<td>Newfoundland / Labrador</td>
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<td>NRCan</td>
<td>Natural Resources Canada</td>
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<td>NS</td>
<td>Nova Scotia</td>
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<td>ON</td>
<td>Ontario</td>
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<td>PEI</td>
<td>Prince Edward Island</td>
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<td>QC</td>
<td>Quebec</td>
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<tr>
<td>SK</td>
<td>Saskatchewan</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>VC</td>
<td>Valued Component</td>
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### Glossary

**Cumulative Effects Assessment**
The evaluation of “changes to the environment that are caused by an action in combination with other past, present, and future human actions” (Hegmann et al. 1999, p.3).

**Empirical Studies**
Scholarly, peer-reviewed or primary scientific (ecological) literature – particularly referring to studies involving *indicators*.

**Environmental Impact Assessment (EIA)**
(EIA) There are numerous technical definitions for EIA, however for the purposes of this study, EIA is a planning process that informs decisions regarding major proposed land use changes (i.e., development projects) by evaluating the potential for adverse effects to environmental components of value or concern (i.e., *valued component*).

**EIA Documentation**
Documents of relevance to my research on EIA (*Environmental Impact Statement*, technical appendices, project descriptions, and guidelines from EIA regulators).

**Environmental Impact Statement**
(EIS) The main EIA document for which potential impacts on the environment are assessed.

**EIS Section**
Refers to a particular chapter of the *Environmental Impact Statement*.

**Explicit Indication and Indicators**
Explicit indication is an *indication* that is clearly specified with the use of an *indicator* term (e.g., indicator species, surrogate), or an *indication statement*. Explicit indicators are involved in explicit indication.

**Formal Indication and Indicator**
Formal indication is an *indication* that presents indicators in sections of the EIS that outline formal EIA methods. Formal indicators are involved in formal indication.

**Impact Area**
The area encompassing both the project footprint and area around the footprint for which direct or indirect impacts on *valued components* are expected to occur (often referred to as the 'Local Study Area' in an *Environment Impact Statement*).
Implicit Indication and Indicator
Implicit indication involves the *ad hoc* description of potential impacts (or lack of perceived impacts) for a subset of species, rather describing impacts on all species occurring within a *wildlife component* (e.g., explaining impacts on ‘Grizzly Bear’ to inform impacts on ‘Mammals’) in the absence of *indicator* terms or *indication statements*.

Indication
For the purposes of this research, indication is the use of *indicators* to make inferences about *wildlife components*.

Indication Statement
A statement of the hypothesized relationship between the *indicator* and the indicated *wildlife component* (e.g., “‘Grizzly Bear’ is meant to represent impacts on ‘Furbearers’”).

Indicator
For the purposes of this research, an indicator is any *terrestrial wildlife* species or suites of species (referred to as “indicator species” or “indicator groups”, respectively) that are used to make inferences about *wildlife components*. Indicators are represented in capitals and single quotes throughout the text (e.g., ‘Grizzly Bear’).

Informal Indication and Indicator
Informal indication involves the *ad hoc* presentation of indicators during the description of potential impacts on *wildlife components*. In other words, indication is not formally identified in *EIS sections* that describe EIA methods. Informal indicators are involved in informal indication. Note that *informal indication* is distinct from *implicit indication*.

Nested Indication
Indication between an *indicator*, a *wildlife sub-component*, and a *wildlife valued component* in a hierarchical fashion (e.g., ‘Grizzly Bear’ indicates impacts on ‘Furbearers’ which, in turn, indicates impacts on ‘Mammals’).

EIA Practitioner
Professionals that are involved in conducting the EIA (i.e., environmental consultants).

Project
Refers to the proposed major development project for which an EIA is conducted.

Proponent
The primary advocate of the proposed project. At times, the work of *EIA practitioners* is reflected in using the term *proponent*, as they are hired by the proponent to conduct an EIA.
Regulator

Government professionals that regulate and review the EIA (CEA Agency, provincial EIA departments, and government experts).

Residual Effects

Expected impacts on valued components after proposed mitigation measures are taken into account.

Reviewer

Government professionals that evaluate the contents of EIA documentation to inform EIA decisions.

Scientific Integrity

For the purposes of this research, scientific integrity is the transparent and scientifically rigorous use of indicators in EIA.

Scientific Rigour

For the purposes of this study, scientific rigour is the use of certain methods of indicator selection and application recommended from empirical studies.

Stakeholders

Parties with interests either in the project or in potential impacts of the project.

Terrestrial Wildlife

Animal species that live and may bear potential project impacts primarily in the terrestrial environment (terrestrial vertebrates and invertebrates).

Transparency

For the purposes of this research, transparency is the formal and explicit disclosure of using indicators as a method of evaluating impacts on wildlife components.

Valued Component

(VC) Environmental components of value or concern (e.g., cultural, commercial, recreational, ecological) that structure the EIA. VCs are represented in capitals and single quotes throughout the text (e.g., ‘Mammals’).

Wildlife Component

Refers to both wildlife VCs and wildlife sub-components. Represented in capitals and single quotes throughout the text (e.g., ‘Mammals’ or ‘Furbearers’).

Wildlife Indication

Each individual relationship between a wildlife indicator and indicated wildlife component.

Wildlife Sub-Component

A sub-set of wildlife VCs. Represented in capitals and single quotes throughout the text (e.g., ‘Furbearers’).

Wildlife Valued Component

Wildlife species or groups of value or concern. Represented in capitals and single quotes throughout the text (e.g., ‘Mammals’).
Reading This Document

This document makes reference to peer-reviewed works, *EIA documentation* (see *Glossary*), and other online EIA sources. The References section is reserved primarily for peer-reviewed citations. Citations for EIA documents are included in *Appendix B*. Hyperlinks are bold within the text and take the reader either to a relevant section of this document, or to other electronic sources. For electronic EIA documentation sources, hyperlinks are only provided the first time that they are referenced in the text.

Figures and tables are embedded throughout the document and will occur shortly after first being referenced in the text. Supplemental tables contain more details about this research. Supplemental tables are referenced in the *Appendices* and are available as external files.

While acronyms and terms are explained in text, the *List of Acronyms* and *Glossary* sections are available for reference.
Chapter 1. Introduction

The rapid rate of biodiversity loss has received international attention since the 1980s (United Nations Convention on Biological Diversity 1992; Union of Concerned Scientists 1992; Raustiala & Victor 1996). Yet, scientists continue to warn humanity that there is little to show for global efforts to curb spiralling population trends (Ripple et al. 2017). Risk of species extirpation and extinction continues to rise with anthropogenic pressures (e.g., resource extraction, invasive species, pollution, and effects of climate change; Butchart et al. 2010), threatening the resilience and functioning of ecosystems (Cardinale et al. 2012). Habitat loss in general remains one of the greatest threats to biodiversity (Venter et al. 2006; Hanski 2011). Given the dramatic increase in human population and pressures on the land base to sustain such growth, it is crucial that nations take advantage of opportunities to understand and mitigate further impacts on species and ecosystems that are so important for ecosystem services upon which human well-being depends (Millennium Ecosystem Assessment 2005; Díaz et al. 2006; Cardinale et al. 2012; Ripple et al. 2017).

Plant and animal species have been used frequently as indicators to simplify and facilitate the understanding of broader environmental phenomena that is necessary for making conservation and environmental management decisions (Siddig et al. 2016). For example, indicator species can be used to infer specific aspects of environmental condition (e.g. water and soil quality; Sládeček 1983; Schloter et al. 2003), ecological characteristics (e.g., ecological integrity and species richness; Pearson 1994; Carignan & Villard 2002; Fleishman et al. 2005), and they can be used as proxies for other species that may be more difficult to assess directly (e.g. rare or imperilled species, and entire taxonomic groups; Block et al. 1987; Silvano et al. 2017). The term “focal species” has been used to refer to individual species or suites of species that are the focus of assessment, and encompasses indicator species concepts that are applied in
conservation (e.g., indicator, keystone, umbrella and flagship species; see summary of definitions and applications in Table 1; Zacharias & Roff 2001; Rempel et al. 2004).

Table 1 Types of focal species and their applications

<table>
<thead>
<tr>
<th>Focal species</th>
<th>Definition</th>
<th>Examples</th>
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| Indicator species| Species that are closely related to specific environmental factors (also known as management indicators). | i) population indicators: indicate species presence / absence or populations  
ii) guild-, biological-, or taxon-based indicators: indicate species within a particular taxonomic group, guild, or niche  
iii) condition or bio-indicators, sensitive or sentinel species: indicate environmental health or stress  
iv) composition, ecological, environmental or structure-based indicators: indicate various habitat types  
v) biodiversity indicators: indicate species diversity |
| Keystone species | Species that have disproportionate importance to ecological function relative to their abundance or biomass. | i) predators, prey, plants, mutualists, and habitat modifiers (e.g., beaver, Castor canadensis) |
| Umbrella species | Conservation of this species ideally serves to conserve numerous other species (also known as coarse-filter species). | i) area-, resource-, dispersal- or process-limited species (e.g., grizzly bear, Ursus arctos) |
| Flagship species | Charismatic species of public value that garner support for protection of their habitat and consequently other species. | i) usually threatened species or species of concern (e.g., woodland caribou, Rangifer tarandus caribou) |

Content in this table is summarized from Zacharias & Roff 2001 and Rempel et al. 2004.

While “focal species” and its associated terms all involve the use of species to make inferences (or indications) about the environment, the term “indicator” is applied in the same way across numerous disciplines and is prevalent in the literature (Heink & Kowarik 2010). Therefore, for consistency, any species or suites of species that are used to make inferences about natural phenomena are henceforth referred to as “indicator species”, “indicator groups”, or “indicators”
when making reference to both indicator species and groups. Although certain applications of the indicator species concept are empirically-supported (e.g., bioindicators; Goodsell et al. 2009), there is considerable debate in the literature concerning their true merit in indicating habitat and species-level responses to anthropogenic impacts (Landres et al. 1988; Lindenmayer et al. 2002; Cushman et al. 2010).

Depending on how indicator species are defined and selected, they can either be a reliable or fallible tool for environmental management. One of the major sources of contention concerning the use of indicator species is a lack of an indicator selection and application framework (Dale & Beyeler 2002; Niemeijer & de Groot 2008; Lin et al. 2009). A rigorous indicator framework would include well-defined objectives, clear selection criteria, methods for the evaluation of candidate indicator species, and a monitoring plan to validate assumptions about the relationship between indicators and indicated phenomena (Landres et al. 1988; Girardin et al. 1999; Rempel et al. 2004; Rice & Rochet 2005; Niemeijer & de Groot 2008; Goodsell et al. 2009). In the absence of an indicator selection framework, arbitrary choices of indicator species can lead to misinterpretations about the state of the environment (Wade et al. 2014), potentially resulting in poor decisions, with environmental consequences (Lindenmayer 1999). Where indicator species are used to inform environmental management decisions, critical analysis of indicator species selection, application, and their role in the environmental planning process is required.

Environmental Impact Assessment (EIA) is a planning process that informs decisions regarding major proposed projects or other activities by evaluating the potential for adverse effects on environmental components of value or concern, commonly referred to as ‘valued components’ or VCs (Jay et al. 2007; Olagunju 2012). VCs can include any aspect of the environment of interest to the government, public, scientists, or Indigenous communities (e.g., water and air quality, and culturally, commercially, or ecologically important species and species assemblages; Lynch-Stewart 2004; CEA Agency Guide on
VC Selection 2016, 2018). Potential impacts on VCs can be assessed directly if feasible, or indirectly using indicators, such as species (Landres et al. 1988; Atkinson & Canter 2011; CEA Agency Guide on VC Selection 2016, 2018). Though the use of indicator species in environmental management and conservation has been broadly reviewed and critiqued for decades (e.g., Landres et al. 1988; Lindenmayer et al. 2002), there has yet to be a focused and in-depth investigation of how, in practice, indicator species are selected and applied to evaluate potential impacts on VCs in EIA. Given the broad application of the indicator species concept in environmental assessment and management, and the controversy surrounding the correct use of indicators, it would be beneficial to examine how indicator species are being used in the EIA process to inform decisions that have ramifications for valued aspects of the environment.

Canada supports one fifth of the world’s forests, one quarter of all wetlands, and over 70,000 known species (Federal, Provincial and Territorial Governments of Canada 2010). However, major proposed development projects pose significant threats for species and ecosystems in Canada (Venter et al. 2006; Favaro et al. 2014; Palen et al. 2014; Green et al. 2017). A Natural Resources Canada review in 2017 identified 471 major projects across the energy, forestry, and mining sectors planned or under construction in Canada (NRCan 2017). Such project proposals are typically assessed through an EIA process that is administered federally, provincially, or by both governments (i.e., coordinated EIAs).

EIA in Canada has evolved over nearly a century of environmental impact investigations (e.g. British Columbia Trail Smelter of the 1930s; Couch et al. 1981), and 50 years of legal regimentation. Since the first formal Canadian federal EIA process was established in the early 1970s (Environmental Assessment and Review Process, 1973), there have been several other legal iterations that have led to the current Canadian Environmental Assessment Act, 2012 (CEA Act 2012 or the Act, S.C. 2012, c.19, s.52). Under this Act, a typical EIA conducted by the Canadian Environmental Assessment Agency (CEA
Agency) follows a strict sequence of steps that starts with a decision as to whether or not an EIA is required for a proposed project. If an EIA is required, the regulator prepares and issues project-specific EIA guidance to the proponent. The proponent then conducts studies, often with the services of EIA practitioners (i.e., environmental consultants), to assess whether there is the potential for the project to have significant adverse effects on VCs, after applying proposed mitigation measures (i.e., residual effects). In addition, if residual effects are expected to occur to particular VCs, those VCs are included in a cumulative effects assessment that evaluates “changes to the environment [or VC] that are caused by an action in combination with other past, present, and future human actions” (Hegmann et al. 1999, p.3). The proponent compiles the environmental assessment studies and cumulative effects assessment into an Environmental Impact Statement (EIS), which the proponent submits to the regulator. The regulator then reviews the EIS and submits a summary report of the potential project impacts and recommendations to the Minister of the Environment, who then decides whether the project is likely to have significant adverse environmental effects. If the Minister decides that the project is likely to have significant adverse environmental effects, the Governor in Council (the Governor General acting on the advice of federal Cabinet) decides whether the significant adverse effects are justified in the circumstances (summarized from CEA Agency 2018; Figure 1).

Despite decades of EIA policy and practice, there are still issues to be addressed in the Canadian EIA regime (e.g., Gibson 2012; Olagunju 2012; Lees et al. 2016; Government of Canada 2017). The CEA ACT 2012 has been under scrutiny since its enactment. Gibson (2012) predicted only days after the Act came into effect that the EIA regime would likely result in discretionary, non-transparent, ineffective, inefficient, and unfair assessments “despite interests focused only on faster and cheaper” (Gibson 2012, p.186). In 2016, the Minister of Environment appointed an expert panel to review federal EIA processes. The panel traversed Canada and invited submissions or presentations from all sectors (industry, Indigenous groups, not-for-profit, government, and public) to
gather insight about the effectiveness of the current EIA regime (Government of Canada 2017). Based on hundreds of submissions, the panel and independent researchers found the current federal EIA regime to be ineffective and lacking transparency and scientific rigour (Government of Canada 2017; Jacob et al. 2018). Furthermore the panel identified a lack of federal capacity to support EIA, and frequently referred to gaps in regulatory guidance: “There is a need for comprehensive review of federal expert research initiatives, standards and guidance to support EIA” (Government of Canada 2017, p.43). While the panel called for more transparency, scientific rigour, and regulatory guidance, it did not provide specific ways to address the issues identified in EIA. Lack of transparency and questionable assessment methods in EIA documents are associated with uncertainty and delays at the expense of both regulators and proponents (Beanlands & Duinker 1983; Greig & Duinker 2011; Gibson 2012). Hence, there is a critical need to enhance transparency and rigour, and ultimately improve the integrity and credibility of the EIA process.

Inappropriate uses of indicator species may contribute to the lack of transparency and scientific rigour of the EIA process. One study on the selection of VCs and indicators for watershed-based cumulative effects assessments in Saskatchewan suggested that indicator selection was subject to regulator (i.e., government) and proponent bias, and was not scientifically-informed (Ball et al. 2012). However, this finding was based on EIAs regulated by different authorities (province vs. federal vs. coordinated) within a single watershed and one type of ecosystem (aquatic). It is of interest to know how prevalent such problems regarding indicator use are in federal EIAs across Canada, and in other types of ecosystems. Canadian EIA is currently under federal review, and the Canadian Senate is considering a new Impact Assessment Act, Bill C-69 (Parliament of Canada 2018). The expert panel on EIA in Canada identified the need “to restore public trust in EIA; introduce new, fair processes, and; get resources to market” (Government of Canada 2017, p.2). Therefore, new research catered towards understanding issues of the current federal EIA regime would be timely and informative for the implementation of new EIA policies and practices.
In this paper, I assess the use of indicator species to evaluate potential impacts on valued terrestrial species (i.e., wildlife VC) across recent Canadian federal EIAs for ten proposed major development projects. Specifically, I aim to answer two research questions: 1) Are indicator species used in a transparent and rigorous way? and; 2) Is there regulatory guidance for using indicator species reliably?
The proponent submits a description of project components and activities, and baseline environmental conditions; the regulator reviews the project description and determines whether a federal EIA is required according to CEAA 2012.

If an EIA is required...

The regulator drafts, finalizes and administers project-specific guidelines for conducting an EIA and preparing an Environmental Impact Statement (EIS) based on federal expert input, and comments from the public, Indigenous groups and stakeholders.

The proponent (and hired environmental consultants) conducts environmental studies and prepares an EIS in compliance with the regulator’s guidelines; the proponent submits the EIS to the regulator for review; the regulator may request further information or changes to the EIA based on federal expert, public, Indigenous group, or stakeholder comments; the proponent revises and resubmits the EIS if necessary.

If the EIS meets regulator requirements...

The regulator drafts an EIA report including: regulator conclusions regarding potential environmental effects of the project, mitigation measures, remaining adverse environmental impacts expected, and follow-up program requirements; the report is updated to incorporate public, Indigenous group, and stakeholder comments, and finalized.

The EIA Report is submitted to the Minister of the Environment; the Minister posts decision about whether there will be likely significant adverse impacts of the project; the Governor in Council (Cabinet) determines whether likely significant adverse impacts are justified or not; Minister posts EIA decision with conditions the proponent must comply with for the project to proceed.

Figure 1  Key milestones in federal Environmental Impact Assessment
This diagram depicts the detailed stages of the EIA process under CEA Act 2012 (or CEAA 2012). The symbol represents periods of public consultation. The graphic was obtained from a Government of Canada open-source site (CEA Agency 2018).
Chapter 2. Methods

2.1. EIA Sample

I focused on federal EIA projects (henceforth ‘projects’) that were assessed after the enactment of the current federal legislation, the CEA ACT 2012. Given that there are several ways to conduct a federal EIA, I chose one type of EIA for consistency of process evaluation: federally and provincially coordinated EIAs, where the Canadian Environmental Assessment Agency (CEA Agency or Agency) is the regulator or responsible authority (henceforth referred to as ‘regulator’). This excludes EIAs reviewed by the National Energy Board (NEB) or the Canadian Nuclear Safety Commission (e.g., pipelines, oil exploration, and nuclear generators), which operate under additional Acts and licensing requirements in congruence with CEA ACT 2012. Furthermore, I only included those projects that were currently under review (i.e., all impact assessment documents have been submitted to the regulator) or were complete (the Minister of Environment had issued a decision statement to approve or deny the project) between the dates of 6 July 2012 and 1 January 2017. This was to ensure that the necessary information was available for evaluation at the time of my analysis. Furthermore, I narrowed the scope of my study to evaluate the use of indicators for assessing project impacts on terrestrial wildlife. This precluded offshore projects such as marine oil exploration drilling, port terminal expansion, and deep-water multi-purpose wharf projects. An additional four Quebec-based projects were removed due to the lack of English translations for some of the EIA documents.

After inputting criteria into the ‘Advanced Search’ engine of the Canadian Environmental Assessment Registry (CEA Registry), I identified 16 candidate EIAs (Table 2). Of these, I selected at least one project from each of the seven provinces that had a candidate EIA. If a province had more than one candidate EIA, I selected two projects so I would be able to compare EIA practices within provinces. I also sought to include representation of different types of projects.
Because there was only one EIA for three project types (liquefied natural gas or LNG terminal, an all-season road, and an hydroelectric dam), I included all of these EIAs. Mine (or quarry) projects were more numerous across jurisdictions (13 of 16 candidate EIAs), therefore, I randomly selected among these projects where possible for each jurisdiction, resulting in seven mine projects in my final sample (See Figure 2 for a map of Canadian jurisdictions and selected EIA projects). Selected projects varied in many aspects, including project size, project lifetime, proposed resource output, and environmental history of the area (details for selected projects are presented in Appendix A).

I excluded several jurisdictions from my analysis. No federal EIAs of any type had commenced under CEA ACT 2012 in northern jurisdictions (i.e., Yukon, NorthWest Territories and Nunavut) or Prince Edward Island (PEI), and, therefore, could not be evaluated. Alberta EIAs were not included because the federal EIAs that took place in that province were either regulated by the NEB, evaluated by review panel, or had not yet submitted documentation for regulatory review. Lastly, only one federal EIA was posted for New Brunswick, but was excluded because it also regulated by the NEB. The absence of candidate EIAs in these regions does not mean that there are no major proposed developments for these areas. Rather, this could be due to the restricted scope of CEA ACT 2012 (proposed projects that would have previously triggered a federal EIA may now be subject only to provincial or territorial review), the redistribution of regulatory authority over certain types of projects from the CEA Agency to the NEB and Canadian Nuclear Safety Commission (Gibson 2012), or the relatively short time-frame (4.5 years) between the enactment of CEA ACT 2012 (6 July 2012) and my sample cut-off date (1 January 2017).

My sample size is comparable to other Canadian federal EIA studies that reviewed 11 (Olagunju 2012) and 12 (Lees et al. 2016) projects. All sample sizes were constrained by researchers’ EIA sample criteria (e.g., particular province, type of project, timeframe), or poor access to information. Though small sample sizes cannot produce inferential statistics, it is still possible to detect trends,
identify good and poor practices in EIA, and make recommendations (Olagunju 2012; Lees et al. 2016).

Table 2  Candidate EIA projects

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Candidate EIA Project</th>
<th>Selected for Review (Yes / No)</th>
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<tbody>
<tr>
<td>British Columbia</td>
<td>1. Blackwater Gold Mine</td>
<td>Yes</td>
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<tr>
<td></td>
<td>2. Brucejack Gold Mine</td>
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<td></td>
<td>3. Murray River Coal Mine</td>
<td>No</td>
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<td></td>
<td>4. Pacific NorthWest Liquefied Natural Gas Terminal</td>
<td>Yes</td>
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<td>5. Red Mountain Underground Gold Mine</td>
<td>No</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>6. Tazi Twé Hydroelectric Dam</td>
<td>Yes</td>
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<tr>
<td>Manitoba</td>
<td>7. Project 4 - All-Season Road Connecting Berens River to Poplar River First Nation</td>
<td>Yes</td>
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<tr>
<td>Ontario</td>
<td>8. Côté Gold Mine (Pilot Study)</td>
<td>No</td>
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<td></td>
<td>9. Goliath Gold Mine</td>
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<td></td>
<td>10. Hardrock Gold Mine</td>
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<td></td>
<td>11. Magino Gold Mine</td>
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<td></td>
<td>12. Rainy River Gold Mine</td>
<td>Yes</td>
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<tr>
<td>Quebec</td>
<td>13. Whabouchi Lithium Mine</td>
<td>Yes</td>
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<tr>
<td>Nova Scotia</td>
<td>14. Black Point Quarry</td>
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<td></td>
<td>15. Beaver Dam Gold Mine</td>
<td>Yes</td>
</tr>
<tr>
<td>Newfoundland / Labrador</td>
<td>16. Howse Property Iron Mine</td>
<td>Yes</td>
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Figure 2  Map of selected EIA projects
Symbols represent the types of projects (แร mines and quarries; LNG terminal; hydroelectric dam; and road). The precise locations of projects occur at the centre of each symbol. This map was produced using R Studio statistical software (Version 1.1.423; R Core Team 2018), with the “ggplot2” package (Wickham 2016).
2.2. Data Sources

I obtained all federal EIA documentation for each project from the CEA Registry, including project descriptions (i.e., project proposals), Environmental Impact Statements or EIS (i.e., proponent’s evaluation of potential impacts on the environment), and supporting technical appendices. Furthermore, I gathered all relevant regulatory guidance available through government EIA websites that outlined regulator expectations for conducting an EIA and preparing an EIS. Because my sample EIAs were federally and provincially coordinated, I incorporated both sources of government guidance. This included project-specific guidance (e.g., CEA Agency Environmental Impact Statement Guidelines or EIS Guidelines issued by the regulator for the specific project), and general guidance documents that were applicable to all EIAs (e.g., operational policy statements). Though proponents did not necessarily cite the latter in their EIS reports, I included all relevant regulator-generated documents to represent the EIA guidance that was openly available for proponents (See Appendix B for a list of acquired documents).

2.3. Pilot Study

Prior to developing a systematic review protocol, I reviewed a pilot EIA case study (Côte Gold Mine). Based on this review, I constructed comprehensive Excel spreadsheets that represented both quantitative and qualitative information regarding the use of indicator species. While this pilot EIA was useful in developing my protocol, I did not include it in my final analysis as it consisted of separate EIAs for two project components (i.e., mine and transmission line), that was unique compared to the other EIAs in my study, and would have resulted in redundancy or discrepancy in data collection. For instance, the separate EIAs for the project components of Côte Gold Mine were conducted so differently, that I was not able to make clear determinations about VC and indicator selection practices.
2.4. Criteria for Transparency and Scientific Rigour

After a review of the literature, I identified several common recommendations for transparent and scientifically rigorous selection and application of indicators (Table 3). Transparency in EIA is defined by the expert panel as “[the ability] to see and understand how the process is being applied, how assessments are being undertaken and how decisions are made” (Government of Canada 2017, p.13). In the panel review, emphasis is placed on improving transparency through public participation, access to information, and explicit reasoning for EIA decisions (Government of Canada 2017; Jacob et al. 2016). However, where transparency has been of most value with regards to indicators is in the explicit justification of indicator selection and application methods (Niemeijer & de Groot 2008; Gibbons et al. 2009; Feld et al. 2010; Hoare et al. 2010; Kershner et al. 2011) to inform conservation or environmental management decisions. Therefore, I focused on methodological transparency for using indicators to evaluate impacts on wildlife VC s that abides by a fundamental principle of the scientific research method: methods are clear and explained prior to implementation (Kothari 2004). I defined methodological transparency operationally to include two parameters: formality and explicitness. Formality refers to whether (formal indication) or not (informal indication) an indicator was formally presented in a methods section prior to the presentation of EIA results (e.g., the ‘EIA Methods’ section or at the start of a VC assessment section). Explicitness refers to whether (explicit indication) or not (implicit indication) the practice of indication was clear with the use of indicator terms (e.g., focal species terms in Table 1) or an indication statement (e.g., “Species X represents impacts on Species Y”). Formality and explicitness are not mutually exclusive parameters, therefore, any combination can interact to reflect varying levels of transparency, as illustrated in Figure 3.
Table 3  Summary review of parameters for transparent and rigorous indicator practices

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<tr>
<td>1. Clearly define 'indicator' terms</td>
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<td>2. Establish clear objectives of the indicator</td>
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<td>3. Choose an indicator selection framework</td>
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<td>4. Identify selection criteria</td>
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<td>5. Evaluate candidate indicators</td>
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<td>6. Monitor indicator relationships</td>
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<td>7. Inform adaptive management</td>
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A science-informed EIA is “entirely based on evidence that is, and is seen to be, unbiased, accurate, accessible and complete” (Government of Canada 2017, p.14). Using this statement and the parameters described in Table 3, I operationalized scientific rigour to mean the inclusion of: 1) clear objectives and measures for the indicator and indicated phenomenon; 2) an indicator selection framework (selection criteria and evaluation of indicator candidates); 3) a detailed monitoring plan to evaluate indicator relationship hypotheses; 4) evidence that indicators are used to inform adaptive management; and 5) empirical justification for the use of indicators and generalizations made with regards to indicators or indicated phenomena (i.e., citing empirical studies). While indication inherently involves generalization or extrapolation of results from indicator species to other indicated wildlife, rigorous application of
indicators requires that assumptions be verified, either with support from empirical evidence, or monitoring programs (e.g., Peters et al. 1997).

2.5. Systematic Review

I reviewed a total of 173 EIA documents, including regulatory documents (i.e., government EIA guidance) and technical documents (i.e., proponent impact statements and appendices) for information about the selection and application of indicator species (Appendix B).

For the purposes of this study, a wildlife indicator was any wildlife species or species assemblage that was used to make inferences about ‘indicated’ wildlife species assemblages, identified as wildlife VCs (e.g., ‘Migratory Birds’) and wildlife sub-components (e.g., ‘Songbirds’ and ‘Waterbirds’). Perceived impacts to wildlife VCs ultimately inform the EIA decision, whereas perceived impacts on indicators and sub-components contribute to understanding about impacts on wildlife VCs. While wildlife VCs can also be individual species (e.g., ‘Grizzly Bear’), I found that species identified as VCs tend to be directly assessed, whereas species assemblages may require indirect means of evaluation (i.e., indicators). Therefore, I focused on wildlife groups as VCs and sub-components, collectively referred to as wildlife components. Where sub-components are used, indicators represent sub-components that, in turn, represent VCs. This application of indicators across a hierarchy of species classifications is referred to as nested indication. I also included non-wildlife VCs (e.g., Environmental Health) that had wildlife Sub-Components (e.g., ‘Health of Raptors’) to which a wildlife indicator was applied (e.g., ‘Bald Eagle’). Each individual relationship between a wildlife indicator and indicated wildlife component was referred to formally as a wildlife indication (see Figure 4 for a diagram of nested indication and wildlife indication). Wildlife indications are also described in the text as indicator relationships or indicator hypotheses.
Figure 4  Wildlife indication schematic
This schematic illustrates how wildlife indicators are used to ultimately represent impacts on wildlife VCs. If sub-components are present, wildlife indicators are used to represent impacts on wildlife sub-components, and consequently, VCs through nested indication.

In my systematic review, I first searched for indicated wildlife components identified within the EIS. I then searched all EIA documentation (regulatory and proponent documents) for information about indicators using NVivo qualitative data analysis software (QSR International Pty Ltd. Version 11 2015), by conducting a word query for indicator terms (“focal” OR “indicator” OR “guild”, “target species” OR “surrogate” OR “umbrella” OR “representative species” OR “keystone” OR “flagship” OR “bioindicator” OR “sentinel” OR “proxy” OR “receptor”). I then extracted key information for indicator application by using standardized review questions (Table 4). Much of the data collected were qualitative in nature, such as the wildlife component categories (e.g., ‘Forest and Grassland Birds’) and indicator species (e.g., ‘Canada Warbler’), whether indicators were species at risk (e.g., special concern, threatened, or endangered), and what rationales were provided for selecting them. Quantitative
data include information like the number of species that were expected or observed in the project impact area (i.e., area in or around the project where indirect or direct impacts on wildlife VCs are anticipated to occur), according to the EIA. I was as objective as possible when identifying and interpreting both quantitative and qualitative information by having a standard protocol as described above and in Table 4, and a carefully constructed Excel spreadsheet. Appendix B highlights the type of information extracted from each EIA document.

For my analyses, I quantified data by tallying ‘presence’ of qualitative parameters (e.g., number of particular indicator selection rationales), and keeping track of ‘absence,’ ‘no data,’ or ‘not applicable’ information in MS Excel. As well, I incorporated details of qualitative data in neighbouring columns for context (refer to Appendix C for accessing raw data). I calculated descriptive statistics with pivot tables in Excel and conducted a qualitative exploration of the data with R Studio statistical software (Version 1.1.423; R Core Team 2018).
Table 4  Review questions for gathering indicator selection and application data from EIA documents

Are indicators being used in the EIA? If so,
- What are the wildlife VCs?
- What are the wildlife sub-components, if any?
- What are the wildlife indicators? Are they groups or species? Are they species of socio-political interest (e.g., species at risk)?
- How many species that are confirmed in the proposed project impact area are encompassed in wildlife components or indicator groups?

How are wildlife indicators referred to, if at all?
- What indicator terms are being used, if any?
- Are there definitions provided for indicator terms?

Are indicators applied in a transparent way?
- Formality parameter:
  - Are the indicator species or groups used in the EIA present in the EIA methods prior to presentation of results? (i.e., formal indication); or
  - Do indicators only appear ad hoc during the presentation of results? (i.e., informal indication)
- Explicitness parameter:
  - Is there a statement of the relationship between the indicator and indicated component? (i.e., explicit indication); or
  - Is indication implied through the ad hoc description of potential impacts for species or groups in the absence of indicator terms or indicator statements under a wildlife component section of the EIA? (i.e., implicit indication)

Is there a rigorous indicator selection framework in place?
- Are there formal indicator selection criteria?
- Are candidate indicators identified and evaluated for final selection?

Are assumptions or uncertainties for indicator application identified, verified, and tested?
- Is evidence cited from the empirical literature to support the selection and application of indicators?
- In the case of indicator groups and indicated components, are generalizations regarding potential impacts within or between these groups explained and verified with empirical evidence?
- Are monitoring plans described to evaluate the proposed causal relationship between indicators and indicated components?

Are indicators used to inform an adaptive management framework?
- Are indicators described in adaptive management plans to inform project mitigation of impacts on wildlife components?

Does regulatory guidance provide instructions for indicator selection and application?
2.6. Replicability Study

Though I was the only reviewer involved in the analysis of all EIAs, there is potential for inconsistency between EIA reviews. To address this, I conducted a replicability study, following the approach of an extensive review of EIAs in the European Union (Drayson et al. 2017). I repeated my analysis for the first-reviewed EIA (i.e., Blackwater) eight months after I first reviewed it. I then compared results of the two reviews using the alternative (one-tailed) hypothesis that the proportion of identical answers between reviews is greater than 95%. The results rejected the null hypothesis that the proportion of identical values between the first EIA review, and the re-review was less than or equal to 95%. Of 199 data points for Blackwater, there were only 8 points of difference in the analysis (96.4% identical). Therefore, my methods have high replicability.

2.7. Potential Limitations

Other EIA studies highlight the difficulties of comparing across EIAs because of differences when referring to VCs (e.g., Ball et al. 2012; Olagunju 2012). I found the same issue, as some studies had used different terminology (e.g., Environmental Component). In cases where VC terminology differed, I identified the wildlife VC as the highest level of wildlife categories for which potential impacts and mitigation measures were summarized. I treated any lower level of organization under this category as a sub-component or indicator. For example, what Tazi Twé describes as wildlife VCs (e.g., ‘American Marten’) were in fact used as indicators for broader environmental components, or wildlife ‘Groups’ (e.g., ‘Furbearers’; Tazi Twé EIA, Table 15.1-1). In this case, ‘Furbearers’ is at the highest level of organization for which impacts are postulated using ‘American Marten’ as an indicator.

Furthermore, as I only reviewed designated wildlife sections of the EIA, I did not incorporate any additional indications that may have been made between other EIS sections that are relevant to wildlife, like ‘Terrestrial Vegetation’ or
‘Wetlands’ sections. For instance, non-animal indicators that might have occurred in those sections (e.g., ‘Whitebark Pine Habitat’ as an indicator for ‘Clark’s Nutcracker’, or ‘Presence of Tree Cavities’ as an indicator for ‘Bats’) could have informed impacts on wildlife on a more habitat-specific level. However, I scoped this research only to include terrestrial animal indicator species and their respective indicated wildlife components.
Chapter 3. Results

3.1. What wildlife components did EIAs assess?

In general, EIAs identified wildlife VCs as broad wildlife categories (e.g., ‘Wildlife’ and ‘Species of Concern’) or entire taxonomic groups (e.g., ‘Amphibians’, ‘Bats’ and ‘Birds’). The number of wildlife species encompassed by defined VCs, and identified as occurring in the project impact area, ranged from 2 to 196 (mean = 50 species per VC; n = 21 VCs; 10 projects). Accordingly, federal and provincial guidance documents also defined wildlife VCs quite broadly to mean any level of biological classification (individual species to species assemblages) of interest to the public (e.g., ‘All Terrestrial Wildlife’; CEA Agency Guide on VC Selection 2016, 2018). Similar to VCs, wildlife sub-components were defined on a relatively high level (e.g., ‘Mammals’ and ‘Migratory birds’), representing between 2 and 137 species confirmed within project impact areas (mean = 42 species per sub-component, n = 11 sub-components; 6 projects).

However, the majority of sub-components were relatively small categories of wildlife (e.g., ‘Large Herbivores’, ‘Waterbirds’ and ‘Furbearers’) representing between 3 and 55 species each (mean = 21 species per sub-component; n = 20 sub-components; 5 projects). Wildlife components with fewer species represented cryptic, less diverse, or rare species (e.g., ‘Amphibians’, ‘Bats’, ‘Ungulates’ and ‘Species at Risk’). Despite covering such a broad range of species with wildlife VCs, ‘Biodiversity’ as a general category was not identified as requiring formal assessment (i.e., as a VC) in any of the EIAs examined.

3.2. Were indicators used to evaluate impacts on wildlife components?

All projects used wildlife indicators, though to different extents, with a total of 137 wildlife indications summed across all projects. Figure 5 illustrates the variable number of wildlife indications among projects, as well as both among and within provinces. However, variability in number of wildlife indications did not
appear to coincide with the geographic size of the project or number of confirmed wildlife species in the project area.

Figure 5  Total number of wildlife indications across projects and provinces

This figure shows the number of wildlife Indications (i.e., the number of indicator relationships made, not the number of different wildlife indicators used) across projects and provinces, and how it relates to the size of the project area or the number of species confirmed within the project area. (*) means the project area was estimated from a map of the project footprint, and (n.d.) means no data was provided. Symbols represent the types of major development projects (mines; LNG terminal; hydroelectric dam; and road).

Wildlife indicators were typically used to infer the responses of wildlife VCs to potential impacts of a project. Although I did not identify the potential impacts evaluated for each wildlife VC, some examples of potential impacts on wildlife considered in EIAs were: direct mortality (e.g., collisions with vehicles, buildings, power lines), indirect mortality (e.g., changed predator-prey dynamics or increased access to hunting areas), habitat loss and fragmentation (e.g., forest clearing activities), altered dispersal or movement (e.g., linear infrastructure), and general disturbance (e.g., noise and light). Examples of such inferences or
indicator hypotheses made in EIAs are demonstrated in Figure 6. Individual indications can be discerned by following the coloured connections between indicators at the dashed black line and indicated components at the solid black line. For example, ‘Common Snapping Turtle’ at the top of the diagram is linked with a green line to ‘Herptiles’ (or amphibians and reptiles) at the bottom of the diagram, meaning: “if there are anticipated impacts of a project on ‘Common Snapping Turtle’, then there are anticipated impacts of the project on all ‘Herptiles.’” Not all connections occur between the dashed and solid lines, however. Connections made within the solid black line region demonstrate the linkages between wildlife VCs and sub-components. Figure 6 also shows the relative frequency of indicator and indicated component use by the size of the coloured boxes affiliated with a particular species or species assemblage. For example, ‘Waterfowl’ and ‘Moose’ were relatively common indicators, while ‘Wildlife’ and ‘Migratory Birds’ components were indicated particularly often.

The purpose of my research is not to conduct an in-depth analysis of the merit of each indication, but to demonstrate trends in the selection and application of indicators. Therefore, I will not comment on each indicator relationship presented in Figure 6, but instead will highlight a couple of key findings from this illustration. Many indicators are species at risk, (depicted in red) and are used to represent other species at risk or broader wildlife groups. Also, invertebrate components (e.g., ‘Insects’) are disproportionately small compared to the number of species that would be encompassed in these categories. In other words, very few indicator species are used to represent a hugely diverse group of wildlife.
Figure 6  Example indicator relationships observed across projects (formal explicit indicators only)

This diagram illustrates formal explicit relationships (only used in Blackwater, Tazi Twé, Project 4 and Hardrock) between indicators (dashed black line) and indicated wildlife components (solid black line). Light red indicators are those of federal or provincial conservation status, whereas grey indicators represent common species or species assemblages. ‘Species of Concern’ is also an indicated component that encompasses all potentially impacted species at risk. The size of the boxes indicates the relative use of a particular wildlife component or indicator in wildlife indications across projects.
3.3. How were indicators labeled and defined?

EIAs varied in their use of indicator terms (listed on page 17), from none at all (Rainy River, Whabouchi, Beaver Dam, Black Point, and Howse Property), to the majority of terms being used (Blackwater). For the five EIAs that used indicator terms (Project 4, Pacific NorthWest, Blackwater, Hardrock, and Tazi Twé), “indicator”, “representative species”, and “surrogate”, were used most frequently (3 to 4 projects), while “focal species”, “proxy”, “sentinel”, “receptor”, and “bioindicator” (1 to 2 projects) were less common. All project-specific federal guidance documents (i.e., CEA Agency EIS Guidelines) used the term “indicator” when referring to indicators of ecological health and integrity. Other general federal guidance documents also used the terms “surrogate” and “indicator” (CEA Agency Guide on VC Selection 2016, 2018). Only one project-specific provincial guidance document (from British Columbia) used indicator terms; these were “indicator”, “representative species”, and “surrogate” (BC VC Guide, BC EAO 2013). The terms “indicator”, “representative”, and “surrogate species” were often used interchangeably within EIAs (e.g., Blackwater, Hardrock and Tazi Twé). Synonyms were also used in cases where indicator terms were associated with a particular function, such as representing impacts of environmental contamination (e.g., “sentinel”, “receptor” and “bioindicator”; Tazi Twé, Project 4 and Hardrock).

While all projects used wildlife indicators, only one EIA – Blackwater – provided definitions for the use of indicators. One provincial (BC) government document (BC VC Guide, BC EAO 2013) and one federal guidance document (CEA Agency Guide on VC Selection 2016, 2018) also provided definitions. Indicators were defined as “…aspects of the VC used to understand and evaluate the potential effect on the VC” (Blackwater Terrestrial VC Selection Chp 5.4.1, p.6), “…metrics used to measure and report on the condition and trend of a VC” (BC VC Guide, BC EAO 2013, p.12), and “…surrogate to predict environmental effects on other species or another ecologically justifiable grouping” (CEA Agency Guide on VC Selection 2016, 2018). There are two different
interpretations of an indicator’s purpose observed here: 1) the use of indicators to report and measure current condition and trends of the environment or VC (i.e., descriptive indicator); and 2) to predict the future state of the environment or VC (i.e., prescriptive indicator; Heink & Kowarik 2010).

3.4. Were indicators transparent?

Projects varied considerably in the level of transparency in reporting their use of wildlife indicators, both within and among provinces. For example, Hardrock strictly used formal and explicit indication, whereas Rainy River primarily applied informal and implicit indication; both projects are based in Ontario. Of all wildlife indications, 60% (n = 82 of 137; 7 projects) were included formally in EIA methods sections (i.e., formal indications; black bars, Figure 7; see Glossary for definitions), whereas 40% of indications (n = 55 of 137; 8 projects) only appeared ad hoc within other areas of the EIA, including technical appendices (i.e., informal indications; grey bars, Figure 7). With regards to stated indicator relationships, I found that 66% (n = 91 of 137; 5 projects) were stated explicitly in the EIA documents (i.e., explicit indications; top, Figure 7), while 34% (n = 46 of 137) of wildlife indications did not use indicator terminology or make clear statements about the implied indicator relationship (i.e., implicit indication; bottom, Figure 7). Interestingly, I also noticed a geographical trend, where EIAs in western provinces tended to identify indicators explicitly, while EIAs in eastern provinces implied their use in EIA.

The Beaver Dam EIA provides an example of implicit indication. In the absence of any indicator terminology, indicator statements, or indicator selection criteria, this EIA described potential impacts on ‘Common Snapping Turtle’ and ‘Eastern Mainland Moose’ in the ‘Priority Terrestrial Fauna’ wildlife component section of the EIS. Furthermore, potential impacts on ‘Common Nighthawk’, ‘Barn Swallow’, and ‘Bank Swallow’ were described in the ‘Priority Birds’ section (Beaver Dam EIA). Collectively, ‘Priority Terrestrial Fauna’ and ‘Priority Birds’ represented 27 confirmed species in the impact area, with an additional 27
species expected to occur in the area. Given that numerous other species of concern were confirmed or had the potential to occur in the impact area, but only five species were discussed in detail, the focus on these five species implies that they were used as indicators for up to 49 other species of concern that may be in the area.

Given the varied transparency (i.e., formality and explicitness) across projects and jurisdictions, I evaluated total indications (i.e., all formal / informal / explicit / implicit) and formal / explicit indications separately to observe whether there was an effect of indicator transparency, to test for differences in indicator selection or application.

![Figure 7 Transparency of wildlife indications](image)

This figure shows the relative transparency of wildlife indications across projects and provinces. Black bars represent formal indications; grey bars represent informal indications. Explicit indications are above the dashed line; implicit indications are below the dashed line.
3.5. How and why were indicators selected?

A formal framework for selecting indicators would include defined selection criteria, explicitly stated indicator candidates, and clear evidence supporting the indication. Only one project used aspects of such a formal selection framework – Blackwater. Indicator selection criteria presented in Blackwater for indicators were: relevance, responsiveness, measurable, predictable, and practical (BC VC Guide, BC EAO 2013; Blackwater Terrestrial VC Selection Chp 5.4.1). However, a formal evaluation was not conducted to select among indicator candidates using these criteria, as all candidates were included in the final EIA.

How and why were indicators selected in the absence of formal criteria? In the EIA documents, it was unclear how indicators were selected because there were no formal methods of indicator selection presented. However, in many cases I was able to infer why indicators were selected, as most proponents (7 of 10) did provide a rationale or justification for the use of a particular indicator. For instance, Tazi Twé outlined rationales for selecting indicators in a table, where ‘American Marten’ was chosen as an indicator for ‘Furbearers’ because it is a “valued economic species and a mid-trophic predator in boreal ecosystems” (Tazi Twé EIA, Table 15.1-1). Quebec and Nova Scotia EIAs did not provide rationales for indicator selection, potentially because of their implicit (non-transparent) use of indicators. I grouped various rationales for indicators into three categories: ‘ecological’ (e.g., ecosystem function, life history traits or habitat requirements), ‘relevance / feasibility’ (e.g., high abundance, sensitivity to impacts, conservative approach), and ‘socio-political’ (e.g., species at risk, Indigenous or socio-economic value; Figure 8A). While conservation status may be considered an ecological rationale rather than a socio-political one, few ecological justifications were given for using species at risk as indicators (e.g., demonstrated to be indicators of ecological requirements of other species). Therefore, I interpreted the “species at risk” rationale as selection based primarily on legal obligation rather than on the ecological efficacy as wildlife indicators.
I calculated frequencies of rationales that were used across projects as relative weights, and standardized them for the number of wildlife indications per project, to allow for cross-project comparisons:

\[ Z = \frac{Y}{X} \]

Where \( Z \) = relative weight of rationale importance  
\( X \) = total # of indications per project  
\( Y \) = total # of times a rationale was used per project.

Rationales are ranked by these weightings in Figure 8.

There was variability in how important each rationale was across projects, illustrated in the relative differences in bar size in Figure 8A (i.e., the use of a particular rationale for all indicators within a project, the more important it is). Cumulatively, indicator selection was more often based on socio-political concerns rather than ecological traits (7.6 vs. 4.7, respectively; Figure 8B shows the sum of relative weights across rationales within each type of rationale). However, the greater relative frequency of socio-political rationales did not apply to all individual projects (e.g., Blackwater had more ecological than socio-political rationales).

Because of the apparent importance of socio-political value in indicator selection, I was interested to see whether socio-politically valued indicators were always accompanied by socio-political rationales. Of all wildlife indicators, 91% (n = 117 of 128) were identified to have socio-political value (i.e., were of management, conservation, economic, recreational, or cultural concern), but only 59% (n = 69 of 117) of those were accompanied with stated socio-political rationales. When looking only at formal and explicit indicators, however, 96% (n = 66 of 69) were of socio-political concern, and 86% (n = 57 of 66) of them were provided with a socio-political rationale. Transparent indicators (formal and explicit) placed more emphasis on socio-political rationales than all indicators combined (including informal and implicit; 86% vs. 59%, respectively).
Figure 8  Relative importance for indicator selection rationales across projects

Figure 8A lists various rationales that fall under separate categories. Ecological Rationales are those that are relevant to an indicator’s life history (e.g., migratory), habitat requirements (e.g., large or small home range), or role in the ecosystem (e.g., key function and representative niche or guild). Relevance / Feasibility Rationale speak to whether an indicator is considered an indicator of ecological phenomena (i.e., biodiversity, ecological health), whether there are perceived potential impacts on an indicator, and feasibility of an indicator (i.e., sensitive, present, abundant). Socio-political Rationales include management considerations such as socio-economic importance, Indigenous, public, or federal concern, and conservation status. ‘Other management’ encompasses international legislation (e.g., Migratory Birds Convention Act, 1994), and provincial or regional management plans. While ‘species at risk’ can be argued to fall under ‘ecological’ rationale, the proponent is obligated to assess and report any potential impacts on listed species, as they are federally and/or provincially protected. Different coloured bars show the sum of relative weights of rationale importance, standardized for number of indications: Figure 8B sums all of the bars from 8A to give a cumulative total of relative importance across rationale categories.
'Species at risk’ was the most cited rationale for choosing indicators (2.9 relative weight; Figure 8A). Congruently, ‘Species at Risk’ indicators represented 47% of total (n = 52 of 110) and 36% of formal and explicit (n = 22 of 60) indications. Other common rationales were ‘niche, guild, or habitat representation’ (2.1) ‘Indigenous value’ (1.75) ‘other / general potential impacts’ (1.45) and ‘socio-economic value’ (1.4; Figure 8A).

3.6. Did indicators have monitoring plans?

Monitoring plans are key for testing assumptions and validating indicator relationships (Landres et al. 1988; Girardin et al. 1999; Rempel et al. 2004; Urban et al. 2012). None of the EIAs provided monitoring plans for all indicators. Six projects, however, did allude to monitoring some, but not all indicators (usually individual species at risk). As indicators did not have detailed monitoring plans, they were not likely to be incorporated into an adaptive management process. Accordingly, indicators were not explicitly mentioned in environmental management plans. Furthermore, while regulatory guidance documents did require the proponent to monitor VCs where appropriate, they did not specify the need for monitoring plans to verify an indicator’s effectiveness and inform adaptive management.

3.7. Were decisions and assumptions concerning indicators justified with empirical evidence?

Interestingly, not one of the 137 wildlife indications was justified with citations of published empirical studies. However, one project (Project 4) did reference non-academic documents in their explanations:

“The bird and habitat associations [of wildlife indicators] provide ecological context for other species that occupy various habitat types and ecological niches across the region and would be proxies for over 80 other species of birds (Joro consultants 2015a)” (Project 4 Terrestrial Environment IA Chp 9, Joro Consultants 2016, p.35).
There was generalization of impacts within indicator groups and between indicated wildlife components in the absence of empirical justification. All projects incorporated suites of species within defined wildlife indicator groups. For instance, ‘Waterfowl’ was an indicator group that includes various species of ducks and geese. 20% of indications (n = 28 of 137) involved indicator groups, and approximately half of those were formal indicators. The number of group indications varied by taxonomic group (Table 5). Avifauna group indicators were particularly common among group indications (75%; n = 21 of 28). Invertebrates (e.g., ‘Dragonflies’ and ‘Butterflies’), herptiles (e.g., ‘Amphibians’), and ‘Mammals’ made up the remaining 25% of group indications (n = 7 of 28).

<table>
<thead>
<tr>
<th>Category of Indicator Groups</th>
<th>#</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avifauna</td>
<td>21</td>
<td>75.0</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>4</td>
<td>14.3</td>
</tr>
<tr>
<td>Herptiles</td>
<td>2</td>
<td>7.1</td>
</tr>
<tr>
<td>Mammals</td>
<td>1</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Wildlife indicator groups encompassed between 1 and 41 indicator species confirmed to occur within a project’s impact area. However, when I analyzed how wildlife indicator groups were evaluated, I found that perceptions of potential impacts were generalized across all species within indicator groups. Many of these groups were broad taxonomic categories (e.g. ‘Upland Breeding Birds’, ‘Mammals’ and ‘Herptiles’), not selected explicitly as representing a feeding guild or other ecologically functional assemblage. For instance, there are ecological guilds within ‘Waterfowl’, such as diving ducks and grebes, and
dabbling ducks and coots, that utilize resources in inherently different ways (Pöysä 1983).

There were only two cases (7%; n = 2 of 28 indicator groups) in which the proponent conducted in-depth assessments of all species within indicator groups. The Rainy River EIA evaluated impacts on the ‘Woodland Birds’ indicator group by assessing the potential displacement of 57 woodland bird species (Rainy River EIA & Mitigation Chp 7). In another case, the Whabouchi EIA estimated numbers of waterfowl pairs per species potentially impacted by mining activities for the 'Waterfowl' indicator group (Whabouchi EIA). Other EIAs did not explicitly discuss impacts on any particular species within an indicator group, but instead generalized impacts across the entire indicator group. Given that only 7% of indicator groups were assessed in a comprehensive way (i.e., all or most species within an indicator group were explicitly analyzed), the use of indicator groups did not imply that all species within those groups – or even any species within those groups – were individually assessed for potential impacts.

Additionally, impacts were generalized across indicated wildlife components through nested indication. 50% (n = 53 of 107; 7 projects) of all wildlife-specific indications (excluding environmental health VCs) were part of nested indications, and 81% (n = 43 of 53; 4 projects) of those were formal indications. For example, the Hardrock EIA selected ‘Bald Eagle’ as an indicator for the ‘Raptors’ sub-component, that in turn represented impacts on the ‘Wildlife and Wildlife Habitat’ VC (Hardrock Wildlife EIA Chp 13), thus being a three-layer indication. Another notable generalization between indicated groups was the use of a single dragonfly species and a single butterfly species as indicators for all ‘Dragonflies’ and ‘Butterflies’ (i.e., sub-components), and subsequently for all ‘Terrestrial Invertebrates’ (i.e., VC; Blackwater Invertebrates IA Chp 5.4.15). The Blackwater EIA confirmed 85 dragonfly and butterfly species in the project impact area, with an unknown, but certainly a large number of terrestrial invertebrate species likely occurring in the impact area, including all of the orders of invertebrates that are not dragonflies or butterflies. Hence, there is a high level
of uncertainty in predictions between impacts that are generalized within indicator groups, to impacts generalized across broad wildlife components that are inadequately represented.

3.8. Do regulatory documents provide guidance for using indicators?

Approximately half of the regulatory documents that I analyzed (n = 13 of 27) mentioned indicator terms. The majority of these (n = 12 of 13) were federal documents. Of the documents that promoted the application of indicators in EIA, there was very little instruction for using them. For example, a federal VC identification guide stated:

“In an EA, [an indicator species] may be used as a surrogate to predict environmental effects on other species or another ecologically justifiable grouping. While such an EA approach is reasonable and often used, one species may have a different degree of sensitivity to disturbances than others; therefore, caution is warranted in use of indicator species.” (CEA Agency Guide on VC Selection 2016).

Such vague guidance leaves EIA practitioners to interpret what constitutes “ecologically-justifiable” and how to implement “caution”. Federal departments responsible for terrestrial wildlife protection (i.e., Canadian Wildlife Service or CWS) also offered examples of potential wildlife indicators:

 “[Species at risk] may act as an early warning indicator of project-induced changes in the ecosystem, because they are sometimes more sensitive to disturbance by human activity [and] predicted changes to wildlife at risk are more likely to be significant and therefore influence project decisions.” (EIA SAR Best Practice Guide, Lynch-Stewart 2004).

CWS further suggested that other species be included in conjunction with species at risk, that indicators should be representative of the ecosystem, and should occur in sufficient numbers to be monitored, following the recommendations of Peters et al. (1997). While this guidance makes reference to
ecological literature, there was still no clear and direct federal instruction for the process of indicator selection, evaluation, or monitoring.

Nevertheless, federal agencies provided instructions in EIS Guidelines for evaluating and reporting impacts on VCs. Quotes from the Blackwater EIS Guidelines are presented in Table 6 and serve as an example of federal guidance applicable to all EIAs. A key observation is that federal guidance promotes proponent discretion over the conduct and presentation EIAs. However, despite proponent discretion over the EIA, there are many federal requirements that proponents must follow. For example, proponents must use and describe the best available methods for evaluating impacts on VCs, provide statistical error estimates for extrapolations of data, justify and test assumptions, identify and address gaps in scientific knowledge, state uncertainty and reliability of conclusions, and describe methods of monitoring and follow-up programs (summarized from Table 6).

Of 14 provincial guidance documents, only one provided explicit guidance for selecting and applying indicators, including selection criteria and the practice of nested indication (BC VC Guide, BC EAO 2013). The Blackwater EIA complied completely with that guidance. However, another EIA that was subject to the same instruction (Pacific NorthWest) did not incorporate the prescribed indicator selection criteria.
### Table 6  Federal regulatory instructions for evaluating and reporting impacts on VCs, based on Blackwater EIS Guidelines

<table>
<thead>
<tr>
<th>Quotes from the CEA Agency EIS Guidelines</th>
<th>EIS Guidelines Page #</th>
</tr>
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<tbody>
<tr>
<td>Except where specified by the Agency, the proponent has the discretion to select the most appropriate methods to compile and present data, information and analysis in the EIS.</td>
<td>p.1</td>
</tr>
<tr>
<td>The proponent will describe how the VCs were selected and what methods were used to predict and assess the adverse environmental effects of the project on these components.</td>
<td>p.12</td>
</tr>
<tr>
<td>If the baseline data have been extrapolated or otherwise manipulated to depict environmental conditions in the study areas, modeling methods and equations will be described and will include calculations of margins of error and other relevant statistical information, such as confidence intervals and possible sources of error.</td>
<td>p.17</td>
</tr>
<tr>
<td>In undertaking the environmental effects assessment, the proponent will use best available information and methods. All conclusions will be substantiated. Predictions will be based on clearly stated assumptions. The proponent will describe how it has tested each assumption.</td>
<td>p.28</td>
</tr>
<tr>
<td>In describing methods, the proponent will document how it used scientific, engineering, traditional and local knowledge to reach its conclusions. Assumptions will be clearly identified and justified. All data, models and studies will be documented such that the analyses are transparent and reproducible. All data collection methods will be specified. The uncertainty, reliability and sensitivity of models used to reach conclusions must be indicated. All significant gaps in knowledge and understanding related to key conclusions presented in the EIS must be identified. The steps to be taken by the proponent to address these gaps will also be identified.</td>
<td>p.28</td>
</tr>
<tr>
<td>[For Follow-up Programs] The proponent will describe the reporting methods to be used, including frequency, methods and format.</td>
<td>p.34</td>
</tr>
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</table>
3.9. Is it possible that more work is going into indicator selection, application, and regulation than is documented?

More work may have gone into the selection and application of indicators than was reflected in my analysis of EIS sections pertaining to terrestrial wildlife. For instance, I did not review ‘Public Consultation’ sections of the EIS that may have informed indicator selection. Alternatively, rigorous studies or consultation may have been left out of the EIA, in which case my analysis would reflect sloppy EIA reporting rather than of inadequacies in the analysis itself. If there were indeed more details about indicator selection, this would highlight the need for transparency in EIA documentation, as the process should be made accessible for all stakeholders (i.e., regulators, Indigenous groups, the public, and experts). Matrunola (2007) and Drayson et al. (2017) found that details for monitoring, follow-up, and environmental management are sometimes provided after a decision to approve the project has been made, post-EIA. Therefore, I searched for post-EIA annual reports (i.e., project progress reports by the proponent) in the CEA Registry. There were two published post-implementation annual reports at the time of my analysis (Whabouchi 2017 and Rainy River 2015). Of the two, only Rainy River outlined a detailed monitoring plan, for just a small subset of indicators that happened to be species of concern; the Eastern Whip-poor-will and the Bobolink.

With regards to regulatory guidance, any communication concerning indicators that was provided outside of EIA documentation was excluded from my original analysis. When I searched for communication between federal regulators and proponents in the CEA Registry, I found additional commentary and guidance for selecting VCs or indicators and developing monitoring plans – but only after the EIA was conducted and submitted for review. Commentary and guidance were in the form of information requests from the regulator to the proponent. Only five of 10 projects publicly posted information requests (Beaver Dam 2017, Howse Property 2016, Hardrock 2017, Project 4 2016, and Pacific
NorthWest 2015); two of which critiqued the use of indicators (Project 4 2016 and Hardrock 2017). These information requests highlight the issues raised in my analyses:

“The selected bird VCs do not adequately represent birds listed under the *Migratory Birds Convention Act, 1994 (MBCA)*. All bird species selected for assessment as VCs are included either on provincial or federal species at risk legislation. However, the nature of species at risk (low occurrence, low populations, potentially limited distribution, difficult to observe during surveys) means that these species are not representative proxies for more commonly occurring species that are listed under the *MBCA*. Species that are not at risk are also more likely to be resources for public and Aboriginal local users.” (Project 4 2016).

“Section 13.1.3 states that “the effects to [rabbit (i.e., snowshoe hare), ruffed grouse, great grey owl, beaver, marten, black bear, lynx, and wolf] are addressed through habitat assessments of similar species because they occupy similar habitat.” However, in the case of mammals, only moose, caribou and bats were retained as measurable parameters. Large mammals such as moose and bear have large home ranges, however, these species behave quite differently within those ranges and within an annual timespan. The other animals have insufficient similarities in terms of biology and life habits for large mammals to be an adequate surrogate species. Small mammals and other categories of wildlife should be assessed separately.” (Hardrock 2017).

The level of detail and content of the above comments demonstrates that: 1) regulators were paying attention to the use of indicator species and guiding their selection; 2) regulators did ask for ecological rationales for the selection of indicators; and 3) there was a contrast between guidance provided in information requests concerning the use of species at risk indicators, and the formal published guidance from the Canadian Wildlife Service (Lynch-Stewart 2004), where the latter condoned species at risk indicators, and the former outlined challenges associated with species at risk indicators.

Furthermore, all of the publicly posted information requests did indicate that monitoring plans were unsatisfactory. But regulator information requests did not necessitate the monitoring of indicators to verify indicator relationships.
Chapter 4. Discussion

The recent Canadian EIAs examined in this study consistently defined broad wildlife groups as VCs that encompassed numerous species for which direct assessment of potential responses of all species to project impacts would be infeasible. To address this, these EIAs often used an indirect means — indicators — to characterize impacts on wildlife VCs efficiently. However, indicators were reported, selected and applied inconsistently despite operating under the same federal EIA regime. Where there is variability in the conduct of an EIA, there is potential for discrepancies in the credibility and quality of information presented across EIAs. My results suggest that indicator species are not used in either a transparent or a rigorous way in the majority of EIAs that I reviewed. Furthermore, there is little regulatory guidance provided for using indicator species reliably. This not only has implications for the transparency and rigour of wildlife impact assessments, but also for the poor overall design of the current federal EIA system.

4.1. Tower of Indicator Babel: The potential for (mis)interpreting synonymous and undefined indicator terms

Speaking the same scientific language with a clear understanding of terminology and their definitions is necessary for effective communication and consistent interpretation of ecological concepts (Peters 1991). However, it appears that there is variable language for describing indicator use in EIAs, as there was a diversity of indicator terms (e.g., “surrogate”, “proxy”, “focal species”) within and across projects, as well as a general lack of, or inconsistent, definitions of indicators. Multiple terms and lack of a clear definition for indicators can result in disparate interpretations of meaning among stakeholders (Heink & Kowarik 2010). The absence of indicator definitions in the majority of EIAs and regulatory documents I reviewed suggests that their meaning was considered a priori or common knowledge. However, in the three documents (of 173) where
Indicators were defined, the purpose of an indicator was defined as either a
measure of current condition of a VC, or as a predictor of future trends or
condition of a VC (see Section 3.3), which negates the presumption that
interpretations of indicators are the same for all EIA practitioners and regulators.
Interpretations of wildlife components also varied across projects. For example,
given the various indicators used to evaluate the ‘Migratory Birds’ VC, I deduced
that ‘Migratory Birds’ was construed as either *birds protected by the Migratory
Birds Convention Act* (no corvid or raptor species as indicators; Project 4), or *all
birds that migrate* (includes corvids and raptors as indicators; Blackwater).
Differences in interpretations for indicators and wildlife VCs explains some of the
variability in EIA practices, and provides evidence for the variable extent and
quality of assessments across projects in what should be a standard process.

The observed variation and ambiguity in communicating the indicator
species concept is not just a problem in EIAs; the ecological literature exhibits a
variety indicator terms and varying interpretations of indicator meaning (reviewed
in Zacharias & Roff 2001; Heink & Kowarik 2010; Siddig et al. 2016). For
example, Armstrong and Caro (2002) discuss different interpretations of the
terms “focal species” and “surrogate species” that have been made since their
conception, and the issues with using these terms “widely and with apparent
abandon” (Caro 2000, p.1569). Mainly, the general use of these terms results in
the loss of their original meaning (as defined in Lambeck 1997 and Caro 2000;
Armstrong & Caro 2002), unclear conservation objectives (e.g., setting
boundaries for conservation areas, assessing population trends of rare species,
or raising public awareness), and downplays the importance of data collection for
showing that focal and surrogate species achieve the objectives effectively or not
(Caro 2000). The diversity of indicator terms and inadequate definitions creates
barriers for effective communication (McKibben et al. 2010), for the ecological
community and EIA process.
Recommendation 1: Standardize and define indicator terms

To avoid consequences of potential confusion among synonyms and divergence of understanding, ecological and indicator terms should be standardized and have clear definitions that are used consistently within and among EIAs (Peters 1991; Heink & Kowarik 2010). In regulated land use planning processes like EIA, outlined terms and definitions are expected to be used in the way they are described in regulations; not doing so may put EIA applications at risk of delays associated with addressing information requests from regulators. Standardizing terms and definitions in EIA regulations would prevent “indicators” and similar terms from becoming meaningless buzzwords, improve communication among EIA practitioners and the broader ecological community (Peters 1991; Heink & Kowarik 2010, p.584), enhance the rigour and efficiency of regulatory review, and provide greater transparency of indicator meaning.

4.2. The potential for (mis)leading perceptions of impacts on VCs through informal and implicit indication

Transparency issues cause a lack of confidence in risk-assessment decisions, starting with the evaluation of raw data and continuing throughout the process (Schreider et al. 2010, p.5). However, that lack of confidence begins even sooner in the process – with the methodology. Of all the projects I reviewed, only Hardrock was consistently transparent for all indicators. The majority of EIAs (n = 8 of 10) in my study were not transparent in the use of indicator species or groups as formal methods of impact assessment (informal indications; Figure 7), and half of the EIAs – that happened to be on the eastern part of Canada – demonstrated cases of not identifying indicators at all (implicit indications; Figure 7). Informal and implicit indications are problematic because they do not promote scientific accountability for the information presented. By not identifying and incorporating indicators explicitly in the formal EIA methods, their presentation throughout the EIA appears to be ad hoc and arbitrary. Arbitrary indicators can
be the result of opportunistic selection in order to produce inferences of low project impact on wildlife VCs. For example, some projects (Blackwater Forest & Grassland Birds IA Chp 5.4.9, Rainy River EIA & Mitigation Chp 7, and Tazi Twé EIA) used species that are considered to be resilient to habitat fragmentation, like the ‘Red-tailed Hawk’, ‘Common Raven’ and ‘Bald Eagle’ (Prather & Messmer 2010; Vilella & Nimitz 2012), as indicators for a variety of other raptor and bird species. Providing details about robust species could give a false impression of the true impacts borne by wildlife VCs. Using indicators in a non-transparent way may contribute to a perception of proponent bias in how impacts are characterized for wildlife VCs.

**Recommendation 2: Prohibit the use of informal and implicit indicators**

Methodological transparency is fundamental to producing credible and unbiased results among the academic and applied science community (Schreider et al. 2010; Government of Canada 2017), and precludes informal and implicit indication. Regulators should be aware of informal and implicit indicators and prohibit their use. Any discussion of wildlife species that are not defined in EIA methods should not be used to inform the formal determination of potential for significant adverse effects to wildlife VCs. It is important that all indicators be formally included in the methods and explicitly identified (with indicator term or indication statement) prior to the presentation of EIA results, so that regulators and reviewers are prompted to take the necessary precautions when considering indicator inferences about wildlife VCs.

**4.3. Implications of (mis)sing a rigorous indicator selection framework**

Methods for indicator selection and application should be as transparent, justifiable and replicable as the methods of any peer-reviewed scientific study (reviewed in Treweek 1996; reviewed in Cashmore 2004). However, there is a paucity of detailed methods concerning the use of indicators – at least as
depicted in EIA documentation. Such an empirical gap can lead to arbitrary decisions and unscientific conclusions (Lin et al. 2009, p.7). Despite recommendations for a rigorous indicator selection framework within the literature (Table 3), EIAs that I examined failed to incorporate these recommendations. Of particular note, EIAs did not use selection criteria (except Blackwater), or describe detailed monitoring plans for evaluating the effectiveness of indicators. This finding has implications not only for the scientific rigour of the indicator selection process, but also for the scientific rigour of EIA decisions.

Rather than developing formal indicator selection criteria, most EIAs had justified indicator selection by providing rationales, and at times did not even do that. For the purposes of this study, the difference between criteria and rationales is that the former are involved in objective indicator selection through the evaluation of candidate indicators against set parameters, and the latter are casual explanations for selection that can vary across all indicators within a project. Informal and implicit indicators typically did not have rationales, supporting my postulation in Section 4.2 that these indicators were selected arbitrarily (additional issues regarding rationales are discussed in Section 4.4). In their literature review, Niemeijer and de Groot (2008) show that criteria varied considerably across empirical studies, resulting in different indicators for similar subject matter or geographical areas, and consequently, different interpretations of the status of the environment. Similarly, the pervasive lack of selection criteria and highly variable or non-existent rationales observed in my study likely contributes to the variability in number and types of indicators (species vs. groups) used across EIAs.

Another key parameter for indicator selection is a clear determination of an indicator’s specific role or purpose (Dale & Beyeler 2002; Heink & Kowarik 2010) – distinct from the general definition of what an indicator is and how it is interpreted (Section 4.1). In other words, “What is the indicator meant to represent about wildlife component?” and “How will the indicator be measured to reflect this?” For example, an indicator of potential impacts on 'Migratory Birds'
may be used to evaluate potential mortality by counting the number of corpses of indicator species along roads and transmission lines. *Explicit indication* statements in the EIAs I reviewed did not provide details of what was represented or measured (e.g., “Upland breeding birds, waterbirds, and the bald eagle have been identified as [indicators] to represent the broader category of migratory birds” Tazi Twé EIA, p.820). Simply identifying a species or group as an “indicator”, “representative”, or “surrogate” for a phenomenon of study leaves the correlation between the indicator and indicated component only vaguely specified and difficult to test (Heink & Kowarik 2010, p.587). By incorporating explicit measures into a statement of indicator function, the indicator relationship is clear and testable (Heink & Kowarik 2010), informs the selection of indicator criteria, and sets up an indicator monitoring plan (Caro & O’Doherty 1999; Dale & Beyeler 2002).

As many indications are untested hypotheses (Andelman & Fagan 2000; Lindenmayer et al. 2006; Cashmore et al. 2010), there is uncertainty about whether indicators represent what they are intended to represent. Monitoring plays an important role in addressing this uncertainty. Detailed indicator monitoring plans that are designed for testing indicator hypotheses were missing across all EIAs. Federal information requests for EIAs also determined that the descriptions for monitoring programs were insufficient (*Section 3.6*). Missing or insufficient monitoring plans implies that assumptions concerning indicator hypotheses were not verified or used to inform adaptive management. Neglecting to address uncertainty in appropriate depth and through effective means has been a long-standing issue in Canadian EIA (Lees et al. 2016). Inadequate follow-up monitoring, also termed “comfort monitoring”, does little to support effects-based management (Noble & Birk 2011), and has been sustaining predictions of ‘negligible impacts’ to wildlife in Canada for decades (e.g., Fraser & Russell 2016). If assumptions regarding indicator effectiveness for evaluating potential impacts on wildlife VCs are incorrect, the failure to monitor and adapt indication and mitigation measures accordingly could be detrimental to the
wildlife species that indicators are intended to represent (Lambeck 1997; Lindenmayer 1999).

**Recommendation 3: Adopt a rigorous indicator selection framework and monitoring plan as the new EIA status quo**

For a standard and fair EIA process, consistency in methods across Canadian federal EIAs is desired. However, given the excessive variability in the number and types of wildlife components and indicators (Figure 7), hypothesized indicator relationships (Figure 6), and selection rationale (Figure 8; Ball et al. 2012; Olagunju 2012), consistency does not exist among EIAs. While variability in number and types of indicators is not a problem *per se* – as indicators should be relevant to their distinct environmental context (Tzilivakis et al. 2016) – it is important that regulators require a transparent and scientifically rigorous indicator framework that will serve as mandatory best practices for EIA practitioners. Identifying ‘best’ indicator selection and application methods to compliment this framework is outside the scope of my research. However, there are numerous existing studies that recommend various indicator frameworks, selection criteria, and evaluation methods, summarized in Appendix D (Tzilivakis et al. 2016). A standard framework would promote similar indicator qualities and practices across EIAs (Wong et al. 2016). As new scientific evidence emerges, the framework can be flexible to reflect advances in understanding of indicators (Niemeijer & de Groot 2008). Furthermore, regulators should promote the careful construction of formal monitoring and research studies to establish the legitimacy of indicator relationships and inform adaptive management (Peters et al. 1997; Noss 1999; Schultz et al. 2013). EIA provides a practical opportunity to contribute to the scientific literature where there are gaps in knowledge concerning ecological impacts (Cashmore 2004; Green et al. 2017). Testing indicator hypotheses through rigorous monitoring programs in EIA can support much needed research to confirm indicator hypotheses that are persistent in conservation and environmental management.
4.4. Are valued wildlife species also valuable indicators? The (mis)take of conflating socio-political with rigorous ecological rationales

Socio-political indicators are value-laden, and paint a ‘picture’ of the system that is biased toward those components deemed to be important to society (Turnhout et al. 2007, p.218). Nearly all indications (91%) in the EIAs I studied involved indicators selected because of socio-political value, which is consistent with the observations of other studies (Ball et al. 2012; Olagunju 2012). However, in my study, wildlife VCs were often defined as broad species assemblages (e.g., ‘All Wildlife,’ ‘All Birds,’ ‘Invertebrates’) that encompassed species of little to no socio-political significance. The necessary question is whether indicators selected because of social or legal mandated value (i.e., species at risk, migratory birds, and species of socio-economic or Indigenous concern) are ecologically meaningful as indicators for accurately predicting impacts on all of the species EIAs claim to evaluate. However, there is no a priori rationale why this would be the case.

Socio-political indicator species, such as ‘Species at Risk’, do not necessarily reflect the requirements or responses of other species encompassed by wildlife VCs. ‘Species at Risk’ indicators were common among EIAs (Figure 8), however there is debate in the literature concerning their effectiveness as indicators for other species (Cf. Block et al. 1987; Noss 1990; Lambeck 1997; Simberloff 1998; Andelman & Fagan 2000; Lawler et al. 2003; Andreasen et al. 2001; Rempel et al. 2004). Two simulation studies that investigated the effectiveness of species at risk indicators produced opposite results, in that they either performed the best (Lawler et al. 2003) or the worst (Andelman & Fagan 2000) among other suites of indicator species. A typical rationale for the inclusion of species at risk as indicators was that species at risk are more sensitive to environmental impacts than other species; but this is not always true. For instance, the Olive-sided Flycatcher – a migratory, edge-loving and federally-threatened bird – was used to predict responses of ‘All Songbirds’ to habitat loss
and fragmentation in an EIA (Blackwater Forest & Grassland Birds EIA Chp 5.4.9; Project 4 Terrestrial Environment EIA Chp 9; Howse Property Biological Environment EIA Chp 7.4). Yet, other studies illustrate that bird species respond differentially to habitat loss and fragmentation (as summarized in Lindenmayer et al. 2002; Alexandrino et al. 2016; Pfeifer et al. 2018). Poor detectability of species, lack of data, and unique ecological requirements that are not attributable to other species, are just some of the other challenges associated with species at risk indicators (Peters et al. 1997; Lindenmayer 2002). Therefore, selecting indicator species primarily for their socio-political value (i.e., conservation status) can lead to erroneous assumptions about ecological responses of indicated wildlife species. While there is some support in the literature for using species at risk as indicators (e.g., endangered Northern Spotted Owls as indicators of old-growth forest health, Doak 1989), their effectiveness ultimately depends on what they are indicating (Reid & Beazley 2003), which may preclude using them to predict impacts on other wildlife species.

Socio-political indicators include those species of management concern aside from conservation management, such as species that are of commercial, recreational, or cultural value. Valued species under these categories (e.g., ‘Moose’, ‘American Marten’ and ‘Grizzly Bear’) are often subject to single species management. Simberloff (1998, p.249) argues that such species are no longer indicators, because “if the species' status is artificially improved, it no longer indicates the status of all the species it is supposed to represent.” Migratory bird indicators, another component of political protection through the Migratory Bird Convention Act, may produce false inferences of potential response to impacts due to extrinsic factors anywhere along their migration route (Landres et al. 1988). The presence of external influence prompts critical thought about whether one should use these wildlife groups or species as indicators for other wildlife components. Lastly, there are also challenges with assumptions that underlie ecological and feasibility rationales, and other inferences made with regards to indicator applications (See Appendix E for a description of challenges).
Why are so many socio-politically valued indicators used in EIA? There are several potential reasons for this. First, proponents are obliged to inform the federal government of potential impacts on matters within federal jurisdiction (e.g., climate change, fish and fish habitat, migratory birds, species at risk, etc.; Ball et al. 2012), according to the CEA ACT 2012. Second, the current federal EIA process encourages the structure of the assessment to be based around VCs that inherently incorporate socio-political values (Olagunju 2012). Third, there may be pressure from the public or stakeholders to directly evaluate certain wildlife groups or species as VCs or indicators (Olagunju, 2012). The problem is not that indicators have socio-political value; it is that socio-political value influences the selection of indicators more than the ecological affinity of an indicator to what it is indicating, and the challenges of socio-political indicators are ignored.

Recommendation 4: Ecological rationales should inform rigorous indicator selection, and caution is warranted when considering candidate indicators of socio-political value

Though the premise of EIA is the sustainable management of ‘valued’ components, great care should be taken when using socio-politically valued species as indicators (Landres et al 1988). Although socio-politically valued wildlife may not serve as the most reliable indicators (Landres et al. 1988), that does not mean they should be excluded from evaluation in the EIA as individual VCs (Peters et al. 1997). It simply precludes them from being used as indicators to make inferences about other wildlife species or groups (Noss 1990). Some federal departments already acknowledge the complications of using species at risk to evaluate impacts on other species, and advise against the use of species at risk indicators for evaluating impacts on other species in EIA (Lynch-Stewart 2004; Section 3.9). However, this is not yet regular guidance or practice (given the number of indicators that are species at risk in EIA), and would require national coordination to make it a new standard in Canada. Evaluation of species with socio-political value should be kept separate from the selection and
evaluation of ecological indicators (Landres et al. 1988; Hilty & Merenlender 2000; Niemeijer & de Groot 2008; Heink & Kowarik 2010; Kershner et al. 2011). In this way, ecological indicators would be selected objectively based on their indication power and ecological affinities to indicated components, and socio-politically valued species would still be evaluated in the EIA.

4.5. Implications of absent empirical justifications and (mis)generalizations

A scientific research article without citations to support its claims would raise a red flag in any objective evaluation and would not be seen as legitimate by the scientific community. The absence of empirical citations that justify or support the use of indicators in EIAs should sound alarm bells. Despite hundreds of recent scientific articles on organismal indicators (817 articles from 2001-2014; Siddig et al. 2016), not one EIA that I examined provided empirical citations for the use of indicators. There is a stark disconnect between the practices adopted by the research community and by EIA practitioners. Scientific researchers based selection of indicators on previous research (40% of 817 articles; Siddig et al. 2016), whereas in my results, EIA practitioners justified indicator selection and application primarily on conservation status (Section 4.4), feasibility, or a combination of the two (Figure 8). These rationales were much less frequently used in scientific studies (5-25% of 817; Siddig et al. 2016). Even more jarring, 99% of studies statistically evaluated indicator performance (Siddig et al. 2016), compared to a disappointing 0% for the EIAs I examined. Without reference to independent and peer-reviewed investigations, how can there be confidence in the rigour with which indicators were applied?

Generalizations are useful to compound and sum up meaning from details; however, generalizations made in the absence of empirical justification can result in erroneous indicator inferences. Most of the EIAs that I examined generalized potential impacts within indicator groups and/or across indicated components (i.e., nested indication), all of which were unsubstantiated. The second most
common rationale for selecting indicators was that indicators were representatives of a niche, guild, or habitat type (Figure 8A). However, the assumption that species within a guild, habitat, taxonomic group, or ecological hierarchy respond similarly to disturbance, has been criticized in ecological research (Landres et al. 1988; Caro & O’Doherty 1999; Lindenmayer et al. 2002, 2006). For example, while generalizations about avian group indicators and indicated components were particularly common among the EIAs I examined (75% of all indicator groups), studies on avian indicator species have demonstrated that individual species do not effectively represent habitat requirements of all species in a guild (Block et al. 1987), and that species respond differently to anthropogenic disturbance (Alexandrino et al. 2016; Lindenmeyer et al. 2002). Similar to the concept of nested indication, Noss (1990) organized biodiversity hierarchically, where broad ecological components (e.g., landscapes) would encompass narrower components (e.g., ecosystems and habitats to species and populations). However, he stipulates that environmental stresses felt at one level can be expected to reverberate through other levels, but in different and unpredictable ways (Noss 1990). Therefore, it is irresponsible to generalize within ecological groupings or across ecological levels of hierarchy in the absence of other supporting evidence or justification of strong ecological affinities between species (Block et al. 1987).

**Recommendation 5: Require the inclusion of references to available literature to justify the use of indicators and generalizations and avoid the practice of nested indication**

Though strong scientific practices for EIA have been published for decades, they are not yet commonly utilized in practice in Canadian EIA (Greig & Duinker 2011). This is also true with regards to indicator selection and application practices. Therefore, addressing information flow between empirical research and EIA scientists and practitioners can enhance scientific rigour of indicator practices. EIA practitioners should pay attention to researchers who have dedicated their work to informing and improving environmental management and
conservation through indication – the literature does exist (see Siddig et al. 2016). Stand-alone opinions of environmental consulting or regulatory “experts” cannot be acceptable, as is the case in environmental management currently (Niemeijer & de Groot 2008), and in EIA. Scientists are expected to consult the literature, think critically, and support their opinions with rigorous science or well-articulated and compelling justifications. It is baffling that EIA is not being held to the same rigorous scientific standards, at least when using indicators. Reasoning concerning indication should be transparent and based on the best available science (i.e., according to the literature), especially when using and making generalizations about indicators and indicated components. Lastly, nested indication should be avoided, or each step in the relationship should be justified with a standardized process of indicator selection. Where empirical evidence does not exist to support indicator hypotheses, assumptions and uncertainties should be presented in a way that they can be addressed through evaluations and monitoring, as discussed in Section 4.3.

4.6. Insufficient regulatory guidance as an underlying cause of indicator variability and (mis)use

Instructions concerning the use of indicators were absent from most of the regulatory guidance documents I examined (except BC VC Guide, BC EAO 2013); but this does not necessarily mean that regulatory guidance was inadequate overall. Federal guidance provided clear expectations for conducting an EIA that, in theory, would promote transparency and scientific rigour (e.g., clearly state and test assumptions; use best available methods; Table 6). However, these expectations did not carry over to the use of indicators as a method of evaluating impacts on VCs. For example, indicator assumptions at times were not stated (i.e., implicit indication), were not tested (i.e., lack of indicator evaluation or monitoring), and references to the literature were not made to identify “best available methods” of indicator selection and application (Section 4.5). Therefore, general federal regulatory guidance is not being followed or enforced, and there is no detailed federal guidance about the use of
indicators. Even when provincial guidance was provided for selecting indicators (BC VC Guide, BC EAO 2013), compliance was not consistent among projects in the jurisdiction for which guidance applied (e.g., Blackwater complied exactly whereas Pacific NorthWest did not). This suggests that guidance may be prescribed differentially across EIAs, or that regulatory guidance is not obligatory or enforced.

When federal regulators did provide instructions for using indicators, I identified several issues with the level of detail and reactivity of federal guidance. Federal guidance supported the use of indicators as an acceptable tool for evaluating impacts on VCs (CEA Agency 2016, 2018), but did not add detail for how indicators should be used in a transparent and scientifically rigorous way. Vague instruction leaves indicator practices up to the discretion of proponents and their consultants. Allowing proponent discretion over the conduct and presentation of an EIA (Table 4) is questionable and criticized as being susceptible to proponent bias (Government of Canada 2017; Van Hinte et al. 2007; Section 4.2). Moreover, project-specific guidance concerning the selection of VCs and indicators was more reactive than proactive (Section 3.6), contributing to delays and an inefficient process. As information requests frequently highlighted the inadequacy of monitoring programs, current federal EIA guidance (EIS Guidelines) for devising monitoring programs are insufficient (Section 3.6).

Multi-jurisdictional coordination may also explain some of the variability in indicator practices (e.g., Figure 7; Suter II 2008; Gibson 2012). In coordinated EIAs, rather than conducting two separate EIAs, one EIA is typically conducted to meet the requirements of both jurisdictions. Under these circumstances, the jurisdiction with the most detailed guidance may have more prescriptive power over the conduct of the EIA. Given that the language and content in federal project-specific guidance documents were constant across EIAs (e.g., Table 4), any differences in provincial guidance across provinces (both EIA and non-EIA regulations) may explain some of the variation with regards to VC selection and
indicator practices in Canadian coordinated federal-provincial EIAs. The Blackwater EIA is evidence for this, as there was compliance to the detailed provincial guidance for the selection of VCs and indicators in the absence of detailed federal instruction. Furthermore, geographical location may explain some similarities or differences observed between EIAs. For example, EIAs in eastern provinces were exclusively associated with implicit indication, whereas EIAs in western provinces used explicit indication (Figure 7). Despite providing standardized federal guidance, federal EIAs are not being conducted in a standardized way, due in part to provincial influence and disparate provincial EIA requirements.

Recommendation 6: Adopt and enforce EIA guidance to reflect transparent and rigorous indicator selection and application recommendations of the scientific literature

Regulatory guidance interprets and operationalizes legislation by outlining the minimum requirements for an acceptable EIA. Such policy tools can positively influence EIA practices to promote transparency and scientific rigour of indication for wildlife VCs. I have shown that regulatory guidance can have considerable influence over how an EIA is conducted, from the selection of VCs, to the evaluation of VCs with indicators (consistent with Olagunju 2012). However, issues of non-compliance, lack of enforcement, bias due to proponent discretion over EIA methods, and inadequate harmonization restricts the potential for regulatory guidance to promote transparent and rigorous EIAs.

Relying on proponent discretion in using indicators has not promoted standard practices across Canadian EIAs and seems unlikely to do so in the future without clear regulation or guidance. It is important that such issues of vague or little guidance be addressed (Broadbent 2014), particularly with regards to the selection and use of indicators (Wong et al. 2016). Detailed guidance that requires less interpretation and discretion on the part of the proponent can also help to address issues of proponent bias; although it would be preferable to have complete disassociation between proponent and EIA consultant (Van Hinte et al.
2007; Broadbent 2014), as in some other EIA regimes (e.g., United States EIA regime under NEPA; Robinson 1992). Furthermore, any regulatory changes concerning indicator guidance will require better harmonization of expected requirements from both federal and provincial governments, as recommended by the EIA panel review (Government of Canada 2017). In addition, early regulator involvement in indicator selection and EIA planning in general could alleviate the delays and costs associated with information requests (Government of Canada 2017). Finally, EIAs should be rigorously reviewed for compliance, and properly enforced, which will require more reviewer capacity.

4.7. **Cumulative Effects Assessments: Indicate no evil, identify no evil**

Given the pervasive and overlapping nature of anthropogenic activities on the land base, and the complexity of how activities interact to affect ecosystems, particular attention has been afforded to cumulative effects in EIA and the academic community. In federal EIA, cumulative effects assessments ultimately determine the potential for significant adverse environmental effects that inform the EIA decision (CEA Agency 2015). The selection and application of VCs and indicators from the start of an EIA can influence how cumulative effects assessments are conducted (Olagunju 2012). If indicators are selected and applied inadequately, they might yield a false negative conclusion about the potential for residual effects to VCs, and thereby negate their inclusion in the cumulative effects assessment (CEA Agency 2016). Such a trickle-down effect of improper indicator use has major implications for EIA decisions. While the focus of this research was not explicitly on the use of indicators in cumulative effects assessments, numerous studies provide guidance for using VCs and indicators for evaluating cumulative effects; namely adopting a standard, systematic, and holistic selection process (e.g., Canter & Atkinson 2011; Ball et al. 2012; Sutherland et al. 2016). So long as project-level cumulative effects assessments inform EIA decisions, it is crucial to be mindful of the implications of indicators for influencing the selection of VCs in cumulative effects assessments.
4.8. A policy window for transparency and scientific rigour in wildlife impact assessment

My research identifies a specific case where transparency and scientific rigour of EIA can be improved, realistically and feasibly, within the legislative bounds and policy tools that regulate the federal EIA process. In the new proposed Bill C-69 legislation (Parliament of Canada 2018), the Agency (i.e., CEA Agency or federal regulator) must “exercise their powers in a manner that adheres to the principles of scientific integrity, honesty, objectivity, thoroughness and accuracy” (Sec 6(3)), and “promote uniformity and harmonization in relation to the assessment of effects across Canada at all levels of government” (Sec 155(c)). Some of these powers include: carrying out studies or establishing research and advisory bodies for matters related to EIA, developing guidelines and codes of practice, and establishing monitoring committees for matters related to follow-up programs and adaptive management plans. There is a legal window of opportunity for the CEA Agency to address issues in indicator practices through research, detailed regulatory guidance, and improved monitoring programs with my outlined recommendations.

4.9. Indicator alternatives, global issues and outstanding considerations

In general, scientists view indicators as a means to an end – making conservation and land management decisions with finite resources and limited data (Siddig et al. 2016). With insufficient data, it is difficult to establish causality in indicator hypotheses (Cushman et al. 2010), and EIA practitioners have not been able to adequately communicate that uncertainty. In a process that often produces insufficient baseline data (Noble & Storey 2005), and is judged as unable to make accurate predictions of future impacts (Tennøy et al. 2006), perhaps further uncertainty associated with the indicator species concept should be avoided altogether in EIA. Some researchers have promoted the movement away from species-level conservation and management to a more holistic
ecosystem-based management approach “which focuses on protecting ecosystem structure, function and processes to maintain ecosystem resources and services” (e.g., Andreasen et al. 2001; Lindenmayer et al. 2006; Kershner et al. 2011, p.1). Site or landscape level indices based on habitat measurements are illustrated to be more cost-effective than evaluating species (Andreasen et al. 2001; Lindenmayer et al. 2014). As long as wildlife VCs continue to be defined broadly to encompass many more species than are feasible to assess, other approaches to the species-level wildlife impact assessment should be explored.

EIAs around the world show similar issues with characterizing ecological impacts. Treweek (1996), in his review of studies that critiqued EIAs in the European Union, found that ecological assessments had weak prediction, failed to measure explanatory variables (e.g., indicators), over-relied on descriptive and subjective methods (e.g., lack of formal selection criteria), were biased towards certain taxonomic groups of socio-political importance (see also Bigard et al. 2017), had poor replicability (i.e., method transparency), and neglected to estimate ecological significance. Similarly, an extensive review of 130 Sri Lankan EIAs observed low explanatory power of ecological assessments: EIAs provided merely “tokenistic presentation of reconnaissance-level species lists” that lacked detailed quantitative analyses of impacts to particular organisms or communities and testable predictions that could be monitored (Samarakoon & Rowan 2008, p. 441). Furthermore, describing and addressing uncertainty has not been done transparently or effectively in EIA (e.g., Geneletti et al. 2003; Tennøy et al. 2006; Lees et al. 2016), and the overall quality of information presented in EIAs is poor; reflecting issues in the institutional processes, level of training or capacity of EIA practitioners, or proponent compliance (Morgan 2012).

It seems then that the questionable use of indicators is just one detectable symptom of a broader affliction. Careful incorporation of the best available collaborative planning processes (e.g., Selin & Chavez 1995; Gunton 2006; Van Hinte et al. 2007) and methods to enhance science-informed decisions (e.g., Beanlands & Duinker 1983; Cashmore 2004) are required for effective
management of the environment (Government of Canada 2018). Process-level changes that will meet public and stakeholder expectations and foster trust in the integrity of EIA, including the incorporation of collaborative planning processes that would occur before the actual EIA, and alternatives to a proponent-devised EIA, are recommended in the expert panel report (Government of Canada 2017). Whether new legislation will reflect these recommendations is another matter. A long history of academic recommendations for strengthening EIA have gone unnoticed or ignored (Greig & Duinker 2011), and past legislative changes in EIA have consistently fallen short of addressing public concerns (see discussion in Jacob et al. 2018). If great leaps of systemic procedural change are politically or otherwise constrained, then small steps in the right direction are better than standing still; starting with enhancing the transparency and rigour of Canadian federal EIAs.
Chapter 5. Conclusion

My study is one among numerous other critiques regarding the use of indicator species in environmental management and conservation, but is unique in its in-depth analysis of how wildlife indication is being used in current land use planning processes. Despite numerous recommendations for appropriate use of indicators in the available literature, not one of the EIAs I examined provided all of the necessary elements to ensure transparency and scientific rigour of indicator species selection and application. As a result, indicators were ill defined and prone to misinterpretation, arbitrary and unscientific selection, and unjustified application, with implications for the conduct of cumulative effects assessments, and ultimately, EIA decisions. While the purpose of this research was not to identify the best methods for using indicators in EIA, it highlights the need for a standard, transparent and rigorous process.

Regulators have the tools and the responsibility to investigate and address issues of transparency and scientific rigour in the implementation of EIA policy. My results may encourage regulators to take steps towards enhancing the quality of wildlife impact assessments by addressing identified issues with detailed guidelines that are standardized, harmonized and enforced. In addressing the systemic failure to uphold minimal standards of evidence in current practices within Canadian federal EIA, the regulators can effectively reduce uncertainty, subjectivity, and bias in the predictions of potential impacts, advance mitigation measures and adaptive management, contribute to filling the gaps in indicator knowledge, as well as set a precedent for other EIA and land use planning processes to follow suit.

The rigorous characterization of impacts to wildlife and biodiversity is of great global and national importance. Canada was a leader in signing the Biodiversity Convention (UN 1992) to incorporate biodiversity considerations into environmental planning processes, policies and legislation. Therefore, Canada has pledged to upholding national values and international commitments by
ensuring that decisions with the potential to impact biodiversity are based on the best scientific evidence. But Canada, along with many other nations, is falling behind in characterizing and mitigating potential anthropogenic impacts on species. Where the expert panel review identified a wide range of high-level issues in Canadian EIA, my research identifies specific opportunities to improve how impacts to VCs (wildlife) are evaluated. Through the advancement of science-informed decision-making, EIA can do a better job of sustainably managing invaluable wildlife resources, and upholding Canada’s international obligation to preserve biodiversity.
References


Appendix A. Selected EIA Project Details

Supplemental Table 1a: General project description, EIA status, and environmental details for selected projects

File Name: FergusonL Appendix A.xlsx
Excel Tab: Supplemental Table 1a

Supplemental Table 1b: Spatial and temporal scope of selected projects

File Name: FergusonL Appendix A.xlsx
Excel Tab: Supplemental Table 1b
Appendix B. EIA Documentation Sources

Supplemental Table 2: List of EIA project data sources and types of information scanned or data collected from each document

File Name: Ferguson L Appendix B.xlsx
Appendix C. Raw Data

Raw Wildlife Indication Data and Framework Data is available upon request. I prefer to have direct contact with the reader to explain the data and collection process. Any questions regarding my research and data can be directed to my institution email.
Appendix D. Indicator Literature Review

Supplemental Table 3a: Literature review of indicator criteria and traits
File Name: FergusonL Appendix D.xlsx.
Excel Tab: Supplemental Table 3a

Supplemental Table 3b: Literature review of indicator frameworks
File Name: FergusonL Appendix D.xlsx
Excel Tab: Supplemental Table 3b
Appendix E. Challenges of Indicator Selection Rationales

Supplemental Table 5: Challenges with wildlife indicator assumptions (summarized from Landres et al. 1988)

<table>
<thead>
<tr>
<th>Context</th>
<th>Assumptions</th>
<th>Challenges</th>
<th>Conclusion</th>
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<tbody>
<tr>
<td>Indicators of Population Trends</td>
<td>1) Maintaining the habitat of an indicator species will ensure suitability of conditions for other species of the same guild.</td>
<td>a) Although guild species may use similar habitat, they do not necessarily interact with or respond to changes to the environment in the same way (e.g., diverse life history, breeding and foraging behaviours, diet). b) Interspecific competition between very similar guild members with respect to resource exploitation may cause competitive exclusion. c) Guild definition criteria do not typically consider factors limiting the population (e.g., habitat availability, predation, disease, extreme weather, and occurrences on migration routes or overwintering grounds).</td>
<td>&quot;Because neither conceptual nor empirical considerations support use of indicators as surrogates for population trends of other species, this approach to wildlife assessment should be avoided. If such use is necessary, it must be justified by research on populations of the species involved, over an extensive area and time.&quot; (p.319)</td>
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<td>Indicators of Habitat Quality</td>
<td>2) The population density of an indicator is an index of habitat quality for that species. 3) One or more species may indicate habitat suitability for other species. 4) Species-habitat relationships can be adequately modeled.</td>
<td>a) Density is influenced by other factors aside from habitat quality (e.g., dominance status, reproductive success, predators, seasonal fluctuations in resources and abiotic conditions). b) Density estimates may be inaccurate, particularly over the short-run, and for species with low population density (i.e., rare or threatened species), and hence preclude reliable assessment. c) Using indicator species to assess habitat quality involves multi-variate indices that are associated with their own challenges. d) There are conceptual and mathematical problems in Habitat Suitability Models (HSI), despite being commonly used by resource managers to evaluate effects of habitat change to wildlife. e) If defining 'habitat quality' as the entire structure and functioning of a community or ecosystem, it is unlikely that a single species can be a proxy for structure and function of communities or ecosystems. f) There is a difference between indicating past or current and future environmental conditions from HSI or other models - factors outside a species-habitat relationship (i.e., weather, disease, anthropogenic disturbance) in addition to other issues above, can reduce accuracy of predictions. g) Circularity issue exists when using indicators to assess habitat conditions, because choice of indicator often depends on those habitat conditions.</td>
<td>&quot;Using one or more vertebrates to indicate habitat quality for other species should not be undertaken until research confirms the validity of this approach...model validation and examination of extrinsic factors must be incorporated into the process of using indicators for predicting habitat quality, if this approach is used.&quot; (p.320)</td>
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<td>Context</td>
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<td>Sensitivity</td>
<td>5) Effective indicators are sensitive to the environmental conditions or</td>
<td>a) Cause and effect relationship between indicator and indicated necessary (not just correlative), otherwise influence of habitat change on indicator population trends is inseparable from influences of extrinsic factors.</td>
<td>Cause and effect relationships between sensitive species and habitat attributes should be present prior to using as an indicator, and an examination of potential extrinsic factors should be incorporated.</td>
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<td></td>
<td>habitat attributes of concern.</td>
<td>b) Management agencies are restricted to selecting indicators that are sensitive to habitat attributes that the agency can control.</td>
<td>Insensitive species should not be the only indicator of habitat attributes. (p.320)</td>
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<td>6) Increase in abundance of insensitive or tolerant species may provide</td>
<td>c) Density of tolerant or insensitive species may increase for extrinsic reasons.</td>
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<td></td>
<td>information on habitat conditions.</td>
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<td>Variability</td>
<td>7) Effective indicators exhibit low levels of variability in response to</td>
<td>a) Variability can be explained by within-individual (e.g., hunger, reproduction, dominance status, age, acclimatization, etc.) and among-individual (genetic, experience, etc.) differences.</td>
<td>Contribution from each significant source of variation must be identified. (p.320)</td>
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<td>of Response</td>
<td>environmental factors of interest.</td>
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<td>Specialists</td>
<td>8) Specialists are better indicators than generalists as they are more</td>
<td>a) Managing for specialists may provide suitable habitat for some, but not all species, as they require combinations of habitat types in certain proportions and spatial arrays.</td>
<td>Indicators should not be selected solely on the basis of whether they are specialists or generalists. (p.321)</td>
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<td>vs.</td>
<td>sensitive to habitat changes.</td>
<td>b) Specialists may be less abundant than generalists, with consequent sampling issues and higher survey costs.</td>
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<td>Generalists</td>
<td>9) Meeting needs of specialists will provide for generalists as well.</td>
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<td>Size</td>
<td>10) Species of large body size are better indicators than smaller species</td>
<td>a) Scale of disturbance relative to the indicator and species of interest needs to be determined; smaller species using microhabitats may be unaffected by macro-environmental changes, and larger species ranging over several habitats may be poor indicators of smaller-scale disturbance.</td>
<td>&quot;...to track short- and long-term responses to environmental perturbation, it may be important to monitor both small and large species...size per se is a poor selection criterion.&quot; (p.321)</td>
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<td>because they have slower turnover rates and are more stable.</td>
<td>b) Large species may not reflect community-level responses, as they take longer to reach equilibrium than smaller species that reach maximum population biomass per unit area relatively quickly.</td>
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<td>11) Small species exhibit greater variability in space and time (i.e.,</td>
<td>c) Assumption (11) is only supported for fugitive or pioneer species. Many species of similar size do not exhibit fugitive or pioneering life-history strategy.</td>
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<td>here today, gone tomorrow) than larger species.</td>
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<td>Residency</td>
<td>12) Permanent resident species are better indicators of on-site environmental</td>
<td>a) Assessment objectives may specifically include monitoring of migrants that breed on managed lands, or of environmental conditions in areas used by migrants during the winter.</td>
<td>Migrant species are subject to extrinsic factors during overwintering and migration, therefore are not reliable indicators of environmental condition. (p.321)</td>
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<td>Status</td>
<td>conditions.</td>
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<td>Habitat</td>
<td>13) Managing for a single species with larger area requirements than other</td>
<td>a) Species with large area requirements may be able to adapt to environmental conditions by shifting resource use within its home range, thereby a poor indicator of environmental effects.</td>
<td>&quot;Area per se is a tenuous criterion unless resource confirms that a species with large home range can serve as an indicator of habitat quality or of an entire community in that particular location.&quot; (p.322)</td>
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<td>Range</td>
<td>species in the community can effectively cover the spectrum of resources</td>
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<td>needed by other species in that area (i.e., umbrella species).</td>
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