Landscape Analysis in Environmental Impact Assessment: Is there Potential to Improve Biodiversity Conservation through Better-Informed Decisions?

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Geography

Carleton University
Ottawa, Ontario

Abstract

Biodiversity is in severe decline globally, attributed in a large part to anthropogenic land use change. The conservation literature refers to the landscape scale as important in mediating biodiversity. However, environmental impact assessment (EIA), a prevalent tool to inform decision-making with respect to ecological considerations such as biodiversity impacts, rarely takes a landscape perspective. Decisions are often made for individual projects, at local scales, with little attention paid to landscape contexts. The cumulative impact of project-by-project decision-making all too often results in alteration of ecological networks in the landscape with associated losses in biodiversity. A disconnect is apparent between scales of analysis for biodiversity conservation and those used for impact assessment.

Landscape ecology studies landscape patterns and processes at a range of scales and has potential to bridge this disconnect. This thesis examines the potential to improve biodiversity conservation by better incorporating landscape ecology-based analysis into project EIA. The mixed-methods research follows three lines: (1) identifying gaps between the science of landscape ecology and the practice of EIA, (2) examining the challenges faced by EIA practitioners when considering broader-scale analysis in EIA and associated opportunities for overcoming them, and (3) testing an accessible approach to landscape analysis that incorporates a scenario-based simulation model of cumulative project decision-making. Research was focused on Ontario, Canada, and its multi-jurisdictional EIA regime.

Results revealed gaps in how landscape context was considered in EIA, such as the ability of the whole landscape to support species movement and dispersal, and in comparing project-induced land use change to landscape-based ecological targets and thresholds. Quantitative and spatial analyses were infrequently used to assess landscape composition and configuration. Challenges exacerbating these gaps are both policy- and science-based. Weak policy and guidance for broader-scale analysis and a lack of multi-level policy support undermine practitioners' ability to incorporate landscape analysis into EIA. Better multi-jurisdictional data and data management systems are recommended, as well as increasing knowledge of ecological thresholds within the science-practitioner communities. If these challenges can be overcome, the modelling exercise demonstrated that incorporating even simple landscape considerations in project-based decision-making can have a positive effect on biodiversity indicators.

Acknowledgements

Firstly, I would like to express my sincere gratitude to my supervisors, Dr. Scott Mitchell and Dr. Mike Brklacich, for their unwavering support of my PhD study, and for guiding me in my research with patience, motivation, knowledge and understanding. They never failed to provide me with opportunities to succeed and to grow as a researcher and academic community member.

Besides my supervisors, I would like to thank my committee member, Dr. Kathryn [Freemark] Lindsay, for her insightful comments and encouragement throughout the process, and for her inspiring repertoire of landscape ecology knowledge and application. I am also grateful to Dr. John Bolte of the University of Oregon for his enthusiasm, creativity and perseverance in helping me with the more technical aspects of spatial simulation modelling.

My sincere thanks also go to Dr. Iain Wallace, who led many thought-provoking discussions in our program's core seminar class, and the late Dr. Doug King, who provided such encouraging feedback on my early PhD field course papers. Also, many thanks to Erin Johnston, for her patience and cheerfulness in navigating me through the program administrative requirements!

I would also like to acknowledge my funding support from Carleton University, from Environment and Climate Change Canada, and by the Social Sciences and Humanities Research Council of Canada Joseph-Armand Bombardier Canada Graduate Scholarship –

Doctoral. Without this support it would not have been possible to conduct this research and share ideas at conferences both here and abroad.

Last but not least, I would like to thank my family: my partner Kanwaljeet for believing in me and joining me on this journey, my daughter Madeleine for bringing such joy and perspective to each day, my parents (Betty and Reinhold), brother (Peter) and sister-in-law (Kathryn) for their unfailing support and encouragement, and the many friends and extended family that were so supportive of this endeavor. And of course, to Harley, Cleo, Gypsy and Pickle for their companionship and unconditional feline support.

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Chapter 1: Introduction

1.1 The Biodiversity Crisis – Are Decision-Makers Given the Right Information?

The extent of current global biodiversity loss is alarming, with some scientists warning of the sixth great extinction episode in the Earth's history (Chapin III et al., 2000; Hamid, 2013). Anthropogenic land use change is a primary driver: increasing human pressures lead to disconnection of ecological networks and the biodiversity that landscapes support (Pietsch, 2018). It is critical that those making decisions on land use are informed as accurately as possible about the breadth and scale of projected impacts of land use change on biodiversity. Yet these impacts are not easy to ascertain, particularly due to the multi-dimensional nature of biodiversity as well as the complex pathways that are transforming earth system processes (e.g., Purvis and Hector, 2000; Rockström et al., 2009).

Environmental impact assessment (EIA) aims to inform decision-making with respect to ecological considerations, such as impacts on biodiversity (Pietsch, 2018). EIA decisions are typically made for individual projects, at local scales, with little attention paid to broader landscape and ecological contexts (Botequilha Leitão and Ahern, 2002; Gagné et al., 2015; Gontier, 2006; Tambosi et al., 2014). The cumulative impacts of project-by-project decision-making all too often result in a loss of habitat and fragmentation of the landscape with associated losses in biodiversity (Botequilha Leitão and Ahern, 2002; Therivel and Ross, 2007). Information on impacts to biodiversity ascertained at local scales for each individual project may be missing the critical bigger picture about the role of landscape in supporting biodiversity. If decision-makers were to recognize the need for and use of information on potential impacts to biodiversity at a broader, landscape scale, could this improve biodiversity conservation outcomes? How could such information make its way into EIA process and practice?

Describing and quantifying landscape structure at a range of scales, and linking it to ecological processes and components such as biodiversity, has been a major focus of landscape ecology for more than 25 years (McGarigal and Marks, 1995). This field of study examines the ecology of spatial heterogeneity and pattern, spatial and temporal dynamics, and typically broader spatial extents than those traditionally studied in ecology (Freemark et al., 1993; McGarigal and Marks, 1995). However, much of the science and tools from landscape ecology have not yet made their way into mainstream EIA and planning processes (Gontier, 2006; Harker et al., 2021). A landscape perspective is not common when planners and government agencies make decisions that affect land use; Gagné et al. (2015) found that knowledge from landscape ecology was seldom used in land use decision-making, and that the abundance of literature on ecological guidelines had made little change in terms of informing decisions. While a few authors have explored this disconnect in Europe (Balfors et al., 2010; Gontier, 2006; Karlson and Mörtberg, 2015; Mörtberg et al., 2007; Pietsch, 2018; Scolozzi and Geneletti, 2012), Brazil (Dalloz et al., 2017), and Hawaii (Griffith et al., 2002), many questions still remain. These lines of research suggest there is considerable potential to improve biodiversity conservation through decision-making that is better informed by incorporating landscape ecology-based analysis into project assessment practices.

1.2 Research Purpose and Rationale

This research evaluates the potential for landscape ecology to better inform EIA with respect to biodiversity conservation, especially as it relates to current disconnects between scales of analysis used in EIA and those relevant to biodiversity conservation.

This is a crucial area of current research, as the decline in biodiversity we are witnessing globally needs to be reversed (Hamid, 2013; Rockström et al., 2009). While the issue is a global one, several factors have contributed to my focus on the Canadian context. Canada has a history built on its natural resource base (Rudd et al., 2011), and has developed a complex, multi-jurisdictional system of EIA legislation to mitigate impacts of its development (Noble, 2015). Canada has a diversity and abundance of ecosystems, habitats and species, including a large fraction of major global ecosystems such as boreal forest, Arctic tundra, wetlands, mixedwood forests, lakes and streams (OMNR, 2012; Rudd et al., 2011), making biodiversity an important consideration for the country. Canada has formal goals for biodiversity conservation (EC, 2015) related directly to the Convention on Biological Diversity's Strategic Plan for Biodiversity and Targets for 2020 (the Aichi Targets), which include reducing the direct pressures on biodiversity and improving the status of biodiversity by safeguarding ecosystems, species and genetic diversity (CBD, n.d.). Finding ways to integrate the conservation of biodiversity with growing natural resource demands is essential. Taking a landscape ecology approach to EIA may help mitigate the "death by 1000 cuts" (Therivel and Ross, 2007) from cumulative, project-by-project land use changes that each assess impacts at a site-level scale. My research is focused on exploring the practical and theoretical implications of using landscape ecology approaches to inform EIA policy, practice, biodiversity, and human-environment systems.

1.3 Research Objectives

The broad purpose of evaluating the potential for landscape ecology to better inform EIA with respect to biodiversity conservation is investigated via three interrelated research objectives (Table 1). The first explores the nature of the disconnect between landscape ecology and EIA in order to identify gaps between the science of landscape ecology and the practice of EIA, using the province of Ontario, Canada as a case study. The second objective examines these gaps with a view to understanding why these exist, where the greatest challenges are to bridging the gaps, and examines related opportunities for improving EIA. Finally, the third objective presents a technical evaluation of one way in which landscape analysis might be used to inform project decision-making with respect to biodiversity considerations, using existing data and tools, and uncovers strengths and limitations of the approach. Examining the research question from these three angles reflects the multi- and interdisciplinary nature of the challenges faced. While the first two objectives are framed through an EIA lens examining the contribution and relevance of landscape ecology, the third uses a broader environmental management perspective to bring a spatial modelling lens to EIA. This research approach reflects the diversity of knowledge fields needed to advance biodiversity assessments and conservation and examine the potential for interdisciplinary solutions.

Table 1. Research goal, objectives, guiding questions and organization

Research Goal Evaluate the potential for landscape ecology to better inform EIA with respect to biodiversity conservation		
Objective 1 Gap identification	**Objective 2** Challenges and opportunities analysis	**Objective 3** Technical evaluation
To what extent has landscape ecology informed EIA in Ontario over the past ten years?	*What are the current challenges and opportunities for incorporating landscape ecology and landscape analysis into EIA?*	*How might landscape analysis be incorporated into EIA and project decision-making, and how might it influence regional biodiversity trends?*
Chapter 4	Chapter 5	Chapter 6

While each objective can stand alone as its own piece of research, together these components tell a broader story regarding the potential to improve biodiversity assessment and outcomes through better-informed EIA.

1.4 Research Scope

My research focuses on the nexus across biodiversity, landscape ecology, and EIA: three distinct but related research fields. As each field is introduced and reviewed in the following chapter, the scope of the reviews is necessarily selective to those parts at this nexus among fields, and is intended to provide a foundation for interpreting research findings presented in this document rather than a summary of knowledge accrued in each field.

Additionally, the research addresses conceptual and applied aspects of landscape ecology and EIA as they relate to biodiversity, and therefore parts of the research must be grounded in specific contexts. Canada, Ontario, and eastern Ontario have been selected for this research as knowledge and concerns around biodiversity, landscape ecology, and EIA have advanced substantially in each of these constituencies over the past decades (e.g., Doyle and Sadler, 1996; EC, 2015; MNRF, 2015; OAG of Canada, 2013; OAG of Ontario, 2016) but integration across these fields has been limited. Collectively these venues embody the current state of EIA and biodiversity practice and thereby may provide information that is transferable to other similar regions. Additional scoping elements providing context and focus to this research at a finer level are identified throughout the review of the research fields in the following chapter. These boundaries established for this research provide a solid foundation for exploring the interplay between the conceptual and the applied aspects of biodiversity, landscape ecology, and EIA.

1.5 Thesis Structure and Chapter Overview

Two major parts comprise this dissertation and reflect the interdisciplinary challenges that are common to environmental planning. The first part, which includes Chapters 2 and 3, presents the intellectual foundations for the empirical work presented in the second part, represented by Chapters 4 to 6.

Within this first part, Chapter 2 reviews the multi-faceted concept of biodiversity and provides a brief overview of landscape ecology and how the discipline and its tools for

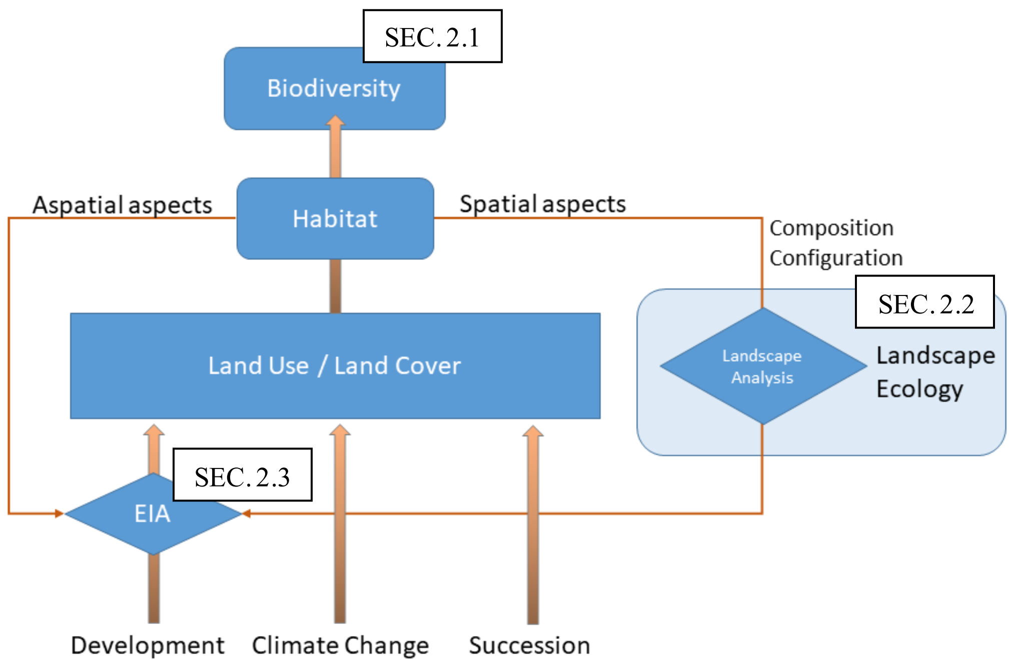
landscape analysis can provide valuable insights into biodiversity. The chapter also introduces EIA and its current practice and challenges with respect to biodiversity assessment. It concludes with a summary of current research on landscape ecology in EIA and planning applications to situate my contributions within the broader context of knowledge in this area. The biodiversity, landscape ecology, and EIA summaries presented in Chapter 2 are intended for readers with limited background in one or more of these fields and aim to provide a common foundation before delving into the more complex questions that are addressed in the subsequent parts of this thesis.
Chapter 3 follows with an explanation of my overall research framework in terms of theoretical underpinnings and methodology, and describes the context of eastern Ontario as my study region.

Following these introductory chapters, Chapters 4 to 6 present the empirical research on each of my three research objectives in stand-alone paper format. Finally, Chapter 7 synthesizes the knowledge gained, and provides a discussion of the collective results in relation to the overall research goal.

Chapter 2: Developing Bridges among Biodiversity, Landscape Ecology and EIA

This chapter establishes the foundation for the overall research effort by providing a conceptual background and context for the main subject areas of my research: biodiversity, landscape ecology, and environmental impact assessment (EIA). The backgrounders set the foundation for research presented in subsequent chapters. The following sections therefore present a concise assessment of the current state of knowledge in each area with the aim of supporting further development of interdisciplinary approaches to advance landscape analysis in EIA science and practice. This promotes an informed understanding among all actors of the individual research areas as well as the connections required to bridge the fields of biodiversity, landscape ecology, and EIA.

Figure 1 illustrates the conceptual links across these fields to assist with the subsequent backgrounders on each field and, more importantly, with investigating the ability to assess biodiversity through the combined lenses of landscape ecology and EIA.



Informed by, e.g., Freemark et al., 2002; Mayer et al., 2016; Mörtberg et al., 2007

Figure 1. Relationships among biodiversity, landscape ecology, and EIA

Biodiversity (Section 2.1) is at the core of this research, with the ultimate aim being to aid in its conservation and that of the ecological processes maintaining it through the mediation of habitat and land use/land cover change arising from human development choices. Landscape ecology (Section 2.2) – particularly a quantitative branch of the field known as landscape analysis – provides the science and foundation for describing the composition and configuration of habitat and using the connection between spatial patterns and ecological processes to predict changes to biodiversity. EIA (Section 2.3) provides the means by which changes to habitat arising from human development activities may be moderated through a decision-making filter, informed by landscape analysis and other aspatial habitat assessments. Note that these conceptual linkages illustrated in Figure 1 are not exclusive: impacts on biodiversity, for example, may also be addressed in EIA outside of a habitat context. However, this conceptual framework is useful in illustrating how the three research fields of biodiversity, landscape ecology, and EIA relate to one another.

The chapter begins with an overview of the current understanding of biodiversity, followed by sections on key advances and current understanding of research in the fields of landscape ecology and EIA, respectively. Within these two sections, a discussion of how each field approaches biodiversity is presented. Together, Sections 2.1 to 2.3 are intended to provide a background in each field for those readers who come to this nexus of work with greater familiarity with one area than the others. Those well-versed in all three research fields are welcomed to move directly to Section 2.4. This final section in this chapter builds on the assessments of the three research fields and lays the foundation for advancing interdisciplinary and integrated approaches to biodiversity assessment through landscape analysis in EIA, looking at what is known, and what is yet to be understood.

2.1 Biodiversity

Biodiversity refers to the "variety and variability among living organisms and the ecological complexes in which they occur" (OTA, 1987, p. 3). It is a multi-faceted and complex concept, with broad consensus with respect to its value, decline, and primary threats (e.g., Ehrlich and Ehrlich, 1992; MEA, 2005; UNEP, 1992) but it is more contested in terms of its practical measurement, monitoring, and the best means of ensuring its conservation and that of the processes that maintain it (e.g., Duelli and Obrist, 2003; Mayer et al., 2016; Phalan et al., 2011). The following sections define the concept and how it will be used in the context of my research, summarize what is known about its global decline, and, with my research in mind, outline ongoing questions when it comes to conservation strategies, measurement and monitoring of biodiversity.

2.1.1 Defining Biodiversity

Biodiversity is by nature a multi-dimensional concept. Biodiversity represents the vast array of genetically distinct populations and species of plants, animals, and microorganisms with which humans share the Earth, as well as the variety of ecosystems of which they are all functioning parts (Ehrlich and Ehrlich, 1992). While biodiversity is often used interchangeably with species diversity in both common and scientific usage (Walz and Syrbe, 2013), it technically ranges from the genetic diversity within species to the diversity of ecosystems within landscapes and regions (Chapin III et al., 2000; Noss, 1990; Syrbe et al., 2013; UNEP, 1992; Walz, 2015). As in hierarchy theory, it is thought that higher levels of organization incorporate and constrain behaviours at lower levels (Noss, 1990).

The term 'biodiversity' was first coined in 1986 by conservation biologists who wished to bring awareness and political support to a global crisis of species and habitat loss (Neumann, 2009). Biodiversity is an inherently normative term as it is routinely tied to the goal of conserving biodiversity in all its forms (Norton and Ulanowicz, 1992). Biodiversity entered mainstream discourse after the 1992 United Nations Conference on the Environment and Development (Earth Summit) in Rio de Janeiro (Castree, 2003; Raustiala and Victor, 1996), where the Convention on Biological Diversity (CBD) defined it broadly as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (UNEP, 1992, p. 3). Here, 156 countries signed onto the CBD and agreed to its three central objectives: the conservation of biological diversity, the promotion of its sustainable use, and the equitable sharing of the benefits of genetic resources. Since then, Canada, a signatory to the CBD, has expanded the definition beyond its constituent components to include the ecological processes that allow them to evolve and adapt to a changing world (EC, 2006; Rudd et al., 2011).

The normative view of biodiversity is nuanced, however, particularly at this species level. For example, species that are not native to an area can be highly detrimental to the persistence of native biodiversity if they become invasive (McNeely, 2004). The CBD therefore recognizes an issue with such alien species which "threaten ecosystems, habitats, or species" (UNEP, 1992, p. 6). At the same time, because biodiversity is dynamic, expansion and contraction of species ranges and ecosystems can confound definitions of native biodiversity (McNeely, 2004) if biodiversity is defined solely as the representation of genes, species and ecosystems (Moritz, 2002). The processes that sustain biodiversity and ensure its persistence through ecological and evolutionary means are therefore an important part of its definition (Moritz, 2002; Rudd et al., 2011).

For the purposes of my research, where I refer to biodiversity in terms of species diversity, it is primarily to recognize this intermediate and most commonly referenced level of biodiversity, with the understanding that it is but one component of overall biological diversity. Complex systems theory indicates a level in a hierarchy influences the characteristics of the next lower level, while being constrained in turn by the next level above it (Müller, 1992), thereby suggesting the potentially adverse impacts of the scope limitation employed in this research are manageable. Thus species diversity, with its intermediate level positioning within broader biodiversity, can be seen to contribute to lower level genetic diversity while being constrained by higher level ecosystem diversity and the processes that maintain it. The focus on the species level allows this research to be discussed in the context of existing literature that tends to use species richness and diversity as a 'common currency' of biodiversity (Gaston, 2000), and aligns with indicators of biodiversity from a policy and planning perspective which use species at the basic unit of analysis for assessing biodiversity trends at any geographic scale (Neumann, 2009; Singh, 2012).

2.1.2 Biodiversity Loss and Conservation

Loss of biodiversity at all levels is of increasing global concern. Biodiversity is critical for earth life support functions, provision of ecological goods and services, economic development, and aesthetic and ethical values (Ehrlich and Ehrlich, 1992; MEA, 2005). Primary reasons for the decline are attributed to habitat loss, alteration and fragmentation, invasive species, pollution, resource overuse and depletion, and climate change (MEA, 2005; OAG of Canada, 2013; Walz and Syrbe, 2013). With respect to terrestrial biodiversity, land use change is an important driver that is expected to have an increasing impact on many ecosystems (Gagné et al., 2015; MEA, 2005; Sala et al., 2000) including the physical and functional disconnection of ecological networks (Pietsch, 2018). The resulting habitat loss, alteration, and fragmentation are widely considered critical threats to biodiversity worldwide (Ewers and Didham, 2006; García-Llamas et al., 2018; Jaeger, 2000; Schindler et al., 2008; Schmiedel and Culmsee, 2016), although there is some debate on the role of habitat fragmentation per se; see Sections 2.2.3 and 4.2.1 (Table 3). It is these biodiversity impacts brought about by land use change leading to habitat loss and alteration that are the focus of my research, and where landscape ecology may show potential to assist with biodiversity assessment in EIA.

The objective of biodiversity conservation is the long-term persistence of the Earth's biodiversity (Wiens, 2002). Biodiversity conservation activities aim to minimize exposure of biodiversity features to threats and to ensure as much as possible that biodiversity and the processes that maintain it can persist in the landscape (Gaston et al., 2002). Biodiversity represents the balance between speciation and extinction (Singh, 2012) and depends on the presence of ecosystems and habitat. Habitat conservation can take many forms, ranging from various levels of management within formally protected areas (Gaston et al., 2002) to habitats without formal protection but maintaining viable populations within managed resource landscapes (Hobbs et al., 1993; White et al., 1997). With an estimated 50-70% of the terrestrial surface in human land uses (Barnosky et al., 2012), there is a compelling line of thought in conservation that long-term biodiversity conservation will depend on maintaining hospitable environments and viable populations within managed landscapes as opposed to preserving them solely within protected areas (Freemark et al., 2002; Gaston et al., 2002; Margules and Pressey, 2000; Mora and Sale, 2011; Walz and Syrbe, 2013; White et al., 1997). While parks and protected areas have an important role in biodiversity conservation, the majority of biodiversity exists outside of protected areas and must coexist with human land uses in working landscapes (Franklin, 1993; Polasky et al., 2005; Sutherland et al., 2009). It is these working landscapes that are the focus of my research.

Conservation biologists and wildlife ecologists have pointed to the need to examine habitat variation and the effects of that variation on ecological processes and species populations at a range of scales (McGarigal and Marks, 1995). There is increasing agreement on the landscape level (see Section 2.2.1) being important for the management of biodiversity, as it provides a larger scale perspective of ecological processes than traditional site-based evaluations (García-Llamas et al., 2018; Walz, 2011). While the conservation of unique habitats and sites is important, it is becoming more recognized that biodiversity can only be conserved through a mosaic of suitable habitat patches at the landscape scale (Waldhardt, 2003).

2.1.3 Biodiversity Measurement and Monitoring

Research and monitoring of biodiversity is currently much more developed in Europe than in North America, with the E.U. reporting on indicators of landscape diversity (the diversity of ecosystems) as early as 2000 (Walz, 2015). Biodiversity is however notoriously difficult to measure. Species richness is often used as a simple measure for biodiversity (Gaston, 2000), but it does not give the full picture. The concept usually includes a consideration of relative frequency or abundance of each species or entity (Noss, 1990). Additionally, ecologists maintain that biodiversity should be surveyed at different organizational levels: regional landscape, community-ecosystem, species-population, and the genetic level (Hou and Walz, 2013; Noss, 1990), yet even within a small, bounded area, biodiversity is far too complex to be fully measured and quantified (Duelli and Obrist, 2003). Changes in alpha diversity (the species diversity at a specific site or habitat patch), for example, cannot always be extrapolated to gamma diversity (the total regional diversity) of the landscape and region (Henle et al., 2014; Kuipers et al., 2019). Using the example of invasive species, the introduction of non-native species to a site can increase species diversity at a local scale, yet dramatically decrease regional biodiversity (McNeely, 2004).

Because of the breadth of the concept, what one intends to measure and monitor must be clearly defined. Failing and Gregory (2003, p. 124) go so far as to call biodiversity a ‘metaconcept’, that “achieves operative sense only when it is clearly defined and used in context”, i.e., to inform management decisions in specific ecosystems with specific indicators. An indicator refers to “any measurable correlate to the entity to be assessed: a particular aspect of biodiversity” (Duelli and Obrist, 2003, p. 89). Indicators may show either quantitative relationships to overall biodiversity (i.e., correlates) or qualitative connections to biodiversity measures (i.e., surrogates) (Waldhardt, 2003).

There is no clear consensus as yet on the best indicators for biodiversity, and indeed, perhaps there are no universal indicators for all situations. Duelli and Obrist (2003) argue that most studies claiming to measure or indicate biodiversity using indicator species make the assumption that the organisms they study are representative of biodiversity; however, only in very few cases has this correlation been measured and published. There are also difficulties in seeing consistent relationships between taxa. While it might simplify measurement to use one group of species to indicate overall species richness (Margules and Pressey, 2000), there is often little correlation in species richness between taxa (Dauber et al., 2003). However, in the absence of ideal indicators, one must often use the best available. Birds are among some of the best studied organisms as they are present in all habitats worldwide, are sensitive to environmental change both from the bottom-up and top-down, are accessible to monitor, and their ecology is relatively well understood; therefore they are often used as proxies to assess biodiversity in the absence of information on other taxa which may be more difficult to sample (Bacaro et al., 2011; Bani et al., 2006; Gregory, 2006). However, they may not necessarily reflect the health of all taxa under their umbrella (Gregory, 2006).

Biodiversity is inherently tied to habitat, whether that habitat can be considered to be supporting the species and genetic levels of biodiversity or representing the ecosystem level of biodiversity (Walz and Syrbe, 2013). Thus habitat-based analysis is often used in biodiversity monitoring as another convenient proxy (Schultz, 2010), and is particularly relevant to working landscapes with shifting land uses that can impact habitat diversity and structure (Walz, 2011). Here, the intersection of biodiversity and landscape ecology, in particularly its quantitative sub-field of landscape analysis, is of particular relevance. This important connection is discussed further in Section 2.2.3, and represents a key tenet of the research efforts presented in Chapters 4 to 6.

At all levels, biodiversity is influenced by spatial and temporal processes (Hou and Walz, 2013), and any indicators selected should be responsive to the processes to which one wishes to gauge a response.

Biodiversity is a complex concept, difficult to define, measure and monitor; however, an understanding of the different levels at which it operates is necessary to its conservation and that of the processes that maintain it.

2.2 Landscape Ecology

Among the fields with expertise to help assess overall biodiversity is landscape ecology, a spatial science with interdisciplinary roots. Due to its foundations in ecology, geography, and land use planning, among others (Wiens, 2002) and its emphasis on multiple scales of assessment (Freemark et al., 2002), landscape ecology may have unique advantages in providing an understanding of the complex problem of biodiversity loss driven by land use change. This section presents key concepts in landscape ecology associated with habitat, spatial pattern and scale that will be used throughout my research. Landscape ecology has reached reasonable consensus on these concepts; however, areas of current focus and debate are also mentioned later in this section. Landscape analysis, the analytical tools and quantitative work of landscape ecology, is presented next. Finally, I identify landscape ecology approaches and opportunities specific to biodiversity with potential to improve EIA practice and decision-making.

2.2.1 Evolution of Landscape Ecology Science and Practice

Landscape ecology refers to the study of spatial patterns on the land and their relationship with ecological and human processes (Freemark et al., 1993). A subdiscipline of ecology (Turner, 2015), landscape ecology explicitly considers how time and space affect environmental patterns and the processes that shape them (Mayer et al., 2016). It can be differentiated from traditional ecology by its focus on spatial heterogeneity and pattern, spatial and temporal dynamics, typically broader spatial extents than those traditionally studied in ecology, and human influences on landscape pattern and processes (Freemark et al., 1993; McGarigal and Marks, 1995). Landscape ecology is based on the principle that the heterogeneity and pattern of landscape elements have a strong influence on ecological characteristics (Botequilha Leitão and Ahern, 2002; McGarigal and Marks, 1995), functions and processes (Gustafson, 1998). It seeks to understand and advance knowledge of the relationships between spatial patterns of land use change and ecological, biophysical or socio-economic processes (Mairota et al., 2015; Nagendra et al., 2004). Key themes include *pattern* and *scale*, discussed below.

Pattern

Landscape ecology tends to use a specific hierarchical terminology, summarized here in order to establish the definitions for these terms as they are used throughout my research. Habitat refers to the spatial extent of a resource for a particular population or species

(Bunce et al., 2013), consisting of biotic and abiotic variables (Mairota et al., 2015). Habitat may also be defined for a community of species that share the same ecological requirements, termed an ecosystem or biotope (Bunce et al., 2013). At a higher level, a landscape refers to a mix of ecosystems or land use types repeated over the land (Forman, 1995a). A landscape can be defined by its structure as a complex or mosaic of habitat elements and resources at various scales (Bunce et al., 2013; Freemark et al., 1993; Kotliar and Wiens, 1990). Habitat elements in a landscape may include patches, corridors, and an intervening matrix (the patch-matrix model, or patch-corridor-matrix model, of a landscape; Walz, 2015). Patches are relatively homogeneous areas at a given scale that differ from their surroundings, with a relatively distinct transition to adjacent areas (Forman and Godron, 1986; Gustafson, 1998; Kotliar and Wiens, 1990). Corridors are relatively linear habitats joining patches of similar habitat (Wiens, 2002). Patches and corridors are located within a landscape matrix, representing the dominant type of landscape element in an area, usually the most extensive and most connected (Forman and Godron, 1986; McGarigal and Marks, 1995). Landscape structure is described by its composition (presence and amount of patch types) and configuration (spatial distribution or arrangement of patches) (Freemark et al., 1993; McGarigal and Marks, 1995). Above landscape, a region is the next higher level, which refers to a non-repetitive and coarse-grained pattern of landscapes (Forman, 1995a). These terms are representative of various concepts in landscape ecology which may be found in EIA and planning processes (e.g., CEAA, 1996; Dale et al., 2000), depending on the extent to which landscape or broader-scale context is considered.

The patch-matrix model of a landscape is used extensively in landscape ecology (Gustafson, 1998), but it is also important to recognize alternative models are available. Some represent the landscape as a continuous surface, rather than as discrete patches, exploring spatial gradients in habitat suitability and landscape resistance (e.g., Fischer and Lindenmayer, 2007, 2006; Manning et al., 2004). Continuous models have advantages and disadvantages compared to discrete models, most notably the use of point-data analysis (geostatistics) to examine the spatial structure of a system property (Botequilha Leitão and Ahern, 2002) means that fewer a priori assumptions are made about the nature of spatial structure (Gustafson, 1998). However, downsides of this method can include statistical artifacts and difficulties relating observed trends to ecological explanations (Gustafson, 1998). Continuous landscape representations tend to be used in heterogeneous environments where patch boundaries are not easily defined (Bruton et al., 2015), whereas discrete landscape representations are typically applied to disturbed or regenerating landscapes (Bruton et al., 2015; Fischer and Lindenmayer, 2006) where a patch structure tends to emerge (Lausch et al., 2015).

For the purposes of my research, a patch-matrix landscape model will be assumed, due to both its prevalence in the landscape ecology literature and its applicability to disturbed or patchy landscapes which occur in the context of working landscapes with both human developments and habitat features, such as those typically studied in EIA. The patch-matrix model will therefore inform the research efforts in Chapters 4 to 6. While the language used tends to distinguish between undisturbed habitat (patch) and anthropogenically disturbed (matrix) landscape features (Kuipers et al., 2019), which I will adopt for the sake of consistency, I also acknowledge that in reality, landscapes are not fully binary (habitat and non-habitat) but consist of a gradient from more or less hospitable areas that different species may perceive differently (Fischer and Lindenmayer, 2007).

Scale

Scale is an important concept within landscape ecology that represents both the spatial and temporal domains of a study (Henle et al., 2014). This is in contrast to levels of organization, which refers to the hierarchical differentiation between levels in a system such as the genetic, species and ecosystem levels of biodiversity described in Section 2.1. Spatial scale includes both grain and extent (Forman and Godron, 1986; McGarigal and Marks, 1995). Grain refers to the size of individual units of observation, or the lower limit of resolution of a study (McGarigal and Marks, 1995); it also refers to the smallest scale at which an organism responds to patch structure (by differentiating among patches) (Kotliar and Wiens, 1990). At smaller scales, the organism perceives its environment as functionally homogeneous (Kotliar and Wiens, 1990). Extent, on the other hand, refers to the overall area included in an investigation, the area of a delineated landscape, or the upper limit of resolution of a study (McGarigal and Marks, 1995). It also represents the largest scale of heterogeneity to which an organism responds, which is usually the home range of the individual (Kotliar and Wiens, 1990). Temporal scale relates to the duration and rate at which ecological or anthropogenic processes of change occur (Henle et al., 2014). It can be related to spatial scale in a hierarchical way, in which smaller spatial systems change according to faster temporal dynamics than do larger systems of which they are a part (Norton and Ulanowicz, 1992). Temporal connectivity has been observed across a range of organisms and habitats, in which species persist in a landscape for a limited period of time following losses of habitat structure and quality until such time as suitable habitat conditions are restored (Auffret et al., 2015).

2.2.2 Landscape Analysis

Landscape analysis refers to a branch of landscape ecology that employs analytical tools and methods to characterize and understand landscapes and habitat change (Farina, 2006). It uses a variety of metrics to quantify the composition and configuration of landscapes, many of which can be relatively simply derived from remotely sensed data and organized within geographic information systems (GIS). These tools can be used for analysis, evaluation, design, communication, and monitoring and adaptive management of landscapes and regions, thus incorporating ecological knowledge into planning and assessment (Botequilha Leitão and Ahern, 2002). Landscape metrics have also been used to assist with assessing ecosystem services, forest monitoring, urban sprawl control, and regional biodiversity conservation (Yu et al., 2019).

Landscape metrics quantify and capture the composition and configuration of landscape elements at a given time (Botequilha Leitão and Ahern, 2002), and can describe their size, shape, number, type, and spatial arrangement (Walz, 2015). The multiplicity of landscape metrics employed to quantify different aspects of spatial heterogeneity of patches, classes (types of patches) and landscapes (Botequilha Leitão and Ahern, 2002; Gustafson, 1998; McGarigal and Marks, 1995) allows for landscape analysis across a wide range of contexts (Yu et al., 2019). This provides flexibility and versatility, but presents challenge such as identifying core sets of ecologically-relevant, independent metrics (Botequilha Leitão and Ahern, 2002; e.g., Dauber et al., 2003; Hou and Walz, 2013; Jaeger, 2000; Mairota et al., 2015; Walz, 2011). Correlated metrics that measure multiple components of the same spatial pattern (Botequilha Leitão and Ahern, 2002; Gustafson, 1998) can mask actual relationships between landscape structure and biodiversity and thereby contribute to unreliable assessments (Schindler et al., 2015).

Landscape metrics that quantify temporal dynamics and landscape variability over time are less developed (Gustafson, 1998), yet important as the rate of change of landscape pattern (including the temporal correlation or synchronicity of patch changes) is critical to the survival of species populations (Freemark et al., 2002). This is an ongoing area of research (e.g., Auffret et al., 2015).

The ease with which these types of analytical tools can be integrated into existing planning and assessment processes have potential to improve biodiversity assessment if interpreted and used appropriately. These various kinds of landscape analysis tools provide information to support a broader-scale perspective on habitat change, which is needed for effective biodiversity conservation. Landscape analysis thus represents a key area with potential for contributing to biodiversity assessment in EIA.

2.2.3 Landscape Ecology Approaches to Biodiversity

Landscape ecology has been intertwined with biodiversity since its inception, recognizing that landscape structure, composition and configuration is tied to biodiversity at a variety of spatial and temporal scales (McGarigal and Marks, 1995; Wiens, 2002). Among landscape ecology's ongoing work and contributions to conservation knowledge, there are three research areas in particular that I introduce briefly here as important approaches for advancing interdisciplinary biodiversity work. These include ongoing research into spatial pattern-ecological process connections, scale interactions, and spatial/quantitative planning tools (already introduced above as landscape analysis).

Spatial Pattern-Ecological Process Connections

Uncovering relationships between the composition and spatial arrangement of land uses and the corresponding response of biodiversity as it changes is an important contribution to knowledge for biodiversity conservation. Landscape ecology's focus on these pattern-process relationships can offer theory and empirical evidence upon which to understand and compare the effects of different spatial configurations of land cover in terms of biodiversity (Botequilha Leitão and Ahern, 2002; Forman, 1995a). Three areas of ongoing work appear particularly relevant, examining questions of (1) how much habitat to conserve to ensure species persistence, (2) whether and how spatial arrangement of habitat can aid or detract from species persistence, and (3) how the nature and quality of the matrix or dominant land use type (often anthropogenic) affect species persistence.

The question of how much habitat is enough is complex and ongoing. There has been considerable work on determining threshold values sufficient to ensure species persistence, but these appears to be quite landscape- and species-specific. For example, species native to landscapes with greater heterogeneity, high endemism, and a natural disturbance regime that occurs on a large scale will require more habitat area (Freemark et al., 2002). Similarly, species with low reproductive potential and risky dispersal strategies typically require more habitat to persist (Fahrig, 2001). While 20-30% suitable habitat in a landscape is thought to ensure persistence of most species (Andrén, 1994; Fahrig, 1997; Freemark et al., 2002), Mönkkönen and Reunanen (1999) suggest that the most sensitive species in a region be used to determine regionally-specific thresholds to conserve biodiversity rather than using average values across species and regions.

In the absence of definitive answers on this question, some authors have developed general guidelines for biodiversity persistence in landscapes for various ecosystems and regions. For example, the *How Much Habitat is Enough* series compiled by Environment Canada, founded on landscape ecology-based information, recommends habitat amount guidelines related to forests, grasslands, wetlands, and riparian areas within the settled landscapes of the lower Great Lakes and Mixedwood Plains of southern and eastern Ontario (EC, 2013). For these ecoregions, a minimum of 30% forest cover at the watershed scale is equated to a high-risk approach that may only support less than one half of the potential species richness. At least 40% forest cover at the watershed scale is equated to a medium-risk approach that is likely to support more than one half of the potential species richness, while at least 50% forest cover or more at the watershed scale is equated to a low-risk approach that is likely to support most of the potential species.

As habitat is increasingly lost in a landscape, the configuration of remaining habitat becomes increasingly important. However, there is considerable debate in the field about the relative effects of habitat loss and fragmentation on biodiversity (e.g., Didham et al., 2012; Fahrig, 2017, 2013, 2003; Haddad et al., 2017). Their relative importance may depend on the landscape in question. For example, Andrén (1994) found that the relative effects of habitat loss, patch size and isolation differ with the degree of habitat fragmentation, such that in landscapes with >30% suitable habitat, effects were mainly due to habitat loss, whereas in landscapes with <30% suitable habitat, patch size and isolation add to the effect of habitat loss and the loss of species or population decline was larger than that expected from habitat loss alone. Kareiva and Wennergren (1995) suggested that the spatial arrangement of habitats could mitigate the risks of species extinction from habitat loss, but other studies indicate that the effects of habitat loss outweigh effects of habitat fragmentation (Fahrig, 1997). Mairota et al. (2015) confirmed experimentally the theory advanced by Didham et al. (2012) that there are important cross-level interactions and interdependence of spatial configuration effects that determine ecological effects of fragmentation. Adding to the complexity, local increases in biodiversity are sometimes observed at fragmented sites due to the presence of invasive species and habitat generalists moving in; however, regional and global biodiversity can simultaneously decline if habitat specialists that depend on contiguous interior habitat are lost (Bender et al., 1998; Fahrig, 2017; Kuipers et al., 2019).

In contrast, there is relative consensus in the field on the importance of the landscape matrix in promoting species persistence and biodiversity in disturbed landscapes, and in mediating the effects of fragmentation and habitat edges. Thus it is not only the characteristics of a habitat patch that are necessary to predict species persistence; the nature and structure of the landscape surrounding a patch are also important (Fahrig, 2001; Freemark et al., 2002, 1993; Humphrey et al., 2015; Mairota et al., 2015; Mazerolle and Villard, 1999).

Landscape pattern characteristics that relate to biodiversity are discussed further in Section 4.2.1 (Table 3), and inform the research design advanced in Chapter 6.

Scale Interactions

Scale interactions are important in this research from at least two perspectives, ecological and jurisdictional. An ecological perspective begins with an understanding that ecological processes act on multiple scales, creating and responding to patterns at a matching scale, whereas a jurisdictional perspective is tied to administrative units for environmental planning and management and delivery of biodiversity conservation programs.

The landscape level is important in biodiversity conservation, with changes in land use and landscape structure considered key to reducing the problem of biodiversity loss (Walz and Syrbe, 2013). However, the spatial extent of a landscape can vary depending on the organism or ecological process of interest, resulting from an interaction between the scale at which an organism or process operates and the scale of the landscape pattern (created by disturbance processes) (Freemark et al., 2002, 1993; Gustafson, 1998; McGarigal and Marks, 1995). Betts et al. (2014) concluded that much of the earlier inconsistencies in empirical assessments of landscape pattern effects on biodiversity could be attributed to different scales at which ecological processes function and at which species respond to change. Assessments of future biodiversity therefore need to consider the scale of current processes and potential future disturbances.

The hierarchy of patch structure (e.g., Kotliar and Wiens, 1990) may provide a conceptual framework for linking policy scales to appropriate conservation targets. For example, highly mobile species such as migratory birds are a challenge for conservation planning because their persistence depends on conservation actions across their dispersal range, which can be at the national or continental scale (Donovan et al., 2000). Several researchers make the case that a comprehensive conservation strategy needs to consider multiple geographic scales from local to continental, and multiple temporal scales (Donovan et al., 2000; Freemark et al., 2002; Poiani et al., 2000). Relating conservation management across these scales to levels of a patch hierarchy, local management would be nested within regional systems, and regional within national to continental institutions. At each level, conservation objectives can be defined corresponding to populations with mobility and dispersal dynamics at that scale. Donovan et al. (2000) present an example of a top-down conservation planning approach for migratory birds in which local-scale planning is influenced by regional-scale objectives. In this case, local and regional managers work together to develop priorities at a regional scale, which then trickle down to local managers to address local priorities within this regional context. Combining alternative scenarios with dynamic population models can help answer questions of how to assess and manage a landscape to achieve regional population objectives (Donovan et al., 2000).

Landscape Analysis Tools

Landscape analysis tools include metrics (introduced in Section 2.2.2) and models that can provide an indication or surrogate measure for biodiversity, linking species diversity to land use structure (Syrbe et al., 2013). Landscape heterogeneity and spatial arrangement, for example, are often thought to be good proxies for species diversity (Duelli and Obrist, 2003; Syrbe et al., 2013). The idea of using landscape metrics to indicate biodiversity is theoretically sound, since biodiversity declines are strongly linked to habitat reduction (Schindler et al., 2015); however, using landscape metrics as relevant and universal indicators of biodiversity is difficult because indicator performance is dependent on both the landscape context and the targeted taxon (Fahrig, 2003; Schindler et al., 2015; Walz, 2011). Some landscape metrics can predict the presence of one species quite well, but be meaningless for another species of the same taxonomic group. Optimal sets of metrics, however, have been found to correlate well with variation in species richness (Schindler et al., 2015). Landscape analysis tools derived from landscape ecology can provide a bridge between science-based management actions and policy, supporting decision-making at multiple scales (Mayer et al., 2016; Opdam et al., 2013).

2.3 EIA

Effective environmental planning, including assessing the environmental impacts of potential land use change, is important for the conservation of biodiversity. EIA is now considered an essential tool for environmental decision-making (Dalloz et al., 2017; Noble, 2015) and assessing impacts on biodiversity (Gontier, 2006; Gontier et al., 2010; Pietsch, 2018). This section provides an outline of the evolution of EIA, including areas of ongoing challenge such as cumulative effects assessment. Finally, approaches to biodiversity assessment in EIA are introduced and critiqued.

2.3.1 Evolution of EIA Science, Policy and Practice

EIA originated in the U.S. with the invoking of the National Environmental Policy Act of 1969, and has become one of the most widely practiced environmental management tools worldwide (Dalloz et al., 2017; Noble, 2015). At its simplest, EIA is a decision support tool for environmental planning, referring to a systematic process of identifying, predicting, evaluating, and mitigating the biophysical, social and other relevant effects of alternative development proposals in advance of major decisions and commitments (Igondova et al., 2016; Jaeger, 2015; Noble, 2015). The overall goal of EIA is to facilitate consideration of the environment in planning and decision-making in order to promote decisions that lead to more sustainable actions and developments (Noble, 2015). EIA may also be referred to as environmental assessment (EA) or impact assessment (IA), with the terms often used interchangeably (Hanna, 2009; Noble, 2015).

EIA may be applied to individual projects, to groups or classes of projects (Class EA), to regions (Regional Strategic EA), or to broader policies, plans and programs (Strategic Environmental Assessment, SEA). SEA in particular is discussed in the literature as an opportunity within which to better incorporate landscape and broader scale effects assessment, as it has been required by E.U. Directives since 2004 (Balfors et al., 2010; Gontier, 2006; Mörtberg et al., 2007). SEA is currently much more developed in Europe than North America. In Canada, a federal Cabinet directive requires SEA be applied to federal plan, policy or program proposals in a manner similar to project EIA (Government of Canada, 2010), while various forms of SEA can be found across provinces and territories. Common challenges include the lack of future alternatives or scenarios, and their disconnection from larger and more formal system of integrated decision-making (Noble et al., 2019). The coming into force in 2019 of a new federal *Impact Assessment Act* in Canada (Government of Canada, 2019) added a new emphasis on regional and strategic assessments, the impact of which will be interesting to explore in coming years.

Though variations exist, the main steps in the process of EIA include screening, scoping, assessment and evaluation of impacts (sometimes with the development of alternatives and mitigation measures), reporting, review, decision-making, and monitoring (Igondova et al., 2016; Pietsch, 2018). The focus of EIA is typically on 'valued ecosystem components' (VECs), which are followed throughout the stages of EIA (Beanlands and Duinker, 1984; Duinker and Greig, 2006). While the primary goals and process of EIA tend to be common across nations, each country's use of EIA is distinct, and the legislation, policy directives, and guidelines for EIA are unique to each country (Noble, 2015). The Canadian context for EIA is outlined in further detail in Section 3.2.

Benefits of EIA are that, when applied early enough in the decision-making process, it can provide information on the consequences of specific development activities in a way that can inform project and mitigation decisions (Heiner et al., 2019). EIA can sustain environmental values in the face of developments that might compromise those values (Duinker and Greig, 2006).

However, the promise and the practice of EIA are somewhat different. EIAs have been criticized for being too vague or making unsubstantiated predictions (Drayson et al., 2017; Jaeger, 2015), having poor treatment of uncertainty (Pavlyuk et al., 2017) and trade-offs (Brownlie et al., 2013; Gibson, 2013), over-emphasising local scales, and lacking predictive analysis to determine significance of effects (Jaeger, 2015). A known area of weakness in EIA is the assessment of cumulative effects, discussed in the following section. This shortcoming affects the ability of EIA to effectively assess biodiversity in the context of an individual project, as it tends to be the cumulative impact of project-by-project decision-making that results in habitat loss and fragmentation of the landscape with associated losses in biodiversity (Botequilha Leitão and Ahern, 2002; Therivel and Ross, 2007).

2.3.2 Cumulative Effects Assessment

Questions of broader scale impacts necessarily involve questions of cumulative effects. Noble et al. (2017) use the Canadian Council of Ministers of the Environment definition, which explains a cumulative effect as “a change in the environment caused by multiple interactions among human activities and natural processes that accumulate across space and time” (CCME, 2014, p. 1). Cumulative effects assessment (CEA), then, refers to the systematic process of identifying, analyzing, and evaluating cumulative effects (Gunn and Noble, 2012). CEA recognizes that each additional project or activity in an area, regardless of magnitude, represents a marginal change in the environment which may add up to a significant impact over time (EBI, 2003; Noble, 2015). For example, local impacts stemming from a single project on a relatively common species may be considered insignificant when considered in isolation, but may become significant when project effects are replicated in multiple venues within a region (Gontier, 2006).

In Canada, CEA has been a requirement under federal legislation since the Canadian Environmental Assessment Act of 1995, which required consideration of “any cumulative effects that are likely to result from the project in combination with other projects or activities that have been or will be carried out” (Duinker and Greig, 2006, p. 153). Similar requirements exist in Europe for including indirect, secondary, and cumulative effects (Jaeger, 2015), and in the U.S., where federal agencies must consider incremental impacts of the action when added to other past, present and reasonably foreseeable future actions (Schultz, 2010).

In theory, CEA provides a necessary link to the landscape or regional level in terms of biodiversity impact assessment; however, in practice it has not typically been well executed (Duinker and Greig, 2006; Gunn and Noble, 2012; Jaeger, 2015; Parkins, 2011). Effective CEA requires proper scoping (identifying appropriate spatial and temporal boundaries), prospective and retrospective analysis of cumulative effects, and management of cumulative effects once identified (Noble, 2015). Challenges include balancing the difference in objectives between project-centred EIA and VEC-centred CEA (Duinker and Greig, 2006), knowledge of regional thresholds and carrying capacities for different environmental aspects under consideration, and uncertainties associated with future projections, among others (Noble, 2015).

It has been argued that CEA and management of cumulative effects may be best accomplished in a broader strategic or regional setting outside the regulatory requirements of specific projects (Duinker and Greig, 2006; Kristensen et al., 2013; Noble, 2015; Sheelanere et al., 2013; Sinclair et al., 2017). However, with processes for development approval being well-established at the project level, there are currently more opportunities to improve practice at this level while continuing to move towards better regional and strategic assessment processes (Duinker et al., 2013; Duinker and Greig, 2006; Therivel and Ross, 2007).

Given the current debates around the requirements, effectiveness and applicability of formal CEA to project EIA, it would be beneficial to better incorporate landscape level information into project EIA in order to improve the quality of biodiversity information and assessment. My research therefore focuses primarily on the application of landscape analysis within project-based EIA, in relation to project effects on land use and associated cumulative impacts on regional biodiversity.

2.3.3 EIA Approaches to Biodiversity

EIA is an important tool for integrating biodiversity concerns into planning and decision-making. This section provides a review of biodiversity inclusion in EIA, and identifies areas where its effectiveness is currently adequate and where it can be improved. It provides context for the use of landscape ecology principles and analysis to enhance EIA, and lays a foundation for my research with respect to identifying current challenges and areas of opportunity for bridging biodiversity, landscape ecology and EIA.

EIA application to biodiversity occurs at multiple levels. It is featured as an important project planning tool within international conventions including the CBD, the Ramsar Convention and the Convention on Migratory Species (IAIA, 2005), and in assisting with the objectives of conservation, sustainable use and equitable sharing of biodiversity outlined in the CBD (Secretariat of the CBD, 2006; UNEP, 1992). EIA also supports biodiversity conservation within lower level contexts, in conjunction with regional planning, biodiversity laws and strategies, and protection of special management areas (Henle et al., 2014).

The CBD and the International Association for Impact Assessment (IAIA) have made the inclusion of biodiversity within the scope of EIA explicit and comprehensive. In April

2002, the Conference of the Parties of the CBD endorsed a set of draft guidelines for incorporating biodiversity-related issues in EIAs, recommending that impacts be evaluated across all levels of biodiversity and encompass the appropriate temporal and spatial scales (EBI, 2003). The decision emphasized that the term ‘environment’ in EIA legislation should fully incorporate the concept of biodiversity as defined by the CBD. Subsequently, the IAIA and the CBD each published a set of guidelines for biodiversity-inclusive EIA in 2005 and 2006, respectively (IAIA, 2005; Secretariat of the CBD, 2006). Best practices in biodiversity assessment, according to these guidelines, include assessing changes to biodiversity at all levels in terms of its composition, structure (distribution in space and time), and key processes including ecosystem function (Secretariat of the CBD, 2006). These guidelines also note that potential impacts on biodiversity can be identified without having a complete description of that biodiversity; if an action is expected to result in changes to composition, structure, or key processes, this then gives reason to expect that ecosystems would be more broadly affected.

Canada was an early adopter of the inclusion of biodiversity in federal EIA, and the initial *Guide on Biodiversity and Environmental Assessment* was introduced 25 years ago (CEAA, 1996). Among the guiding principles promoted in the document are a consideration of no net loss of the ecosystem, species populations or genetic diversity; maintenance of natural processes and adequate areas of different landscapes for wild flora and fauna and other wild organisms; providing a regional context for impact analysis by defining the spatial parameters that characterize ecological processes and components; and examining the cumulative effects of other activities in the area or region to date and evaluating the added effect that the project, and others likely to follow, will have on biological diversity. However, the guide was written with legislation of the time in mind and has not yet been updated to match the requirements of current federal law.

There have been several critiques of biodiversity assessment in EIA that span over two decades. One criticism is that standard biodiversity assessments in EIA tend to focus solely on direct impacts (e.g., habitat loss for certain species due to the project footprint), and do not consider indirect, long-term, cumulative or widespread effects (Byron et al., 2000; EBI, 2003; Gontier, 2006; Khera and Kumar, 2010). Neither do they tend to include a broader-scale context for habitat changes, leading to poor treatment of habitat loss and fragmentation effects (Gontier, 2006; Karlson et al., 2014; Scolozzi and Geneletti, 2012) and seldom consider impacts at the ecosystem or landscape levels (Gontier, 2006). Delineation of the impact assessment study area is often made without reference to scales of ecological processes (Karlson et al., 2014).

Other criticisms include a general lack of quantitative methods (Geneletti, 2006; Gontier, 2006; Karlson et al., 2014), and assessments being descriptive rather than analytical and predictive (Byron et al., 2000; Gontier, 2006; Jaeger, 2015; Karlson and Mörtberg, 2015; Khera and Kumar, 2010). Gontier (2006) related the issues with the descriptive content of EIA to little use of quantitative methodologies and vague data focused on inventories of protected species and habitats rather than functional assessments at the ecosystem and landscape levels.

Khera and Kumar (2010) also found a lack of representation of all levels of biodiversity (habitat, species and genetic) and forms (compositional, structural, functional) throughout the impact prediction, mitigation measures, and monitoring plans in EIA. However, Karlson et al. (2014) did note an improving trend over the period of 2005 to 2013 with respect to the treatment of impacts on biodiversity in EIA, which is encouraging for future work in this field.

2.4 Advancing Interdisciplinary Approaches – Using Landscape Analysis to Further Biodiversity Assessment in EIA

Given the plethora of work in landscape ecology specifically related to biodiversity and the relationship between landscape pattern and ecological processes that mediate biodiversity, and recognizing the gaps in the current treatment of biodiversity in EIA, it appears evident that bridging these fields could promote more effective biodiversity assessments and better-informed decision-making.

2.4.1 Areas of Existing Study

Surprisingly, there is relatively little research that addresses this specific area. Research has focused on the use of geographic information systems (GIS) in EIA to analyze and model landscape patterns (e.g., Treweek and Veitch, 1996), including the ability to integrate more advanced and quantitative analyses of connectivity and fragmentation (Gontier, 2006).

The summary of studies presented in Table 2 shows the application of landscape analysis to advance biodiversity assessments within EIA remains a work in progress. Case studies have been attempted in several venues, demonstrating the widespread, perhaps global, interest in building more effective bridges across landscape ecology, biodiversity and EIA in order to assess development across a range of EIA jurisdictions that consider a wide range of development initiatives in highly varied environments.

Table 2. Examples of case studies examining the application of landscape analysis to advance biodiversity assessments within project EIA

Study	Venue	Development Proposal	Analytical Approach	Biodiversity Metrics Employed	Other Information
Griffith et al. (2002)	Hawaii	Geothermal development	Landscape ecology assessment of alternative development scenarios	Landscape diversity, Habitat aggregation, Patch shape and edge	Results depended on the sensitivity of the landscape pattern metrics to the simulated land use change processes.
Geneletti (2004)	Italy	New highway	Spatial landscape ecology indicators combined with a value function to compare alternative locations	Core area, Disturbance, Isolation	Metrics were chosen based on their ability to capture a range of fragmentation effects, ease of interpretation, and ability to be computed using typical GIS functionality. The authors found little operational guidance on determining the impacts of a project on landscape fragmentation, and suggested that this was due to the complexity of fragmentation effects and the fact that modelling was still in an experimental phase.

Study	Venue	Development Proposal	Analytical Approach	Biodiversity Metrics Employed	Other Information
Karlson and Mörtberg (2015)	Sweden	Road network	Spatial ecological assessment of fragmentation and disturbance effects, using habitat suitability models for hypothetical species	Habitat amount, Connectivity	The authors noted that habitat suitability models depend on detailed knowledge and data on the habitat requirements of species, which can pose a problem for widespread application.
Dalloz et al. (2017)	Brazil	New power line	Use of connectivity metrics to analyze impacts of alternative project locations on target species	Habitat availability, Habitat amount, Patch number, size and isolation	Habitat availability was found to be the most sensitive metric to the linear disturbance proposed.
Pietsch (2018)	Germany	New road	Use of connectivity metrics to analyze impacts of alternative project locations on target species	Probability of connectivity	Results were strongly affected by different dispersal probabilities and distances in the models. The author noted that use of target species requires considerable ecological knowledge of the species and their dispersal abilities, which may present an obstacle for EIA practitioners and planners.

These studies suggest that landscape ecology concepts and analyses can be used to provide important biodiversity information that can assist in EIA and decision-making. Landscape ecology tools can be particularly useful for large linear projects that cross many habitats and landscapes, because they can be applied over large geographic areas (Dalloz et al., 2017). They can also provide quantitative analytical methods to bridge the issues of overly descriptive EIA and lack of predictive ability (Gontier, 2006). Another benefit is that while direct impacts of land use change can be identified relatively simply, predicting indirect and cumulative effects is more challenging. Because landscape ecology offers the ability to consider land use change at multiple scales, it can provide a source of information on broader-scale effects to inform land use decisions (Mayer et al., 2016; Opdam et al., 2013).

At the same time, common challenges include the ecological knowledge required to calibrate models to the needs of target species (Dalloz et al., 2017; Karlson and Mörtberg, 2015; Pietsch, 2018), the choice of landscape metrics sensitive to the relevant land use change process (Dalloz et al., 2017; Griffith et al., 2002), and the potential for very different assessment outcomes depending on the quality of ecological data entered into models (Pietsch, 2018). Model-building based on best available information continues to provide insights into this area (e.g., Bonnot et al., 2013; Burgman et al., 2005).

Despite the case studies tabled above, gaps are still apparent across landscape ecology, EIA and biodiversity assessment. Scolozzi and Geneletti (2012) reviewed EIA literature for papers mentioning “habitat connectivity”, “habitat loss” or “habitat fragmentation” published between 1997-2010, finding a total of 90 papers. Of these, 71% only mentioned or claimed to consider these topics, with no further analysis. The authors concluded that there was still a knowledge gap between the fields of landscape ecology and EIA. Similarly, Jaeger (2015) reviewed treatment of landscape-level impacts in EIAs for road projects, finding gaps in the areas of landscape-level effects, knowledge of ecological thresholds related to habitat loss and fragmentation, and uncertainties in ecological responses, among others.

Interestingly, there is evidence of a shift towards greater interest in landscape ecology and spatial analyses in assessment and planning practices overall. Recently, habitat fragmentation models were reviewed for their ability to improve modelling of land use impacts on biodiversity in life cycle impact assessment (Kuipers et al., 2019). There are also indications that agencies are looking for broader-scale approaches in order to move towards more effective biodiversity conservation. For example, Henle et al. (2014) suggested that EIA could be used to help mitigate negative impacts on green infrastructure in the E.U. as part of a broader, strategic approach to biodiversity planning and conservation. In Ontario, the Ministry of Natural Resources and Forestry (MNRF) moved towards taking a landscape approach to strategic conservation of ecosystems and species by focusing on efforts at a landscape level (MNRF, 2015). For the MNRF, implementing a landscape approach means managing over broader areas and longer time periods, so that individual conservation efforts are no longer independent of each other and of the patterns and processes occurring across higher spatial scales (MNRF, 2015). While not specific to EIA, the approach indicates the recognition of the importance of landscape ecology and landscape-level analysis to effective conservation.

2.4.2 Summary and Areas to Advance

This chapter sets the context for the research efforts in the following chapters. The complex, multi-dimensional concept of biodiversity is at the centre of the research, with the goal of promoting its persistence in working landscapes through mediation of anthropogenic land use changes that lead to habitat loss and alteration. Landscape ecology is uniquely positioned to inform how biodiversity can be affected by changes to habitat composition and configuration at a range of scales, linking landscape pattern to biodiversity processes and providing analysis tools with which to quantify landscape structure and habitat change. As described in Section 2.2.3, three important research areas in particular can contribute to advancing interdisciplinary work with biodiversity in EIA: pattern-process connections and related ecological thresholds, scale interactions and multi-scale analysis, and landscape analysis tools.

EIA itself provides an instrument to inform decision-making with respect to proposed land use change and thus offers a vehicle for incorporating biodiversity concerns. While critiques have been levelled at EIA practice, including the use of vague or unsubstantiated predictions and predictive analysis, poor treatment of uncertainty, over-emphasis on local scales, and weak treatment of cumulative effects (see Section 2.3.1), there are also benefits in that the approach is well laid-out and well-established in legislation. With processes for development approvals linked to EIA at the project level, there are opportunities to improve the treatment of biodiversity in project EIA in a material way while continuing to move towards better cumulative, regional and strategic EIA systems. To date, approaches to biodiversity in EIA have varied in quality but have been criticized for their generally narrow focus on direct impacts and poor consideration of cumulative, long-term, indirect or widespread effects (including landscape processes) and little use of quantitative methods (Section 2.3.3). There is therefore considerable scope for improvement in approaches to biodiversity in EIA using science and tools from landscape ecology.

Existing research on the intersection of these three areas has identified valuable benefits of integrating landscape ecology and EIA approaches: tools can be applied over large geographic areas, the science can contribute quantitative analytical methods to the assessment, and there is potential to incorporate information on broader-scale effects into project EIA. To date, research integrating these fields has tended to focus on the use of quantitative analysis tools such as modelling and landscape metrics in EIA. Ongoing technical challenges and gaps include the representation of landscapes, choice of landscape metrics, and the need for specialized ecological knowledge to calibrate models to target species as outcomes often show differing results depending on the quality of ecological data entered into models. While interest in landscape ecology approaches is slowly growing with respect to land use planning processes, it has not yet gained momentum with respect to EIA.

This background shaped the current study by focusing it on the current gaps or disconnects between the fields, the reasons behind those gaps and ways to bridge them, and testing how bridging the gaps using a feasible landscape-based method might influence regional biodiversity, with particular emphasis on the Canadian context. The current research provides an in-depth look at developing bridges between landscape ecology and EIA in support of more effective biodiversity assessments and better-informed land use decisions when it comes to biodiversity impacts and mitigation.

The following chapter lays out the research framework, along with the geographical scope of study. It is followed by three chapters that form the bulk of the research effort, from identifying specific gaps where landscape ecology can enhance biodiversity assessment in EIA, to delving into the challenges and opportunities for doing so faced by current practitioners, to using scenario modelling to examine one way in which landscape analysis might be used to inform project decision-making and its implications for regional biodiversity persistence.

Chapter 3: Research Framework

This chapter describes the mixed-methods research used in my study of the application of landscape ecology and environmental impact assessment (EIA) methods to address biodiversity issues, and how the individual research objectives fit together in working towards the overall research goal of evaluating the potential for landscape ecology to better inform EIA with respect to biodiversity conservation. While the research goal and objectives are broadly relevant across biophysical and sociopolitical landscapes, given the highly applied nature of EIA, the research must be situated within specific contexts and the Province of Ontario has been selected. This chapter therefore presents a blend of fundamental approaches used to apply landscape analysis and EIA as well as information that is germane to Ontario.

3.1 Framework and Methodologies

The three key objectives of my research introduced in Section 1.3 each form unique but complementary pieces of the larger research goal (Figure 2). This section explains the interrelationships among the research components and presents an overview of the methodology, with fuller descriptions found within each of the corresponding three chapters. A synthesis (Chapter 7) brings together the research components at the end with reference to the overall research goal.

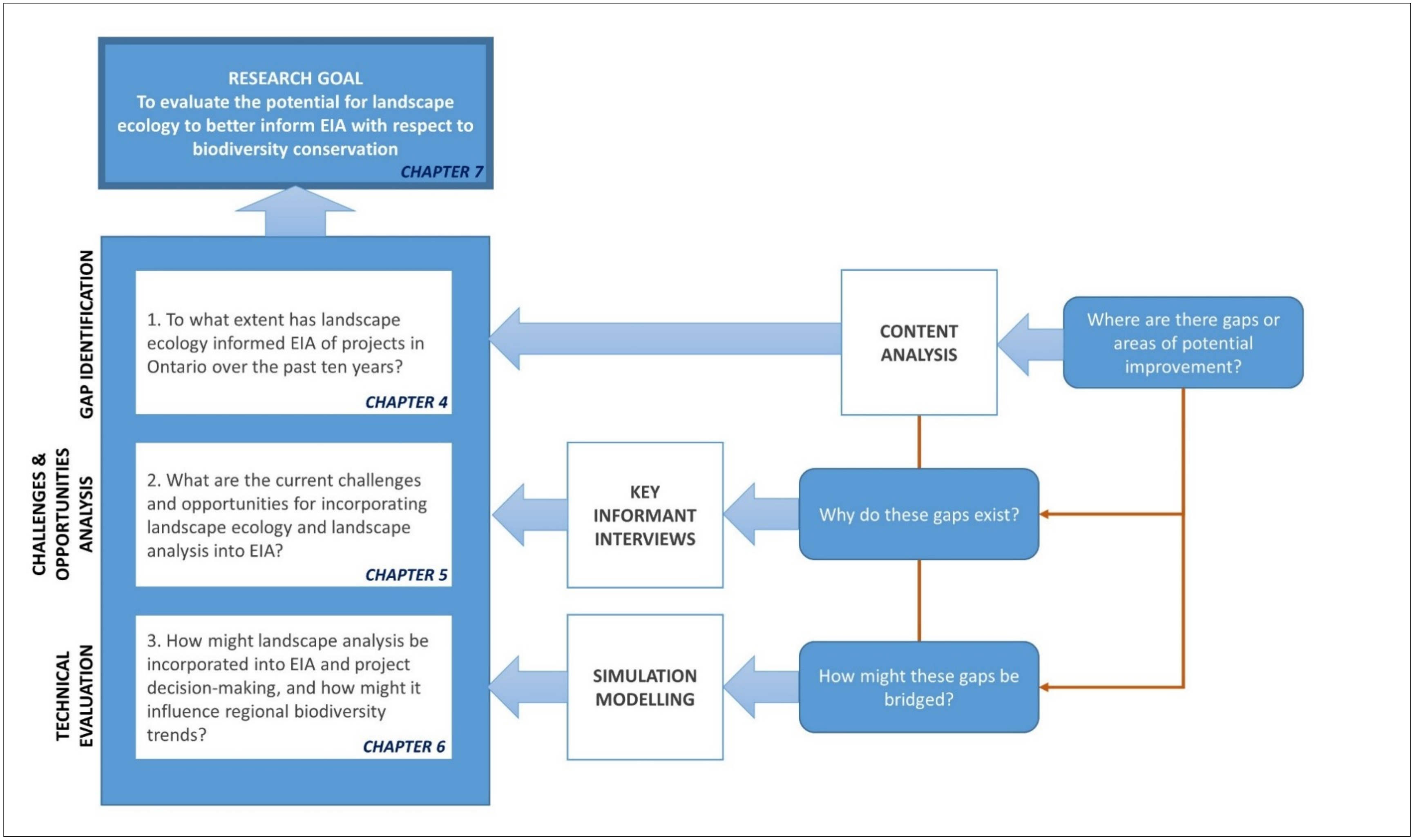


Figure 2. Research framework

Content Analysis

The first objective focuses on assessing the extent to which landscape ecology, including broader scale spatial assessments of habitat and biodiversity impacts, has informed EIA in Ontario, Canada. This research builds on the work of previous studies (see Section 2.4) but emphasizes the integration of landscape ecology and landscape analysis aspects, and how these may be related to biodiversity, in EIA and in the Canadian context. Research methods consisted of a content analysis of selected EIAs to ascertain the greatest gaps in EIA in terms of identifying landscape-level impacts on biodiversity. This followed a review of the content of EIA policy and guidance documents related to issues of biodiversity and cumulative or broader-scale effects in order to tease out how gaps in EIA practice were related to gaps in the corresponding guidance. The methods set a foundation at the outset for understanding the ways in which landscape ecology concepts and science were included or omitted from EIA practice.

This first component creates a research baseline for the dissertation by establishing levels of (dis)connections between landscape ecology and EIA in terms of biodiversity assessment. The 2007 to 2016 time frame for the content analysis captures the decade following the publication of two major international reports advocating the use of best practices in assessing biodiversity as part of EIA (IAIA, 2005; Secretariat of the CBD, 2006), with an emphasis on evaluating impacts on biodiversity composition, structure, and key processes in a regional contexts as well landscape ecology's role in impact assessment. A ten-year window was selected as it provides sufficient time to assess the extent to which EIA practice has adjusted to guidelines advocated within the reports.

Key Informant Interviews

The second objective complements the first by exploring reasons why important landscape-level information is typically not well-translated to the practice of typical EIA, identifying priority challenges, and looking at opportunities to bridge identified gaps. This research component connects the gaps identified in the initial content analysis with the current institutions, application, and practice of EIA.

To address the research questions, I used key informant interviews with EIA practitioners involved in projects in Ontario across federal, provincial and local jurisdictions. I chose to follow a modified Delphi approach, starting with a set of semi-structured interviews in order to gather a breadth and depth of responses. After coding and consolidating responses, I used a follow-up questionnaire to narrow in on the most important challenges and opportunities among the ideas raised by participants, in which participants had the opportunity to learn from and respond to each other's thoughts on the subject matter. The process stopped short of a full Delphi approach where complete consensus is sought, as I did not wish to take away from interesting outlier responses. This modified process and the semi-structured nature of the initial interviews allowed for an in-depth understanding of how key informants perceived and understood the issues, while maintaining the necessary flexibility to follow emerging paths of inquiry (e.g., Silverman and Patterson, 2014).

Simulation Modelling

Finally, the third objective addresses the potential use of landscape analysis as a vector for incorporating biodiversity into project EIA, bringing together existing tools and data, and exploring its strengths, limitations, and links to bridging cumulative impacts on regional biodiversity. This objective had two main components: first, to introduce a technically feasible way in which landscape analysis might be used to support biodiversity assessment in project decision-making, and second, to examine the potential relevance, strengths and limitations of the approach in a cumulative project development setting, in which different possible project development and decision-making scenarios were modelled.

The landscape analysis approach tested here involved the use of existing guidance on habitat-based targets for forest, grassland, and wetland at the landscape level applicable to the ecoregion of the illustration area, an urban-agricultural region of Eastern Ontario, Canada. To technically evaluate this approach applied to project assessment in a cumulative regional context, a spatially-explicit, agent-based simulation model, Envision (Bolte, 2020), was used. Habitat-based indicators of regional biodiversity were used to assess the resulting landscapes following four decades of simulated project decision-making on urban growth areas, aggregate extraction locations, and habitat restoration zones. The biodiversity indicators were compared between five decision-making scenarios that varied in the type of landscape-scale information (including the landscape analysis approach) used by the simulated decision-making agents.

The choice of a modelling experiment to address this question was based on practical experimental considerations. Because it is difficult to experiment at a broad scale, models allow the consequences of alternative policies and management scenarios to be explored using simplified representations of key ecological mechanisms (Schmolke et al., 2010). Modelling methods are increasingly being used as a means to empirically explore implications of landscape change in the face of the high levels of uncertainty inherent in current knowledge of land use dynamics and problems such as biodiversity loss. For my research purposes, agent-based modelling was the most effective way of simulating decision-making that takes into account differing considerations, which then influence the resulting patterns of land use on the landscape over time.

This final research component rounds out the picture of the potential for landscape ecology to better inform EIA with respect to biodiversity conservation by demonstrating one way in which current gaps between the disciplines may be bridged. Together, these three research efforts come at the research goal from different angles and methods and thus provide a robust, multi-faceted examination of interdisciplinary approaches between landscape ecology, biodiversity, and project EIA from the perspective of advancing both theory and practice.

3.2 Study Area

Three practical factors led to the situating of my research within the Province of Ontario, Canada: a history of biodiversity commitments, development of multi-level EIA legislation, and unique geography which includes a biodiverse ecology combined with regional population increases and development pressures.

First, federal commitments to biodiversity in Canada date back to 1992, with Ontario following suit in 2005 (CEAA, 1996; ECO, 2012). Second, Ontario's *Environmental Assessment Act* (EA Act) is the oldest in the country, predating the 1995 federal legislation by 20 years (Graci, 2009; Hanna, 2009). These two factors provide decades of experience with biodiversity and EIA in both the province and the country from which to draw insights. Additionally, with responsibility for EIA in Canada divided between federal, provincial and even municipal jurisdictions, interplay across these three levels allows for an examination of how institutional scale relates to scales of assessment and associated challenges and opportunities for landscape analysis in EIA. Finally, Ontario's diverse ecoregions provide a wide variety of habitats with a high level of biodiversity (Hillmer and Bothwell, 2020; OBC, 2012); this, combined with high population and resources pressures, particularly in southern Ontario (Government of Ontario, 2019; Horn et al., 2019; OBC, 2012), make it an ideal location for exploring effective EIA. This section provides a brief overview of biodiversity commitments, EIA legislation and jurisdictional responsibilities in Canada and Ontario, followed by an introduction to Ontario's geography, as context for the following research chapters.

History of Biodiversity Commitments

Canada and Ontario have established track records in support of biodiversity conservation. Canada was the first signatory of the 1992 United Nations Convention on

Biological Diversity (CBD; UNEP, 1992) and has since nationalized a Canadian Biodiversity Strategy across Canadian jurisdictions (CEAA, 1996). Canada has made it clear that EIA is a key element in both meeting the obligations of the CBD and the Canadian Biodiversity Strategy (CEAA, 1996). Ontario recognized these commitments in 2005 with the launch of the Ontario Biodiversity Strategy, and its subsequent renewal (ECO, 2012; OBC, 2012) and reconfirmation (OMNR, 2012). This long-standing commitment to consideration of biodiversity, particularly within EIA, on a national and provincial level brings relevance to the current research in this area.

EIA Legislation

Canada and Ontario have a well-developed EIA history which demonstrates the complexity of multi-jurisdictional assessment regimes and provides a rich interplay that allows for an examination of how institutional scale relates to scales of assessment. Responsibility for EIA in Canada is shared among federal, provincial, and territorial governments, as each province has authority to manage and make decisions regarding its natural resources (Noble, 2015). In federal legislation, EIA was introduced in 1973 as a guidelines order, and formally legislated in 1995 as the *Canadian Environmental Assessment Act* (Gunn and Noble, 2012; Hanna, 2009). Subsequent amendments in 2012 led to the *Canadian Environmental Assessment Act, 2012* (CEA Act 2012). The most recent federal legislative amendment came into force on August 28, 2019. This new *Impact Assessment Act* (Government of Canada, 2019) replaces the CEA Act 2012 and includes new requirements for assessment of climate change, Canada's international environmental obligations, gender-based analysis, and explicit consideration of

Indigenous knowledge, among others, and also contains new provisions for regional assessments. However, the types of projects to which the federal legislation applies remains generally the same as under the CEA Act 2012. Projects subject to federal EIA include, for example, works related to pulp and paper mills, all-season public highways greater than 50 km in length, electrical transmission lines with voltage over 345 kV or greater than 75 km on new right-of-way, facilities developed within federal parks, large-scale mine development, and uranium mining and waste management. Prior to 2012, the scope of projects covered by earlier federal legislation was much wider, consisting of all projects that were initiated, funded, or permitted to occur by a federal department or agency as well as projects located on federal lands, provided they did not appear on the Exclusion List (Hanna, 2009).

The first provincial environmental assessment legislation in Canada came into effect in Ontario in 1975. Initially the EA Act applied only to Ontario government undertakings, but was modified significantly in 1996 and now includes works by other public sectors (Ontario municipalities and other public bodies such as Conservation Authorities, Ontario Power Generation and Hydro One) and designated private sector undertakings (Graci, 2009). Public sector projects assessed under the EA Act typically include public roads and highways, transit facilities, waste management facilities, sewage, water works and flood protection, and electrical generation and transmission facilities, while designated private sector projects often include landfills, waste transfer processing stations, and incineration projects (Graci, 2009). Many projects, including most municipal infrastructure projects, fall under a streamlined Class Environmental Assessment process that covers routine activities with predictable and mitigable environmental effects (City of Ottawa, 2012; Graci, 2009). However, more complex projects with potential to cause significant environmental effects may require an individual EIA.

There are also municipal applications of EIA in Ontario. While some municipal infrastructure may be included under provincial EIA legislation, local governments may set their own requirements for EIA of development projects as part of their official plans. For example, the City of Ottawa's Official Plan requires an Environmental Impact Statement (EIS) from the project proponent when a development is proposed in or adjacent to part of the City's natural heritage system. The EIS must include a description of the existing environment, the proposed project, and the mitigation measures to be used to ensure the development will not negatively impact significant natural heritage features or functions (City of Ottawa, 2012).

Geography

Ontario provides a unique opportunity to advance research across the fields of biodiversity, landscape ecology, and EIA due to its biophysical heterogeneity leading to high natural biodiversity as well as substantial socioeconomic demands causing pressures on its land and resource base. The Province of Ontario includes two distinct regions, northern and southern Ontario, that vary widely with respect to ecology, land use pressures and corresponding EIA issues. Northern Ontario, underlain by the Canadian Shield physiographic region, is dominated by boreal forest and issues related to mining, roads and forest fragmentation are paramount (BEAN, 2009; Horn et al., 2019; OBC, 2012). In contrast, southern Ontario is the most densely populated region in Canada, holding a third of Canada's population (Horn et al., 2019). Most of the original hardwood forests of southern Ontario have been cleared (Horn et al., 2019), and the region now consists of urban, agricultural, and other human-modified land uses interspersed with remnant forest, grassland, and wetlands (OBC, 2012). Overall, loss of habitat is the primary threat to biodiversity in Ontario (OBC, 2012).

Because jurisdiction for EIA and biodiversity protection extends to the local/municipal level, I also chose a local study area within the province within which to focus on local EIA processes and practice. Southern Ontario is commonly divided into informal regions known as eastern and western Ontario. A portion of eastern Ontario, encompassing two rural counties and a major city (Ottawa) became the local focus for the current research (Figure 3). Together these three administrative divisions are approximately 8400 km^2 in size, forming a large urban-agricultural landscape (e.g., Forman and Godron, 1986) that encompasses several ecosystems and species populations. Reasons for its selection, explained below, include its high biodiversity, intermediate levels of habitat loss and alteration, and mix of urban and rural land use pressures.

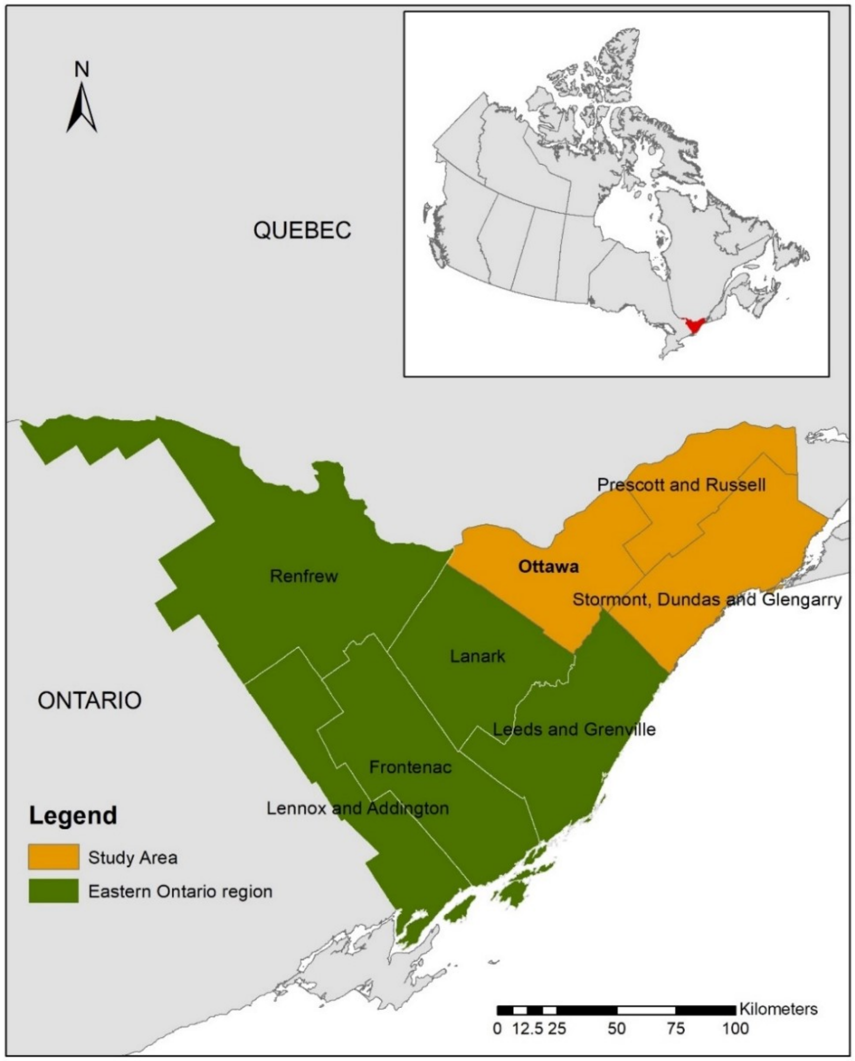


Figure 3. Counties of eastern Ontario, showing the three selected as a local study area

The local study area is located within the Mixedwood Plains, the smallest of Ontario's four ecozones. The ecosystems and habitats of this ecozone have undergone a high degree of alteration, changing from a mosaic of forests, wetlands, prairies and alvars to a landscape dominated by agriculture and human settlements (OBC, 2012). Despite these changes, the Mixedwood Plains is still Canada's most biodiverse region overall (OBC, 2012).

A unique physiographic and ecological zone runs through the Ottawa Valley, at the west end of the local study area, which represents a transition area between the Canadian Shield and St. Lawrence Lowlands physiographic regions (Hillmer and Bothwell, 2020; Minnes and Douglas, 2013). This area contains flora and fauna species of both regions as well as its own unique characteristics combining ridges of granite and limestone rock with fertile agricultural soils and scattered woodlots; as a result, it is one of the most biodiverse areas of Ontario (Minnes and Douglas, 2013). To the south and east of the Ottawa Valley, the local study area is predominantly agricultural, with one major city (Ottawa) – the largest in eastern Ontario – and several smaller population centres. Remnant forests, grassland, and wetlands are sprinkled throughout the region, forming a patchwork of habitats for the area's species. This high local biodiversity and patchy structure of the landscape makes it an ideal study area for landscape ecology.

Agriculture remains a dominant part of the economy in the easternmost counties of the eastern Ontario region (Prescott-Russell and Stormont-Dundas-Glengarry), which are contained within this local study area (Minnes and Douglas, 2013). In contrast, forests remain the dominant landcover in the northernmost county of Renfrew, which is just outside the local study area. This means that a greater portion of the local study area has been altered to anthropogenic land uses as compared to the rest of the eastern Ontario region, although not as much as in the remainder of southern Ontario (i.e., the western Ontario region) where less than 15% of the original habitat remains (Crins et al., 2009). An intermediate level of habitat in the study area means that much of the original biodiversity likely persists (e.g., Andrén, 1994; Estavillo et al., 2013; Fahrig, 1997; Freemark et al., 2002), but the configuration of the remaining habitat becomes increasingly important (Andrén, 1994; Crouzeilles et al., 2014). As such, EIA that is informed by robust landscape analysis becomes even more critical.

The eastern Ontario region, including the local study area, is subject to several current land use pressures that threaten the habitats and biodiversity of the area. While the region is still dominated by an agricultural land use base, the population is expected to increase over the upcoming decades, much of which is predicted within urban centres and urban expansion (Waldick et al., 2017). Urban expansion can come at the expense of prime agricultural land and natural habitats; when poorly planned, development can lead to urban sprawl, a continually increasing network of roads and linear disturbances, and the loss, alteration and fragmentation of natural habitats (OBC, 2012). Additional pressures attributed to the growing population include the increased consumption of natural resources, energy and goods, increased transportation demands, and the associated pollution and production of waste (Minnes and Douglas, 2013; OBC, 2012). The complexity of population and resource pressures on the already threatened biodiversity in the study area along with the existing patchiness of the landscape makes it a valuable area for research on landscape ecology in EIA.

Chapter 4: Patchy Landscapes, Patchier EIA: A Gap Analysis of Landscape Ecology and EIA in Ontario

4.1 Introduction

The global loss of biodiversity is of pressing concern. Assessing impacts of natural resource and development projects on biodiversity is an important component of environmental impact assessment (EIA), recognized by international conventions (Secretariat of the CBD, 2006) and Canadian federal and provincial commitments (CEAA, 1996; ECO, 2012; OAG of Canada, 2013). Impacts on biodiversity are often difficult to ascertain as biodiversity itself may be hard to define, occurring on a range of scales from genes to species to ecosystems (Noss, 1990; UNEP, 1992), and it is often mediated by broad-scale processes where landscape to regional contexts are critical (Franklin, 1993; Waldhardt, 2003; Walz and Syrbe, 2013).

Land use change is a widely-cited driver of terrestrial biodiversity loss (Gagné et al., 2015; MEA, 2005; Sala et al., 2000). Including an accurate assessment of biodiversity impacts within the scope of EIA is therefore an important task that can aid decision-makers to understand potential implications of major decisions and commitments. The International Association for Impact Assessment and the Convention on Biological Diversity have each published guidelines for biodiversity-inclusive EIA (IAIA, 2005; Secretariat of the CBD, 2006), and other countries have published their own related guidance (e.g., CEAA, 1996) (Igondova et al., 2016). Common to these guidance documents is a focus on biodiversity impacts at all levels, on an ecosystem approach which emphasizes longer time frames and broader scales than typical project-based assessments, and on direct and indirect drivers of change. Despite the availability of guidance, biodiversity assessments in EIA are often conducted at the local level and seldom consider broader-scale impacts at the ecosystem or landscape levels (Balfors et al., 2010; Gontier, 2006; Jaeger, 2015).

Landscape ecology has been advancing our understanding of factors affecting biodiversity in this broader, landscape-level context. It studies the relationship between spatial pattern and ecological processes, including how habitat structure and function change as land use changes, and how biodiversity responds to these changes (Mayer et al., 2016; Nagendra et al., 2004). In this way, landscape ecology can provide a scientific basis or framework for linking land use patterns at this broader scale to biodiversity, and help predict biodiversity response to land use changes brought on by proposed projects. Identifying where EIA is falling short in this regard can help identify priority areas for improvement. Are there certain principles or ideas in landscape ecology that are being well-translated in current EIA? Conversely, are there areas of knowledge that are being passed over entirely? Identifying the nature of the gaps between biodiversity assessment in EIA and landscape ecology concepts and tools is important to bridging science and practice for the ultimate goal of better-informed decisions.

Overall, application of landscape ecology concepts and tools to aid in decision-making is rare in EIAs (Dalloz et al., 2017; Igondova et al., 2016). Three studies looked specifically at the content of transportation system EIAs to assess the use of road and spatial ecology concepts. Freiitas et al. (2017) analyzed 16 EIAs of road developments in Brazil from 1997-2015, finding that EIA quality was low overall and that the studies poorly addressed impacts recognized in the road ecology literature such as habitat loss, modification, fragmentation, isolation and connectivity. Gontier et al. (2006) reviewed 38 EIAs of road and railway projects from four member countries of the E.U. from 1999-2006 to evaluate the integration of biodiversity issues, the use of prediction methods, and the consideration of effects of habitat loss and fragmentation in biodiversity assessments. EIAs were found to be often descriptive and considered only direct impacts, such as local habitat loss for some species, without analyzing indirect impacts associated with overall habitat fragmentation on a landscape level. Similarly, Karlson et al. (2014) reviewed EIAs from the transportation sector within the time frame between 2005-2013 in Sweden and the U.K. The authors assessed the content of each EIA with respect to a checklist of 17 problem categories identified previously through a literature review of EIA, strategic environmental assessment, biodiversity, and transportation infrastructure. The results showed an improving trend over time in terms of the treatment of impacts on biodiversity in EIA; however, issues remained around the treatment of fragmentation, the absence of quantitative impact analysis, and the delineation of the impact assessment study area without reference to scales of ecological processes.

Other studies have analyzed the content of EIAs for the inclusion of biodiversity information in general. Khera and Kumar (2010) analyzed 22 EIA reports from different sectors in India. They found that biodiversity-related information was either missing or described only superficially in most cases. The authors described limitations of current practices including weak descriptions of indirect, secondary and cumulative impacts on biodiversity, and lack of representation of all levels of biodiversity (habitat, species and genetic) and forms (compositional, structural, functional) in impact prediction, mitigation measures, and monitoring plans. Other studies found similar weaknesses regarding the treatment of landscape ecological context in biodiversity assessment in EIA (Bigard et al., 2017; Byron et al., 2000).

While this literature draws attention to the recent treatment of biodiversity in EIA practice across several countries, it does not explore landscape ecology's application within EIA as a mechanism to improve biodiversity conservation. While certain concepts were evaluated by Freiitas et al. (2017) with respect to road ecology, a comprehensive assessment of the use of biodiversity-related landscape ecology principles in EIA across sectors has not yet been done. Additionally, the extent to which these principles are included in EIA guidance versus EIA reports has not been assessed, and can provide valuable information regarding the nature and level (policy, guidance, or application) of the gaps between science and practice.

In this paper, I examine the use of landscape ecology concepts and science within EIA, specifically looking at to what extent landscape ecology is expressed in EIA for projects located in Ontario, Canada. More specifically:

a. How are landscape ecology terms and concepts represented in EIA?
b. To what extent is landscape ecology represented in EIA policy and guidance documents, as compared to within project EIA reports?

c. Are there any differences or trends in how landscape ecology is represented within different regulatory jurisdictions or project sectors?

d. Finally, where are the greatest gaps between the science of landscape ecology and the practice of EA, in terms of concepts, application, regulatory jurisdictions, and project sectors?

The answer to this last question can help shape priority areas for interdisciplinary work between landscape ecology and the EIA research community.

I start with a description of the study methods, beginning with a synthesis of the landscape ecology literature to identify primary elements of landscape spatial structure that affect biodiversity. Elements identified in this review provided a framework for cross-walking key terms used in landscape ecology and EIA, against which a selection of EIAs were evaluated. I then present and discuss the results in relation to the study objectives and the context of existing EIA research and critiques. I conclude with key learnings about the current intersection between landscape ecology and EIA and identify priority areas for future interdisciplinary work.

4.2 Study Methods

4.2.1 Crosswalking the Vocabulary: Landscape Ecology and EIA

Language and terms used in landscape ecology are not necessarily common to EIA, and therefore my first step was to crosswalk the terms used in each discipline when referring to the themes and key concepts distilled from the landscape ecology literature. Table 3 is a distillation of key landscape ecology terms and concepts that could inform EIA and are used to find the common ground and disconnects between a selection of EIA guidance and policy documents and landscape ecology. The aim of this exercise was twofold: to evaluate where and how landscape ecology concepts appeared in EIA guidance, and to create a cross-disciplinary lexicon of terminology related to landscape ecology concepts to ensure that correct keyword searches could be used in a subsequent content analysis of EIA reports.

Table 3. An overview of themes in landscape ecology that relate landscape structure to biodiversity

Theme	Connection to Biodiversity	Applications	Strengths	Limitations	Key References
Habitat Amount	Thought to be the primary determinant of biodiversity Closely related to the area of habitat patches – large areas tend to support higher biodiversity over the long term because they contain many individuals leading to low population extinction rates, can contain different habitat types, and are usually subject to less frequent and less intense disturbances	Measured as total area of habitat in a landscape or area of habitat patches	Has a proven biodiversity connection – habitat loss by land cover change has been the most important driver of biodiversity loss over the past 60 years; the positive relationship between species number and area is a universal pattern in ecology; and the idea is supported by results of theoretical and experimental work with landscapes	Habitat loss does not typically have a linear relationship with species loss – the relationship can be confounded by early habitat loss causing disproportionately large effects in relatively intact landscapes, while landscapes with low habitat amounts may still contain high biodiversity due to time lags between habitat loss and species response (extinction debt)	Betts et al. (2017) Leroux et al. (2017) Gagné et al. (2015) Jackson and Sax (2010) MEA (2005) Fahrig (2003, 2001, 1997) Andrén (1994)
Landscape Composition	Diversity of habitats in a landscape (heterogeneity) is an important component of biodiversity, particularly for wide-ranging species that require several different habitat types during their lifecycle	Measured by considering both abundance and evenness of the distribution of habitat types	Has greater relevance when measured at eco-geographical scales such as watersheds	While maximizing the representation of rare habitat types can increase evenness, it may come at the expense of habitat area of other more common habitat types which may be problematic to species with large area requirements	García-Llamas et al. (2018) Gagné et al. (2015) Katayama et al. (2014)

Theme	Connection to Biodiversity	Applications	Strengths	Limitations	Key References
Landscape Context	Local habitat quality depends strongly on surrounding patch and landscape context The quality of the matrix (the dominant land use type in a landscape) affects the ability of the landscape to support natural processes, including facilitating or impeding dispersal – a hostile matrix can impede species movement and dispersal and increase edge effects, while a hospitable matrix can help mitigate effects of habitat fragmentation and maintain diversity at the landscape level by providing small-scale habitat	Measures include degree of naturalness (hemeroby), linear disturbance measures, landscape permeability	Matrix quality can be improved by minimizing the intensity of land use, e.g. agricultural practices, urbanization, resource extraction, traffic volumes	The trade-off is that reduced anthropogenic land use intensity could lead to wider expansion of human activities into habitat, which may be less desirable as habitat amount is generally a more important biodiversity determinant	Kuipers et al. (2019) Gagné et al. (2015) Mairota et al. (2015) Walz (2011) Fischer and Lindenmeyer (2007) Ewers and Didham (2006) Dunford and Freemark (2004) Fahrig (2001) Franklin (1993)

Theme	Connection to Biodiversity	Applications	Strengths	Limitations	Key References
Habitat Configuration	In general, there is a weaker effect between landscape and habitat configuration and biodiversity; however, there are important aspects of configuration related to connectivity, edges, and isolation of habitats. The configuration of individual habitat patches can also affect their biodiversity: patch shape, for example, impacts the proportion of edge versus interior habitat, and can impact patch dynamics of immigration/emigration dynamics and predation rates.	Measures include habitat connectivity (the degree to which the movement of organisms or ecological units among habitats is facilitated by their surroundings), inter-patch distances, patch shape and edge metrics	Connectivity increases with the presence of corridors, stepping stones of suitable habitat within the matrix, short inter-patch distances, and suitable matrix habitat. Most conservation biologists agree that landscape connectivity enhances population viability for many species and is important to the persistence of populations in fragmented landscapes.	Connectivity may mean different things to different species - for some species such as migratory birds, habitat corridors and stepping stones are effective at enhancing inter-patch connectivity and mosaic permeability; for plants and less mobile animals, connectivity may require wider corridors that display landscape-level dynamics. Ongoing debates surrounding the effects of habitat fragmentation *per se*. Local increases in biodiversity may be observed at fragmented sites due to invasive species and habitat generalists moving in; however, rare specialist species that depend on core habitat away from edges can decrease, leading to regional to global biodiversity loss.	Kuipers et al. (2019) Fahrig (2017, 2013, 2003, 2001) Haddad et al. (2017, 2015) Leroux et al. (2017) Thompson et al. (2017) Gagné et al. (2015) Ewers and Didham (2006) Bennett (2003) Freemark et al. (2002) Tischendorf and Fahrig (2000) Beier and Noss (1998) Bender et al. (1998) Hanski (1998) Andrén (1994)

Policy and guidance documents were selected across four categories: international guidance, Canadian federal policy and guidance, Ontario provincial policy and guidance, and municipal policy and guidance, using the City of Ottawa within the province of Ontario (Figure 4) as a sample mid- to large-sized city experiencing considerable current growth (Statistics Canada, 2017). Ontario is Canada's most populous province, with corresponding population and resource pressures, particularly in southern Ontario (Government of Ontario, 2019; Horn et al., 2019), making effective EIA increasing important. The province is also the jurisdictional home of Canada's first EIA law, enacted in 1975, which has made Ontario both a model and a focus of critique for EIA legislation worldwide (Graci, 2009).

Figure 4. Geographical location of Ottawa, Ontario, Canada

Policy and guidance documents – including operational policy statements, technical guidance and practitioners' glossaries – from each of these four categories were selected for analysis if they referred to EIA, biodiversity and cumulative or regional effects. In total, fourteen EIA policy and guidance documents spanning 1994 to 2015 were reviewed, including three documents specific to biodiversity assessment, four addressing cumulative effects, three glossaries of terms, two general documents on preparing an EIA, and two pertaining to determining the significance of effects in EIA (Table 4). Two of these documents were from international sources, nine from the Canadian federal government, two from the Ontario provincial government, and one from the City of Ottawa municipal government. These provided a breadth of coverage across time, topics, and jurisdictions.

It must be noted that since the original data were collected in 2017, federal EIA in Canada has undergone a shift. The coming into force of the *Impact Assessment Act* (IAA; Government of Canada, 2019) initiated a surge of new federal policy and guidance documents related to new factors to be considered, new Indigenous knowledge requirements, and regional assessments, among others. The development of these documents fell outside the time frame for the current study, yet they may be of interest to future work.

Table 4. EIA policy and guidance documents reviewed for their use of landscape ecology concepts

Year	Jurisdiction[1]	Document
Guidance on Biodiversity Assessment		
1996	Federal	Guide on Biodiversity and Environmental Assessment (CEAA, 1996)
2005	International	Biodiversity in Impact Assessment (IAIA, 2005)
2006	International	Biodiversity in Impact Assessment (Secretariat of the CBD, 2006)
Guidance on Cumulative Effects Assessment		
1999	Federal	Cumulative Effects Assessment Practitioners Guide (Hegmann et al., 1999)
2007	Federal	Operational Policy Statement - Addressing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act* (CEA Act) (CEAA, 2007)
2014	Federal	Technical Guidance for Assessing Cumulative Environmental Effects under the CEA Act 2012 (CEAA, 2014)
Guidance on Cumulative Effects Assessment (continued)		
2015	Federal	Operational Policy Statement - Addressing Cumulative Environmental Effects under the CEA Act 2012 (CEAA, 2015a)
Glossaries of Terms used in EIA		
2006	Federal	Glossary - Terms Commonly used in Federal Environmental Assessment (CEAA, 2006)
2014	Provincial	Terms Commonly used in Ontario Environmental Assessments (Government of Ontario, 2014a)
2015	Federal	Practitioners Glossary for the Environmental Assessment of Designated Projects under the CEA Act 2012 (CEAA, 2015b)
Codes of Practice for Preparing EIA		
2014	Provincial	Code of Practice - Preparing and Reviewing Environmental Assessments in Ontario (Government of Ontario, 2014b)
2015	Municipal	Environmental Impact Statement Guidelines (City of Ottawa, 2015)
Guidance on Determining Significance of Effects		
1994	Federal	Determining Whether a Project is Likely to Cause Significant Adverse Environmental Effects (FEARO, 1994)

Year	Jurisdiction[1]	Document
2015	Federal	Operational Policy Statement - Determining Whether a Designated Project is Likely to Cause Significant Adverse Environmental Effects under the CEA Act 2012 (CEAA, 2015c)

[1]International, Federal (Canada), Provincial (Ontario), or Municipal (City of Ottawa)

The documents were collected in QSR International's NVivo 11 qualitative analysis software (2015) and their content examined. Similar to the document analysis conducted by Pavlyuk et al. (2017), each document was reviewed in detail for explicit or implicit use of landscape ecology terms and concepts. The review included a manual scan of each document for elements related to landscape ecology to make sure that no implicit uses of terms and concepts were missed. This was not simply a search of key terms, as the goal was to understand the terminology for how the landscape ecology concepts are expressed within the EIA field, rather than assuming that the same technical terms would be used as in the landscape ecology literature. The completed crosswalk of key concepts and terms became the indicator framework against which the EIA reports were evaluated in the following content analysis stage.

4.2.2 Content Analysis of EIA Reports

Purposive sampling of EIA reports was used in order to cover a breadth of jurisdictions (federal, provincial, and municipal), project sectors (mining, electricity transmission, municipal development/infrastructure, and transportation), and time (2007-2016). This scope was set based on the jurisdictions involved in EIA in the province, the project sectors most likely to alter terrestrial habitat in ways that impact biodiversity, and a time period over which advances in biodiversity agreements and EIA-related guidance might reasonably be expected to inform Canadian and Ontario EIA. This 10-year time period follows the publication of two key international documents providing guidance on biodiversity-inclusive EIA in 2005 (IAIA, 2005) and 2006 (Secretariat of the CBD, 2006). It encompasses two different pieces of federal environmental assessment legislation, the original CEA Act (1995), in force until mid-2012, and the CEA Act 2012 which replaced it up until August 2019 when a new *Impact Assessment Act* came into force. The period from 2007-2016 was a relatively stable one in terms of provincial EIA legislation in Ontario and municipal EIA in Ottawa, apart from the City of Ottawa's new Environmental Impact Statement guidelines published in 2015.

Similar to the methods used by Karlson et al. (2014) and Gontier et al. (2006), I limited the EIA reports to those project sectors that would be expected to alter terrestrial habitat in ways that would impact biodiversity and represent a selection of both areas and linear disturbances on the landscape. Excluded projects included nuclear energy assessments, for example, where the majority of the issues involved deep geological storage of radioactive material, geological stability and exposure risk, and focused less on landscape pattern and processes for biodiversity conservation. This scoping led to the four selected project sectors of mining, municipal development, electricity transmission, and transportation.

Also falling outside the scope of the current study was the commercial forestry sector, which falls under provincial jurisdiction and is managed slightly differently than other provincial resource sectors in terms of EIA. Until 2020, Ontario had an Order under its

Environmental Assessment Act for forest management on Crown lands in the province which required the development of forest management plans for forestry activities. These plans were developed in relation to work at a landscape scale and were required in several places to "address the conservation of biodiversity at the landscape and stand and site scales" (Declaration Order MNR-75, s.14.a.iii-iv and s.14.c.ii). In 2020 the Order was revoked, however, citing duplication with the MNRF's Forest Management Planning Manual.

In contrast to forest management, projects in the four selected sectors tend to have a specific, local development footprint. However, the impacts of these projects, according to landscape ecology, could influence biodiversity persistence at the landscape to regional scale (e.g., Waldhardt, 2003; Walz and Syrbe, 2013). Because of this scale disconnect, the use of landscape ecology within EIAs in these project sectors is not self-evident, so focusing a gap analysis here was expected to provide valuable insight into where concepts of landscape ecology were included or omitted.

To obtain the reports, I searched the Canadian Environmental Assessment Act Registry (CEAR) and CEAR Archives for projects located in Ontario with EIAs completed between 1 January 2007 and 31 December 2016. Reports were selected from both pre- and post-2012 federal legislation, and from across the four project sectors as described above. Similarly, I obtained a sample of EIA reports from the Ontario provincial database, and from the City of Ottawa's Development Application Search Tool. All reports were publicly available. Again, the timing of data collection in 2017 meant that federal EIA reports subject to the 2019 IAA were not assessed in the current context, but are recommended for follow up in future work.

In Ontario, individual project EIAs account for less than 5% of Ontario's assessed projects, with the majority of projects of smaller scale being assessed as part of a standardized Class Environmental Assessment (Class EA) process due to their routine nature and presumably predictable and mitigable environmental effects (Graci, 2009; OAG of Ontario, 2016). To cover these types of projects in the content analysis, I also included Class EA documents for each of the four selected project sectors. These included the Class EA for Ontario Ministry of Northern Development and Mines Activities under the *Mining Act* (amended 2014), Hydro One's Class EA for Minor Transmission Facilities (amended 2016), the Municipal Engineer's Association Municipal Class EA (amended 2015), and the Ministry of Transportation Class EA for Provincial Transportation Facilities (amended 2000). This last Class EA document was technically outside of the 2007-2016 range, but was the most current document used for Class EA of transportation projects in the province and thus considered applicable to minor transportation projects taking place within the selected time period.

In total, I collected 28 reports covering a breadth of project sectors, jurisdictions, and time span (Figure 5). These reports focused on a range of environmental issues and habitats.

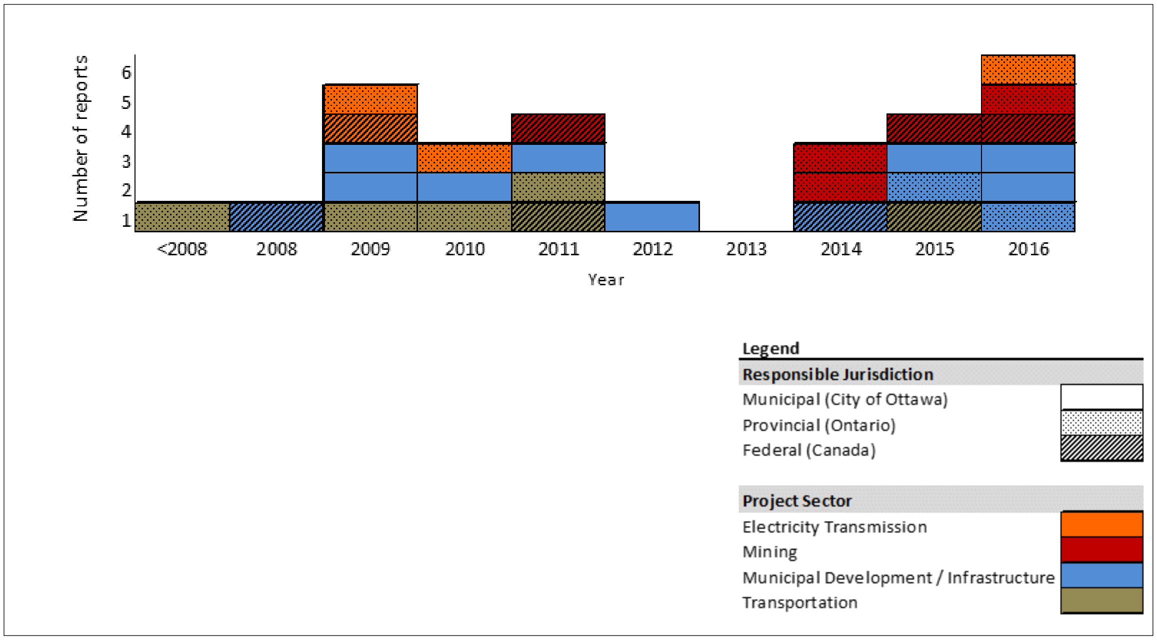


Figure 5. Distribution of the 28 EIA reports reviewed in this study, by year of publication, responsible jurisdiction, and project sector

All reports were imported and analyzed in NVivo. Both top-down and bottom-up coding (e.g., Kaefer et al., 2015) were used to identify whether the reports contained mention of the key concepts from landscape ecology. Using a top-down approach, I conducted key word searches based on the developed lexicon, and explored whether and how these concepts were used. I also used this initial search to set the scope for more detailed analysis and coding of the relevant paragraphs, looking for use of landscape ecology ideas and influences within these scoped passages in more detail as to their content, context and intent within the report. Similar to the method employed by Khera and Kumar (2010), each key concept developed in the lexicon was scored as to whether it was expressed in the EIA report fully (1 point), partly (0.5 points), or not at all (0 points). Where a key concept from landscape ecology was considered to be partly expressed, it meant that the concept was present, but was not quantified, or expressed explicitly in a spatial sense, or used for effects assessment in a meaningful way. The EIA policy and guidance documents reviewed (Table 4) were also coded as to the presence or absence of each concept.

To calculate the total score for each concept, the score for each report (1, 0.5, or 0) for that concept was summed and the total divided by 28 (the number of reports) to obtain a percentage score. Thus, if all 28 EIA reports fully expressed a given concept, that concept would score 100%. A 50% score would mean that either 50% of the reports fully expressed a given concept, or that 100% of the reports partly expressed the concept, or a combination thereof. Percentage scores were calculated for each concept overall, and separately for each jurisdiction and project sector.

For the EIA policy and guidance documents where only presence or absence of each concept was coded, the percentage score was simpler and just represented the percentage of the 14 documents that contained reference to a given concept.

4.3 Results

4.3.1 Synthesis of Landscape Ecology-Based Concepts in Biodiversity Assessment

The indicator framework developed included 19 key concepts in landscape ecology with known relationships to biodiversity, grouped under the four themes synthesized in Table 3 (Table 5). Where related terms were used in the EIA policy and guidance documents, they were noted in the corresponding column. Most terms used were similar across disciplines and used with similar meaning. The only concept without an equivalent found in the EIA policy and guidance documents was that of landscape permeability (under the Landscape Context theme).

Table 5. Key themes and concepts from landscape ecology related to the conservation of biodiversity, and related terms used in EIA policy and guidance

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
1. Habitat Amount		
1.1 Habitat amount	Habitat amount is of central importance for biodiversity conservation (Fahrig, 2003), holding true across a range of landscapes and dispersal distances and behaviours (Jackson and Fahrig, 2016).	Amount of natural vegetation[1] Habitat area(s)[1], Core habitat area[2], Adequate areas[3] Total habitat[4], Total (forest) cover[1] Habitat loss, Loss of habitat[1,2,4,5,6,7,8,9] Total (cleared) area, Percent of area disturbed[2] Landscape / habitat 'nibbling'[4] No net loss[1,3,4,6,7]
1.2 Habitat alteration	Indirect habitat changes can occur that affect the amount of suitable habitat present in a landscape (e.g., as a results of sensory disturbance, avoidance behaviour). The habitat structure may be present, but the function is altered. The amount of altered habitat can often be quantified in terms of an "effect zone", in addition to any structural loss of habitat (Karlson and Mörtberg, 2015).	Habitat availability[4,6], Available habitat[2,4] Habitat suitability[4] Sensory alienation[4] Avoidance[2,4,9] Disturbance buffers[4]
1.3 Patch size	Species-area relationships are well-established in the literature, with larger areas tending to support more species (Leroux et al., 2017). Patch size is related to species richness, composition, and abundance (Freemark et al., 1993). Patch area or size, and patch size distribution are often-used terms.	Habitat patch size[2]

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
1.4 Habitat thresholds or targets	Habitat thresholds, targets, or guidelines are all used as terms in the literature, relating to ecological tipping points at which species populations may show drastic decline (Jaeger, 2015). There are often species-specific, as species with lower reproductive rates and dispersal ability tend to need larger amounts of habitat to persist (Fahrig, 2001).	Thresholds[2,4,6,7], Critical thresholds[7], Regional thresholds[4] Limits of tolerance[4], Levels of capacity[7] Targets[7] Objectives[6,7] Standards[2], Legal standards[7] Benchmarks[2]
2. Landscape Composition		
2.1 Landscape composition	Landscape composition, also land cover and land use composition, refers to the relative proportion of habitat types in a landscape and is an important factor for sustaining biodiversity (Duflot et al., 2017).	Baseline environment[2] Composition, Ecosystem composition[7], Vegetation composition[4] Land cover[1,7]
2.2 Landscape heterogeneity	Spatial heterogeneity, describing the non-uniform range of forms of land use, is a key element for understanding the presence and distribution of species (Syrbe et al., 2013). Landscape heterogeneity is often studied as a proxy for species diversity (Duelli and Obrist, 2003; Morelli et al., 2018). Diversity is measured by considering both abundance and evenness of the distribution of habitat types, or habitat representation in the landscape (Tews et al., 2004).	Ecosystem diversity[3,6,7,10], Ecosystem-level diversity[7] Landform representation, Landform diversity, Vegetation community diversity[1] Relative abundance / scarcity[1]
2.3 Unique landscape features	Unique landscape features offer unique habitat opportunities. The protection of rare ecosystems is often considered the single most important function of biodiversity conservation, as the rarer the feature the higher the probability of its disappearance (Geneletti, 2003).	Landscape features[4,7] Valued landscape quality[7] Hotspots[4], Hot spots[7]

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
3. Landscape Context		
3.1 Landscape matrix	Habitat patches do not exist in isolation: the nature and structure of the landscape surrounding a habitat patch (the matrix) is important to population persistence within a habitat patch (Fahrig, 2001; Freemark et al., 2002, 1993; Mairota et al., 2015; Mazerolle and Villard, 1999). The quality of the matrix (its ability to support natural processes) affects landscape connectivity and maintains diversity at the landscape level (Franklin, 1993) and mediates the severity of edge effects and isolation (Ewers and Didham, 2006). Matrix quality is often inversely related to land use intensity (agricultural practices, urbanization (Dunford and Freemark, 2004; Gagné et al., 2015).	Ecological context[9,10], Environmental context, Natural context[1], Landscape-level context[3], Landscape level[2,4] Setting (within the landscape and/or watershed)[1], Ecological setting[2], Environmental setting[1,4,11,12] Adjacent area(s)[1], Surrounding areas, Surrounding environment[1,2,4] Intensity (of land use, physical activities, development)[2,4] (Highly) fragmented landscape[7], Highly transformed landscape[2], Post-mining landscape[4], Predominantly developed landscape[1], Urban landscape[1], Landscape already disturbed[4] Natural landscape(s)[5], Undisturbed landscape[4]
3.2 Landscape permeability	Refers to the ability of the landscape as a whole, including the matrix, to provide connectivity and passage for species dispersal and ecological processes (Anderson and Clark, 2012).	No equivalent / related terms found

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
3.3 Linear feature density	There are several impacts linked to linear disturbances (increased isolation of habitat patches, decrease in patch size, increased exposure of habitat to external disturbances, barrier effects, habitat degradation; (Gontier et al., 2006) that increase with the degree of linear feature density in the landscape and affect the nature of species diversity (Jaeger, 2000; Syrbe et al., 2013).	Linear feature density[2], Access density, Road density[4] Breaks (e.g., in the canopy)[1,4] Blockage of (wildlife) movement[4], Block(ing) migration[2] Barriers to wildlife movement, Barrier factor[4], Barrier effects[7], Natural barriers[2]
4. Habitat Configuration		
4.1 Landscape configuration	Landscape configuration or structure is characterized by the spatial arrangement or geometry of habitat and non-habitat elements across the landscape (Freemark et al., 1993), which has a close relationship with biotic abundance and diversity (McGarigal, 2000). May also be characterized as a mosaic.	Landscape-level metrics[2] Landscape indices, Landscape indicators[4]
4.2 Habitat configuration	Habitat configuration is characterized by the shape of habitat elements themselves. Species can respond to the arrangement, shape, and size of individual habitat elements (Walz and Syrbe, 2013). In patches with more convoluted shapes, individuals are more likely to encounter habitat edges, leading to increased turnover and variability in population size than in more compact habitat patches (Ewers and Didham, 2006). Can refer to patches, patch shape, gradients, and flows.	Patches of (natural) habitat[7] Block(s) of habitat[2,4] Landscape-scale patches[4] Gradients[2,7]

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
4.3 Habitat contiguity	Contiguity refers to the proximity of habitats in relation to each other and is related to habitat aggregation, as the opposite of habitat isolation. A landscape with contiguous patches of high quality habitat may support higher population growth rates than a landscape with more habitat, if the habitat is fragmented or is of relatively low quality (Larson et al., 2004). Species response to contiguity is dependent on their life history; for habitat generalists, for example, disturbed landscapes are likely to be more contiguous whereas habitat specialists prefer a much more homogeneous contiguous habitat (Betts et al., 2014). Contiguity of environmental gradients is also important for interactions of selection and migration processes that maintain population viability and genetic diversity (Moritz, 2002).	Habitat contiguity[7], Contiguous (habitat)[2], Contiguous blocks of habitat[4] Contiguous (forested) area, Contiguous (forest) communities[1]
4.4 Habitat isolation	Habitat isolation negatively affects species dispersal and distribution patterns (Ewers and Didham, 2006) and can increase local vulnerability to extinction (Watling and Donnelly, 2006). Isolation can impact species richness, composition and abundance for species sensitive to these processes (Freemark et al., 1993). In landscapes with intermediate (10-50%) habitat cover, isolation becomes more important (Andrén, 1994; Crouzeilles et al., 2014).	Isolated (patches, genotypes)[3,7], Isolation[6,7]
4.5 Interior habitat	The presence of interior habitat away from edge influences is of greater importance to specialist species (Bender et al., 1998). Interior habitats tend to be more stable than at edges, where changes in biotic and abiotic parameters make ecological processes more variable (Ewers and Didham, 2006).	Interior habitat, Interior forest[1]
4.6 Edge habitat	Edge habitats can be a valuable transition zone that forms a habitat in itself (Hou and Walz, 2013). Edges are often more beneficial to habitat generalists than specialists, however, so increasing edge habitat often decreases biodiversity at the regional or global scale (Kuipers et al., 2019). Can refer to edge or ecotones.	Length of edge, Edge area[4]
4.7 Connectivity	Habitat connectivity facilitates the maintenance of biodiversity by allowing species dispersal between suitable patches (Thompson et al., 2017). Species with intermediate movement capacity tend to be most sensitive to changes in landscape connectivity (Karlson and Mörtberg, 2015; Saura and Rubio, 2010).	Connectivity[1,4,6,7], (Natural) landscape connectivity, Connection[1]

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
4.8 Corridors	Corridors are valuable conservation tools that provide landscape connectivity for dispersing species through a hostile matrix (Beier et al., 2008; Beier and Noss, 1998; Bennett, 2003). Often, more than one corridor/linkage between isolated natural areas is needed to maintain connectivity over time, while wider corridors that display landscape-scale processes may be required for less mobile species to maintain contact with other populations (Freemark et al., 2002).	Ecological corridor[6,7], Natural corridor[1,7] Wildlife corridor(s)[4], Movement corridor(s) [1,4], Animal / wildlife movement corridor[1], Migration corridor(s)[2,7]
4.9 Fragmentation	Fragmentation could cause a reduction in biodiversity through three main effects: increasing the isolation of habitat patches, decreasing patch size, and increasing the exposure of the habitat to external disturbances (Geneletti, 2004). However, its impact may be softened by the presence of a high-quality matrix (Ewers and Didham, 2006). Effects on biodiversity are often species-specific (Haddad et al., 2015; Kuipers et al., 2019), with species with low dispersal ability being the most vulnerable (Ewers and Didham, 2006).	Habitat fragmentation[2,3,4,5,6,7,9], Landscape fragmentation[4]

[1]Environmental Impact Statement Guidelines (City of Ottawa, 2015)

[2]Technical Guidance for Assessing Cumulative Environmental Effects Under the CEA Act 2012 (CEAA, 2014)

[3]Guide on Biodiversity and Environmental Assessment (CEAA, 1996)

[4]Cumulative Effects Practitioners Guide (Hegmann et al., 1999)

[5]Determining Whether a Project is Likely to Cause Significant Adverse Environmental Effects (FEARO, 1994)

[6]Biodiversity in Impact Assessment (IAIA, 2005)

[7]Biodiversity in Impact Assessment (Secretariat of the CBD, 2006)

[8]Terms Commonly Used in Ontario Environmental Assessments (Government of Ontario, 2014a)

[9]Operational Policy Statement – Determining Whether a Designated Project is Likely to Cause Significant Adverse Environmental Effects Under the CEA Act 2012 (CEAA, 2015c)

[10]Glossary of Terms Commonly Used in Federal Environmental Assessment (CEAA, 2006)

[11]Operational Policy Statement – Addressing Cumulative Effects Under the CEA Act (CEAA, 2007)

Key landscape ecology themes and concepts	Relevance to biodiversity	Related terms used in the EIA policy and guidance documents
[12]Code of Practice – Preparing and Reviewing Environmental Assessments in Ontario (Government of Ontario, 2014b)		

4.3.2 Content Analysis

Twelve of the 28 EIA reports analyzed mentioned biodiversity or biological diversity explicitly (five federal, four provincial, and three municipal); in the others, it was implied only. Landscape ecology concepts related to the Habitat Amount theme were expressed the most overall in both the EIA reports and the EIA policy and guidance documents, while concepts related to the Landscape Context theme were expressed the least (Table 6).

Table 6. Representation of landscape ecology in federal, provincial and municipal EIA documents (2007-2016)

	EIA Policy and Guidance (14)[1]	**Percentage score (%)[2] of EIA reports expressing this concept**							
		EIAs (28)	Federal (8)	Provincial (12)	Municipal (8)	Mining (6)	Electricity Transmission (4)	Development/ Infrastructure (12)	Transportation (6)
1. Habitat Amount									
1.1 Habitat amount	43	30	50	17	31	50	25	29	17
1.2 Habitat alteration	29	20	63	4	-	42	13	13	17
1.3 Patch size	7	16	31	8	13	33	-	13	-
1.4 Habitat thresholds or targets	43	11	19	-	19	17	-	13	8
2. Landscape Composition									
2.1 Landscape composition	29	18	19	13	25	33	13	17	8
2.2 Landscape heterogeneity	21	25	38	4	44	25	13	29	8
2.3 Unique landscape features	21	34	38	25	44	33	50	38	42

	EIA Policy and Guidance (14)[1]	Percentage score (%)[2] of EIA reports expressing this concept							
		EIAs (28)	Federal (8)	Provincial (12)	Municipal (8)	Mining (6)	Electricity Transmission (4)	Development / Infrastructure (12)	Transportation (6)
3. Landscape Context									
3.1 Landscape matrix	21	14	31	8	6	25	-	13	17
3.2 Landscape permeability	0	4	6	4	-	8	-	-	8
3.3 Linear feature density	14	5	6	8	-	8	13	-	8
4. Habitat Configuration									
4.1 Landscape configuration	7	11	19	8	6	17	13	8	8
4.2 Habitat configuration	29	16	13	8	31	17	-	21	17
4.3 Habitat contiguity	29	25	31	4	50	17	13	33	8
4.4 Habitat isolation	21	9	6	4	19	8	-	13	8
4.5 Interior habitat	21	30	25	8	69	25	-	46	8
4.6 Edge habitat	7	27	38	17	50	17	-	42	25
4.7 Connectivity	29	32	38	21	44	17	25	33	17
4.8 Corridors	36	34	31	25	50	42	13	42	8
4.9 Fragmentation	50	39	50	50	13	67	50	21	75

[1]The number in brackets after each category heading represents the number of EIA reports in that category.
[2]Reports received a score of 1 if the concept was fully expressed and explored in the report; a score of 0.5 if the concept was partly expressed (i.e., not quantified, described spatially, or considered in the effects assessment); and a score of 0 if not expressed at all in the report. Scores are then reported as a percentage of the total number of reports from that category.

Within the EIA policy and guidance documents, the most frequently expressed concepts included habitat amount (43%), habitat thresholds or targets (43%), and fragmentation (50%). Concepts with the least expression in these documents were linear feature density

(14%), patch size (7%), landscape configuration (7%), and edge habitat (7%) (Table 6). As mentioned above, the concept of landscape permeability did not appear at all in the EIA policy and guidance documents.

In the EIA reports, fragmentation had the highest score related to its expression (39%), followed by unique landscape features (34%), corridors (34%), connectivity (32%), habitat amount (30%), and interior habitat (30%). All of these are relatively low scores, however, below 50% (Table 6).

Concepts with the least representation in the EIA reports from either a qualitative or quantitative perspective included landscape permeability (4%), linear feature density (5%), habitat isolation (9%), habitat thresholds and targets (11%), and landscape configuration (11%) (Table 6).

Reports with the greatest expression of landscape ecology concepts came from a range of project types, jurisdictions and years, showing no clear pattern (Table 6). However, reports with the lowest representation of landscape ecology concepts overall tended to be the Ontario Class EA documents, and electricity transmission and transportation sector EIAs.

Among jurisdictions the greatest expression of a landscape ecology concept was for interior habitat in municipal EIA reports (69%) and habitat alteration in federal EIA reports (63%). Habitat thresholds and targets were not expressed at all in provincial EIAs.

Municipal EIA reports from the City of Ottawa did not include any mention of habitat alteration, landscape permeability, or linear feature density (Table 6).

Across the project sectors examined, fragmentation was scored highly for EIA reports from the transportation (75%) and mining (67%) sectors. There were several concepts that did not appear in electricity transmission EIA reports, including patch size, habitat thresholds and targets, landscape matrix, landscape permeability, habitat configuration, isolation, interior habitat, and edge habitat. Municipal development / infrastructure EIAs did not contain any mention of landscape permeability or linear feature density. Patch size was not expressed in transportation EIA reports (Table 6).

4.4 Discussion

The differences in expression of key landscape ecology concepts between EIA guidance documents and EA reports are important to note, as they indicate how well the EIA guidance documents are being translated into practice. A corollary is that if a key concept from landscape ecology does not appear (or appears infrequently) in EIA guidance, it would not be expected to be well expressed in EIA reports.

EIA guidance and EIA reports were relatively closely aligned in terms of the expression of overarching themes, with Habitat Amount showing the greatest expression and Landscape Context the least expressed. However, the expression of key concepts showed some interesting differences, discussed in the following sections. Notable differences between jurisdictions and project sectors are also discussed under their corresponding theme. When discussing jurisdictional differences, however, I am mindful that municipal EIA is solely represented here by the City of Ottawa; variation between municipal jurisdictions within Ontario is also likely to be present.

4.4.1 Habitat Amount

Within the Habitat Amount theme, habitat amount was expressed to a slightly higher degree in the EIA guidance (43%) compared to EIA reports (30%); however, the results for habitat thresholds or targets differed even more widely. Forty-three percent of EIA policy and guidance documents referred to habitat thresholds or targets, on par with the expression of habitat amount overall (Table 6). In contrast, habitat thresholds or targets were expressed in only four of the EIA reports, scoring 11% as two of the reports only mentioned the idea of thresholds but did not quantify these. Of the two that did use quantitative thresholds, one was in reference to disturbance thresholds in boreal caribou range (a federal mining EIA) and the other referred to a City of Ottawa target for tree cover (a municipal development EIA). Provincial and electricity transmission EIA reports had no mention of habitat thresholds or targets.

While several EIA reports provided a quantification of the amount of direct habitat that would be lost permanently or temporarily through project development, and some related it to the percentage of habitat in a study area, few provided a before and after quantification of the amount of habitat in the broader landscape. Without any connection to an ecologically relevant target or threshold, such descriptions may have limited potential to inform decision making with respect to biodiversity protection practices. A possible reason for the lack of thresholds or targets may be that regional or landscape-based habitat thresholds may not have been known at the time the EIAs were prepared; thresholds on the effects of habitat loss and increasing road density on species viability, for example, are not well-established (Jaeger, 2015). However, the reports did not cite a lack of existing thresholds or targets either.

Habitat patches (sometimes referred to as ‘blocks’ in the EIA reports) were not described in spatial relationship to other habitats within the broader landscape, and patch sizes or areal extents were rarely discussed in EIA reports. However, as patch size was mentioned in just 7% of guidance documents, perhaps this last result is not surprising. Electricity transmission and transportation EIA reports did not mention sizes of habitat patches. The general lack of spatial analysis associated with habitat amount information is in line with results from other regions, where Karlson and Mörtberg (2015) and Dalloz et al. (2017) found that quantitative spatial analyses were rarely included in EIAs, even when aerial imagery and maps were available. Similarly, both Karlson et al. (2014) and Karlson and Mörtberg (2015) noted that not even basic landscape characteristics like habitat amount and number of patches were used to inform decision-making for EIAs of the transportation sector in the E.U. This is an evident gap in EIA practice in Ontario, Canada as well.

Of the four project sectors examined here, mining EIAs had the highest expression of concepts of habitat amount. As a driver of large areal disturbance, it could be that concepts of habitat amount are perceived to be of greater relevance to the impacts of the mining sector as compared with the linear disturbances of transportation and electricity transmission. It could also be associated with the practices of the industry to analyze trade-offs as part of Impact and Benefit Agreements with affected communities (e.g., Sosa and Keenan, 2001).

4.4.2 Landscape Composition

Overall, EIA reports were good at qualitatively documenting the dominant habitats and local ecological setting. However, they seldom gave a sense of the habitat diversity, heterogeneity or homogeneity in the landscape.

A surprising result was that unique landscape features appeared with greater frequency in EIA reports than in guidance documents (34% versus 21% respectively), and in this limited context EIA practice appears to be ahead of EIA policy. It could be that this concept is relatively simple to report on, with easily available data. Unique and rare landscape features, along with protected areas and rare species, tend to be well tracked in data inventories and conservation databases (Gontier, 2006).

What is interesting about the focus on unique landscape features in EIA reports is that this one concept dominates the expression of the landscape composition theme, but it represents only one piece of a larger picture of biodiversity. Unique habitats or landscape features are indeed extremely important as a component of landscape composition and diversity, and they offer unique habitat opportunities. At the same time, maximizing the representation of rare habitat types can come at the expense of habitat area of 'common' habitat types, which may be problematic for species with large area requirements (Gagné et al., 2015).

Concepts of landscape composition were expressed about evenly across jurisdictions and project sectors, with slightly less expression of landscape heterogeneity in provincial and transportation sector EIAs.

4.4.3 Landscape Context

Expression of landscape context and matrix quality were low overall across guidance and EIA reports. Missing from several of the EIA guidance documents was the importance of the landscape matrix, or the dominant land use/land cover type in a landscape, in contributing to the overall habitat quality of the landscape and of permeability of the landscape to species dispersal between preferred habitats (e.g., Dunford and Freemark, 2004; Freemark et al., 2002). The concept of permeability, which refers to the ability of a landscape as a whole to facilitate or impede flows and ecological processes (Anderson and Clark, 2012), was not expressed in the EIA guidance documents, and there were no related terms to describe the idea. The general idea behind landscape permeability was marginally touched on (not quantified) in two reports, a federal transportation EIA and a provincial mining EIA. These reports did not use the term permeability, however, and did not go into any detail. Linear feature density also had a low score of 5% among EIAs reviewed, with 14% of guidance documents expressing this concept.

A result of neglecting to assess changes to the landscape matrix and to landscape permeability is that EIA results may miss changes to critical biodiversity processes, even if delineated habitat patches are retained. For example, a residential subdivision built on an abandoned field may avoid an important local forest habitat, yet it may still affect the biodiversity of that forest patch by changing the permeability of the landscape as a whole as fields become suburban development, the matrix becomes more hostile, and processes such as species dispersal are slowed. This may alter the ability of the landscape to maintain biodiversity over time. It may also degrade the quality of the habitat itself, for example through increased predation from the introduction of roaming household pets, particularly cats (Dunford and Freemark, 2004).

4.4.4 Habitat Configuration

Habitat fragmentation was a popular concept expressed relatively frequently both in the EIA guidance (50%) and the EIA reports (39%), and it was generally used in the same sense as in the landscape ecology literature, in conjunction with habitat loss and loss of connectivity. Fragmentation had particularly high expression in EIAs from the transportation (75%) and mining (67%) sectors. The related concepts of corridors (34%) and connectivity (32%) also scored relatively high in the EIA reports.

Of note here is that while descriptions of connectivity appeared to be becoming more specific and quantified, few EIAs overall made use of quantitative measures or discussed these concepts in a spatially-explicit way, in relation to the overall landscape. This lack of quantitative effects analysis of fragmentation and barrier effects was also noted by Jaeger

(2015). It may be that the ideas of fragmentation and connectivity are being used more as conservation buzzwords rather than in terms of meaningful analysis, or it may be that knowledge of the analytical tools and methods, including their use and interpretation, are lacking (Karlson and Mörtberg, 2015).

It may be expected that project sectors that represent large linear disturbances on the landscape, such as transportation and electricity transmission, would score higher in relation to aspects of habitat configuration such as connectivity and fragmentation due to the nature of the disturbance (Dalloz et al., 2017). However, this did not appear to be the case: the transportation sector scored low for several concepts including corridors, interior habitat, habitat isolation, habitat contiguity, and landscape configuration and the electricity transmission sector did not have any mention of concepts of interior or edge habitat, habitat isolation, or habitat configuration.

Both edge habitat (27%) and interior habitat (30%) had a higher score in the EIA reports than in the guidance (7% and 21%, respectively). However, these could be skewed by the high scores of municipal EIA reports for these concepts. The City of Ottawa policy and guidance document requires EIA to report on 'significant woodlands' under the Ontario provincial *Planning Act*, which includes in their definition "interior forest habitat located more than 100 m inside the edge of a forest patch" (City of Ottawa, 2012). This requirement would necessarily lead to higher expression of edge and interior concepts.

It must also be kept in mind that, in terms of what we're learning from landscape ecology, the other three themes (habitat amount, composition, and context) appear to have a larger impact on biodiversity. In terms of biodiversity assessment, improvements in this aspect may have a marginal difference compared to potentially more substantial improvements in the other themes.

4.5 Conclusion

My results add to a key finding from previous studies, namely landscape ecology science is still not well-integrated into EIA practice. There were two main types of gaps where EIA practice omitted important landscape ecology concepts from biodiversity assessment: (1) gaps where both EIA guidance and practice omitted a concept, and (2) gaps where the concept was discussed in EIA guidance but was not yet translated into practice in EIA reports. This latter gap could arise from time lags common between policy implementation, dissemination of guidance documentation, and practice, and may shrink in future years.

With respect to the former category, the greatest gap found across EIA guidance and practice was the importance of the broader landscape context in contributing to both habitat quality and landscape permeability to species dispersal between preferred habitats, a broad-scale process that is important in maintaining biodiversity. This could be an area to target for joint knowledge-sharing, in which EIA policy and guidance could be re-evaluated to document some of the recent findings in landscape ecology in this field. A second notable gap across guidance and practice was that, while overall landscape composition is commonly discussed in EIA, the size and shape of habitat patches were not often characterized. These are important biodiversity considerations. Similarly, while concepts of fragmentation and connectivity were often discussed qualitatively, few EIAs made use of quantitative measurement techniques or discussed the concepts in a spatially-explicit way in relation to the overall landscape and its biodiversity. One can speculate that these gaps may be attributed to the established practice of EIA as being project- and site-specific, and therefore adding a landscape component represents not just a simple expansion of EIA practice but a major reform.

With respect to the latter type of gap, EIA guidance discussed widely the need for ecologically relevant habitat targets and thresholds when evaluating habitat amount in EIA, but this was rarely followed through in practice. It would appear that, while landscape ecology methods have advanced to a level where incorporation within EIA applications is technically feasible, the current absence of thresholds with which to add meaning to project-specific assessments imposes severe restrictions on the use of landscape analysis to protect future biodiversity. This may present an opportunity to better link EIAs with regional initiatives, including greenbelt plans or natural heritage systems, or provincial or federal conservation targets.

While there were no obvious distinctions between project sectors or jurisdictions in terms of their inclusion of landscape ecology, it was evident that where a jurisdiction had a clear policy in place that required a specific landscape consideration in EIA, the concept was present. This would indicate that clear policy plays an important role in determining EIA content.

This review and appraisal of the inclusion of landscape ecology within EIA guidance and practice draws attention to the multiplicity and complexity of integration across these research areas. Within the EIA field, gaps continue within the Ontario context, suggesting time lags between the incorporation of landscape analysis into guidance documentation and the expansion and adjustment of practitioners' operating practices to consider the broader landscape. The absence of universally accepted targets and thresholds for habitat amount and other landscape parameters required to maintain or restore biodiversity adds another challenge to EIA practice embracing landscape ecology approaches and methods. EIA practitioners are routinely required to estimate future changes and perhaps more importantly interpret the impact of estimated future changes on biodiversity. Habitat thresholds are vital to this interpretive step in EIA practice, and without open cross-disciplinary discussion and critical examination of such thresholds in the absence of scientific consensus, gaps between EIA and landscape ecology are likely to persist.

Chapter 5: Problems of Science or Practice? Identifying Challenges and Opportunities for Advancing Landscape Analysis in EIA

5.1 Introduction

Environmental impact assessment (EIA) can be an important tool in reversing the current decline of biodiversity, yet it does not always capture important elements at broader spatial scales that influence biodiversity. EIA tends to focus on the immediate project scale (González et al., 2014; Heiner et al., 2019), lacking in broader landscape analysis and in the quality of biodiversity assessments (Dibo et al., 2018; Gontier, 2006). The scholarly literature is replete with calls for broader-scale approaches to biodiversity assessment in order to improve the quality of EIA and decision-making (Bigard et al., 2017; Dibo et al., 2018; Duinker and Greig, 2006; Gontier, 2006; Heiner et al., 2019; Jaeger, 2015; Karlson et al., 2014). EIA guidance documents generated by public agencies have mirrored these recommendations, advocating for a focus on impacts on biodiversity at all levels, on an ecosystem approach which emphasizes longer time frames and broader spatial scales, and on direct and indirect drivers of change (IAIA, 2005; Secretariat of the CBD, 2006).

Landscape ecology is a discipline that explicitly considers how time and space affect environmental patterns and the processes that shape them (Mayer et al., 2016). It focuses on those broader scales of analysis advocated for biodiversity assessment, and has developed a sophisticated set of tools and analyses that can be applied at landscape to regional scales (Gontier, 2006; Karlson and Mörtberg, 2015). Yet the application of landscape ecology concepts and tools to aid in decision-making does not appear to be well-translated to the practice of EIA (Dalloz et al., 2017; Igondova et al., 2016). The poor quality of biodiversity treatment in EIAs is of concern given that various specific guidelines on biodiversity and ecological assessment have been available in Canada, the U.S. and Europe for over 20 years (CEAA, 1996; Jaeger, 2015).

So, after two decades of recommendations for broader-scale approaches to biodiversity assessment in EIA, why are these approaches so uncommon in EIA practice? Why is the disconnect between science and practice still so apparent in this area? The aim of this paper is to examine this gap in terms of identifying primary challenges or hurdles to incorporating landscape analysis in EIA, and prioritizing opportunities to advance this area.

Previous authors have examined disconnects between science and practice in similar contexts, and have identified challenges with respect to incorporating ecological science in EIA and other policy processes (e.g., Beanlands and Duinker, 1983; Mackinnon et al., 2018). These challenges have been characterized as legislative (political), scientific, technical (e.g., Treweek, 1996), practical (e.g., Arnold, 2014) and institutional (e.g., Ekstrom and Young, 2009; Mayer et al., 2016). Identified legislative or policy challenges to incorporating ecological science in EIA practice include wording ambiguities and key omissions in legislative requirements, which have constrained the ability of some assessments to consider broader-scale, long-term or cumulative ecological impacts in a meaningful way (Treweek, 1996).

From a perspective of scientific challenges, Treweek (1996) identified that the inherent complexity and dynamic nature of ecosystems made them difficult to understand, model and predict changes within an EIA setting. Duinker et al. (2013) also identified a lack of foundational knowledge of ecological thresholds on which to base regulatory EIA thresholds. Others discussed the lack of long-term scientific monitoring and the difficulties it posed to understanding landscape change and species-habitat relationships (Dibo et al., 2018), aspects required for sound biodiversity assessment in EIA.

Technical challenges identified include difficulties in basing spatial assessment boundaries on ecological boundaries, and the need for information and knowledge management resources (Dibo et al., 2018). Uncertainty and a lack of guidance on analysis tools, methods, and interpreting results posed widespread difficulties to incorporating ecological science in EIA and planning processes (Botequilha Leitão and Ahern, 2002; Dibo et al., 2018; Geneletti, 2004). Similarly, the complexity of ecological models, their data requirements and interpretation were suggested as limitations to the widespread use of such models (Gontier, 2006; Karlson and Mörtberg, 2015; Pietsch, 2018). Practical challenges with implementing best available science into regulatory practice were discussed by Arnold (2014), and included the often large workloads, constrained budgets, and multiple demands faced by individuals.

In addition to these factors, another dimension that can pose challenges is related to the fit and interplay between institutions and ecological processes (e.g., Young, 2002). One area of potential misfit, or misalignment between ecology and institutions, relates to different definitions and interpretations of scale. While scale in ecology describes a spatial grain and extent and temporal period at which a process unfolds, jurisdictional scale describes different levels of governance from local to state/provincial to national and international (Cash et al., 2006). The interaction between these levels, and with ecological processes, may cause challenges or opportunities for policy, decision-making, and biodiversity management (Henle et al., 2014). Potential scale mismatches between institutions and ecological systems may be spatial, temporal, or functional in nature (Cumming et al., 2006). Such mismatches may affect how landscape ecology science and concepts are used (or omitted) from assessment and planning processes, as current institutional provisions may not align with landscape-level ecological processes (e.g., Ekstrom and Young, 2009). For science to support policy decisions, the ecological scale needs to be relevant to the species, process, pattern or policy of interest and to the organization level at which it can be implemented (i.e., local, provincial or federal jurisdictions); this match between organizational level and ecological scale is not always straightforward (Mayer et al., 2016).

These previously identified challenges to linking ecological science and regulatory practice may play a role in the lack of adoption of landscape analysis in EIA, or it may be that other factors are at play. Additionally, the relative importance of these different types of challenges from a practitioner's viewpoint are not well understood. The challenges and opportunities specific to landscape and broader-scale analysis within EIA practice remain vague.

In this paper, I analyze the perspectives of Canadian EIA practitioners, reviewers and decision-makers to identify the current challenges in incorporating landscape analysis into EIA, and the related opportunities to bridge gaps between science and practice. I also test the idea that jurisdictional level may interact with ecological scales by examining how perspectives on landscape and broader-scale analysis of biodiversity differ between levels of regulatory jurisdiction among federal, provincial, and municipal EIA practitioners. While the specifics of the case study are from the Canadian context, broader implications and learnings may be applicable elsewhere.

5.2 Methods

My research methods followed a modified Delphi approach (Figure 6), starting with a set of semi-structured interviews with EIA practitioners, reviewers and decision-makers across federal, provincial, and municipal jurisdictions with projects in the province of Ontario, Canada. Delphi approaches are considered to be effective when the research goal is to improve understanding of problems, opportunities and solutions (Skulmoski et al., 2007). Using a modified approach, starting with exploratory interviews, allows for a more in-depth understanding of how key informants perceive and understand the issues and maintains the necessary flexibility to follow paths of inquiry as they emerge (e.g., Silverman and Patterson, 2014). Following the interviews, participants were given the opportunity to review and respond to each other's thoughts through a follow-up questionnaire. In line with the overall purpose of this research, it was important to reflect on the full range of responses in order to develop a nuanced insight into issues of broad-scale landscape analysis in EIA, and therefore the usual concluding step in Delphi analysis of seeking consensus was not performed. All research protocols were cleared by the Carleton University Research Ethics Board (see Appendix A).

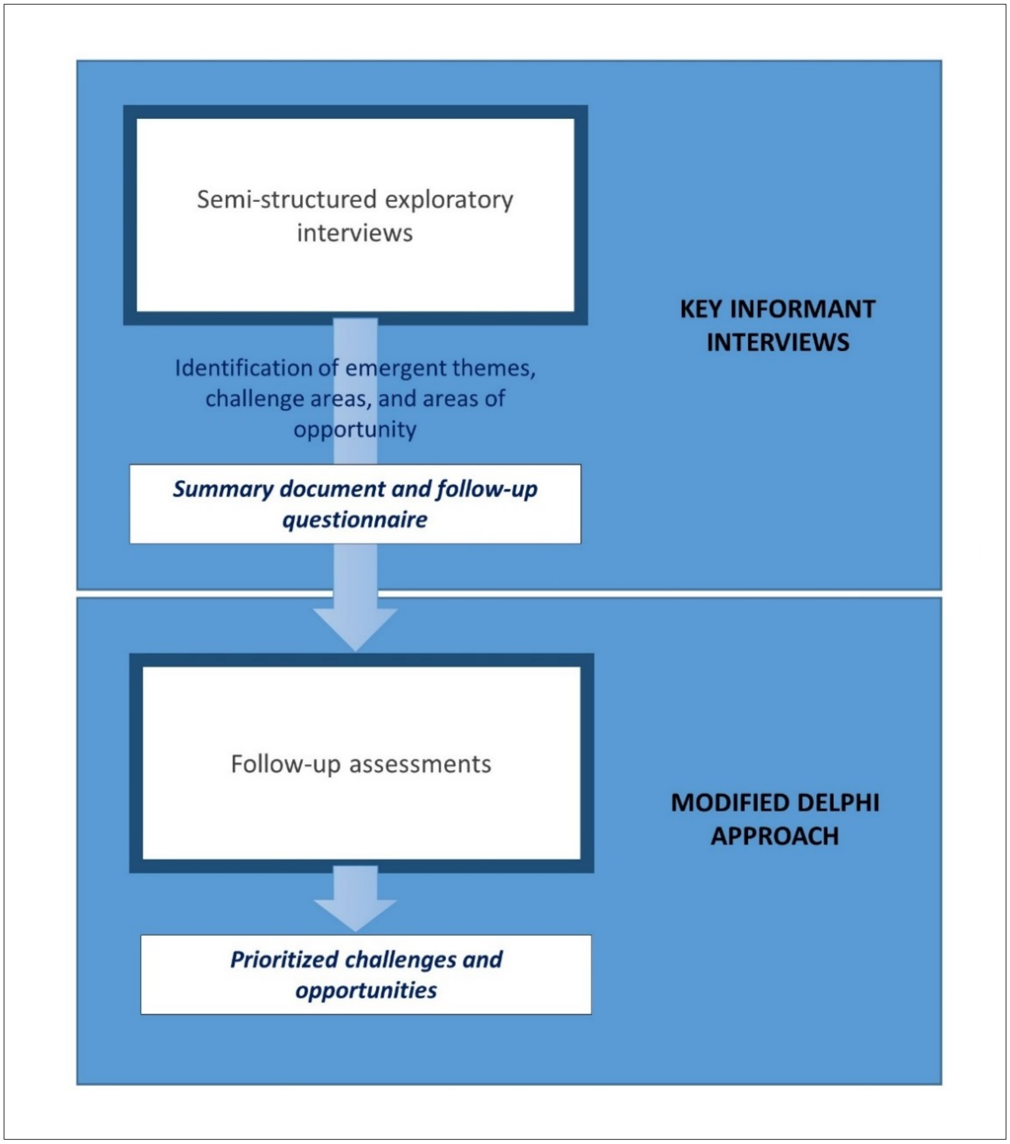


Figure 6. Modified Delphi approach used for evaluating challenges and opportunities

5.2.1 Key Informant Interviews

I set an initial target of 15 to 20 participants for the study, in order to provide a breadth and depth of responses (e.g., Hsu and Sandford, 2007; Okoli and Pawlowski, 2004). Targeted participants included EIA practitioners, reviewers and decision-makers involved in public sector (federal, provincial, and municipal) EIA, whose work involved a combination of EIA of projects located in Ontario, a focus on terrestrial biodiversity, and issues of landscape or broader-scale extent. Participants were recruited via two means: posting a notice of study through a professional affiliation newsletter (the Ontario Association for Impact Assessment), and contacting specific departments within government agencies with EIA responsibilities to explain the study and ask for volunteers. Snowballing was also used to expand the participant list based on participant recommendations of others working in this field (e.g., Silverman and Patterson, 2014). Saturation was reached when recommendations did not uncover any additional departments or contacts from those previously identified.

A total of 18 participants were interviewed: seven from federal departments, seven from provincial departments, and four from municipalities and Conservation Authorities responsible for local watershed management. An additional 12 potential participants were approached, but declined due to time constraints or because they considered their work and expertise to be a poor fit for the study. The participants who volunteered for the study tended to be senior analysts or managers with over ten years of experience working in EIA, and were typically in roles which required them to review EIA reports from proponents and consultants, make recommendations to decision-makers, and oversee EIA processes.

One-on-one telephone discussions were held with participants to explore their experiences with and thoughts on broader-scale approaches in EIA. These were semi-structured interviews of approximately 60 minutes and took place between November 2018 and April 2019. Guiding questions (Table 7) were developed based on study objectives to assess the challenges faced by participants with respect to landscape analysis in their EIA experience in terms of biodiversity assessment, and allowed for an open discussion of opportunities participants might see to overcome these challenges in their work.

Table 7. Guiding questions used for the semi-structured interviews

1. Introduction and preliminaries
• Introductions • Review goals and structure of interview • Review rights of participant and participant confidentiality • Questions
2. Participant background and professional context
Can you tell me a bit about your role, and typical involvement with the EIA process? Additional prompts: • What elements of biodiversity do you typically consider in your role? • How long have you been in this role? • What was your work background prior to this role?
3. Participant understanding and use of landscape analysis
In what ways, if any, do you consider broader scales in your work?

Additional prompts: • Do you use any kind of landscape or broader-scale analysis? Elaborate. • Do you find these to be effective? What about them makes them effective? What would you improve on, if anything? • Are there (other) landscape or broader-scale analysis methods that you are aware of that you might like to use in your work? If so, elaborate. What is preventing their current use?
4. Challenges of landscape analysis
What might you describe as the main challenges or constraints for using different types of landscape analysis in EIA? Elaborate. Additional prompts: • Are there any ways you can think of to overcome these challenges?
5. Benefits and opportunities of landscape analysis for biodiversity
Do you see opportunities for including (more / different types of / more effective) landscape analysis in EIA? Elaborate. Additional prompts: • What would need to happen to take advantage of these opportunities? • Overall, how important do you think it is to capture landscape / broader-scale analysis in EIA? Elaborate.
6. Acknowledgement and next steps
• Thank participants and review next steps • Questions

Interviews were transcribed and analyzed within QSR International's NVivo 12 qualitative analysis software (QSR, 2018). A bottom-up approach to analysis was used, such that similar points raised by participants were coded together, amalgamated, and characterized accordingly. Once coded, these points were grouped into emergent themes, and relevant points characterized as either challenges or opportunities. Challenges were defined as barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments. Opportunities were defined as new benefits that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale landscape approaches might gain greater traction. The summary of points raised, grouped by theme and characterized as challenges or opportunities, were then translated in to a summary document that was circulated back to participants for comment.

5.2.2 Follow-Up Questionnaire

As part of the modified Delphi approach, the summary document created following the interview process was circulated to participants via email in July 2019 along with a follow-up questionnaire (provided in Appendix B). The aim was to develop an understanding and sense of the relative importance of the points raised across participants, and to explore any similarities or differences between jurisdictions in how issues were characterized or prioritized. A second objective was to give participants a chance to correct any interpretive errors, and add any additional thoughts or comments triggered by any point raised by another participant.

Participants were asked to score their perceived importance of each point in the summary table on a scale of 1 to 5, where 1 indicated not important/relevant at all and 5 indicated extremely important/relevant. If a point did not apply to a participant and/or their experience, they were invited to leave it blank or mark as not applicable (a rank of 0). Participants were also able to add additional points as desired, or comment on and clarify their views on existing points in the table. Participants were then asked to identify their top three challenges and top three opportunities from among the points in the table. Finally, participants were asked to score on a scale of 1 to 5 (and comment, if desired) on how important they deemed it for biodiversity conservation that further broader-scale approaches and analyses be developed, (a) in general, and (b) as part of EIA. Nine participants (50%) completed the follow-up assessment: four federal, two provincial, and three local.

In analyzing the follow-up responses, scores for each point were tallied by jurisdiction (federal, provincial, and municipal) and overall. Due to the subjective nature of the scoring scheme, scores were grouped into 'low' (median score <2), 'medium' (median score >=2 and <4), 'high' (median score >=4 and <5), and 'maximum' (median score =5) categories based on the perceived importance of that challenge or opportunity to participants. The top three ranked challenges and opportunities were also tallied from across all participants.

5.3 Results

The following sections present the challenges and opportunities raised in the key informant interviews and the themes that emerged, followed by participants' assessment of the relative importance of these issues with respect to landscape analysis in EIA.

5.3.1 Unpacking Challenges and Opportunities

After analyzing the interview responses from participants, six themes emerged from the discussions of challenges to and opportunities for including more effective landscape and broader-scale analysis in EIA. These themes were used to categorize and frame the challenge and opportunity areas. Participants described variations on 23 challenge areas and 17 areas of opportunity, identified below under the relevant themes.

5.3.1.1 Biophysical Perspectives

There was considerable congruence across the three jurisdictions with respect to biophysical challenges associated with enhancing representation and effectiveness of landscape analysis within EIA (Table 8). Development and implementation of consistent approaches to accommodating differences across landscapes and incorporation of climate change scenarios, including inherent future uncertainties, were identified at all levels as major challenges. Temporal and spatial boundary-related issues, such as reconciling ecologically-relevant assessment boundaries with a seemingly arbitrary spatial area over which there is legislative control for a project, were also a concern at the provincial and federal levels, but not identified as a concern by local authorities.

Trends in biophysical opportunities were markedly different in two ways. First, there were far fewer opportunities identified (only one compared to three) and second, the breadth of concerns was more limited (i.e., identified at the local level only).

Table 8. Biophysical challenges and opportunities

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Challenges			
1. Differences between landscapes	✓	✓	✓
Landscapes can differ significantly in their biophysical and land use attributes and natural history (e.g., amount of remaining natural cover, Crown land vs. private ownership, how species behave in different landscapes), which may necessitate different approaches to assessment. It is difficult to apply a consistent approach.			
2. Climate change	✓	✓	✓
Understanding how climate change will affect landscapes and how species will react to these changes are still unknown, as is how to incorporate climate change information and methods into assessments. Will need to understand not only landscape connectivity, but also climate refugia.			
3. Study boundaries and scope		✓	✓
Appropriate scales of analysis can be unclear. It can be difficult to define ecologically relevant study boundaries and identify relevant zones of influence of a project at both a spatial and temporal scale. The spatial area over which there is legislative control for the project is often arbitrary from an environmental perspective. Difficult to know how far into the future to look for a cumulative effects assessment.			
Opportunities			
1. Strategic restoration opportunities	✓		
Looking beyond protecting what is there on the landscape to also identifying where habitat is lacking and developing strategic restoration objectives would provide a more robust foundation for protecting future biodiversity.			

5.3.1.2 Planning Perspectives

The Planning theme included challenges and opportunities associated with both initial preparatory work for EIA as well as how EIA was conducted and how it fit into broader land planning processes (Table 9). Three major challenges were identified by participants under this theme, each described by two jurisdictional levels. Administrative boundaries between jurisdictions were challenging to local and provincial participants in terms of their ability to conduct broader-scale analysis in EIA, as data sources and planning and implementing mitigation measures were often different in adjacent jurisdictions. This issue was not mentioned as a concern by federal participants; however, both federal and provincial participants did identify the challenges of trade-offs among competing conservation priorities, and of narrowly-scoped planning processes in space and time, as barriers to broader-scale analysis in EIA. These two challenge areas were not raised by local authorities.

This theme differed from the Biophysical theme as more opportunities were raised than challenges (four versus three). Different opportunities were raised by different jurisdictions, however, with only one area of congruence across all three. Proactive planning, including the development of clear EIA guidelines at an early phase to include landscape-level planning, stakeholders, and decision processes, was the common opportunity. Local and provincial levels described promoting partnerships as a key opportunity, especially in terms of leveraging experts in landscape fields. Provincial participants also added the opportunity for strategic big picture planning, in which EIA would be better integrated into other existing environmental strategies (i.e., conservation funding and banking, wetlands strategy). Only federal participants discussed the idea of alternative EIA models and methodology as an opportunity for better incorporating landscape scales.

Table 9. Planning challenges and opportunities

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Challenges			
4. Boundaries between jurisdictions	✓	✓	
These challenges can be related to the assessment process, if different information is collected in different jurisdictions, or to planning and implementing mitigation. Examples include where one county borders another (municipal-municipal), or where a provincial highway meets a municipal road network (provincial-municipal).			
5. Trade-offs		✓	✓
There are often challenging trade-offs, such as species with competing needs where what is good for one species in terms of landscape may be detrimental to another. Other trade-offs may involve choosing a lesser of multiple potential impacts.			
6. Narrow planning processes		✓	✓
The current process of how project planning and EIA take place limits the ability to consider the larger picture (e.g., 5-year planning cycles, project prioritization, legacy of past project locations, regulatory requirements for project-based EIA).			
Opportunities			
2. Proactive planning	✓	✓	✓
Developing strong early-phase guidelines can promote proactive planning on the part of the proponent or responsible agency. Early planning can best influence landscape-level decisions (e.g., involving stakeholders earlier in the process, identifying what should be protected vs. developed vs. flagged for more information required).			
3. Leverage partnerships	✓	✓	
Leveraging partnerships between agencies, including academic collaborations, can help overcome resource constraints. Examples include working with experts and conservation agencies on things like compensation and long-term management of offset lands and identifying wildlife corridors.			
4. Big picture planning		✓	
Developing more strategic approaches to EIA and planning that look beyond a single project and single-project mitigation to approaches such as conservation funding and banking can aid in promoting larger conservation objectives. Requires a paradigm shift in thinking, but may be more effective for conservation with the same time and money. Can achieve multiple benefits through broad plans that incorporate multiple strategies (e.g., Ontario's pollinator strategy, wetland strategy, biodiversity strategy).			

Major themes derived from key respondents at local through federal levels	**Raised By**		
	Local	Provincial	Federal
5. Alternative EIA models			✓
Considering different models of EIA, such as a focus on processes and flows rather than ecosystem components, can promote regional EIA approaches. Encouraging regional study results to be incorporated into project EIA, in advance of and to inform project EIA, can also support broader-scale approaches.			

5.3.1.3 Perspectives on Policy and Institutional Systems

This theme drew a relatively wide range of responses, including five challenges and four areas of opportunity (Table 10). Again, there tended to be few areas of congruence across all three jurisdictions, with a general lack of policy and guidance specific to landscape analysis and broader scales of assessment, and limited environmental mandates identified as key challenges. Local and federal authorities also described a lack of multi-level policy support for common initiatives as a key challenge. Federal participants expanded on this challenge by adding the lack of institutional support and ability to handle the more integrated approaches required for effective broader-scale approaches in EIA. For provincial participants, the legislative focus on individual project assessments limited their ability to apply broader-scale assessment and mitigation.

The one area of congruence across jurisdictions in terms of policy and institutional opportunities described was the flip side of a key challenge: strengthening policy language to better integrate the EIA process with broader initiatives and linking these to authorizations and permitting processes. There were three additional opportunities identified, but by a single jurisdiction only. Provincial participants suggested that bottom-up cultural shifts represented an important opportunity for landscape analysis in EIA, while federal participants identified both the development of geography-based expertise (as opposed to subject-based expertise) within responsible departments, as well as biodiversity banking options, as potential opportunities.

Table 10. Policy and institutional systems challenges and opportunities

Major themes derived from key respondents at local through federal levels	**Raised By**		
	Local	Provincial	Federal
Challenges			
7. Lacking multi-level policy support	✓		✓
It is difficult to advance an approach to EIA or other environmental protection measures without higher-level jurisdiction support (e.g., strong provincial mandate, clear federal guidance). Similarly, without multi-jurisdictional support for common initiatives, assessments can be very different between projects regulated by different jurisdictions and lead to a non-level playing field.			
8. Focus on project-by-project assessment		✓	
Legislation is currently not set up to support assessments and mitigation outside of a project-specific approach (e.g., regional assessments, compensation or offsets outside of project site-specific locations, cumulative effects assessment).			
9. Lack of policy and guidance	✓	✓	✓
Particular areas lacking policy and/or guidance include cumulative effects assessments, assessment and planning of natural heritage features, and habitat compensation and offsets.			
10. Lack of institutional support			✓
Current institutions do not have the ability to handle more integrated approaches needed to effectively manage broader-scale perspectives beyond project- and site- specific regulation.			

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
11. Limited environmental mandates	✓	✓	✓
Environmental initiatives are limited by an agency's mandate. Often agencies have competing priorities and few resources to address them all. Sometimes elements of the landscape within which the assessment and/or mitigation is located fall within another agency's purview, but coordination can be a challenge.			
Opportunities			
6. Strengthened policy language	✓	✓	✓
Drafting clear policy that requires no net loss and/or net environmental benefit from projects would help agencies and regulators. Developing mutually supporting language in policy documents that better integrates the EIA process with broader initiatives such as regional planning and natural heritage system strategies would help to level the playing field between jurisdictions. Emphasize system-wide impacts and include these in permitting and authorization processes.			
7. Bottom-up cultural shifts		✓	
Encouraging bottom-up shifts in organizational culture, including education and learning through success stories and examples, would promote broader-scale approaches.			
8. Geography-based expertise			✓
Developing expertise for more geography-based vs. project-based approaches to EIA would help build institutional capacity for landscape and broader-scale approaches. Building collective knowledge about a geography and the stressors and ecology in that area is important so when a project is proposed there is already a body who has thought through some of the issues.			
9. Biodiversity banking			✓
Developing a biodiversity credit system similar to existing international initiatives could benefit biodiversity at broader scales.			

5.3.1.4 Perspectives on Practicalities and Implementation

An equal number of challenges and opportunities were identified within the theme of EIA practicalities and implementation, although there was no full alignment across all jurisdictions on any of the issues raised (Table 11). At a local and provincial level, deficiencies in contract documents for consultants and contractors challenged participants' ability to incorporate landscape analysis in EIA, as did the management and maintenance of long-term mitigation measures outside of the traditional project scale. At a provincial to federal level, participants found that having mitigation restricted to the project site itself was a logistical challenge in being able to fully incorporate broader-scale assessment across the mitigation phase of EIA.

Opportunities raised were along similar lines to the challenges raised by participants across jurisdictions. Local and provincial authorities saw an opportunity in bringing greater clarity to contract documents to require broader-scale approaches. Local and federal authorities suggested that regional approaches could be promoted through proponent incentives at time of project application. Finally, federal authorities expanded on this idea by suggesting an opportunity for project proponents to plan habitat compensation and offsets as mitigation ahead of time and thus less constrained by the project site location.

Table 11. Practicalities and implementation challenges and opportunities

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Challenges			
12. Deficient EIA contract documents	✓	✓	
There is a need for clear and complete contracts and contract guidelines for consultants/contractors for EIA preparation and/or project implementation, otherwise anything broader in scale or scope can be dropped. Also a clear transfer and oversight of EIA recommendations from the EIA through detailed design and implementation.			
13. Long-term mitigation management	✓	✓	
Responsibility and budgeting for long-term monitoring and maintenance of mitigation measures can be an issue, especially when off-site compensation or offsets are involved. Land ownership of offset lands can be a challenge for long-term protection. In other cases, the resources to ensure protection in the long term may be lacking.			
14. Mitigation restricted to project site		✓	✓
There can be limited logistical ability for a proponent to go off-site to implement mitigation, even if it makes sense for broader ecological objectives.			
Opportunities			
10. Pre-construction habitat offsets			✓
Requiring habitat compensation and offsets to be implemented prior to project construction would promote broader biodiversity conservation initiatives.			
11. Proponent incentives	✓		✓
Implementing incentives for the proponent, such as timeline certainty, payments or tax breaks for avoiding certain no-go areas, or fewer development hurdles in certain pre-approved areas, would promote broader regional approaches.			
12. Clear contracts	✓	✓	
Drafting guidelines for clear EIA and/or project contracts that lay out the expectations for information needs, long-term monitoring and/or maintenance would help with the success of broader-scale initiatives. Secure any off-site land used as compensation or offsets for the long term.			

5.3.1.5 Science and Data Perspectives

Like the Policy and Institutional Systems theme, Science and Data was also a prevalent theme, encompassing five challenges and four opportunities (Table 12). Two of these challenges were congruent across all three jurisdictions: vague terminology and concepts in landscape and biodiversity science, and weaknesses in data and data management systems. Local and federal participants raised a disconnect between theory and practice as a challenge, speaking to the gap between academia and practitioners' communities. A lack of monitoring was cited as a science and data challenge for local and provincial participants, while provincial and federal participants described challenges associated with the lack of knowledge of ecological thresholds with which to compare EIA predictions.

Only one of the four opportunities under this theme was identified by all jurisdictions. Participants emphasized the opportunity associated with better monitoring of EIA outcomes to inform future decision-making and start to build more robust, long-term datasets. Local and provincial participants identified an opportunity to make use of existing tools developed for landscape analysis in other practices and incorporating these into EIA. The other two opportunity areas were identified by just one jurisdiction each: provincial participants suggested that development of habitat prioritization maps (i.e., for conservation or restoration) would be useful for broader-scale EIA approaches, while federal participants identified an opportunity to create multi-jurisdictional data systems to integrate data, observations, and monitoring across scales.

Table 12. Science and data challenges and opportunities

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Challenges			
15. Vague terminology and concepts	✓	✓	✓
Concepts and terminology are vague and difficult to quantify, operationalize or implement (e.g., ecosystem approach, cumulative effects, biodiversity, offsets). There is a need to clarify what these mean and how they can be measured.			
16. Disconnect between theory and practice	✓		✓
The practitioners' community is not routinely part of academic advances in EIA and it can be difficult to keep up to date with the more advanced methods and tools. Science changes more quickly than government organizations can update their plans and programs.			
17. Weak data and data management systems	✓	✓	✓
There is currently a lack of integrated data management systems to support decision making. Need broad-based information availability, fed by consistent monitoring, and supported with institutional arrangements that cross jurisdictions. Sources of information and quality of baseline data is often lacking. Data is expensive. More regional-scale studies and better availability of regional infomation is needed.			
18. Knowledge of ecological thresholds		✓	✓
There is currently little information on specific ecological thresholds, e.g., for quantifying a project's contribution to cumulative effects in a region, and at what scale these should be measured. Need these tools to make decisions easier and more defensible.			
19. Lack of monitoring	✓	✓	
The lack of long-term monitoring data in general, and specifically on projects that took a broader-scale approach to EIA and mitigation, limit evaluation of the success of different EIA approaches.			
Opportunities			
13. Integration of available tools	✓	✓	
Opportunity to take advantage of existing work in connectivity mapping and natural heritage system mapping to inform project EIA (e.g., Circuitscape mapping in Ontario). Use existing criteria from authoritative sources (e.g., Environment Canada's *How Much Habitat is Enough?*) to short-cut more detailed analyses where resources are limited.			

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
14. Multi-jurisdictional data systems			✓
Create a broadly available database (e.g., open science data platform or "Nature Wiki") for agencies and the public to curate and use to inform baseline data. Develop a repository to integrate federal, provincial and municipal information, including spatial information on known and expected development areas, species distributions and observations, and scales at which species respond.			
15. Habitat prioritization		✓	
Add another layer to existing habitat maps that prioritizes those habitats according to the top locations to focus habitat improvements and what those improvements might be, for the purposes of off-site compensation and offset measures.			
16. Monitoring	✓	✓	✓
Implement robust monitoring of project outcomes and measurable results to inform future decision-making and support effective spending. Collecting clear before and after data to start to build a long-term dataset, especially when it comes to mitigation like habitat restoration and offsets.			

5.3.1.6 Perspectives on Social and Economic Influences

Social and Economic Influences was a narrower theme, but distinct in that it described challenges and opportunities associated with external societal factors as well as logistical cost constraints. Four challenge areas dominated this theme, and only a single opportunity was identified (Table 13). Challenges were relatively aligned across jurisdictions, with participants at all levels identifying project costs on the part of the proponent as a limitation to broader-scale assessment, as well as a lack of resources and capacity for such assessment at an institutional level. A lack of external pressure from stakeholders interested in such broader-scale approaches was also expressed as a challenge for local and provincial-level participants. Provincial participants, along with federal counterparts, also described the lack of consistency in government priorities over time to be an operational challenge.

The one opportunity in this theme was brought forward by local and federal participants. Here, participants expressed that growing social awareness around broad-scale issues such as climate change created an opportunity to further other broad-scale EIA initiatives.

Table 13. Social and economic challenges and opportunities

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Challenges			
20. Project costs	✓	✓	✓
There can be a lack of buy-in on the part of the proponent, for financial reasons. Proponents generally have finite resources for EIA and want to be practical. Sometimes there is push-back in implementation.			
21. Lack of institutional resources	✓	✓	✓
The capacity of agencies to promote broader approaches is limited by resources (e.g., time, money, budgets, political will) at an institutional level.			
22. Lack of stakeholder pressure	✓	✓	
There is little incentive to implement initiatives without external stakeholder pressure. There is a need for public and advocacy group support to advance EIA.			
23. Changing government priorities		✓	✓
With changes in government, priorities change and create a lack of continuity for initiatives such as approaches to biodiversity, landscape and cumulative effects assessments. Pressure to balance environmental protection with jobs and economic growth can limit landscape-based initiatives.			

Major themes derived from key respondents at local through federal levels	Raised By		
	Local	Provincial	Federal
Opportunities			
17. Social awareness	✓		✓
Growing awareness of complex, large-scale issues such as climate change creates opportunities to leveraging similar understanding in promoting green infrastructure and habitat networks. There is also an economic interest that can be leveraged in promoting landscape approaches for climate change resilience in terms of green infrastructure.			

5.3.2 Assessment of Relative Importance

This section transitions from the unpacked results presented in Section 5.3.1 to reporting on the relative importance placed upon the six major themes revealed during the first phase of the modified Delphi process. In this follow-up phase, participant responses consistently indicated that two themes, Policy and Institutional Systems, and Science and Data, were of high importance with respect to both challenges and opportunities, followed by Biophysical challenges and Planning opportunities. These last two themes, however, were variably ranked by participants of different jurisdictions. Two other themes, Practicalities and Implementation and Social and Economic Influences were consistently ranked of lower importance for both challenges and opportunities relative to the other four themes (Table 14).

Table 14. Relative ranking of challenges and opportunities for broader-scale analysis in EIA

			Local	Provincial	Federal	Overall	Top-3
Policy and Institutional Systems	Challenges	Lack of policy and guidance	✓	✓	✓	H	❶
		Lacking multi-level policy support	✓		✓	H	❷
		Limited environmental mandates	✓	✓	✓	H	
		Focus on project-by-project assessment		✓		H	
		Lack of institutional support			✓	M	
	Opportunities	Strengthened policy language	✓	✓	✓	H	③
		Geography-based expertise			✓	M	
		Bottom-up cultural shifts		✓		M	
		Biodiversity banking			✓	M	
Science and Data	Challenges	Weak data and data mgmt. systems	✓	✓	✓	H	❸ tie
		Knowledge of ecological thresholds		✓	✓	H	❸ tie
		Vague terminology and concepts	✓	✓	✓	M	
		Lack of monitoring	✓	✓		M	
		Disconnect between theory and practice	✓		✓	M	
	Opportunities	Multi-jurisdictional data systems			✓	H	②
		Monitoring	✓	✓	✓	H	
		Integration of available tools	✓	✓		M	
		Habitat prioritization		✓		M	
Biophysical	Challenges	Differences between landscapes	✓	✓	✓	H	
		Study boundaries and scales		✓	✓	H	
		Climate change	✓	✓	✓	M	
	O.	Strategic restoration opportunities	✓			M	

			Local	Provincial	Federal	Overall	Top-3
Planning	**Challenges**	Boundaries between jurisdictions	✔	✔		**M**	
		Narrow planning processes		✔	✔	**M**	
		Trade-offs		✔	✔	**M**	
	Opportunities	Big picture planning		✔		**H**	①
		Proactive planning	✔	✔	✔	**H**	
		Leverage partnerships	✔	✔		**M**	
		Alternative EIA models			✔	**M**	
Social and Economic Influences	**Challenges**	Project costs	✔	✔	✔	**M**	
		Lack of institutional resources	✔	✔	✔	**M**	
		Changing government priorities		✔	✔	**M**	
		Lack of stakeholder pressure	✔	✔		**M**	
	O.	Social awareness	✔		✔	**M**	
Practicalities and Implementation	**Challenges**	Long-term mitigation management	✔	✔		**M**	
		Mitigation restricted to project site		✔	✔	**M**	
		Deficient EIA contract documents	✔	✔		**L**	
	Opportunities	Clear contracts	✔	✔		**M**	
		Proponent incentives	✔		✔	**M**	
		Pre-construction habitat offsets			✔	**M**	

Legend		
✔	Point raised by a participant of the corresponding jurisdiction during the interview phase	
L	Low importance	❶❷❸ Top-3 ranked challenges
M	Medium importance	
H	High importance	①②③ Top-3 ranked opportunities
MAX	Maximum importance	

The top-ranked challenges overall included (1) a lack of policy and guidance on broader-scale analysis and approaches, (2) a lack of multi-level policy support, and tied for (3) were weak data and data management systems, and knowledge of ecological thresholds. Conversely, the top-ranked opportunities included (1) big picture planning, (2) development of multi-jurisdictional data systems, and (3) strengthened policy language.

Overall, participants believed that broader-scale approaches and analyses were highly important in general (median importance score = 5/5), and as part of EIA processes (median importance score = 4/5).

5.3.2.1 Highest Ranked Themes

Four of five challenges under the theme of Policy and Institutional Systems were ranked of high importance overall. Two of these, a lack of policy and guidance specific to landscape-based approaches, and a lack of multi-level policy support, were ranked as the top two challenges faced by participants overall. The latter was ranked highly important across all jurisdictions, being originally identified by local and federal participants. The lack of policy and guidance was mentioned across all jurisdictions during the interviews, and then ranked of maximum importance by provincial participants, high importance by local-level participants, and medium importance by federal participants. A corresponding opportunity, to strengthen policy language to reflect the need for broader-scale analysis in EIA and to integrate EIA with broader initiatives, also ranked in the top three opportunities identified by participants across jurisdictions. Participants also felt that the challenges of limited environmental mandates and a focus on project-by-project assessment were highly important for conducting broader-scale assessment in EIA.

Two highly important challenges under the Science and Data theme were tied in the top three overall: weak data and data management systems, and knowledge of ecological thresholds. Two opportunities under this theme were ranked high in importance, including the development of multi-jurisdictional data systems (ranked in the top three opportunities overall) and monitoring. This latter opportunity was consistently ranked high across jurisdictions.

5.3.2.2 Lowest Ranked Themes

Themes with the lowest importance rankings for both challenges and opportunities included Social and Economic Influences and Practicalities and Implementation. While several points were raised by participants across jurisdictions in relation to these themes in the interviews, participants considered them of lower relative importance compared to others in terms of their influence on implementing broader-scale analysis in EIA. These themes included factors such as institutional resources and project costs, stakeholder pressure and social awareness, spatial and temporal restrictions on project mitigation, and EIA contract documents.

5.3.2.3 Themes with Inconsistent Importance Rankings

The Biophysical theme contained challenges that were ranked of high importance by participants, but medium importance for the single opportunity under this theme (strategic restoration opportunities). Important challenges included the biophysical differences between landscapes and setting study boundaries and scales, though this latter challenge was ranked of lower importance by federal participants compared with local and provincial participants.

Under the Planning theme, participants ranked two of the four identified opportunities as highly important: big picture planning (ranked in the top three opportunities overall), and proactive planning. These two opportunities collectively refer to the development of more strategic approaches to EIA and planning that are undertaken earlier in the process and look beyond a single project to consider landscape impacts and mitigation and tying into regional initiatives. On the other hand, challenges under this theme did not rank high in relative importance.

5.4 Discussion

Of the six themes that emerged from the interviews, four aligned with existing literature on issues encountered in EIA practice. Issues discussed in the literature related to those expressed by participants under the themes of Policy and Institutional Systems (e.g., Ekstrom and Young, 2009; Mayer et al., 2016; Treweek, 1996), Science and Data (e.g., Treweek, 1996), Biophysical (e.g., Dibo et al., 2018), and Practicalities (e.g., Arnold, 2014). The current study confirms the ubiquity of these issues across aspects of EIA practice, in this case representing challenges and opportunities specific to landscape and broader-scale assessment in EIA. At the same time, two additional themes emerged in the current study: issues related to Planning and to external Social and Economic Influences were unique to this study of landscape and broader-scale analysis in EIA. This suggests that advancing broader-scale ecological assessments also involves broader socio-political considerations that range beyond an EIA itself.

This discussion first considers the areas of highest priority for advancing landscape analysis in EIA, as indicated by the importance rankings given to the challenges and opportunities identified by study participants. It then examines issues that may be considered lower priority, as ranked of lesser relative importance by participants. Finally, differences between jurisdictions are examined in terms of the relative priorities for advancing landscape analysis in EIA at different organizational levels. Findings of the current study are framed relative to broader EIA literature, and implications and opportunities for landscape analysis-EIA research and practice are highlighted.

5.4.1 High Priority Areas for Advancing Landscape Analysis in EIA

The themes of Policy and Institutional Systems and Science and Data were identified as priority areas for advancing landscape and broader-scale analysis in EIA in Ontario. With challenges related to both these themes appearing in earlier EIA literature, it was not surprising that similar issues were considered important in the current study. This study illustrates the pervasiveness of these issues across many aspects of EIA, including the ability of practitioners to use landscape analysis in assessment practices.

Within the Policy and Institutional Systems theme, a lack of policy and guidance and a lack of multi-level policy support were ranked as the top two challenges faced by participants across all themes and jurisdictions, with local- and provincial-level participants ranking these challenges as particularly important (Table 14). Participants identified difficulties with advancing an approach to EIA without higher-level jurisdiction support, such as strong provincial mandates supporting municipal assessments, or clear federal guidance to direct provincial assessments. Issues with legislative wording are not new, having been cited as a known challenge for well over two decades (Treweek, 1996). The current findings reaffirm the importance of addressing ambiguities and omissions in legislative wording, while also highlighting the importance of aligning language across jurisdictional levels.

The perspectives of participants on the lack of guidance contrast with the views of Duinker and Greig (2006), who found that guidance in the EIA literature at that time was available and applicable but was been largely ignored in actual EIA practice. However, their study focused on best practices in EIA science overall, and not explicitly on the issue of landscape and broader-scale assessment.

The timing of the interviews between November 2018 and April 2019 meant that the new federal *Impact Assessment Act* (IAA; Government of Canada, 2019) had not yet come into force, and guidance within its new scope would not have been recognized by participants. New requirements of the IAA spurred a surge of new federal policy and guidance documents related to additional factors to be considered, new Indigenous knowledge requirements, regional assessments, and open source data, among others. How the presence of recent guidance at the federal level would impact participant responses is outside the current scope, but would be a valuable follow-up for future study.

While the lack of policy and guidance appeared most challenging to provincial and local participants, the focus on strengthening policy language itself was identified as an important opportunity at all jurisdictional levels. Participants emphasized the need for drafting clear policy with mutually supporting language to better integrate the EIA process with broader regional planning and natural heritage system strategies, to advance the use of landscape analysis for biodiversity goals. Bigard et al. (2017) found that changes in policy increased the inclusion of biodiversity features in EIA, indicating that improved policy wording does impact EIA practice. This suggests that the opportunity identified by participants may indeed offer an important step forward.

Within the Science and Data theme, two challenges and two opportunities were ranked as highly important overall, indicating additional areas of high priority for advancing landscape analysis in EIA. Important challenges included weaknesses in data and data systems, and knowledge of ecological thresholds to interpret EIA findings; related opportunities included the development of multi-jurisdictional data systems, and better monitoring of EIA outcomes.

Data and data management systems are also not a new challenge for practitioners. Treweek (1996) recommended that availability of data on distributions of species and habitats be improved: for project studies to be placed in a broader spatial context, it was argued that national datasets of the distributions of habitats and species be comprehensive, integrated and regularly updated. Nearly 20 years later, barriers to data access identified by González et al. (2014) included lack of technical infrastructure such as a national biodiversity data repository, data quality issues, problems with metadata, and issues of intellectual property rights limiting the type and availability of information published. Weaknesses in broader data quality and availability can narrow assessments to focus on the local site-specific scale (González et al., 2014), ignoring the broader ecosystem and landscape level. The current study supports these findings, and affirms that data collection and management is still an ongoing issue today.

The literature offers suggestions to overcoming these deficiencies, including the development of national repositories for biodiversity data to allow for long-term data accumulation, which would help in determining cumulative and synergistic effects and improve assessment effectiveness (González et al., 2014). In order to make the assembly of comprehensive regional ecological datasets more common and less expensive, Duinker et al. (2013) recommended that the practitioner and researcher communities develop new measurement tools including field instruments and remote sensing technology. Similarly, Heiner et al. (2019) underscored the need for funding for regional survey efforts in order to encourage proactive landscape-level planning. In the current study, participants went a step further, in identifying a key opportunity in the development of a broadly available, multi-jurisdictional data repository to integrate municipal, provincial, and federal information, including spatial information on known and expected development areas, species distributions and observations, and scales at which species respond to changes in their landscape. This was viewed as an important priority for advancing the use of landscape analysis in EIA.

The second major challenge under the theme of Science and Data is knowledge of ecological thresholds. This challenge was initially raised by both provincial and federal participants and ranked as maximum and high importance respectively. Unlike the issue of data and data management, local participants did not consider it of high importance. The lack of knowledge of ecological thresholds is also an oft-cited challenge in the literature (e.g., Duinker et al., 2013; Duinker and Greig, 2006; Jaeger, 2015), and it is not surprising that it was discussed by participants in the current study. The idea of an ecological threshold is that system components behave in a non-linear way, such that when a threshold is crossed, the rate of change in system behaviour can accelerate and potentially reach irreversible levels (Duinker and Greig, 2006). Population responses to cumulative habitat loss, for example, tend to show non-linear responses (Duinker and Greig, 2006; Jaeger, 2015). The challenge lies in the fact that such thresholds are difficult to determine in the biophysical world (Duinker and Greig, 2006); they are species and ecosystem-specific, and require long-term studies to elucidate (Jaeger, 2015). As Duinker et al. (2013, p. 47) concluded, "physical environment thresholds are much easier to find or develop than biotic and social thresholds. Thus, thresholds related to air, water and soil quality seem more accessible than those dealing with species, ecosystems and people."

There are some established thresholds for effects of forest habitat loss (Estavillo et al., 2013) and of increasing road density on species presence in a landscape (e.g., wolf, Jensen et al., 1986; grizzly bear, Mace et al., 1996), but often little is known about earlier thresholds that would indicate a decline in population viability (Jaeger, 2015; Robinson et al., 2010). Thresholds tend to be species- and landscape-specific, and require long-term studies to assess (Jaeger, 2015).

Without knowledge of such quantitative thresholds regarding landscape and broad-scale effects on biodiversity, landscape analysis can have little meaning and thus little incentive for application; small portions of habitat can be eliminated incrementally without any signal for when the loss and alteration of habitat might reach cumulative significance (Schultz, 2010). To address this issue, Duinker et al. (2013) recommended collaborative efforts between the scientific and policy communities to establish defensible ecological thresholds. While participants did not explicitly mention Indigenous perspectives in the interviews or follow-up, recent legislative changes at the federal level, including the enactment of the IAA, have reaffirmed the importance of Indigenous knowledge in EIA and overall. Local and Indigenous communities can play an important role here in bringing their knowledge and perspectives to the science-policy discussion.

Along a similar line, improved ecological monitoring was identified as a highly important opportunity by participants across all jurisdictions. Participants expressed that robust monitoring of project outcomes and measurable results would help inform future decision-making and help to build much-needed long-term datasets. Such data could also aid in identifying ecological targets and thresholds for a range of species and landscapes.

The need for better monitoring, follow-up, and consolidation and sharing of monitoring results has also been identified widely in the literature for over two decades to better align EIA science and practice, particularly with respect to biodiversity and cumulative effects (Dibo et al., 2018; Duinker and Greig, 2006; Foley et al., 2017; González et al., 2014; Schultz, 2010; Therivel and Ross, 2007; Treweek, 1996). There is a recognized need for structured monitoring programs to test EIA predictions and monitor long-term impacts associated with development (Treweek, 1996), particularly at the landscape scale (Şahin and Kurum, 2009). However, difficulties have included few current incentives or obligations for project proponents to support and share long-term monitoring results (Dibo et al., 2018). Heiner et al. (2019) identified funding for regional survey efforts as a critical practical limiting factor for moving beyond the typical project site surveys conducted for EIA, while Duinker et al. (2013) suggested an opportunity to develop new and inexpensive measurement techniques to aid in the assembly of comprehensive regional ecological datasets. In the current study, the importance placed on ecological monitoring of project outcomes and building a long-term dataset suggests that this area remains an underdeveloped opportunity.

Falling outside of these two priority themes, two other highly important challenges were identified under the Biophysical theme. Biophysical issues were identified as those that had to do with the nature of the ecology and environment itself. Similar to the argument by Treweek (1996), these challenges related to the inherently complex nature of ecological systems. Across jurisdictions, a highly important challenge was the inherent differences between landscapes in terms of their biophysical and land use attributes, which often necessitates different approaches to assessment and makes applying a consistent analysis approach more difficult. The uncertainty associated with this complexity and uniqueness of landscape-scale ecological effects and long-term consequences is generally high (Balfors et al., 2010; Jaeger, 2015; Roedenbeck et al., 2007). To address this, some authors call for more rigorous application of the precautionary principle, in that the more explicit an EIA can be about assumptions and knowledge gaps and disclosure of uncertainty, the better it can inform decisions (Jaeger, 2015; Tenney et al., 2006).

Defining appropriate study boundaries and scales also presented challenges ranked highly import to local-level and provincial participants. This challenge related to defining ecologically relevant boundaries and spatial and temporal zones of influence of a project, which did not always align with the spatial area over which the participants had legislative control. This issue indicates a scale mismatch at lower jurisdictional levels, in which broad-scale ecological processes are assigned to fine-scale social systems (Cumming et al., 2006). Greater inter-jurisdictional cooperation may be required to overcome such challenges.

Also outside of the two priority themes, two highly important opportunities were identified under the Planning theme: big picture planning, and proactive planning. Big picture planning is what participants referred to as the development of more strategic approaches to EIA, which go beyond single-project assessment and mitigation to explore ways to integrate EIA with broader conservation strategies and regional planning. Participants mentioned that such an approach may require a paradigm shift in thinking, but that conservation gains could be substantial for the same investment of resources. This opportunity was initially raised by provincial participants, though participants across jurisdictions seemed to take to that suggestion during the follow-up and ranked it as the top opportunity in terms of incorporating landscape and broader-scale analysis into EIA for biodiversity. This idea represents a novel suggestion for advancing landscape analysis-EIA research and practice through broader approaches to EIA that expand it beyond its typical silo.

Proactive planning presented an opportunity along similar lines, in which participants advocated developing strong EIA guidelines early on in the process in order to best influence landscape-level decisions, engage the appropriate stakeholders, and identifying regional conservation versus development priorities as well as data gaps from the outset. This opportunity is in line with the idea of proactive planning as an alternative to current reactive practice in relation to improving CEA advocated in the literature (Duinker and Greig, 2006). It remains to be seen how the federal IAA and its reemphasis on early planning and on regional and strategic assessments will impact practitioners' views.

Overall, high priority areas for advancing landscape analysis in EIA were largely recognized in EIA literature spanning across multiple problem areas. The current study reaffirms their importance and suggests some new angles on opportunities for moving forward.

5.4.2 Areas of Lower Current Priority

An interesting finding of the study is not only the identification of priority areas, but also which issues were considered lower priority by participants. This suggests areas that are either considered relatively manageable as compared to more immediate challenges, or where EIA may have already made sufficient progress with respect to incorporating landscape and broader-scale analysis for biodiversity. While few issues raised by participants during the interviews were later classified as low importance, there were several that ranked of medium importance during the follow-up. Overall, the two areas that seemed to be least problematic in terms of the current importance of issues were the themes of Practicalities and Implementation, and Social and Economic Influences.

The practice and implementation of EIA itself, including issues and opportunities such as contracts and management of mitigation measures, appeared to be of lower immediate concern as compared to other areas, and did not pose critical challenges for implementing broader-scale assessment in EIA. Exceptions included the opportunity for clearer contracts, ranked of high importance by local participants, and two challenges associated with spatial and temporal limits on mitigation measures, which were ranked of high importance by provincial participants. Of note, the recommendation to explicitly include cumulative effects considerations in EIA terms of reference was also recommended by Duinker and Greig (2006) and by Freiitas et al. (2017). On the other hand, the challenges noted by both Geneletti (2004) and Dibo et al. (2018) related to knowledge and guidance needs on analysis tools and methods did not seem to be of concern to participants in the current study. This may suggest that enough progress has been made in these areas that this challenge was no longer top of mind for participants in the current study.

Issues within the area of Social and Economic Influences were consistently ranked of medium importance overall, though participants at lower jurisdictional levels (local and provincial) ranked project costs, lack of institutional resources, and changing government priorities as highly important challenges. These did not rank as important to federal participants. Factors contributing to these results are speculative, but could be that at lower jurisdictional levels, participants were more directly tied to shorter-term funding cycles and priorities. At a higher federal level, the scale of temporal change of program funding in response to changing priorities may be slower, matching it more closely with ecological system change (Cumming et al., 2006) and the needs of longer-term project assessments.

The relatively lower importance placed on these issues means that these areas can be deprioritized in favour of focusing on the opportunities highlighted above in Section 5.4.1. It also indicates that progress has occurred in some areas, such as the lack of knowledge on landscape and broader-scale analysis tools and methods discussed in earlier literature, which is encouraging for those areas requiring further work.

5.4.3 Jurisdictional Differences

Jurisdictions found alignment in some challenges and opportunity areas, yet diverged in others. Table 15 and Table 16 pull out the respective challenges and opportunities that participants from the three jurisdictional levels ranked of high to maximum importance, in order to graphically illustrate the jurisdictional level(s) at which they were considered important.

Challenges consistently ranked highly important across all jurisdictions included the lack of multi-level policy support for landscape approaches, and the reality of dealing with very different landscapes when attempting to conduct broader-scale analysis. In terms of opportunities, big picture planning ranked highly important across all jurisdictions, as did strengthening policy language to support broader-scale assessments and improving monitoring and the collection of long-term data sets.

Table 15. Important challenges to the implementation of landscape analysis in EIA, by jurisdictional level

<table>
<tr><th></th><th>Local</th><th>Provincial</th><th>Federal</th></tr>
<tr><td rowspan="5">Policy and Institutional Systems</td><td colspan="2">❶ Lack of policy and guidance[1]</td><td></td></tr>
<tr><td colspan="3">❷ Lack of multi-level policy support</td></tr>
<tr><td></td><td>Limited environmental mandates</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Focus on project-by-project assessment</td></tr>
<tr><td colspan="2">Lack of institutional support</td></tr>
<tr><td rowspan="4">Science and Data</td><td colspan="2">❸ Weak data and data management systems</td><td></td></tr>
<tr><td rowspan="3"></td><td colspan="2">❸ Knowledge of ecological thresholds</td></tr>
<tr><td>Vague terminology and concepts</td><td>Disconnect between theory and practice</td></tr>
<tr><td>Lack of monitoring</td><td></td></tr>
<tr><td rowspan="3">Biophysical</td><td colspan="3">Differences between landscapes</td></tr>
<tr><td colspan="2">Study boundaries and scales</td><td rowspan="2"></td></tr>
<tr><td></td><td>Climate change</td></tr>
<tr><td>Planning</td><td>Boundaries between jurisdictions</td><td>Narrow planning processes</td><td></td></tr>
<tr><td rowspan="3">Social and Economic Influences</td><td colspan="2">Project costs</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Lack of institutional resources</td></tr>
<tr><td colspan="2">Changing government priorities</td></tr>
<tr><td rowspan="2">Practicalities and Implementation</td><td rowspan="2"></td><td>Long-term mitigation management</td><td rowspan="2"></td></tr>
<tr><td>Mitigation restricted to project site</td></tr>
</table>

[1]The darker shading indicates challenges that ranked highly important overall when importance scores were tallied across the three jurisdictions (Table 14). The numbers ❶, ❷ and ❸ indicate the top-three challenges ranked by study participants.

Table 16. Important opportunities for the implementation of landscape analysis in EIA, by jurisdictional level

<table>
<tr><th></th><th>Local</th><th>Provincial</th><th>Federal</th></tr>
<tr><td rowspan="2">Policy and Institutional Systems</td><td colspan="3">③ Strengthened policy language[1]</td></tr>
<tr><td></td><td>Geography-based expertise</td><td></td></tr>
<tr><td rowspan="4">Science and Data</td><td colspan="2">② Multi-jurisdictional data systems</td><td></td></tr>
<tr><td colspan="3">Monitoring</td></tr>
<tr><td colspan="2">Integration of available tools</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Habitat prioritization</td></tr>
<tr><td>Biophysical</td><td colspan="2">Strategic restoration opportunities</td><td></td></tr>
<tr><td rowspan="2">Planning</td><td colspan="3">① Big picture planning</td></tr>
<tr><td>Leverage partnerships</td><td colspan="2">Proactive planning</td></tr>
<tr><td>Social and Econ. Influences</td><td colspan="3"></td></tr>
<tr><td>Practicalities and Implementation</td><td>Clear contracts</td><td colspan="2"></td></tr>
</table>

[1]The darker shading indicates opportunities that ranked highly important overall when importance scores were tallied across the three jurisdictions (Table 14). The numbers ①, ② and ③ indicate the top-three opportunities ranked by study participants.

Overall, this study indicated that issues of policy wording and improvements in monitoring were universal across jurisdictions. Both of these issues have been identified in the literature for over two decade in relation to EIA (e.g., Dibo et al., 2018; Foley et al., 2017; Therivel and Ross, 2007; Treweek, 1996), making them persistent as well as widespread across jurisdictions.

Where jurisdictions showed divergence, lower-level jurisdictions appeared to be more challenged by practical implementation issues, resourcing, and socio-economic influences, such as details of EIA contracts or terms of reference, institutional resources, and changing government priorities. This suggests that the local-to-provincial level may be closer to and more affected by social and economic influences and on-the-ground implementation than the higher federal level. Participants at the federal level, on the other hand, ranked the disconnect between scientific theory and practice and lack of knowledge of ecological thresholds as highly important, suggesting that at this level practitioners are grappling with broader questions and ambiguities around the application of landscape approaches in EIA. At this higher jurisdictional level the minutia of daily EIA implementation may be of lesser relative importance.

The intermediate provincial level may suffer from challenges at both ends of this spectrum of issues: while provincial participants ranked the practicalities of high importance like the local participants, they also ranked challenges of vague EIA terminology and concepts and knowledge of ecological thresholds as highly important like their federal counterparts. They also struggled with applying landscape approaches and analysis to the full life-cycle of EIA, including management and monitoring of mitigation outside of the immediate project setting. Overall, provincial participants ranked the greatest number of challenges as highly important, including issues common to both lower and higher jurisdictional levels.

While the data from this study suggest that the provincial level, as an intermediate-level jurisdiction, experiences the greatest challenges, an influencing factor is the overall political context in which the practitioners interviewed at the different jurisdictional levels were operating. At the time of the interviews, federal (Canada) and provincial (Ontario) governments were held by two different political parties that differed markedly in their approach to the regulation of development, including EIA processes. The provincial government of the time was focused on opening the Province for business, de-emphasizing the scope and importance of environmental reviews (e.g., Keil and Üçoğlu, 2021). It is not clear from the current study, therefore, to what extent the high importance placed on so many challenges by provincial participants was a result of the intermediate-level jurisdiction in which they operated, or the political climate and direction of the time.

The divergence between jurisdictions with respect to practical and more theoretical issues also suggests that differences in the connection between EIA practitioners and the biophysical and socio-economic environment they regulate may play a role in how participants perceived the challenges of implementing broader-scale approaches. For example, EIA practitioners working at lower jurisdictional levels may have a greater physical and social connection to the environments and social systems affected by project and EIA outcomes. Particularly at the local level, practitioners tend to live and work in the communities subject to local EIA within their purview. On the other hand, federal EIA practitioners may have a much more abstract connection with their work, often living in an entirely different part of the country from where a federal EIA may be taking place. Thus practical and socio-economic challenges and opportunities may be of greater immediate importance to lower jurisdictional levels, while more abstract questions of theory and practice may be more important at higher levels.

Additionally, issues of boundaries between jurisdictions were a greater challenge to lower-level jurisdictions, supporting the idea that higher-level jurisdictions may be better placed to support landscape and broader-level assessments that cross lower-level jurisdictional boundaries. There may be a role here for co-management structures, or bridging organizations as suggested by Cash et al. (2006), as conscious boundary management that includes cross-level interactions across scale-related boundaries.

This examination of jurisdictional differences in priority areas represents a new angle on the issues identified in EIA, and offers a more targeted understanding of where opportunities may be applied most successfully to advance landscape analysis in EIA.

5.5 Conclusion

This study confirms that issues that have plagued EIA overall are also of concern when it comes to advancing landscape and broader-scale analysis in EIA. It can feel discouraging that many of these challenges have been reiterated in the literature for over two decades. At the same time, there are areas where progress appears to have been made, as identified by lower priority challenge areas such as technical uncertainties around analysis tools and methods, and other issues of implementation. The current study additionally offers a new angle on old challenges, in the identification of priority areas and in offering a targeted understanding of opportunities at different jurisdictional levels.

This study supports that a lack of science alone is not at the root of the disconnect between landscape analysis and EIA practice in Ontario, Canada. Priority challenges for landscape analysis in EIA as identified and ranked by practitioners include a lack of policy and guidance specific to landscape-based approaches, and lack of multi-level policy support for these approaches, particularly at lower jurisdictional levels. Weak data and data management systems were also highly challenging, again especially at lower jurisdictional levels. The one area of science identified as a priority challenge was the lack of knowledge of ecological thresholds, which higher-level jurisdictions found particularly difficult. This suggests a valuable area of focus for future interdisciplinary work between landscape ecologists and the EIA community as well as local and Indigenous communities. In the meantime, greater clarity around assumptions and knowledge gaps and better disclosure of uncertainty can help with transparency and better informing the decision-making process. The current study lends support and urgency to the calls for improvements in these areas if landscape analysis and broader-scale approaches are also to be part of more effective EIA.

Key opportunity areas were also identified in the current study that can help bridge gaps between landscape analysis and EIA practice. These include a renewed emphasis on strengthening policy language across all jurisdictions to support broader-scale analysis and assessment approaches. There is also an opportunity for what participants called 'big picture planning', integrating EIA with broader conservation strategies and regional planning. The study also reinforces calls for better long-term monitoring of EIA outcomes, noted as important across jurisdictions. Robust long-term monitoring and follow-up studies can help close ecological knowledge gaps, and form a foundation for multi-jurisdictional data systems to support analyses of monitoring results. At lower jurisdictional levels where practical issues were more of a challenge, there are opportunities to leverage partnerships, integrate available tools, and clarify wording in EIA contracts and terms of reference. Higher jurisdictional levels may be better placed to support multi-level co-management structures or bridging organizations to help with boundary issues experienced at lower jurisdictional levels. Targeting opportunities at the appropriate jurisdictional level will be important to overcoming challenges with landscape analysis in EIA.

There is a bottom-up school of thought on policy implementation that holds that the beliefs, behaviours and actions of practitioners responsible for implementing policy are arguably more important in shaping policy as the political leaders who designed it (Arnold, 2014). Focusing on the opportunity areas identified by EIA practitioners can thus help shape policy in ways that bridge landscape science and EIA practice, improving the quality of biodiversity assessments in project EIA and promoting better-informed decision-making.

Chapter 6: Landscape Analysis in Project Decision-Making: A Spatial Modelling Experiment of Cumulative Decisions and Biodiversity

6.1 Introduction

The prevention of further biodiversity loss is an increasingly important goal for environmental management (Laurila-Pant et al., 2015). Biodiversity is in severe decline, attributed in a large part to land use change and associated habitat loss and alteration (MEA, 2005). Environmental managers therefore have an important role in guiding decisions and actions that collectively satisfy multiple legitimate and sometimes competing societal goals (Reed, 2013).

Environmental impact assessment (EIA) is a well-established tool facilitating ongoing environmental management (Bailey, 1997; Hanna and Noble, 2015; Morgan, 2012). EIA aims to evaluate consequences of proposed development and land use change on environmental attributes such as biodiversity in advance of project decision-making (Dalloz et al., 2017; Hanna and Noble, 2015; Igondova et al., 2016; Jaeger, 2015; Noble, 2015). EIA can influence management decisions through the rejection of a proposed development activity, identification of and commitment to particular mitigation measures, and discouragement of environmentally detrimental proposals (Hanna and Noble, 2015; Pope et al., 2013). Effective EIA can thus achieve more environmentally sound development and planning decisions than could be achieved without it (Hanna and Noble, 2015).

However, there are important gaps in the information typically provided to decision-makers through EIA. Project EIA is typically conducted at the local scale (Jaeger, 2015), while changes in biodiversity are often driven by land use changes at the landscape to regional scales (Balfors et al., 2010; Botequilha Leitão and Ahern, 2002; also see Chapter 2). Omitting how local land use changes impact the ability of the broader landscape to support biodiversity routinely underestimates the consequences of a project on regional biodiversity (Bergès et al., 2020; Gontier, 2006; Harker et al., 2021).

Landscape structure – composition and configuration – is critical to the persistence of biodiversity (Botequilha Leitão and Ahern, 2002; Forman, 1995a; McGarigal and Marks, 1995; Wiens, 2002). Landscape composition considers both the amount of suitable habitat in a landscape as well as its diversity, including abundance and evenness of habitat types. While habitat amount is important in supporting biodiversity (Andrén, 1994; Fahrig, 2003, 2001, 1997; Gagné et al., 2015; Leroux et al., 2017), a diversity of habitats is required to sustain different elements of biodiversity and fulfill life history requirements for those species requiring multiple habitat types (Gagné et al., 2015). The ability of a landscape to support biodiversity is also influenced by the spatial configuration of habitat (Beier and Noss, 1998; Bennett, 2003; Botequilha Leitão and Ahern, 2002; Forman, 1995b; Forman and Godron, 1986), including the size and shape of individual patches (Ewers and Didham, 2006; Walz and Syrbe, 2013) as well as the connectivity of habitats across the landscape (Auffret et al., 2015; Koen et al., 2014; Tischendorf and Fahrig, 2000). In this way, a local development project is likely to impact biodiversity in the broader landscape as it can alter species movement and fluxes between habitat patches (Bergès et al., 2020). The extent to which the project alters the landscape for biodiversity, however, may depend on the location of the project within the landscape and how habitat composition and configuration are affected (Harker et al., 2021). These aspects are not commonly considered in typical EIA (Gontier et al., 2006; Jaeger, 2015; Karlson et al., 2014; Karlson and Mörtberg, 2015; Scolozzi and Geneletti, 2012; Seiler and Eriksson, 1997), and would therefore be missed in project decision-making.

While it is argued by some that broader scale issues like biodiversity assessment are better evaluated as part of cumulative effects assessments (CEA; Schultz, 2010; Therivel and Ross, 2007) conducted within regional or strategic assessment processes (Dibo et al., 2018; Duinker and Greig, 2006; Jaeger, 2015), current processes for development approvals are tied to project-based EIA and therefore the ability to conduct better biodiversity assessments within project EIA remains important (Duinker et al., 2013). The cumulative impact of multiple individual project decisions altering the landscape over time can have important consequences for the ability of the landscape to support regional biodiversity (e.g., Raiter et al., 2017). The ability, therefore, to consider landscape-based biodiversity information in project EIA is highly relevant.

Biodiversity's complexity and the interactions within landscapes, however, pose considerable challenges for factoring landscape-based biodiversity assessment into EIA. Suggested reasons for the omission of such assessment in EIA include prohibitive data requirements and the complexity of ecological models at broader scales (Botequilha

Leitão and Ahern, 2002; Gagné et al., 2015; Gontier, 2006). For example, several recommended methods include the use of focal species with which to evaluate landscape composition and configuration (e.g., Bergès et al., 2020); however, this requires expert knowledge of species-specific information. Individual species data and expert interpretation can be resource-prohibitive for lower-budget projects, or projects that cover large spatial extents for which species-specific data are often costly and time-consuming to collect (Dalloz et al., 2017; Gagné et al., 2015). On the other hand, high-quality geographic information systems (GIS) data including land use and land cover are becoming easier to obtain through publicly available sources (Harker et al., 2021). Increasingly accessible methods include relating amount and configuration of habitat calculated within a GIS-based environment to known ecological targets and thresholds (Byron, 1999; Gontier, 2006). This strategy offers a window into a possible approach using landscape analysis to inform project decision-making on biodiversity impacts.

Landscape analysis refers to the use of analytical tools and methods to characterize landscape structure and habitat change (Farina, 2006). It is derived from the discipline of landscape ecology, which studies the relation between landscape pattern and ecosystem processes, such as the dynamics that maintain biodiversity (Balfors et al., 2010; Forman, 1995a; Forman and Godron, 1986; McGarigal and Marks, 1995; Wiens, 2002). Based on this body of theory, landscape analysis provides a means to quantify the composition and configuration of landscapes and the habitat they provide, and the possibility to incorporate such knowledge into planning and assessment (Botequilha Leitão and Ahern, 2002).

This paper focuses on the potential use of landscape analysis as a vector for incorporating biodiversity assessment into project decision-making, and potential repercussions for cumulative impacts on regional biodiversity over medium to longer time periods. The objectives of the paper are twofold: to (1) introduce a technically feasible way in which landscape analysis might be used to support biodiversity assessments in project decision-making, and (2) examine the potential relevance, strengths and limitations of the approach in a cumulative project development setting, in which different possible project development and decision-making scenarios were modelled. The paper thus seeks a technically feasible and accessible way to bridge the gap between project-scale assessment and regional biodiversity persistence by using landscape analysis to inform how local land use changes might impact the ability of the broader landscape to support biodiversity. This bridging can aid both EIA practitioners, in providing decision-making support, and environmental managers, in setting the broader EIA policy and direction, to better guide project decision makers with respect to regional biodiversity.

The paper begins with defining the scope of an illustration region and selected biodiversity parameters for the technical evaluation. It then dives into its first objective: introducing the reader to a landscape analysis approach that could be used to inform project decision-making, using existing science, data, and tools. The subsequent sections are devoted to addressing the paper's second objective, outlining the methods and presenting the results of a spatial modelling experiment designed to test the landscape analysis approach to decision-making against other alternative decision-making and development approaches. The experiment is facilitated using a scenario-based, spatially-explicit model to approximate cumulative project decision-making with respect to computer-generated proposed land use projects within the case study area. The discussion in the penultimate section of the paper explores the performance of the modelled scenarios in terms of how the decision-making and development approaches, including those informed by landscape analysis, influenced landscape change trajectories and associated implications for regional biodiversity. It also identifies strengths and limitations of the landscape analysis approach introduced in 6.3, while recognizing some necessary limitations of the illustration model and presenting ideas for future refinements. The paper's conclusion describes how the findings presented can help to bridge the gaps between our understanding of landscape-mediated biodiversity loss and its evaluation in project decision processes.

6.2 Scope and Illustration Area

Like many "proof of concept" experiments, this research employs an illustration region to explore the viability and practicality of making the transition from conceptual framework to actual application. Key criteria informing the choice of illustration area included variability in landscape and habitat characteristics over a substantial land area, current and future development pressures, defined multi-level land use decision-making processes, and readily available and accessible data. The first three criteria span a breadth of major challenges associated with biodiversity assessment in EIA, while the fourth facilitates exploration of the overall approach in this experimental setting.

These selection criteria are met within the three most easterly census divisions in Ontario, Canada, namely Prescott-Russell (PR), Stormont-Dundas-Glengarry (SDG) and the City of Ottawa, collectively referred to as Eastern Ontario for the remainder of this study (Figure 7). This roughly triangularly shaped region covers approximately 8400 km^2 and is a predominantly agricultural area with one major city (Ottawa) and several smaller population centres. Two major waterways, the St. Lawrence River that forms the international boundary between Canada and the USA and the Ottawa River that forms the interprovincial boundary between Ontario and Quebec, form the northern and southern boundaries. The more rural counties of Renfrew, Lanark, and Leeds-Grenville bound the region to the west, with rural Quebec to the region's east. The region encompasses four major watersheds: the Mississippi, Rideau, South Nation, and Upper St. Lawrence (Figure 7). A fifth watershed, the Madawaska, just borders the northwestern corner of the study area. Each of the four major watersheds falls under the jurisdiction of a conservation authority, which acts alongside municipal and provincial actors to define appropriate land use guidelines.

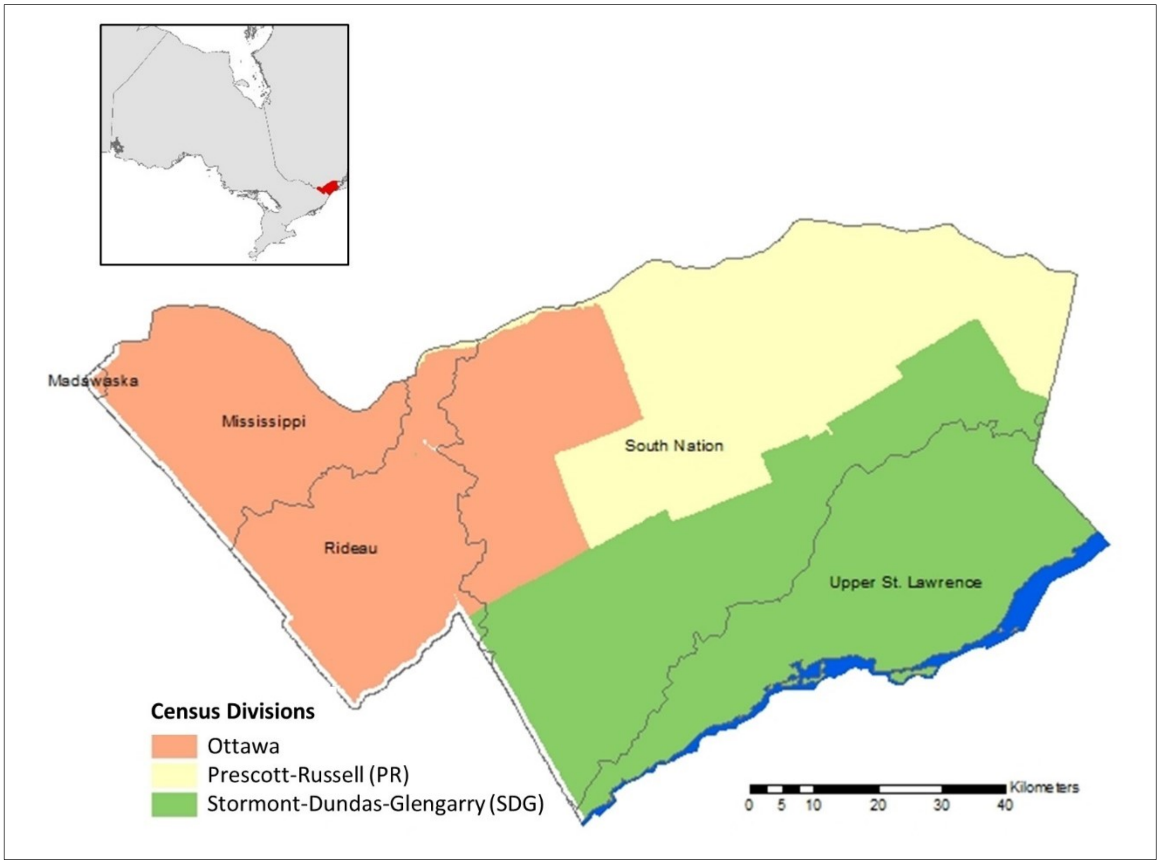


Figure 7. The Eastern Ontario study area, showing watersheds and census divisions

Land use decisions are made primarily by local (municipal) agencies, hence the illustration area is defined using administrative rather than ecological boundaries, which is consistent with the study objectives. Environmental planning and management in the region is a complex process involving multiple actors (e.g., government agencies, watershed authorities) across several levels of government (i.e., municipal, provincial, federal). This level of complexity is typical of many areas of Canada, where project-level EIA is well established but regional level EIA that considers broader interacting issues remains underdeveloped (City of Ottawa, 2015; Graci, 2009; Hanna, 2009; Noble, 2015).

Eastern Ontario forms part of the St. Lawrence Lowlands Ecoregion, within the Mixedwoods Plains Ecozone, notable for its high endemic species richness and high degree of threats to that biodiversity primarily arising from conversion of natural habitats to agriculture and urban areas (Kraus and Hebb, 2020). The region contains an intermediate amount and patchy structure of remnant habitats, factors which make the configuration of remaining habitat in the landscape increasingly important for biodiversity (Andrén, 1994; Crouzeilles et al., 2014; Estavillo et al., 2013; Fahrig, 1997; Freemark et al., 2002). Major habitat types sprinkled throughout the region include remnant forests, grasslands, and wetlands, accounting for 34% of the region's land area and supporting a disproportionate amount of diversity as compared to urban environments and active farmland (Neave et al., 2000; Turrini and Knop, 2015). Throughout this paper, emphasis is placed on forest, grassland, and wetland habitat for their contribution to biodiversity persistence in the region. Like the rest of the province, loss of habitat is among the top threats to biodiversity (OBC, 2012). Development pressures in the region are driven by expanding population base and associated urban expansion and natural resource demands (Waldick et al., 2017), and where poorly planned development can lead to loss of prime agricultural land and the loss, alteration and fragmentation of natural habitats with associated biodiversity impacts (OBC, 2012).

Importantly for illustration purposes, Eastern Ontario is relatively data rich, with ready access to many data types including soils, land use, and 25-year projections for population growth and economic development, which all aid in scenario development and land use modelling. Defining and determining the biodiversity of the region at a specific time, however, remains a challenge.

As biodiversity is such a multi-faceted and complex concept (see Section 2.1), scoping the study also required defining and parameterizing biodiversity. Assessing biodiversity does not involve a straightforward, single-parameter measurement, rather it must be done through the use of a carefully selected array of indicators (Duelli and Obrist, 2003; MEA, 2005; Noss, 1990; Purvis and Hector, 2000). Ecological relevance, sensitivity to the type and scale of land use changes examined, simplicity and data availability guided the choice of indicators for the purpose of this study, and led to the selection of landscape-based habitat indicators to represent regional biodiversity. Landscape-based habitat indicators take their relevance from the ecological connection between habitats and the diversity of ecosystems, species, and genes they represent (Bunce et al., 2013; Walz and Syrbe, 2013), acting as a surrogate for measures such as species richness (Billeter et al., 2008; Morelli et al., 2018; Schindler et al., 2015) that can show greater sensitivity (e.g., White et al., 1997) and is more accessible and less data-intensive than individual species-based approaches especially over large spatial areas (García-Llamas et al., 2018; Morelli et al., 2018; Schindler et al., 2008). Further detail on the selection of biodiversity indicators for this study is provided in Appendix C.

Collectively these scoping considerations allow for a realistic exploration of the current potential for landscape analysis to support biodiversity assessment in project decision-making and to test its technical feasibility within a scenario-based analysis at a regional scale.

6.3 Landscape Analysis for Project Decision-Making

Landscape analysis shows considerable potential to inform decision-making with respect to biodiversity considerations due to its accessibility, availability of data and tools and relatively lower resource requirements as compared with species-specific data and modelling (Harker et al., 2021; Schindler et al., 2008). One feasible approach to landscape analysis would be to calculate a set of landscape metrics using land use/land cover data (LULC) and compare the results against relevant landscape-based habitat guidelines and thresholds, derived from a review of best available science. For Eastern Ontario, a review of this kind has already been conducted by Environment Canada and compiled in a publicly available document that summarizes habitat guidelines related to forest, grassland, wetland and riparian habitats applicable to Ontario ecoregions (EC, 2013). While there are acknowledged limitations to this document, such as the generality of the guidance across regions and species, it is nonetheless a useful tool in providing science-based information and guidelines relating biodiversity to landscape and habitat composition and configuration.

This landscape analysis case study employs quantitative analysis targets for landscape composition and configuration in relation to the major habitat types in the Eastern Ontario illustration area (Table 17). These included three targets for landscape composition (related to wetland, riparian/watershed and forest habitat) and four targets for landscape configuration (related to wetland, riparian/watershed and grassland habitat). These targets capture a representative cross-section of habitat types present in the study area and use measurable landscape parameters, thus supporting biodiversity assessment with simple but relevant measures. Again, these targets do not represent thoroughly tested thresholds, but characterize a reasonable approximation of habitat-based requirements to reduce or minimize impacts of habitat loss and changes in configuration on regional species diversity.

Table 17. Selected habitat guidelines and corresponding landscape analysis targets

Landscape Metric	Habitat-based Guidelines for Biodiversity[1]	Landscape Analysis Targets
LANDSCAPE COMPOSITION		
Percent wetlands in the watershed	Ensure no net loss of wetland area, and focus on maintaining and restoring wetland functions at a watershed and subwatershed scale based on historic reference conditions. At a minimum, the greater of (a) 10% of each major watershed and 6% of each subwatershed, or (b) 40% of the historic watershed wetland coverage, should be protected and restored.	At least 10% wetland cover in each watershed
Percent of an urbanizing watershed that is impervious	Urbanizing watersheds should maintain less than 10% impervious land cover in order to preserve the abundance and biodiversity of aquatic species. Significant impairment in stream water quality and quantity is highly likely above 10% impervious land cover and can often begin before this threshold is reached. In urban systems that are already degraded, a second threshold is likely reached at the 25 to 30% level.	No more than 10% impervious cover in each watershed

Landscape Metric	Habitat-based Guidelines for Biodiversity[1]	Landscape Analysis Targets
Percent forest cover	At least 30% forest cover at the watershed scale is the minimum forest cover threshold. This equates to a high-risk approach that may only support less than one half of the potential species richness, and marginally healthy aquatic systems; At least 40% forest cover at the watershed scale equates to a medium-risk approach that is likely to support more than one half of the potential species richness, and moderately healthy aquatic systems; At least 50% forest cover or more at the watershed scale equates to a low-risk approach that is likely to support most of the potential species, and healthy aquatic systems.	No less than 40% forest cover in each watershed
LANDSCAPE CONFIGURATION		
Wetland proximity	Wetlands that are in close proximity to each other, based on their functions, or that are in close proximity to other natural features, should be given a high priority in terms of landscape planning.	Groups of wetlands within 200 m of each other remain undeveloped
Percent of stream length naturally vegetated	At least 75% of stream length should be naturally vegetated.	At least 75% of lands adjacent to 1st to 3rd order streams remain undeveloped
Grassland patch size	Maintain and create small and large grassland patches in existing and potential local grassland landscapes, with an average grassland patch area of greater than or equal to 50 hectares and at least one 100-hectare patch.	Grassland patches of >=50 ha remain undeveloped
Grassland connectivity	Grassland habitat patches should be clustered or aggregated, and any intervening land cover should be open or semi-open in order to be permeable to species movement.	Land cover between grassland patches within 1 km of each other remain in open or semi-open land cover (rangeland or pasture)

[1]Habitat guidelines and landscape analysis targets are derived from EC (2013)

While EC (2013) includes several additional habitat-based guidelines beyond these seven, those that were qualitative or related more to management practices than spatial composition and configuration were omitted for the purposes of this study.

6.4 Methods: Designing a Spatial Modelling Experiment

In this illustration, scenario-based modelling analyses are employed to extend assessments of individual projects and focus on cumulative regional biodiversity impacts over medium timelines. The remainder of Section 6.4 presents the model's structure, components and data inputs, then summarizes the biodiversity indicators used to analyze regional biodiversity trends, and concludes with the specification of scenarios used in the model.

6.4.1 Model Structure

The conceptual framework for the spatial modelling experiment is illustrated in Figure 8.

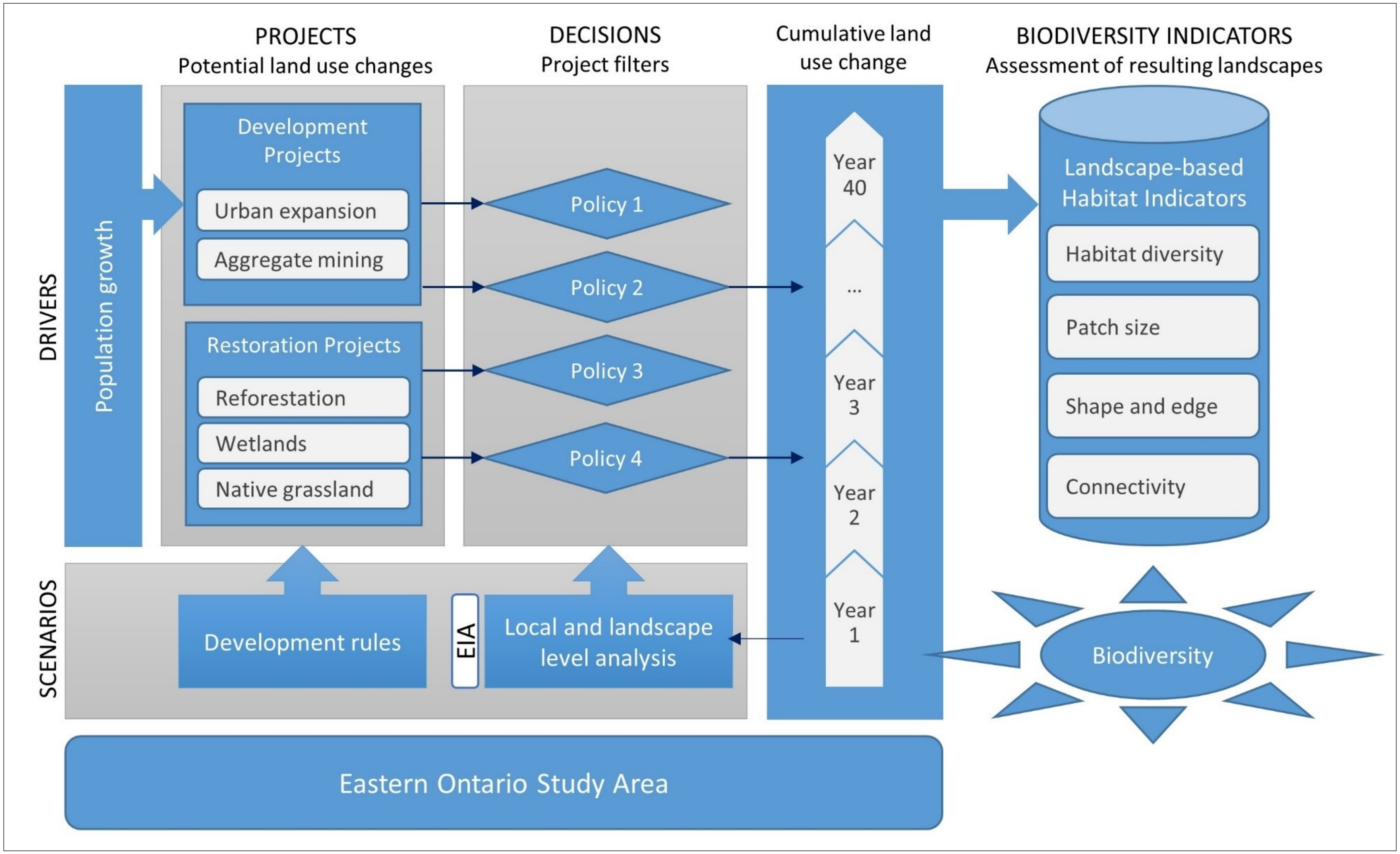


Figure 8. Conceptual framework for the scenario-based spatial modelling experiment

Projects, representing potential initiators of land use change if approved and built, are shown at the top left of the diagram. Project types were tailored to the actual drivers of change occurring in Eastern Ontario, primarily population growth. Projects included development projects, illustrative of habitat loss in the region, and small-scale habitat restoration projects initiated by watershed conservation authorities, illustrative of habitat creation. Projects were designed to be auto-generated by the computer simulation in locations corresponding to criteria defined in the scenarios (development rules; described further in Section 6.4.3).

Before a project could be translated into land use change in the model, it was subject to a decision-making process, represented by the top-centre box in Figure 8. Decision-making policies were defined by scenario and acted as filters, whereby certain projects would be denied and others approved based on the impact that project would have on particular criteria considered by the decision-making agents in each scenario – including, for example, the landscape analysis targets introduced in Section 6.3 (Table 17). This process represented a simplification of EIA-informed decision-making, in that the only action simulated decision-makers could take was to approve or deny a project as proposed in a particular location; in the real world decision makers often consider a variety of potential mitigation measures and conditions of approval. If a project was denied, a new project would be proposed in an alternative location based on the project generation algorithms and the decision-making process would restart. Depending on the scenario, different local and landscape-level analyses informed the decision-making policies, simulating information provided to decision-makers through EIA.

This process of simulating project proposals, decision-making, and subsequent land use changes related to those projects that passed the decision filters was repeated on an annual basis over a 40-year period for each scenario, leading to cumulative changes to the regional landscape. This time period was chosen as the upper limit for projected population projections and growth trends as it allows sufficient time for several project development cycles to alter the landscapes while avoiding higher levels of uncertainty stemming from longer time periods (c.f. Jacobs et al., 2011; NRC, 2014). The model outputs – estimated future landscapes resulting from each 40-year scenario simulation – were then analyzed with respect to a set of landscape-based habitat indicators representing biodiversity (described further in 6.4.2).

A spatially-explicit agent-based modelling platform, Envision (Bolte, 2020), was chosen for this study. It is a predominantly bottom-up, stochastic framework, in which landscape changes emerge from the accumulation of individual actions or decisions taken by agents over a designated time period (Bolte, n.d.), which aligns with the purposes of the study to assess how cumulative individual project decisions taken over time impact the regional landscape and its ability to support biodiversity. Envision was selected due to its ability to integrate spatially-explicit models of landscape change, produce and analyze alternative future scenarios, and use customizable model plug-ins to simulate a variety of processes, decision criteria, and scenarios. Importantly, the platform is open-source, freely available and location independent (Bolte, n.d.), meaning the methods used here can be translated to other locations and scenarios for future applications and refinements of this experiment.

Envision represents the landscape as a GIS-based polygon coverage where each polygon is associated with several attributes such as LULC, population, zoning, environmental characteristics, and other relevant information. These attributes were populated from a variety of open-access data sources including Census of Canada data and the Land Information Ontario data repository maintained by the Ontario Ministry of Natural Resources and Forestry. Further technical details of the Envision model and its baseline data inputs are provided in Appendix D.

As species respond to landscape patchiness in different ways based on how they perceive their environment (e.g., Gontier, 2007; Kotliar and Wiens, 1990; see Section 2.2.1), two hierarchical levels of LULC were used in the model to represent a simple characterization of the hierarchical nature of patchiness in a landscape. This classification allowed for greater nuance in determining the effects of the scenarios on landscape structure and corresponding biodiversity indicators at both coarse and finer LULC levels.

LULC A represented the coarse level of land use definition and included eight broad categories: forest, grassland, wetland, annual cropland, perennial cropland, developed land, water, and other (bare ground and quarries/extraction sites) (Figure 9). LULC B represented the finer level that broke down the LULC A classes into individual forest, wetland, and crop types and pervious and impervious built-up areas (Table 18).

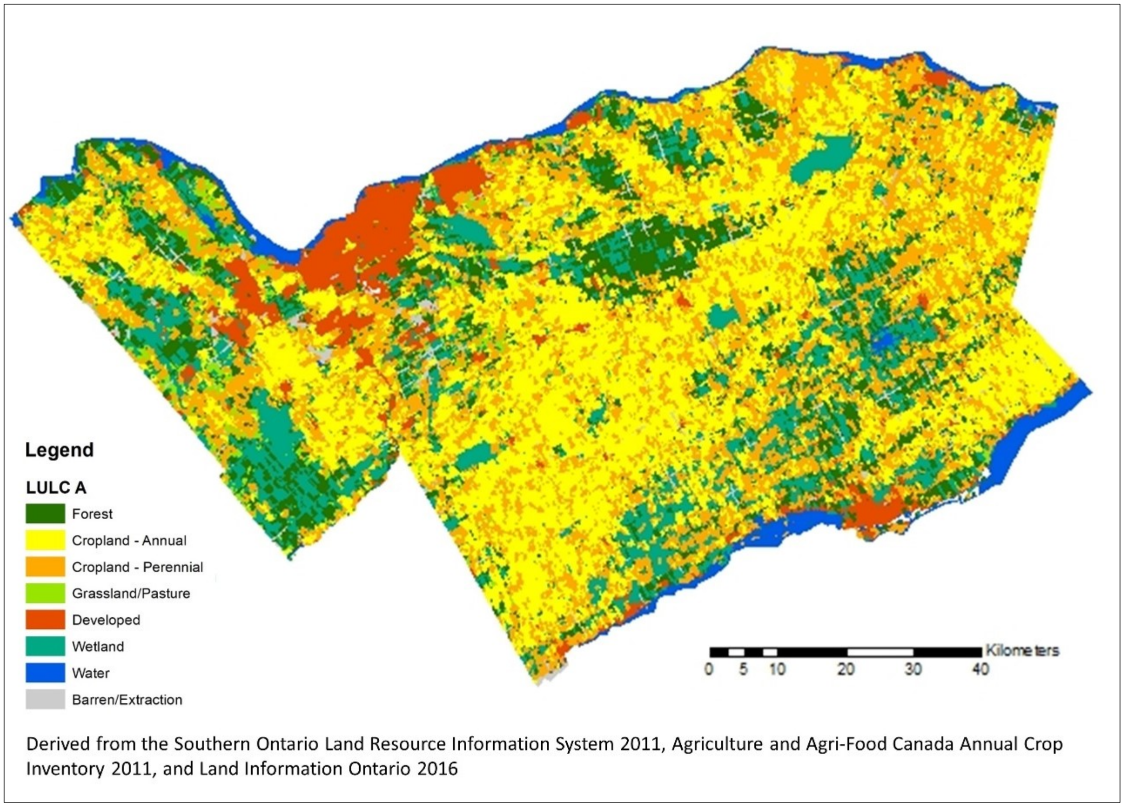


Figure 9. Coarse land cover (LULC A) in Eastern Ontario (2016)

Table 18. LULC in Eastern Ontario (2016)

Coarse Land Cover (LULC A)	Finer Land Cover (LULC B)			% of Study Area
Cropland - Annual	Corn Soybeans Wheat Barley Oats	Potatoes Other Vegetables Other Cereals Too Wet to be Seeded	Beans Peas Buckwheat Herbs	30%
Cropland - Perennial	Alfalfa	Fruits		22%
Forest	Coniferous Broadleaf	Mixed Forest	Hedgerows	17%
Wetland	Swamp Marsh	Bog Fen	Wetland / Undifferentiated	16%
Grassland/Pasture	Grassland	Pasture		5%
Developed	Built-Impervious Built-Pervious	Transportation	Urban / Undifferentiated	5%
Water	Open Water	Water / Undifferentiated		3%
Other / Unknown	Barren	Extraction	Unknown	1%

Derived from the Southern Ontario Land Resource Information System 2011, Agriculture and Agri-Food Canada Annual Crop Inventory 2011, and Land Information Ontario 2016

Comparing the 2016 LULC (Table 18) to the landscape analysis targets in Table 17, one can see that forest cover across the illustration area is considerably below the 40% target; however, wetlands currently cover 16% of the landscape which is greater than the 10% minimum target specified in Table 17. While this comparison is at the level of the entire study area, and not broken down by watershed as specified in the landscape analysis targets in Table 17, these land use classes are relatively well distributed across the study area in Figure 9 and therefore the percentages are assumed to be in a similar range for each of the four study area watersheds (Figure 7). This suggests that forest biodiversity is currently at greater risk in Eastern Ontario relative to wetland biodiversity.

6.4.2 Biodiversity Indicators

Based on the need to balance the criteria of simplicity, sensitivity, and ecological relevance as scoped in Section 6.2, a set of landscape-based habitat indicators was chosen for the current study (Table 19). A set of indicators is recommended over an individual measure in order to reveal distinct aspects of landscape and its processes that contribute to biodiversity (Betts, 2000; Botequilha Leitão and Ahern, 2002). While there are hundreds of landscape metrics available to indicate habitat structure and its associations with biodiversity, many of these are highly correlated with each other which can lead to false results and interpretations if multiple correlated metrics are used to characterize a landscape (Botequilha Leitão and Ahern, 2002; Inkoom et al., 2018; Schindler et al., 2008). The indicators and metrics in Table 19 were therefore selected for their statistical independence of each other (e.g., Inkoom et al., 2018; Riitters et al., 1995; Schindler et al., 2008) as well as their recommendation by several authors for their relevance to biodiversity in spatial planning. All these measures can be easily evaluated in the GIS software ArcGIS (ESRI, 2018) using the free extensions Patch Analyst (Rempel et al., 2012) and V-LATE (Vector-based Landscape Analysis Tool Extension; Tiede, 2004).

Table 19. Selected landscape-based habitat indicators for scenario evaluation

Indicator	Metric	Relationship to Biodiversity	Examples
Habitat diversity	Shannon's Diversity Index (SDI)	SDI is a relative measure of diversity based on the ratio of the number of habitat types (richness) and their proportional area distribution (evenness) (Frank et al., 2012; Wrbka et al., 2004). SDI is equal to zero with only one patch in the landscape and increases with increasing habitat richness and evenness (McGarigal and Marks, 1995). Greater diversity of habitat types tends to increase species diversity (Fahrig, 2001). This relationship also appears to be true in farmland settings (Alignier et al., 2020; Martin et al., 2020).	Alignier et al. (2020) García-Llamas et al. (2018) Ortega-Huerta and Kral (2007)
Patch size	Mean patch size (MPS)	Species and community diversity tends to increase with larger patch sizes (Freemark et al., 2002; Leroux et al., 2017). Often related to the amount of habitat in a landscape (Fahrig, 2003; Lockhart and Koper, 2018).	Inkoom et al. (2018)
Shape and edge	Mean landscape shape index (MSI)	MSI measures the complexity or compactness of the habitat (Frank et al., 2012) and reflects the amount of habitat edge relative to that of a maximally simple and compact shape (i.e., a circle) of the same area (Lockhart and Koper, 2018; McGarigal and Marks, 1995). MSI is equal to 1 when all habitat patches are circular in shape; otherwise, the more irregular the shapes, the larger the MSI value (Lockhart and Koper, 2018; Morelli et al., 2018). Shape metrics like MSI, in contrast to patch size metrics, generally have a weak correlation with habitat amount and can be suitable for distinguishing effects of habitat configuration separately from habitat amount (Lockhart and Koper, 2018). Less complex shapes (lower MSI) tend to increase the richness and abundance of habitat specialists and edge-sensitive species (Lockhart and Koper, 2018). These species are often the first to decline in human-modified landscapes.	Lockhart and Koper (2018) Walz (2015)
Connectivity	Effective mesh size (MESH)	Developed by Jaeger (2000), MESH is based on the probability that two randomly chosen points in a landscape are located within the same non-fragmented habitat patch, and represents the average size of the area that an individual placed randomly in the landscape can access without encountering a barrier (Girvetz et al., 2008). It represents an area of continuous suitable habitat unbroken by roads or other fragmentation geometries. Larger effective mesh size is associated with benefits for generalist species with large home ranges (Di Giulio et al., 2009; Roedenbeck and Köhler, 2006), and those sensitive to roads and similar dispersal barriers (Girvetz et al., 2007).	Inkoom et al. (2018) Wei et al. (2017) Walz (2015) Girvetz et al. (2008) Girvetz et al. (2007)

6.4.3 Experimental Scenarios

Five scenarios were designed and modelled in the spatial illustration. While exploring the inclusion of landscape analysis within project decision-making policies was a priority in designing the scenarios, a range of project development and decision-making policies were also modelled to allow for a wider comparative context. Scenario-based approaches are typically used to represent alternative and plausible future courses and consequences of action across a wide array of situations, leading to spatially-explicit representations of alternative land uses (Hulse et al., 2009) and helping to uncover landscape-level effects of planning and policy decisions (Santelmann et al., 2006). The purpose of these experimental scenarios was not to predict likely future trajectories for the study area, but to provide a tool with which to analyze how variations in project-level decisions (i.e., 'what if' scenarios) might affect future landscape structure and its ability to support regional biodiversity according to measurable indicators, and identify associated uncertainties (e.g., van Vuuren et al., 2012).

As introduced in Figure 8, the scenarios defined the development rules assigned to simulated projects and their locations, and the decision-making policies taken in filtering which projects would be approved and translate to land use change in each annual time step. The five scenarios were therefore designed to span two variables: (1) development concentration (i.e., dispersed to clustered), and (2) level of environmental regulation (i.e., from no restrictions on future land use to site-specific and landscape-based targets guiding future development decisions). Figure 10 plots the five scenarios with respect to these two variables. Scenarios (4) and (5), at the end of the environmental regulation axis where landscape-based targets guided decision-making, specifically included the landscape analysis targets introduced in Section 6.3 as criteria for decision-making.

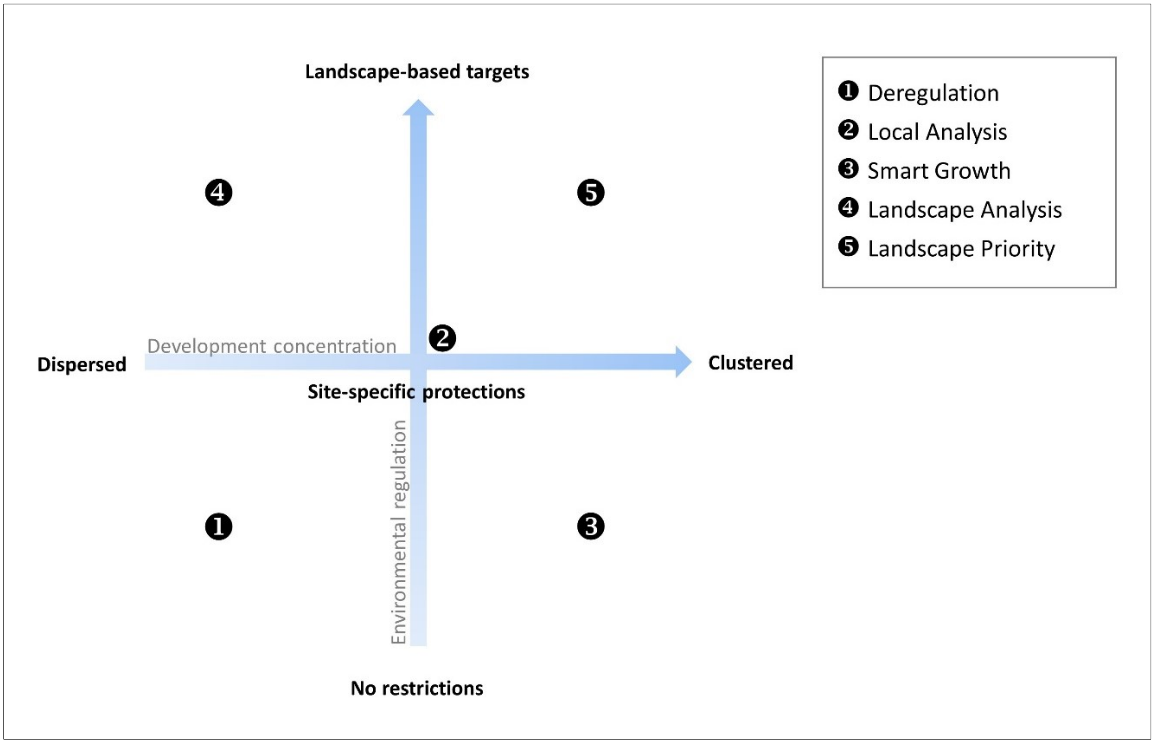


Figure 10. The five scenarios used in the spatial modelling experiment, plotted along two axes representing development concentration and environmental regulation

The types of proposed projects were common to all scenarios (see Section 6.4.1; Figure 8). Development projects included urban expansion and aggregate mining and were driven by population growth projections for the region derived from the Ontario Ministry of Finance Population Projections 2017-2041 reference scenario (Ontario Ministry of Finance, 2018). Projected population growth rates for each of the three census divisions making up the study area were calculated as a linear rate of increase, expressed as percentage of initial population per year: 1.42% for Ottawa, 0.58% for PR, and 0.08% for

SDG. Habitat restoration projects, on the other hand, were not contingent on population growth but based on static annual restoration targets put forward by local conservation authorities (Mississippi Valley Conservation Authority, personal communication, 6 September 2018; Rideau Valley Conservation Authority, pers. comm., 20 September 2018; South Nation Conservation Authority, pers. comm., 20 September 2018). The technical specifics of the development and restoration projects used in the model are detailed in Appendix D.

In each scenario, development rules and decision-making policies were applied to these projects. To add greater realism and an element of stochasticity to the model, the development rules and decision-making policies were weighted, meaning that the rule or policy would be applied less than 100% of the time. This setting captured real world cases in which a particular development might be permitted within an otherwise protected environmental feature despite the adverse environmental effects: circumstances in which, in EIA terms, a project might be considered by decision-makers to be justified under the circumstances. Rules and policies were either hard-weighted or soft-weighted (Table 20), meaning that the harder the policy weighting, the closer its application rate to 100% and the greater the importance placed on that policy in that scenario. The scenarios and their associated development rules and decision-making policies are detailed in Table 20.

Table 20. The five scenarios used in the spatial modelling experiment

Scenario Narratives	Development Rules	Decision-Making Policies
1. Deregulation No rules guided the location of proposed development in this laissez-faire scenario. Decision-makers were entirely hands-off; all proposed projects were implemented.	None	None
2. Local Analysis This scenario used an approximation of the current development concentrations in the study area. Decision-making was guided by site-specific protections informed by analysis of local attributes (e.g., City of Ottawa, 2015; Government of Ontario, 2014c, 2010; OMNR, 2010). This was the closest to a 'status quo' scenario.	Urban expansion soft-weighted towards existing population centres	Based on local-level analysis of environmentally significant features[1]
3. Smart Growth In this clustered growth scenario, proposed development was based on densification and clustered expansion. However, decision-makers were entirely hands-off and all proposed projects were implemented.	Urban expansion hard-weighted towards existing population centres	None
4. Landscape Analysis Development locations were unmanaged in this scenario. Decision-making policies were applied based on both site-specific protections and landscape-based targets, going beyond the status quo to set targets for habitat at a landscape level.	None	Based on local-level analysis of environmentally significant features[1] and landscape analysis[2]
5. Landscape Priority This scenario used both development rules and decision-making policies to guide and regulate land use change: development was based on densification and clustered expansion, while decision-making policies were based on both site-specific protections and landscape-based targets.	Urban expansion hard-weighted towards existing population centres	Based on local-level analysis of environmentally significant features[1] and landscape analysis[2]

Scenario Narratives	Development Rules	Decision-Making Policies

[1]Based on the IDU attributes where the project was proposed, policies limited the number of development projects permitted in provincially significant wetlands (PSWs), natural heritage system features – including Areas of Natural and Scientific Interest (ANSIs), significant woodlands/valley lands, and significant wildlife areas (OMNR, 2010) – and wildlife connectivity areas. Conversely, restoration projects had a greater likelihood of being actioned in or near PSWs, natural heritage system features, and wildlife connectivity areas.

[2]Based on the landscape analysis approach developed in Section 6.3, policies only permitted a development project to proceed in a proposed location if each landscape metric assessed remained within the landscape analysis targets described in Table 17. Additionally, restoration projects had a greater likelihood of being actioned if they contributed to Table 17's landscape analysis targets.

Each of the five scenarios was run ten times in Envision over a 40-year simulation period from 2016 to 2055. At the end of this time period, shapefiles of the resulting landscape were saved and exported into ArcGIS, where the regional biodiversity indicators were calculated using Patch Analyst (Rempel et al., 2012) and V-LATE (Tiede, 2004). Because landscape metrics have highly variable statistical distributions that depend on landscape composition, configuration and spatial autocorrelation (Remmel and Csillag, 2003), statistical tests of significance between the scenario outcomes would not be valid. Conclusions were therefore derived graphically by comparing relative differences between boxplots of the median value of the four indicators for the ten runs under each of the five scenarios.

To verify the differences between scenarios from a geostatistical perspective, the resulting landscapes for the five scenarios were compared with respect to their spatial autocorrelation (pattern of clustering of land use and habitat types) using Moran's *I*. A single-factor ANOVA was used to determine whether there were significant differences in spatial autocorrelation between the five scenarios. Where results showed a significant difference, a Tukey post-hoc test was used to determine which of the scenarios differed significantly from the others. While this test provided a quantitative assessment of landscape pattern and identified statistical differences in pattern between the scenarios, its relationship to biodiversity is as yet unclear (e.g., Biswas et al., 2021) and was used solely for model verification purposes to confirm spatial differences between scenario landscapes.

6.4.4 Aggregation of Results

Outputs from the spatial modelling experiment included boxplots comparing the resulting landscapes under the five scenarios for each of the four biodiversity indicators, at both coarse (LULC A) and fine (LULC B) habitat classification levels. Three of the indicators (patch size, shape and edge, and connectivity) depended on habitat type and are therefore each represented by three boxplots for each of the three primary habitat types in the study area – forest, grassland, and wetland. The fourth indicator, habitat diversity, is a landscape-level indicator that considers the abundance and evenness of all three primary habitat types together and is therefore represented by a single boxplot. In total, 20 boxplots were generated: 10 at the LULC A habitat classification level and 10 at the LULC B habitat classification level.

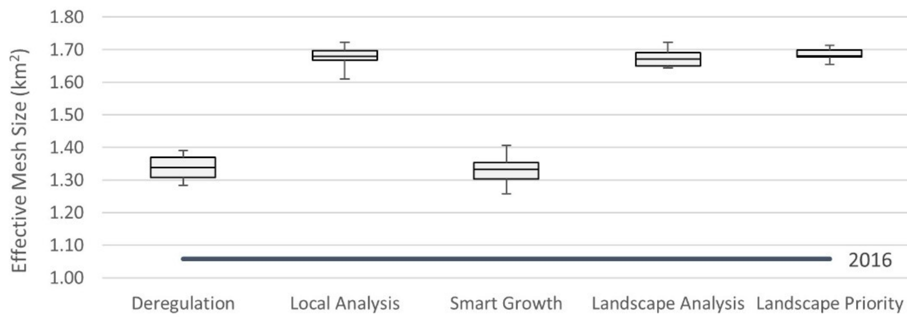
These boxplots represent a wealth of information that can facilitate better understanding of the regional implications for biodiversity under uncertain futures; however, this level of detail is also prone to information overload that could frustrate the utility of the approaches presented in this research. Hence the challenge was to retain the richness of information presented in the 20 boxplots while presenting these assessments in a format that is better aligned with the realities of applied EIA.

To do this, an indication of relative biodiversity trends between scenarios, including the direction and relative magnitude of change, was derived for each indicator based on a graphical analysis of boxplots of the median value of the associated metric calculated from the ten runs of each modelled scenario. The direction of the biodiversity trend, was based on the relationships of the indicators to regional biodiversity established in Table 19 (Section 6.4.2): the potential to support greater regional biodiversity was indicated by higher habitat diversity (higher SDI), larger patch sizes (higher MPS), more regular patch shapes with lower edge-to-interior ratios (lower MSI), and greater habitat connectivity (higher MESH).

Table 21 illustrates an example of the transition from detailed model outputs into a more user-friendly format. This transition also aligns with the overall purpose of employing scenario analyses, namely to conduct comparative assessments in trend changes in biodiversity indicators over a range of future scenarios rather than to provide firm, quantitative predictions of future biodiversity.

Table 21. From detailed boxplot to summary table: example of connectivity of forest habitat at a coarse classification level (LULC A)

Example Boxplot – Connectivity of Forest Habitat (LULC A)



Summary Table (see Section 6.5.2)

Scenario	Biodiversity Indicator by Habitat Type – Forest – Connectivity
Deregulation	
Local Analysis	
Smart Growth	
Landscape Analysis	
Landscape Priority	

Legend:

Direction and relative magnitude of change in the potential of the landscape to support regional biodiversity from 2016-2055 as suggested by the selected biodiversity indicators

Greater decrease
Decrease
No discernable change
Increase
Greater increase

The upper box in Table 21 presents detailed boxplot results for a single biodiversity indicator and habitat type (i.e., connectivity of forest habitat, as measured by the MESH metric) at the coarse (LULC A) habitat classification level under the five scenarios, with the 2016 baseline provided as a reference point. The lower box demonstrates how the boxplot information was compressed to show the direction and magnitude of the change in the biodiversity indicator for each scenario relative to the 2016 baseline. For the purposes of this research, magnitude was used in a relative sense, indicating where a scenario showed a comparatively greater magnitude of increase or decrease in biodiversity relative to the other scenarios (i.e., if the entire range of the boxplot and its error bars showed larger or smaller values of the metric relative to others). If the interquartile range of the boxplot and its error bars overlapped with the values of another scenario, they were assumed to have similar magnitudes of biodiversity change for that indicator. In this example boxplot, the y-axis is truncated in order to better observe the magnitude of the relative differences between scenarios, as these relative differences are the focus of the scenario evaluation rather than an absolute predictive measure.

These data compression techniques were applied to all 20 boxplots, resulting in the single summary table which is presented in Section 6.5.2.

6.5 Results

An example of a landscape analysis approach that could be used in project decision-making was introduced in Section 6.3 and tested as to its feasibility in the scenario-based spatial modelling experiment described in Section 6.4. Results of the modelling experiment are described below.

6.5.1 Model Verification and Landscape Change in the Scenarios

With processes of both habitat loss (development projects) and habitat creation (restoration projects) simulated in the scenarios, overall composition of the resulting landscapes changed only slightly over the 40-year period in each of the scenarios. The percentage of forested land in the region increased by 3-4% from 2016-2055 across all scenarios, as did the percentage of wetlands (<1% change), developed land (urban areas; <1% change) and barren/extraction (aggregate mining; <1% change). Cropland and grassland/pasture decreased by 1-2%. Differences in landscape composition at a coarse scale (LULC A) were minimal between the five scenarios at year 2055.

In contrast, landscape configuration, as measured by spatial autocorrelation (the degree to which landscape features are clustered or dispersed; Moran's *I*) showed significant differences over time and between scenarios ($F_{4,45}=8.15$, $p<0.001$). Spatial autocorrelation is important because it provides a quantitative descriptor of the patchiness of the landscape pattern and allows for a statistical comparison to be made between scenarios (Griffith, 1992). Verifying the scenario results with respect to these changes in spatial pattern provided validation that the scenarios led to significantly different landscape patterns, irrespective of the small changes in landscape composition and habitat amount.

In all scenarios, values for Moran's *I* were between 0.19 and 0.20, indicating a slightly clustered pattern of land use classes, and while the absolute differences are small in magnitude, it is important to note the significant relative differences between resulting landscapes. Post hoc comparisons using the Tukey HSD test indicated that the mean Moran's *I* for the ten runs of the Local Analysis (0.1989), Landscape Analysis (0.1985) and Landscape Priority (0.1986) scenarios were all significantly larger than that of the

Smart Growth scenario (0.1976). The mean Moran's *I* for the Local Analysis scenario was also significantly larger than that of the Deregulation scenario (0.1978) (Figure 11). All scenarios showed a higher Moran's *I* in 2055 compared to the 2016 baseline (0.1903). This analysis demonstrated differences in spatial pattern in which the Local Analysis, Landscape Analysis, and Landscape Priority scenarios all showed a similar degree of land use clustering as compared to the Deregulation and Smart Growth scenarios.

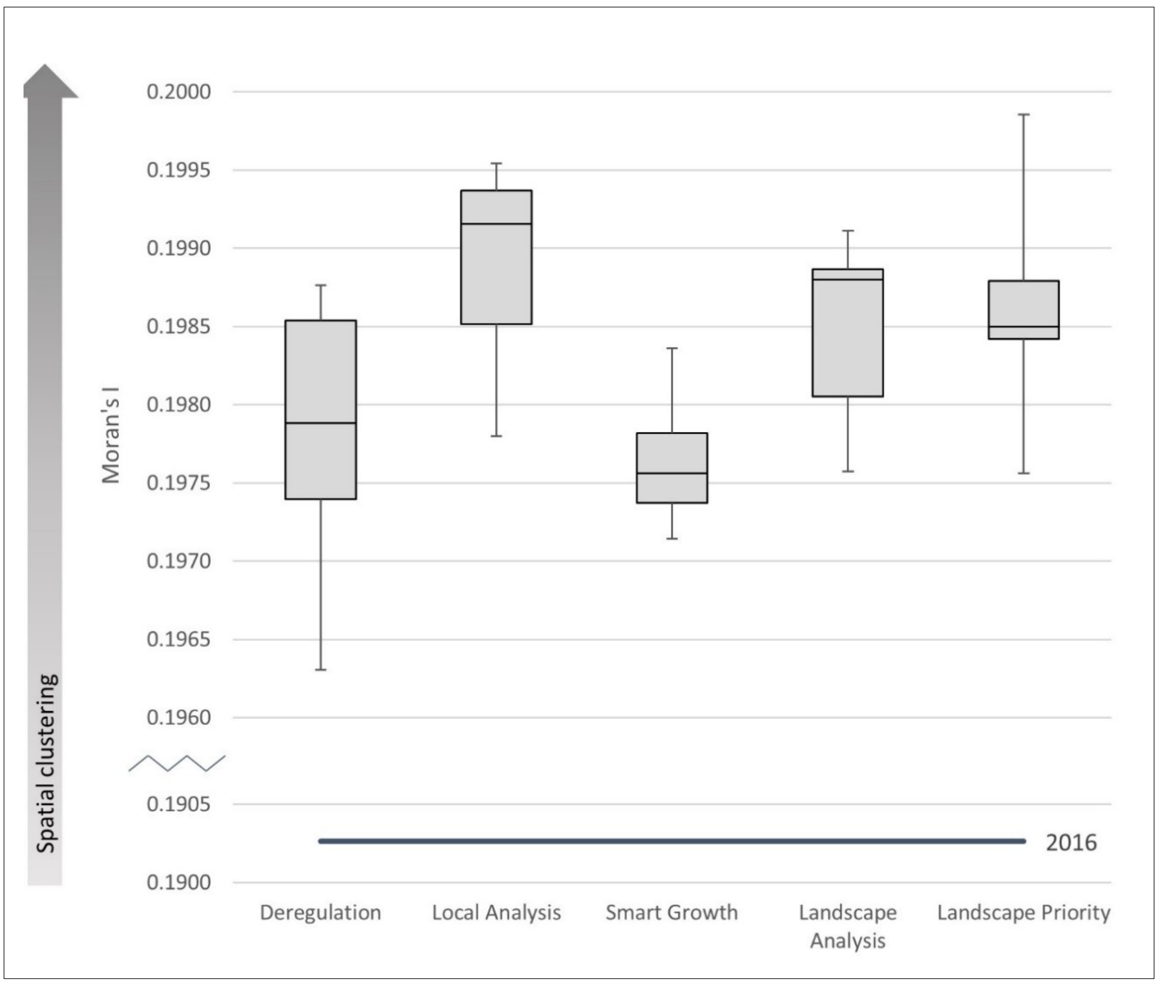


Figure 11. Impacts of modelled scenarios on landscape pattern

To illustrate an example of the land transformations that took place over the 40-year study period, Figure 12(a) to (f) magnifies a portion of the study area at the western edge of the City of Ottawa, which underwent both urban expansion and extension of aggregate mining areas as well as some limited habitat restoration during the five scenario simulations. The black circle in each of the images highlights an area of urban expansion that shows spatial differences in how LULC varied between scenarios. Both the Deregulation (Figure 12b) and Smart Growth (Figure 12d) scenarios show a larger block of urban growth within the black circle, where forest, grassland, and cropland were located in 2016 (Figure 12a). In both these scenarios, the urban lands are clustered, but with considerable urban encroachment onto the existing habitat patch of forest and wetlands to the northwest. In the Local Analysis scenario (Figure 12c), urban development can be seen in the centre of the black circle, replacing a patch of forest and perennial cropland. It is disconnected from the existing urban lands, however. At the same time, a small piece of forest was restored at the eastern end of the circle. Finally, in the Landscape Analysis (Figure 12e) and Landscape Priority (Figure 12f) scenarios, the forest and wetland complex to the northwest became the greater priority, and urban expansion was minimal in this area. Forest restoration also occurred in these scenarios, but this time on cropland and pasture adjacent to existing forest, increasing the size of the forest habitat patch. Impacts of these types of changes on the biodiversity indicators are examined in the following section.

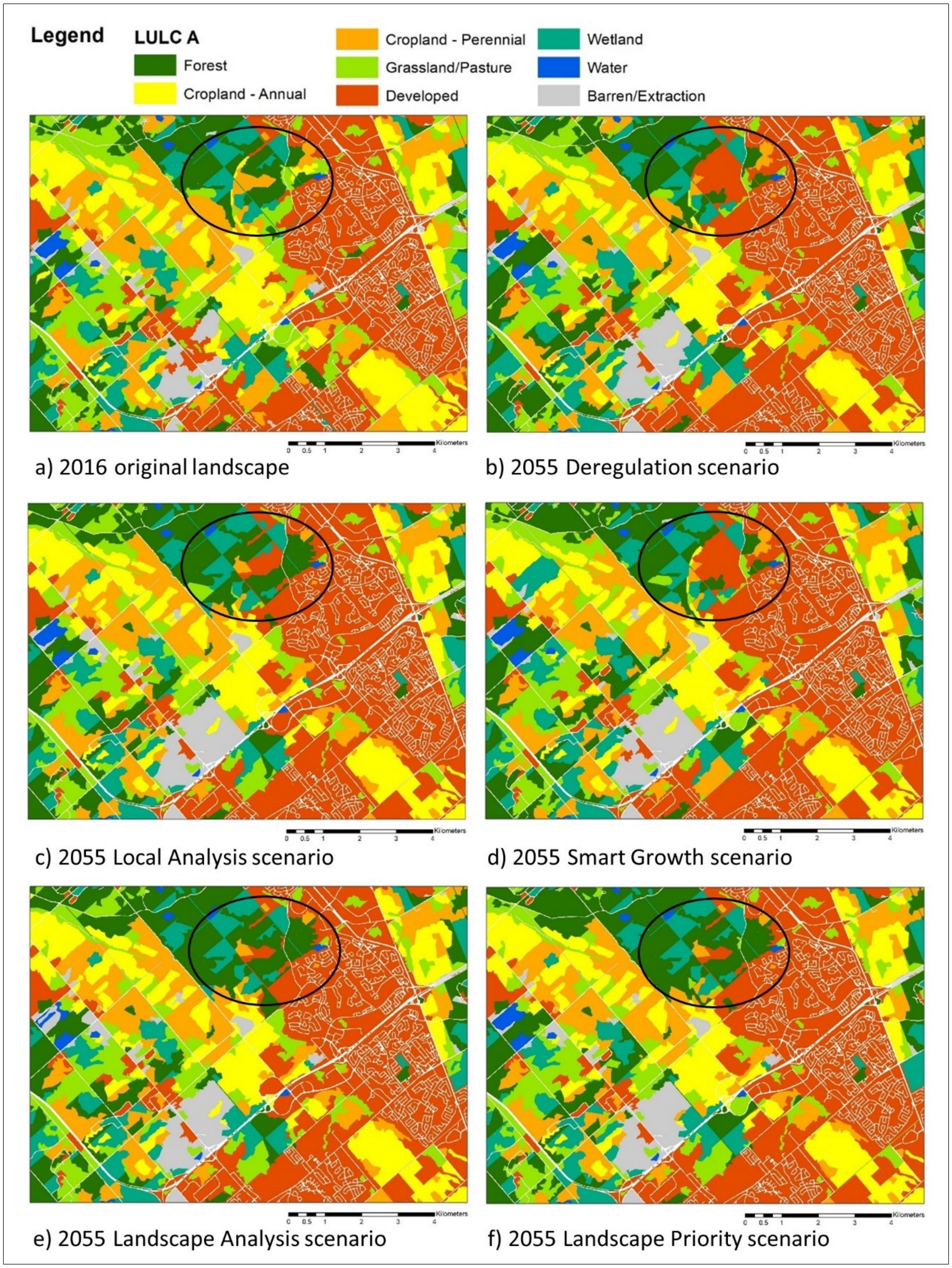


Figure 12. Spatial illustrations of a portion of the original and resulting landscapes under the five scenarios

6.5.2 Evaluation of Biodiversity Indicators

Changes in landscape structure in the scenarios were evaluated against the four selected biodiversity indicators, with results calculated for the three primary habitat types in the study area (forest, grassland and wetland) at both coarse (LULC A) and finer (LULC B) levels of habitat classification. Boxplots showing the median, interquartile range, and maximum and minimum values for each indicator were derived from running each scenario through the 40-year simulation ten times (see Section 6.4.3). As per Section 6.4.4, results were aggregated into a summary table indicating the estimated direction and relative magnitude of the estimated change in biodiversity for each indicator under each scenario (Table 22). The complete results including the boxplots for each indicator are provided in Appendix E.

Table 22. Estimated regional impacts of alternative development scenarios on selected biodiversity indicators (2016-2055)

Scenario	Level of Habitat Class. (LULC)	Regional Biodiversity Indicators (by Habitat Type where applicable)										Overall Trend
		Habitat Diversity	Forest			Grassland			Wetland			
			Patch Size	Shape and Edge	Conn.	Patch Size	Shape and Edge	Conn.	Patch Size	Shape and Edge	Conn.	
Deregulation	A											
	B											
Local Analysis	A											
	B											
Smart Growth	A											
	B											
Landscape Analysis	A											
	B											
Landscape Priority	A											
	B											

Legend: Direction and relative magnitude of estimated change in the potential of the landscape to support regional biodiversity from 2016-2055

Greater decrease	Decrease	No discernable change	Increase	Greater increase

There were four main findings that emerged from Table 22. First was the overall biodiversity trends between scenarios: while there were mixed results depending on indicator and habitat type, and by habitat classification level in some cases, the Deregulation and Smart Growth scenarios showed a slightly decreased overall trend from 2016-2055 in the potential of the landscape to support regional biodiversity (9 of 20 indicators pointing to a decrease and 8 of 20 indicators pointing to an increase), while the Local Analysis, Landscape Analysis, and Landscape Priority scenarios showed an overall increased trend in the potential of the landscape to support regional biodiversity (13 of 20 indicators pointing to an increase and 6 of 20 indicators pointing to a decrease). The results showed a notable dichotomy across all indicators between the former two scenarios, on the one hand, and the three latter scenarios on the other. As the Local Analysis, Landscape Analysis and Landscape Priority scenarios all contained some degree of project decision-making policies (i.e., high on the environmental regulation axis illustrated in Figure 10), they were collectively referred to as the 'Regulation-Based Scenarios'. On the other hand, the Deregulation and Smart Growth scenarios were positioned low on the environmental regulation axis illustrated in Figure 10 and had no decision-making policies applied; these scenarios were referred to as the 'Development-Based Scenarios'.

Secondly, differences were evident in the potential of the landscape to support regional biodiversity depending on the habitat type examined. Forest habitat exhibited the greatest positive changes in regional biodiversity indicators overall, particularly in the Regulation-Based Scenarios. Only shape and edge showed negative changes in biodiversity indicators due to smaller interior-to-edge ratios for forest habitat. Grassland habitat showed mixed results between scenarios, showing little change or negative change in biodiversity indicators for the Development-Based Scenarios and showing positive change in biodiversity indicators in the Regulation-Based Scenarios. Like forest, the shape and edge indicator showed negative changes across scenarios due to smaller grassland interior-to-edge ratios. Finally, wetlands showed mixed results both within and across scenarios. Wetland patch sizes increased in all scenarios at a coarse classification level, but decreased at a fine level of habitat classification. Similarly, wetland connectivity indicated little or positive change at a coarse classification level but a negative change at a fine level of habitat classification.

Third, different indicators showed different biodiversity trends. Habitat diversity showed overall positive changes in biodiversity indicators from 2016 to 2055, but showed little variation between scenarios. Patch size showed considerable variation between scenarios, increasing for forest habitat, showing mixed trends for grasslands, and both increasing and decreasing for wetland habitat depending on habitat classification level. Similar to patch size, connectivity also showed considerable variation between scenarios. In general, connectivity (and the associated ability for the landscape to support biodiversity) increased for forest habitat, showed little change or increased for grasslands, and showed little change to decreased for wetlands depending on habitat classification level. The shape and edge indicator, on the other hand, tended to show an inverse relationship with patch size and connectivity in this modelling experiment. Like the habitat diversity indicator, it showed little variation between scenarios.

A last major finding related to how the habitat classification level impacted the trends shown by the biodiversity indicators. For most indicators and habitat types there was no difference in trend based on habitat classification level. The exception to this was for wetland habitat, where biodiversity indicators showed opposite trends depending on whether the analysis was done on a coarse or fine habitat classification level.

6.6 Discussion

The objectives of this research were twofold: to (1) introduce a technically feasible way in which landscape analysis might be used to support biodiversity assessment in project decision-making, and (2) examine the potential relevance, strengths and limitations of the approach in a cumulative project development setting, in which different possible project development and decision-making scenarios were modelled. This section begins with a summary of the approach to landscape analysis, followed by how it performed in the decision-making scenarios with respect to the selected biodiversity indicators. Strengths and weaknesses of the approach are discussed, followed by some limitations of the testing model and potential for future work to further refine and contextualize study findings and implications for EIA and environmental management.

6.6.1 Incorporating Landscape Analysis in Project Decision-Making

An example of a potential approach to landscape analysis that could be incorporated in current project decision-making was identified in Section 6.3 and applied to the Eastern Ontario case study area. This approach was designed to avoid some of the noted technical challenges around incorporating landscape-scale biodiversity issues in project assessment, such as complex data and modelling requirements (Gontier, 2006) and need for expert interpretation (Pietsch, 2018). Instead, the approach used existing science, tools, and data as its basis. Current landscape ecology science was at the foundation of the guidelines used to identify targets or thresholds for landscape metrics in the ecoregion (EC, 2013), which could be modelled simply in existing GIS applications, using available LULC data. The method was thus possible to calculate and interpret. Usage of such GIS-based methods thus translates concepts of landscape ecology into quantitative and predictive methods for analyzing impacts of land use change on biodiversity (Gontier, 2006).

While several authors have advocated the need to measure and predict changes in landscape structure to assess project effects on biodiversity (e.g., Byron, 1999), others have expressed concern that application of landscape pattern indicators may not be enough to support meaningful biodiversity assessment (Scolozzi and Geneletti, 2012). The approach proposed here used seven metrics related to landscape composition and configuration, which were derived from habitat-based guidelines for the applicable ecoregion (Table 17). They were chosen specifically for their relationship to quantitative landscape analysis targets , thus attempting to bridge the pattern-process gap with best available science. While other authors have used patch size, shape (Griffith et al., 2002; Maurer, 1999), and connectivity (Geneletti, 2004; Karlson and Mörtberg, 2015; Maurer, 1999) to evaluate impacts of projects (typically linear developments) on biodiversity, the difference here was in the specific use of ecological targets and thresholds to guide decision-making, emphasizing the ecological relevance of the metrics to biodiversity.

This approach to incorporating landscape analysis in project decision-making was included in two of five decision-making scenarios in a test environment simulating cumulative project decisions made over time. These scenarios, along with one other, showed promise in terms of a generally positive trend in the potential of the landscape to support regional biodiversity at the end of the simulation period. The technical evaluation showed that the landscape information considered in the simulated project decisions differentially influenced regional biodiversity indicators.

6.6.2 Comparing Scenario Outcomes

As described in Section 6.5.1, each of the five scenarios produced results that differed little from each other in terms of coarse landscape composition after 40 years of project decision simulation. On the other hand, relative differences were found in landscape configuration, as evidenced by geostatistically significant differences in spatial autocorrelation (Figure 11) and differing trends in the selected biodiversity indicators (Section 6.5.2). A similar pattern was observed in a study by Dalloz et al. (2017), in which total habitat amount was found to vary little between alternative locations for linear infrastructure development, but metrics such as habitat availability, patch number, size, and isolation showed considerable change. In the current study, the differences in landscape configuration measures were notable given the relatively conservative drivers behind the simulated projects. As the projections of population growth were relatively low for the study region, existing zoning was sufficient to account for the new population and associated urban growth and aggregate extraction requirements, leading to relatively small changes in land use. However, even these modest amounts of land use change were enough to alter landscape configuration and differentially influence landscape biodiversity indicators. Given this sensitivity, incorporating a landscape analysis approach into project decisions appears valuable even in scenarios with relatively small project developments. If combined with or nested within a regional assessment process (e.g., Duinker and Greig, 2006), such an approach could be even more powerful.

Across all indicators, a noticeable divide was found between the Development-Based Scenarios and the Regulation-Based Scenarios. The Regulation-Based Scenarios all simulated some level of environmental regulation in project decision-making processes (referring back to the y-axis in Figure 10): the Local Analysis scenario simulated site-specific considerations when permitting project development, while the Landscape Analysis and Landscape Priority scenarios also included landscape-scale considerations. Differences in the development trajectory (clustered growth, as in the Smart Growth and Landscape Priority scenarios; see x-axis in Figure 10) had less impact on the selected landscape and biodiversity indicators. Thus the Smart Growth scenario, with its focus on clustered development but no environmental regulation in project decision-making, showed similar results to the Deregulation scenario, with no set development trajectory and also no environmental regulation. Additionally, the Landscape Priority scenario, with its focus on both clustered development and landscape-based environmental regulation in project decision-making, differed little from the Landscape Analysis scenario, with no set development trajectory but the same landscape-based environmental regulation.

An interesting surprise was the performance of the Local Analysis scenario, which mirrored the results of the Landscape Analysis and Landscape Priority scenarios. This was unexpected, as it was hypothesized that including the landscape analysis in addition to site-specific considerations in project decision-making would lead to a greater response in biodiversity indicators. A reason for the unexpected similarity in these scenario outcomes may be found in the decision rules used in the Local Analysis scenario. This scenario took local-scale attributes into consideration when 'approving' projects, such that development projects had a greater likelihood of proceeding if they were located outside of PSWs and natural heritage system features, while restoration projects had a greater likelihood of proceeding if they were within or adjacent to PSWs and natural heritage system features. Natural heritage system features included ANSIs, significant woodlands and valley lands, and significant wildlife areas (OMNR, 2010). Interestingly, the datasets used to identify local natural heritage features may already incorporate aspects of landscape-scale features important to biodiversity. In particular, the dataset from which the significant wildlife areas were derived came from a landscape-based analysis of core habitat areas (the Algonquin to Adirondack (A2A) initiative; OMNR, 2014). This choice of dataset may have therefore already biased the identification of key local habitat features to include key habitat features in a landscape context. If this were the case, the similarity in outcomes between the Local Analysis, Landscape Analysis, and Landscape Priority scenarios would make sense.

The similarities between the local-level and landscape-level analysis scenarios may also have to do with the characteristics of the study area itself. For example, existing forest cover in each watershed was already considerably below the recommended 40% landscape threshold. This meant that decision-makers looking at site-specific characteristics or landscape-based criteria would both count remaining forest as important habitat. Similarly, with the low amount of native grassland in the region at the beginning of the scenario runs, grassland habitat counted as equally important to decision-makers considering either site-specific habitat and broader landscape characteristics. It is possible, then, that in working landscapes with fewer remnant habitat patches, strong site-specific habitat-based decisions would be equally as important to regional biodiversity as considering broader landscape criteria, or at least until minimum habitat thresholds were reached. This runs counter to some findings in landscape ecology, however, in which habitat configuration (namely patch size and isolation) was found to be of greater importance with greater amounts of disturbance (Andrén, 1994; Crouzeilles et al., 2014), and therefore the former explanation may be more plausible. These ideas would need to be explored further in future iterations, with different decision parameters and in different landscapes with varying amounts of habitat and landscape configurations. It may also be that the relatively conservative level of development estimated in this test also contributed to the similarity between these scenarios; if greater project development were simulated, results might show greater divergence. This is also an area for future work.

It was also notable that the Deregulation and Smart Growth scenarios were quite similar in terms of indicator response. While the Smart Growth scenario regulated the location of proposed development (i.e., clustered adjacent to existing development), it still interestingly showed little difference with the Deregulation scenario in terms of biodiversity indicators at the end of the simulation runs. This contrasts with empirical findings of Gagné and Fahrig (2010), who tested the impact of dispersed to compact housing density on forest bird abundance, species richness and evenness in the Ottawa, Ontario area. The authors concluded that compact housing minimized development impacts on forest breeding birds. The lack of noticeable effect on landscape metric indicators of biodiversity between the Deregulation and Smart Growth scenarios in the current study could be a result of how land was selected for development. While development in the Smart Growth scenario could only be proposed in locations adjacent to existing development, the simulation weighted all land use types as equal for development purposes. Thus a wetland or forest adjacent to an urban area could be selected for urban development just as easily as a marginal farm field or rural residential development. These changes in habitat at a landscape level could then impact the chosen indicators. Again, to properly test this effect, future work would need to use higher simulated population growth rates and related development requirements to reveal differences between these two scenarios; however, at the current conservative simulated rate of growth, differences between the scenarios were not noticeable.

6.6.3 Implications for Regional Biodiversity

Overall, the scenario modelling indicated that including landscape information in simulated project decisions differentially influenced regional biodiversity indicators. Results pointed generally to the Regulation-Based Scenarios as producing greater positive changes in the landscape biodiversity indicators compared to the Development-Based Scenarios. At the same time, the differences in indicator response between habitat types indicated species that may benefit disproportionately from the decision-making strategies in the scenarios. Forest habitats tended to show the greatest potential benefits in terms of the biodiversity indicators, though specialist species reliant on forest interior may experience greater challenges as the shape and edge indicator pointed to greater irregularity in patch shapes across scenarios in 2055 and therefore a greater proportion of edge habitat. Forest patch sizes and connectivity showed considerably higher values in the Regulation-Based Scenarios compared to the Development-Based Scenarios, which generally point to greater persistence of regional biodiversity (Fahrig, 2003). For forest species, it is likely that the effects of the larger areas would outweigh the challenges of more relative edge habitat for these forest patches.

It is suspected that a reason for forest habitat showing positive changes in both patch size and connectivity indicators across scenarios was the relatively low forest habitat amount across the study area in 2016 (17%; see Table 18). This percentage is considerably lower than the 40% threshold that would have been considered a minimum under the Landscape Analysis and Landscape Priority scenarios, likely driving increased forest restoration and denying any projects proposed to alter forest land use. Similarly, the Local Analysis scenario would have also considered remaining forest habitat as locally important in decision-making. While the Development-Based Scenarios also showed increases in forest habitat patch sizes and connectivity, albeit to a lesser extent, these were likely influenced by the requirement for forest restoration as these scenarios imposed no restrictions on proposed projects that would have limited their alteration of forest habitats like in the Regulation-Based Scenarios. These effects would need to be tested in landscapes with differing amounts of initial habitat to see if the relationships hold true.

Native grassland habitats also showed increased patch size and connectivity indicators in the Regulation-Based scenarios. There were no notable differences in shape and edge between scenarios; however, where the indicator pointed to a slight decrease in interior-to-edge habitat ratio across scenarios (greater MSI), this change in pattern could have implications for grassland obligate species which tend to respond strongly and negatively relative to MSI (Lockhart and Koper, 2018). While the increased grassland patch size and connectivity in the Regulation-Based scenarios may outweigh this pattern, the decreased indicator trends in the Development-Based scenarios would only exacerbate the issues faced by grassland species.

Wetland habitats showed some interesting diverging trends depending on the habitat classification level, indicating some important scale effects. At the coarse (LULC A) level, wetland patch sizes increased across all scenarios. However, at the finer (LULC B) level, in which wetlands were differentiated by type (e.g., swamp, marsh), habitat patch sizes decreased across all scenarios with larger decreases exhibited in the Development-

Based Scenarios. A similar pattern was shown by the connectivity indicator. These opposing trends based on habitat classification level may be explained by a situation where multiple wetland types exist adjacent to one another (e.g., open marsh adjacent to a forested swamp), forming a larger undifferentiated wetland at a coarser classification level. Over time, the patch size of the larger undifferentiated wetland may increase, but this increase may consist of multiple smaller wetlands within it (e.g., multiple patches of open marsh interspersed with treed swamp). The implications for wetland biodiversity in this case are complex. Since larger patch sizes are typically associated with a greater ability to support regional biodiversity (e.g., Freemark et al., 2002; Leroux et al., 2017), the indicator points to an increased ability of the landscape to support regional wetland biodiversity at the coarse (LULC A) habitat classification level. However, because the decreased patch sizes at the finer (LULC B) level are due to greater diversity of wetland types within the larger wetland patch, the regional biodiversity impacts may depend on the specific wetland species present and their preference for diverse wetland habitat characteristics or large tracts of a specific wetland type at different spatial scales (e.g., Price et al., 2005). Therefore, while the necessarily simplified Table 22 shows a decrease in the ability of the landscape to support regional wetland biodiversity at the LULC B level based on patch size, the actual implications for regional biodiversity may be more nuanced. For environmental managers wishing to choose an appropriate habitat classification level for their analysis, the salient considerations would be the habitat perception and preferences of local species of management concern (i.e., the scale at which the species respond to patchiness in their surroundings; Kotliar and Wiens, 1990).

Of the selected indicators, connectivity appeared the most sensitive to differences between scenarios, followed closely by patch size. The Regulation-Based Scenarios showed consistently greater connectivity for forest, grassland, and wetland habitats compared with the Development-Based Scenarios, indicating positive change in the potential for the landscape to support regional biodiversity. While the relationship between fragmentation and biodiversity is debated (e.g., Ewers and Didham, 2006; Fahrig, 2017, 2013; Haddad et al., 2017), there appears to be general consensus that human fragmentation geometries such as roads dividing habitat patches are detrimental to species diversity due to increased mortality and dispersal issues that limit population persistence (Jaeger, 2015). Greater MESH sizes are therefore indicative of greater species diversity and population persistence, especially for species with large home ranges and dispersal needs (e.g., Girvetz et al., 2008, 2007; Roedenbeck and Köhler, 2006). MESH has been used widely across Europe (Walz, 2015) and in Ontario (OBC, 2015) as an indicator of terrestrial landscape fragmentation, in assessments of ecosystem services including biodiversity (Frank et al., 2012; Inkoom et al., 2018), and in landscape and urban planning (Girvetz et al., 2008), and is well suited to comparing the degree of landscape fragmentation between regions or over time (Jaeger, 2000).

MESH sizes for the different habitats at the coarse LULC A level varied between scenarios from 1.3 to 1.7 km^2 for forest habitat in 2055 (Table 21). These values are comparable to the 2011 MESH values of 1.3 km^2 for the Ontario Mixedwood Plains Ecozone, and 1.1 to 3.3 km^2 for the Kemptville Ecodistrict in which the study area is located, indicating little overall change over the 40-year simulation period (OBC, 2015).

This may be a result of the conservative population growth and associated development estimations used in the scenarios, but it is a positive sign for biodiversity in this illustration. MESH showed consistently greater values (increased potential for the landscape to support regional biodiversity) for the Regulation-Based Scenarios across all habitat types at both LULC A and LULC B classification levels.

In contrast, habitat diversity appeared to be less sensitive to development options as expressed in the five scenarios specified for this study. In this study, no habitat type disappeared entirely from the landscape after the 40-year simulation and therefore the richness of habitat types remained the same across all scenarios. Thus the results of the SDI calculation were driven by the evenness of the habitat types. SDI increased from 2016-2055 in all scenarios, meaning that evenness between habitat types increased relatively consistently across scenarios. This generally indicates greater potential for the landscape to support regional biodiversity; however, the indicator was not able to differentiate between scenarios at the conservative level of population growth and project drivers used in this experiment. Habitat diversity and the SDI metric may be of greater relevance where rare patch types are particularly important to biodiversity in the region (Nagendra, 2002).

Overall, the modelling results support the idea that existing science, tools, and data can be used to incorporate landscape information into project-based decision-making in a way that can differentially impact cumulative effects on biodiversity indicators. At the same time, an unexpecting finding was that identifying natural heritage features in a landscape context prior to conducting standard local-level assessment may show similar results to including landscape analysis in decision-making. Exploring this idea further would help clarify whether these findings hold true in other contexts or whether this similarity was due to features of Eastern Ontario. Additionally, implications for regional biodiversity are nuanced, in that results depended on habitat type, biodiversity indicator, and habitat classification. Decision-makers using such analysis would need to be aware of species-specific implications and target their analysis according to their conservation management objectives.

6.6.4 Strengths and Weaknesses of the Landscape Analysis Approach

The modelling experiment uncovered both strengths and weaknesses of the landscape analysis approach to bridge project and regional biodiversity assessment. This approach, identified in Section 6.3 and applied to two simulated decision-making scenarios in the spatial modelling experiment (Landscape Analysis and Landscape Priority; see Table 20), consisted of evaluating land use change proposed by a potential project against landscape-level targets: if the land use change proposed by the project would cause the landscape-level targets to be exceeded, the project would be denied; otherwise the project would be approved and the land use change would occur.

Important strengths included the accessibility of the approach, including its ability to be assessed using existing tools, data and science. It makes use of current GIS capabilities and publicly available data sources to analyze how a project could impact a landscape, using pre-determined assessment criteria based on known habitat-based guidelines and landscape analysis targets. High-quality GIS data such as the LULC data required by this landscape analysis approach are becoming easier and more accessible to obtain (Harker et al., 2021). Additionally, the approach proved sensitive even under conservative growth scenarios in the current modelling experiment, meaning that scenarios could be differentiated based on its use even with a relatively low amount of proposed development. These differences between scenarios were picked up particularly well by the patch size and connectivity biodiversity indicators. The sensitivity of the approach demonstrates its utility even in regions where development pressures are just emerging, and shows that even the addition of simple landscape-based analyses to project assessment can differentially influence the potential of the landscape to support regional biodiversity.

The approach also bridges project and cumulative effects assessments by incorporating the evolving condition of the landscape directly into project assessment with reference to quantitative landscape targets. Duinker and Greig (2006) emphasize the importance of centering the lens of cumulative effects assessment on valued ecosystem components (VECs); this has been difficult in practice as project-based assessment is typically focused on the impacts of the proposed project. By using landscape-based measures that correlate with biodiversity persistence at a regional scale, the landscape analysis approach presented in this study can help translate VEC-based measures of cumulative effects into project effects. Additionally, by incorporating the approach into an assessment of future activities, it could be expanded to form a basis for a scenario-based regional cumulative effects assessment as recommended by Duinker and Greig (2007).

There are also some limitations to the approach, however. It is highly dependent on the definition and classification of habitats based on land cover in the landscape. For example, with all forest types equally classified as 'forest', a young pine monoculture would be treated as having equal biodiversity to an old growth forest, unless these two very different forest types were defined differently in the habitat classification scheme. Thus the quality of habitat is not factored into this approach – a factor that can highly influence biodiversity persistence in the real world (e.g., Ye et al., 2013). Additionally, the approach does not consider the quality of the surrounding (non-habitat) landscape. The ability of the dominant land use type, known as the landscape matrix, to provide semi-hospitable habitat and increase (or decrease) landscape permeability has been shown to be an important factor in biodiversity persistence in a landscape (Ewers and Didham, 2006; Fahrig, 2001; Fischer and Lindenmayer, 2007; Franklin, 1993; Kuipers et al., 2019; Mairota et al., 2015). The presence of other habitat types in the surrounding landscape may also play an important role in the persistence of some species; for example, turtle species inhabiting wetland patches have been found to respond more strongly to the presence of forest in the surrounding landscape than to configuration of the wetland habitat itself (Quesnelle et al., 2013). As currently presented, the landscape approach does not account for these factors, but these would be valuable areas for future study.

Secondly, habitat-based guidelines may not be as readily available for other ecoregions, and there is uncertainty associated with the landscape targets even for Eastern Ontario. A literature search may be able to uncover data from landscape ecology studies, but this would take time and expertise to interpret. Jaeger (2015) described similar issues with the lack of knowledge of thresholds in ecological response to cumulative effects of habitat loss and fragmentation. Greater priority placed on the development of standards and thresholds for impact assessment and evaluation has been recommended in the literature (e.g., Karlson and Mörtberg, 2015).

Finally, an unexpected finding of the modelling experiment was that it showed little difference between the prior identification of local natural heritage features important in a landscape context (the dataset used for the Local Analysis scenario) and the application of the landscape analysis approach in project assessment (in the Landscape Analysis and Landscape Priority scenarios). While this is not a limitation of the sample landscape analysis approach per se, it does show that there may be other means to achieve similar potential for regional biodiversity persistence, and the choice of approach may be site- and context-specific.

6.6.5 Limitations of the Modelling Experiment and Future Refinements

As an initial technical evaluation study, the scope of the current modelling exercise was necessarily simplified. However, there are increased levels of detail that could be added in future iterations to further refine the model and the resulting outcomes (Table 23).

Table 23. Potential future refinements to the spatial modelling experiment to address current limitations

Limitation	Potential Model Refinements
Development scenarios were based on projected rates of population growth which were conservative and showed relatively low growth	Addition of rules for rezoning land according to specified criteria in the different scenarios, e.g., on a 5-year basis. The current model assumes that existing land use zoning will apply for the length of the 40-year simulation runs, as there is enough capacity within the current zoning scheme to account for the projected population growth. However, future building preferences and possible changes/increases in population growth rates may lead to rezoning portions of the population centres and increasing buildout into rural areas, with associated biodiversity impacts.
Development scenarios were hypothetical and simulated projects were computer auto-generated	Addition of actual proposed and built projects against which to test the model estimations in a regional cumulative effects setting.
Project types were limited to three (urban expansion, aggregate mining, and habitat restoration)	Incorporation of a greater diversity of project types, leading to greater potential diversity of impacts.
The model was static in that it did not include natural vegetation changes or other external factors that impact habitats and biodiversity	Addition of external drivers of landscape change such as vegetation succession models and climate change projections that also act cumulatively on the landscape and can alter habitat suitability and biodiversity in the region.
Testing was limited to landscape metric indicators of biodiversity	Expand the evaluation of regional biodiversity under the scenarios to include alternative indicators such as focal species (e.g., Reed et al., 2002; Santelmann et al., 2006; White et al., 1997) and/or connectivity modelling (e.g., Calabrese and Fagan, 2004; McRae et al., 2008; Pascual-Hortal and Saura, 2006; see Appendix C).

Additionally, the scope of this technical evaluation was limited to the necessary first step of testing feasibility and potential relevance, strengths and limitations of a landscape analysis approach in a spatial modelling setting. The approach was not guided by decision-makers or assessed by practitioners. However, engaging EIA practitioners in all aspects of a future follow-up study, including setting parameters of the simulation model, scenario design, assessment of the capacity of practitioners to adopt the approach, and its potential in real-world decision-making, is a logical next step.

These future refinements could enhance and contextualize the results of the current study, developing further support for or alternatives to the initial results presented here and expanding on our understanding of the ability of landscape analysis to bridge project EIA and regional biodiversity persistence in developing landscapes.

6.7 Conclusion

This study initiated an exploration of two important questions: how might landscape analysis be used to support biodiversity assessment in project decision-making, and how might it affect the potential of the landscape to support regional biodiversity if used to support cumulative project decisions over time. The literature strongly supports the importance of landscape level approaches to regional biodiversity persistence (e.g., Bergès et al., 2020; Freemark et al., 2002; Jaeger, 2015; Walz, 2011), but this study adds a technical evaluation of one way in which landscape analysis might be used to bridge project and regional cumulative assessments through the use of spatially-explicit scenarios. Results suggest that the landscape information considered in simulated project decisions differentially influenced regional biodiversity indicators, particularly in terms of patch sizes and connectivity, even if overall landscape composition changed little given the parameters of this model. These results are even more promising given the simplified nature of the model, in which only two types of development projects were modelled, and driven by a relatively conservative rate of population growth. In a real-world case of multiple project types, potentially proposed at a more aggressive pace, the value of mitigating cumulative biodiversity impacts on a landscape scale would likely be even greater. This knowledge can improve the ability of project EIA to better address biodiversity impacts in a way that is linked to current approval processes, even as processes potentially better suited to broad-scale CEA in the long term such as regional and strategic assessments have a chance to grow and improve in practice.

In examining the five scenarios in the current study, designed to explore a breadth of development and decision-making policies, it was found that having regulatory decision-making policies that permitted or prohibited development projects based on both site-specific and landscape criteria had a greater influence on biodiversity indicators than changing the development trajectory from more dispersed to more clustered. Thus managing for development pattern alone did not appear to play as great a role in regional biodiversity persistence as strong environmental regulation in decision-making policies. Within the decision-making policies, factoring in landscape considerations either proactively, in prioritizing local habitat features, or at the time of decision-making using a landscape analysis approach demonstrated similar results in terms of regional biodiversity indicators. This has important practical implications in that in landscapes where regional assessments have taken place, these assessments could be used to prioritize site-specific habitats within a landscape context prior to conventional site-specific project decision-making. However, if (as in many areas) no regional assessment has yet taken place, landscape-based analysis can be provided to decision-makers based on best available science to yield very similar outcomes. The current study shows that landscape analysis can be relatively simple, considering a few aspects of landscape composition and configuration, and does not need to be exhaustive to influence the potential of the landscape to support regional biodiversity. Future refinements of both the landscape approach and experimental model can help expand on our understanding of the ability of landscape analysis to bridge project EIA and regional biodiversity persistence.

Overall, the spatial modelling experiment demonstrated potential for the ability of landscape analysis to influence regional biodiversity indicators when used to inform project decisions, helping to bridge the gaps between project-scale assessment and regional biodiversity persistence in a practical way. However, results depend on the land cover designated as habitat, as well as the resolution at which that habitat is defined, and environmental managers must be mindful when setting up such a decision-making model. With this caution in mind, study results show important implications for EIA practice: they demonstrate technical feasibility and potential relevance of providing accessible landscape-based information to decision-makers using current science, tools and data. Use of landscape analysis can aid both EIA practitioners, in providing decision-making support, and environmental managers, in setting broader EIA policy and direction, to better guide project decision-making with respect to regional biodiversity.

Chapter 7: Synthesis and Conclusions

My research evaluated the potential for landscape ecology to better inform EIA with respect to biodiversity conservation. Synthesizing the findings from the preceding chapters, one can see that biodiversity is a notoriously difficult component to assess in EIA because of its multi-dimensional definition that encompasses a range of scales of organization (genes to species to ecosystems) and measurement (alpha diversity to gamma diversity), its ongoing challenges with establishing universal indicators, and its mediation by processes occurring at a broad landscape-to-regional scale (Section 2.1). These contrast with the project scale typically used in EIA (Section 2.3). While cumulative effects assessment recognizes and attempts to assess broader-scale impacts of a project in combination with other projects, and regional EIA looks at combined impacts across a region, there are issues associated with current practice that make project assessment a potentially useful avenue for incorporating better biodiversity assessment at the present time (Sections 2.3 and 6.1). Landscape ecology can provide a knowledge bridge between project EIA and regional biodiversity assessment.

Overall, the application of landscape ecology concepts and tools to aid in biodiversity assessment and decision-making continues to be rare in EIAs (Section 4.1). Using Ontario, Canada as a case study, I found that landscape ecology science is still not well-integrated into EIA practice, and quantitative and spatial analyses are lacking from landscape-scale biodiversity assessment in EIA. So where are the gaps between landscape ecology science and EIA and practice? Are there particular gaps to prioritize that offer the greatest capacity for improvement?

Concepts of landscape permeability, or the ability of the landscape as a whole to support species movement, are underrepresented in EIA relative to its importance in maintaining a region's biodiversity (Section 4.5). This is an area to target for joint knowledge-sharing, in order to improve EIA guidance on this topic. On the other hand, habitat targets and thresholds are not often used in EIA practice, though these are well-documented in EIA guidance (Section 4.5). This appears to be a gap in practical application, rather than knowledge from the scientific community. Bridging this gap may require innovative ways of getting at habitat targets and thresholds, such as referencing regional initiatives (e.g., natural heritage systems) or provincial or federal conservation targets within EIA. Another less prominent but still existing gap is in the area of quantitative or spatial analysis of landscape configuration. While concepts of landscape configuration such as habitat connectivity are often described in EIA and tend to be conceptually familiar to EIA practitioners and decision-makers, translating existing tools and measures into practical application is still lagging.

So why do these gaps exist, and how might they be bridged? Barriers can be legislative/political, scientific (lack of information, knowledge or scientific consensus, monitoring of outcomes), technical (understanding of methods), practical (workloads, budgets, competing priorities, high data requirements and complexity), and institutional (fit between institutions and ecological processes, including scale issues) (Section 5.1). In the Canadian context, areas of both challenge and opportunity collectively point to both scientific challenges but also organizational and institutional. The top ranked issues in my study of EIA practitioners and decision-makers practicing in Ontario included: (1) lack of policy and guidance (ranked especially high by lower jurisdictional levels), (2) lack of multi-level policy support (expressed across all jurisdictions), and tied for (3) weak data and data management systems, and knowledge of ecological thresholds (both ranked especially high by lower jurisdictional levels). Similarly, the top-ranked opportunities for these practitioners included: (1) big picture planning (expressed across all jurisdictions), (2) multi-jurisdictional data systems (ranked especially high by lower jurisdictional levels), and (3) strengthened policy language (expressed across all jurisdictions) (Section 5.4).

In terms of policy and institutional systems, a key recommendation to support the use of landscape ecology and analysis in EIA is to strengthen policy language specific to broader-scale analysis in EIA. Combining this idea with the gap in the EIA guidance documents analyzed in Chapter 4, the policy language could be used to emphasize the need for whole-landscape assessment of permeability, and of a broad picture of habitat overall (versus the tendency to focus solely on unique habitats – important for biodiversity, but so is the bigger picture). The policy landscape is continuously evolving, however, and since the time of both the gap analysis (Chapter 4) and the practitioner interviews (Chapter 5), a new piece of federal EIA legislation came into force, with renewed emphasis on habitat and regional assessments, open source data platforms, and the importance of Indigenous knowledge to the process. It remains to be seen how the enactment of the *Impact Assessment Act* (Government of Canada, 2019) influences the application of landscape ecology and analysis in federal EIA and whether there is any trickle-down effect into lower-tier jurisdictions.

An important recommendation for bridging science and data challenges is to improve knowledge of habitat targets and ecological thresholds, and collaborative development of that knowledge among the scientific and policy community as well as local and Indigenous communities. This aligns with the gap finding from Chapter 4 that in practice, EIA tends to lack reference to meaningful benchmarks such as landscape habitat targets and thresholds. Improving data and data systems, and structured monitoring at a landscape scale, would help with this endeavor.

Finally, what are the potential benefits of overcoming these challenges and taking advantage of opportunities to improve landscape analysis as part of biodiversity assessment in EIA? In what ways might regional biodiversity be affected over time if decision-making took landscape ecology principles and analysis into consideration as part of EIA? The scenario-based model in Chapter 6 illustrated the technical feasibility of the use of landscape-based criteria in project decision-making to bridge project and cumulative regional assessment with respect to regional biodiversity. Decision-making on whether to permit development projects in certain locations, when based on landscape considerations, appears to have a greater impact on regional biodiversity indicators than simply planning for clustered development. Again, closing the knowledge gap of ecological targets and thresholds as decision-making benchmarks and sharing these among landscape ecologists, EIA practitioners, and local and Indigenous communities will be important, as these can provide the criteria needed for landscape analysis to be practical in EIA.

Incorporating this knowledge into actual decision-making processes represents an important next step and would include taking this information back to practitioners and local and Indigenous stakeholders for their input. Better-informed decision-making, in the modern context, is not achieved through a top-down exercise but through engagement with all actors involved.

In closing, there are areas where landscape ecology shows strong potential to better inform EIA with respect to biodiversity conservation, other areas of variable potential, and some areas of weaker potential where other forms of knowledge may have greater impact.

Strong Potential

Landscape ecology provides the ability to distill information about the broader landscape context into project EIA in a way that bridges project-specific and regional cumulative effects. Thus it may be a practical aid to addressing current issues plaguing cumulative effects assessment. Modelling results also indicate that providing landscape-based information to decision-makers is technically feasible with existing science, tools and data, and can have a greater impact on regional biodiversity indicators than simply planning for clustered development. Future work in taking landscape analysis approaches back to stakeholders can solidify this potential to better inform decision-making with respect to regional biodiversity impacts of proposed land use change.

Variable Potential

A current challenge exists with respect to ecologically-relevant thresholds for landscape analysis, meaning that practitioners must be comfortable with uncertainty and use of best available science. If landscape ecologists, EIA practitioners, and local and Indigenous communities could work together in developing knowledge sharing and robust, long-term monitoring programs in this regard, bridging this gap would raise the potential of landscape ecology to benefit biodiversity.

Weak Potential

Finally, use of landscape ecology as a science cannot avoid potentially difficult social value decisions associated with conservation. Where species or biodiversity elements have conflicting habitat requirements, spatial solutions alone may not be able to solve potential trade-offs. However, there may be ways of planning that incorporate opposing needs. Within broad regional conservation objectives, for example, it may be possible for local managers and communities to contribute to the needs of one species while other local areas contribute towards persistence of other species with competing habitat requirements (Donovan et al., 2000).

Overall, bridging the three research fields of biodiversity, landscape ecology, and EIA shows considerable potential for addressing current challenges of project decision-making and the persistence of regional and global biodiversity. EIA offers an accepted process of assessing impacts for the purposes of project decision-making, but currently suffers challenges with incorporating the broader scales and cumulative effects assessments necessary to assess impacts on biodiversity. Landscape ecology has advanced knowledge on the relationship between landscape pattern and ecological processes that mediate biodiversity, establishing that broad-scale patterns are important to biodiversity persistence. A quantitative branch of landscape ecology, landscape analysis, offers tools, methods and indicators that can better inform biodiversity assessment in EIA. While challenges remain with bridging these three fields of research of practice, there is strong enough potential to recommend the immediate use of available landscape analysis data and science within EIA. As stated by Theobald et al. (2000, p. 43), "land-use decision making will not wait for scientists to 'get it right'".

Appendices

Appendix A Carleton University Research Ethics Board-A (CUREB-A) Ethics Clearance Certificates

Office of Research Ethics
5110 Human Computer Interaction Bldg | 1125 Colonel By Drive
| Ottawa, Ontario K1S 5B6
613-520-2600 Ext: 2517
ethics@carleton.ca

CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) has granted ethics clearance for the research project described below and research may now proceed. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics Protocol Clearance ID: Project # 108786

Project Team Members: Christina Rehbein (Primary Investigator)
Scott Mitchell (Research Supervisor)
Michael Brklacich (Research Supervisor)

Project Title: Challenges and Opportunities for Landscape Analysis in Environmental Impact Assessment (EIA) [Christina Rehbein]

Funding Source (If applicable):

Effective: **May 02, 2018** Expires: **May 31, 2019**

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to CUREB-A via a Change to Protocol Form. All changes must be cleared prior to the continuance of the research.
3. An Annual Status Report for the renewal of ethics clearance must be submitted and cleared by the renewal date listed above. Failure to submit the Annual Status Report will result in the closure of the file.If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.
5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please contact the Research Compliance Coordinators, at ethics@carleton.ca, if you have any questions or require a clearance certificate with a signature.

CLEARED BY: **Date: May 02, 2018**

Andy Adler, PhD, Chair, CUREB-A

Bernadette Campbell, PhD, Vice-Chair, CUREB-A

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CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) at Carleton University has renewed ethics approval for the research project detailed below. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Title: Challenges and Opportunities for Landscape Analysis in Environmental Impact Assessment (EIA) [Christina Rehbein]

Protocol #: 108786

Project Team Members: Christina Rehbein (Primary Investigator)
Scott Mitchell (Research Supervisor)
Michael Brklacich (Research Supervisor)

Department and Institution: Faculty of Arts and Social Sciences\Geography and Environmental Studies (Department of),

Funding Source (If applicable):

Effective: **July 17, 2019** Expires: **May 31, 2020**.

Please ensure the study clearance number is prominently placed in all recruitment and consent materials: CUREB-A Clearance # 108786.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and cleared by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. During the course of the study, if you encounter an adverse event, material incidental finding, protocol deviation or other unanticipated problem, you must complete and submit a Report of Adverse Events and Unanticipated Problems Form, found here: https://carleton.ca/researchethics/forms-and-templates/

6. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

7. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions.

CLEARED BY: **Date: July 17, 2019**

Natasha Artemeva, PhD, Chair, CUREB-A

Janet Mantler, PhD, Vice-Chair, CUREB-A

Appendix B Challenges and Opportunities Assessment – Summary Document of Interview Phase and Participant Follow-Up Questionnaire

Challenges and Opportunities for Broader Scale Approaches and Landscape Analysis in EIA: Generalized Summary across Local/Municipal, Provincial and Federal Jurisdictions

Primary researcher: Christina Rehbein, christina.rehbein@carleton.ca

Thank you to all participants for the time you took in providing such a richness of responses to the discussion of landscape and broader-scale approaches in EIA. Your experience and perspectives were insightful and invaluable to this research.

Tables 1 and 2 below represent the researcher's attempt to characterize and amalgamate one-on-one discussions regarding challenges and opportunities respectively perceived by participants in their work in relation to broader-scale approaches. Challenges refer to current barriers or hurdles to overcome for the widespread application of broader-scale / landscape approaches in EIA. Opportunities refer to specific ways or means by which broader-scale / landscape approaches might be afforded greater acceptance, as well as new benefits that that might flow from landscape-level assessments.

Some themes you may recognize, while others you may not relate to directly if they were derived from discussions with a participant [representative] from a different jurisdiction. Where two or more participants raised similar concerns or ideas, the researcher attempted to consolidate these under a single point. These are necessarily generalized, however, so if you recognize an item you raised in one of the points below that you think has not been properly characterized or nuanced, please do leave corrections or comments in the right-hand column of the table. Alternatively, I would be happy to discuss any concerns, questions or comments in a follow-up conversation – please feel free to contact me at 403-836-9450.

Objectives for this follow-up exercise

It is our aim to develop an understanding and sense of the relative importance of the points below, which are currently not prioritized in any way. In particular, it will be interesting to explore any similarities or differences between jurisdictions in how issues are characterized or prioritized. We would also like to give participants a chance to correct any interpretive errors, and add any additional thoughts or comments triggered by a point raised by another participant.

Questions

Specifically, you are kindly asked to complete the following in Tables 1 and 2:

1. Score your perceived importance of each point in the table on a scale of 1-5, where 1 is not important/relevant at all and 5 is extremely important/relevant. If a point does not apply to you or your experiences at all, please just mark it as N/A.
2. At the end of Tables 1 & 2 respectively, please identify your top 3 challenges and top 3 opportunities from among the points in the table.

Finally, in Table 3, you are asked to:

3. Score on a scale of 1-5 (and comment, if desired) on how important you think it is for biodiversity conservation that we further develop broader-scale approaches and analyses, (a) in general, and (b) as part of EIA processes. Again, 1 is not important/relevant at all and 5 is extremely important/relevant.

Many thanks once again for your time and contributions!

Table 1. Summary of challenges for broader-scale approaches and landscape analysis and EIA, grouped by theme.

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	**Raised By**			**Importance Score (1-5)**	**Comments**
		Local / Municipal	Provincial	Federal		
Biophysical						
1.1	Differences between landscapes					
	Landscapes can differ significantly in their biophysical and land use attributes and natural history (e.g., amount of remaining natural cover, Crown land vs. private ownership, how species behave in different landscapes), which may necessitate different approaches to assessment. It is difficult to apply a consistent approach.					
1.2	Climate change					
	Understanding how climate change will affect landscapes and how species will react to these changes are still unknown, as is how to incorporate climate change information and methods into assessments. Will need to understand not only landscape connectivity, but also climate refugia.					
1.3	Study boundaries and scales					
	Appropriate scales of analysis can be unclear. It can be difficult to define ecologically relevant study boundaries and identify relevant zones of influence of a project at both a spatial and temporal scale. The spatial area over which there is legislative control for the project is often arbitrary from an environmental perspective. Difficult to know how far into the future to look for a cumulative effects assessment.					
1.4	Other ____________					

<table>
<tr><th rowspan="2"></th><th rowspan="2">Challenge
These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.</th><th colspan="3">Raised By</th><th rowspan="2">Importance Score
(1-5)</th><th rowspan="2">Comments</th></tr>
<tr><th>Local / Municipal</th><th>Provincial</th><th>Federal</th></tr>
<tr><td colspan="7">Planning</td></tr>
<tr><td rowspan="2">2.1</td><td>Boundaries between jurisdictions</td><td>■</td><td>■</td><td></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="4">These challenges can be related to the assessment process, if different information is collected in different jurisdictions, or to planning and implementing mitigation. Examples include where one county borders another (municipal-municipal), or where a provincial highway meets a municipal road network (provincial-municipal).</td></tr>
<tr><td rowspan="2">2.2</td><td>Trade-offs</td><td></td><td>■</td><td>■</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="4">There are often challenging trade-offs, such as species with competing needs where what is good for one species in terms of landscape may be detrimental to another. Other trade-offs may involve choosing a lesser of multiple potential impacts.</td></tr>
<tr><td rowspan="2">2.3</td><td>Narrow planning processes</td><td></td><td>■</td><td>■</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="4">The current process of how project planning and EIA take place limits the ability to consider the larger picture (e.g., 5-year planning cycles, project prioritization, legacy of past project locations, regulatory requirements for project-based EIA).</td></tr>
<tr><td>2.4</td><td colspan="4">Other ____________</td><td></td><td></td></tr>
</table>

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	**Raised By**			**Importance Score (1-5)**	**Comments**
		Local / Municipal	Provincial	Federal		
Policy & Institutional Systems						
3.1	Lacking multi-level policy support It is difficult to advance an approach to EIA or other environmental protection measures without higher-level jurisdiction support (e.g., strong provincial mandate, clear federal guidance). Similarly, without multi-jurisdictional support for common initiatives, assessments can be very different between projects regulated by different jurisdictions and lead to a non-level playing field.					
3.2	Focus on project-by-project assessment Legislation is currently not set up to support assessments and mitigation outside of a project-specific approach (e.g., regional assessments, compensation or offsets outside of project site-specific locations, cumulative effects assessment).					
3.3	Lack of policy and guidance Particular areas lacking policy and/or guidance include cumulative effects assessments, assessment and planning of natural heritage features, and habitat compensation and offsets.					
3.4	Lack of institutional support Current institutions do not have the ability to handle more integrated approaches needed to effectively manage broader-scale perspectives beyond project- and site- specific regulation.					

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	Raised By			Importance Score (1-5)	Comments
		Local / Municipal	Provincial	Federal		
3.5	Limited environmental mandates Environmental initiatives are limited by an agency's mandate. Often agencies have competing priorities and few resources to address them all. Sometimes elements of the landscape within which the assessment and/or mitigation is located fall within another agency's purview, but coordination can be a challenge.					
3.6	Other ____________					

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	Raised By: Local / Municipal	Raised By: Provincial	Raised By: Federal	Importance Score (1-5)	Comments
Practicalities & Implementation						
4.1	Deficient EIA contract documents There is a need for clear and complete contracts and contract guidelines for consultants/contractors for EIA preparation and/or project implementation, otherwise anything broader in scale or scope can be dropped. Also a clear transfer and oversight of EIA recommendations from the EIA through detailed design and implementation.					
4.2	Long-term mitigation management Responsibility and budgeting for long-term monitoring and maintenance of mitigation measures can be an issue, especially when off-site compensation or offsets are involved. Land ownership of offset lands can be a challenge for long-term protection. In other cases, the resources to ensure protection in the long term may be lacking.					
4.3	Mitigation restricted to project site There can be limited logistical ability for a proponent to go off-site to implement mitigation, even if it makes sense for broader ecological objectives.					
4.4	Other ____________					

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	Raised By			Importance Score (1-5)	Comments
		Local / Municipal	Provincial	Federal		
Science & Data						
5.1	Vague terminology and concepts					
	Concepts and terminology are vague and difficult to quantify, operationalize or implement (e.g., ecosystem approach, cumulative effects, biodiversity, offsets). There is a need to clarify what these mean and how they can be measured.					
5.2	Disconnect between theory and practice					
	The practitioners' community is not routinely part of academic advances in EIA and it can be difficult to keep up to date with the more advanced methods and tools. Science changes more quickly than government organizations can update their plans and programs.					
5.3	Weak data and data management systems					
	There is currently a lack of integrated data management systems to support decision making. Need broad-based information availability, fed by consistent monitoring, and supported with institutional arrangements that cross jurisdictions. Sources of information and quality of baseline data is often lacking. Data is expensive. More regional-scale studies and better availability of regional information is needed.					
5.4	Knowledge of ecological thresholds					
	There is currently little information on specific ecological thresholds, e.g., for quantifying a project's contribution to cumulative effects in a region, and at what scale these should be measured. Need these tools to make decisions easier and more defensible.					

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	Raised By Local / Municipal	 Provincial	 Federal	Importance Score (1-5)	Comments
5.5	Lack of monitoring The lack of long-term monitoring data in general, and specifically on projects that took a broader-scale approach to EIA and mitigation, limit evaluation of the success of different EIA approaches.					
5.6	Other ____________					

	Challenge These include barriers or hurdles that inhibit widespread use of landscape-level and broader-scale assessments.	Raised By			Importance Score (1-5)	Comments
		Local / Municipal	Provincial	Federal		
Social & Economic Influences						
6.1	Project costs					
	There can be a lack of buy-in on the part of the proponent, for financial reasons. Proponents generally have finite resources for EIA and want to be practical. Sometimes there is push-back in implementation.					
6.2	Lack of institutional resources					
	The capacity of agencies to promote broader approaches is limited by resources (e.g., time, money, budgets, political will) at an institutional level.					
6.3	Lack of stakeholder pressure					
	There is little incentive to implement initiatives without external stakeholder pressure. There is a need for public and advocacy group support to advance EIA.					
6.4	Changing government priorities					
	With changes in government, priorities change and create a lack of continuity for initiatives such as approaches to biodiversity, landscape and cumulative effects assessments. Pressure to balance environmental protection with jobs and economic growth can limit landscape-based initiatives.					
6.5	Other ____________					

Top 3 Challenges Please enter a corresponding number from Table 1 or, if appropriate, additional information.	
1.	
2.	
3.	

Additional Notes / Comments:

Table 2. Summary of opportunities for broader-scale approaches and landscape analysis and EIA, grouped by theme.

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	**Raised By** Local / Municipal	Provincial	Federal	**Importance Score (1-5)**	**Comments**
Biophysical						
1.1	Strategic restoration opportunities					
	Looking beyond protecting what is there on the landscape to also identifying where habitat is lacking and developing strategic restoration objectives would provide a more robust foundation for protecting future biodiversity.					
1.2	Other _____________					
Planning						
2.1	Proactive planning					
	Developing strong early-phase guidelines can promote proactive planning on the part of the proponent or responsible agency. Early planning can best influence landscape-level decisions (e.g., involving stakeholders earlier in the process, identifying what should be protected vs. developed vs. flagged for more information required).					
2.2	Leverage partnerships					
	Leveraging partnerships between agencies, including academic collaborations, can help overcome resource constraints. Examples include working with experts and conservation agencies on things like compensation and long-term management of offset lands and identifying wildlife corridors.					

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	Raised By			Importance Score (1-5)	Comments
		Local / Municipal	Provincial	Federal		
2.3	Big picture planning					
	Developing more strategic approaches to EIA and planning that look beyond a single project and single-project mitigation to approaches such as conservation funding and banking can aid in promoting larger conservation objectives. Requires a paradigm shift in thinking, but may be more effective for conservation with the same time and money. Can achieve multiple benefits through broad plans that incorporate multiple strategies (e.g., Ontario's pollinator strategy, wetland strategy, biodiversity strategy).					
2.4	Alternative EIA models					
	Considering different models of EIA, such as a focus on processes and flows rather than ecosystem components, can promote regional EIA approaches. Encouraging regional study results to be incorporated into project EIA, in advance of and to inform project EIA, can also support broader-scale approaches.					
2.5	Other _____________					

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	**Raised By**			**Importance Score (1-5)**	**Comments**
		Local / Municipal	Provincial	Federal		
Policy & Institutional Systems						
3.1	Strengthened policy language					
	Drafting clear policy that requires no net loss and/or net environmental benefit from projects would help agencies and regulators. Developing mutually supporting language in policy documents that better integrates the EIA process with broader initiatives such as regional planning and natural heritage system strategies would help to level the playing field between jurisdictions. Emphasize system-wide impacts and include these in permitting and authorization processes.					
3.2	Bottom-up cultural shifts					
	Encouraging bottom-up shifts in organizational culture, including education and learning through success stories and examples, would promote broader-scale approaches.					
3.3	Geography-based expertise					
	Developing expertise for more geography-based vs. project-based approaches to EIA would help build institutional capacity for landscape and broader-scale approaches. Building collective knowledge about a geography and the stressors and ecology in that area is important so when a project is proposed there is already a body who has thought through some of the issues.					
3.4	Biodiversity banking					
	Developing a biodiversity credit system similar to existing international initiatives could benefit biodiversity at broader scales.					

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	Raised By Local / Municipal	 Provincial	 Federal	Importance Score (1-5)	Comments
3.5	Other ____________					
Practicalities & Implementation						
4.1	Pre-construction habitat offsets Requiring habitat compensation and offsets to be implemented prior to project construction would promote broader biodiversity conservation initiatives.					
4.2	Proponent incentives Implementing incentives for the proponent, such as timeline certainty, payments or tax breaks for avoiding certain no-go areas, or fewer development hurdles in certain pre-approved areas, would promote broader regional approaches.					
4.3	Clear contracts Drafting guidelines for clear EIA and/or project contracts that lay out the expectations for information needs, long-term monitoring and/or maintenance would help with the success of broader-scale initiatives. Secure any off-site land used as compensation or offsets for the long term.					
4.4	Other ____________					

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	**Raised By** Local / Municipal	Provincial	Federal	**Importance Score (1-5)**	**Comments**
Science & Data						
5.1	Integration of available tools					
	Opportunity to take advantage of existing work in connectivity mapping and natural heritage system mapping to inform project EIA (e.g., Circuitscape mapping in Ontario). Use existing criteria from authoritative sources (e.g., Environment Canada's *How Much Habitat is Enough?*) to short-cut more detailed analyses where resources are limited.					
5.2	Multi-jurisdictional data systems					
	Create a broadly available database (e.g., open science data platform or "Nature Wiki") for agencies and the public to curate and use to inform baseline data. Develop a repository to integrate federal, provincial and municipal information, including spatial information on known and expected development areas, species distributions and observations, and scales at which species respond.					
5.3	Habitat prioritization					
	Add another layer to existing habitat maps that prioritizes those habitats according to the top locations to focus habitat improvements and what those improvements might be, for the purposes of off-site compensation and offset measures.					
5.4	Monitoring					
	Implement robust monitoring of project outcomes and measurable results to inform future decision-making and support effective spending. Collecting clear before and after data to start to build a long-term dataset, especially when it comes to mitigation like habitat restoration and offsets.					

	Opportunity These include new benefits that that might flow from landscape-level assessments, as well as specific ways or means by which broader-scale / landscape approaches might gain greater traction.	Raised By Local / Municipal	 Provincial	 Federal	Importance Score (1-5)	Comments
5.5	Other ____________					
Social & Economic Influences						
6.1	Social awareness					
	Growing awareness of complex, large-scale issues such as climate change creates opportunities to leveraging similar understanding in promoting green infrastructure and habitat networks. There is also an economic interest that can be leveraged in promoting landscape approaches for climate change resilience in terms of green infrastructure.					
6.2	Other ____________					

Top 3 Opportunities Please enter a corresponding number from Table 1 or, if appropriate, additional information.	
1.	
2.	
3.	

Additional Notes / Comments:

Table 3. Importance of broad-scale approaches in conserving biodiversity.

Importance of broader-scale approaches and analyses to biodiversity conservation			
		Importance Score (1-5)	**Comments**
A.	In general		
B.	As part of EIA processes		

Additional Notes / Comments:

Appendix C Choosing Biodiversity Indicators

Four main types of indicators were evaluated for their suitability for the modelling experiment:

- species richness
- landscape metrics
- focal species habitat suitability/population viability analysis
- connectivity/permeability assessment

Key criteria included operational simplicity, sensitivity to the type and scale of land use changes taking place in the simulated scenarios, and ecological relevance in terms of biodiversity. Simple data requirements and processing are important factors should the model be used further for evaluating regional planning (e.g., Schindler et al., 2008; Walz, 2015).

Species richness is one of the simplest univariate measures of biodiversity and is often considered a ‘common currency’ for biodiversity studies (Gaston, 2000), but it can fail to consider the ecological roles and contributions of species in communities (Morelli et al., 2018). It can also be relatively insensitive to modelled results of land use change across a large region (Hulse et al., 2000; White et al., 1997), which shows discrepancy with reality (Hulse et al., 2000). Species richness can be enhanced by including species’ area requirements to determine the suitability of a unit of habitat based on the size of the patch; however, White et al. (1997) found minimal changes when area requirements were included in the habitat suitability index. Several authors suggest that an approach based on multiple indices or metrics is a better way to assess overall diversity (Morelli et al., 2018; Walz, 2015).

Landscape metrics can be a surrogate measure for species richness (Morelli et al., 2018; Schindler et al., 2015) that is more accessible and less data-intensive especially over large areas (García-Llamas et al., 2018; Morelli et al., 2018; Schindler et al., 2008). The ecological rationale for the connection between landscape metrics and biodiversity is based on the idea that a heterogeneous landscape is expressed in a particular pattern that relates to its land cover composition and configuration. Changes in this landscape pattern change the ecological niches available for species and thus lead to changes in biodiversity (Morelli et al., 2018). Landscape changes can also affect species assemblages, by selecting for a greater abundance of generalist or specialist species (Morelli et al., 2018). Small sets of landscape metrics are typically recommended to adequately capture patterns that relate to biodiversity while avoiding misinterpretation problems associated with many correlated metrics (Inkoom et al., 2018; Schindler et al., 2008; Wei et al., 2017). Landscape metrics have been used in landscape planning for ecosystem services, biodiversity and habitat quality analysis, water quality estimation, landscape aesthetics, and monitoring (Frank et al., 2012).

Focal species habitat suitability analysis requires detailed lifecycle habitat requirements for each species (Santelmann et al., 2006; White et al., 1997), and a suitable choice of representative species. Because of the greater detail in terms of habitat suitability requirements, a more accurate picture of population viability of the species can be assessed (White et al., 1997). It can thus achieve quite detailed outputs and can be a powerful tool to compare alternative plans and relative extinction risks among species (Reed et al., 2002). However, it comes at the expense of operational simplicity, as data requirements are heavy (Reed et al., 2002) and model validation is critical (Larson et al., 2004).

Finally, the rationale behind connectivity or permeability assessment to evaluate biodiversity is that it represents a key process by which biodiversity is maintained, through the dispersal and movement of individuals among populations (Calabrese and Fagan, 2004). However, there are important methodological considerations such as choosing for which species' connectivity should be evaluated, and at what scale(s). Different types of connectivity analysis measuring structural, potential and actual connectivity can be differentiated by the data requirements and level of detail (Calabrese and Fagan, 2004). Circuit theory (e.g., McRae et al., 2008) and graph theory (e.g., Pascual-Hortal and Saura, 2006) are two popular techniques for assessing connectivity and permeability, but require focal species for assessment and expert knowledge of species dispersal and thus come with similar challenges as focal species habitat suitability analysis.

Based on the need to balance the criteria of simplicity, sensitivity, and ecological relevance, a set of landscape metrics was chosen for the current study.

Appendix D Technical Details of the Envision Model

Envision uses a process-based approach to simulate the decisions and actions of agents (individuals, institutions, or group of actors) that interact with each other and the land to affect changes in land use, leading to emergent landscape patterns (Bolte et al., 2006; Bousquet and Le Page, 2004; Matthews et al., 2007). This is a predominantly bottom-up framework in which landscape changes emerge through individual actions or decisions, although top-down constraints may also be employed. An agent-based approach allows for focus on the decision process and criteria used by the decision-making agents, who for the purposes of this study represented regulatory decision-making bodies receiving EIA information. As individual decisions are made by the agents, cumulative changes in landscape patterns emerge over time, simulating the impacts of project-by-project decision making on the broader landscape.

Envision represents the landscape as a GIS-based polygon coverage where each spatial polygon in the landscape has several attributes associated with it such as LULC, population characteristics, zoning regulations, environmental characteristics, and other relevant information. These polygons, termed Integrated Decision Units (IDUs), form the base unit on which decisions are made. IDUs represent the smallest unit that can be changed to another LULC class in the project decision-making process. Clusters of adjacent IDUs of the same LULC class form patches in the landscape, whether habitat patches (i.e, forest, grassland, and wetlands), large aggregate extraction operations, extensive crop fields, or developed urban land. These clusters form the structure of the landscape.

Within this platform, the study area was divided into approximately 112,000 IDUs of approximately 8 ha each (the size of an average individual crop field). The IDUs were derived from previous work in the study area by Agriculture and Agri-Food Canada (AAFC), Environment and Climate Change Canada, Carleton University, Oregon State University and the International Institute for Sustainable Development for the Farms to Regions (F2R) project, which looked at drivers of change in an agricultural region and developing decision support tools to aid strategic planning and adaptive policy development at the landscape level (Waldick et al., 2015). The F2R project identified the LULC for each IDU based on data from the Southern Ontario Land Resource Information System (SOLRIS) 2011 (for wetlands, hedgerows and developed land) and AAFC's Annual Crop Inventory 2011 for all other LULC classes (Waldick et al., 2015; Zaytseva, 2017). Data required to populate new and updated IDU attributes were obtained from open-access census data and the Land Information Ontario data repository, maintained by the Ontario Ministry of Natural Resources and Forestry. Each IDU was populated with the new attributes according to whether it overlapped with 50% or more of the relevant category. For example, if 75% of an IDU overlapped spatially with a provincially significant wetland (PSW), that IDU was marked as a PSW. In a similar manner, IDUs were populated according to 2016 Census Dissemination Area data, assigned zoning categories, and other attributes. A summary of each attribute used in the model and its data source is provided in Table 24, along with the corresponding model components – projects and scenarios – that made use of each attribute. Note that the Deregulation scenario is not listed in the table, as this scenario did not include any additional development rules or environmental decision-making policies, and all projects were permitted to be developed as proposed.

The specifics of the models created to auto-generate projects for assessment in the scenarios are detailed in Table 25.

D.1 Data Sources used in the Envision Model – Eastern Ontario Study Area

Table 24 provides the data and sources used to populate each of the Integrated Decision Unit (IDU) attributes used in the Envision model for the eastern Ontario study area. The Table also shows the corresponding model components – projects (potential land use changes) and scenarios – that used each IDU attribute.

Table 24. Data and sources used to populate the IDU attributes, and the simulated development projects and scenarios that used them

		Projects			Scenarios				
Data Type	**IDU Attributes**	**Urban expansion**	**Aggregate extraction**	**Habitat restoration**	**Status Quo**	**Growth Regulation**	**Landscape Regulation**	**Landscape Orientation**	**Data Sources**
Land Use/Land Cover (LULC)	LULC A LULC B	✓	✓	✓	✓	✓	✓	✓	Farms to Regions (F2R) geodatabase, based on the Southern Ontario Land Resource Information System 2011 and Agriculture and Agri-Food Canada Annual Crop Inventory 2011
	Built-up areas	✓	✓		✓	✓		✓	Land Information Ontario (LIO) – Built-Up Area (2016)
Hydrology	Watershed boundaries						✓	✓	F2R geodatabase (2011)
	Streams (1st to 3rd order)						✓	✓	LIO – Ontario Integrated Hydrology Enhanced Watercourse, Southeast Area (2017)
Natural Heritage Systems	Provincially significant wetlands (PSWs)				✓		✓	✓	LIO – Wetlands (2018)
	Significant valleys and woodlands				✓		✓	✓	LIO – Significant Ecological Area (2018)

		Projects			Scenarios				
Data Type	**IDU Attributes**	**Urban expansion**	**Aggregate extraction**	**Habitat restoration**	**Status Quo**	**Growth Regulation**	**Landscape Regulation**	**Landscape Orientation**	**Data Sources**
Natural Heritage Systems (continued)	Significant wildlife areas				✓		✓	✓	LIO – Algonquin to Adirondack Landscape Analysis, Natural Heritage Information Centre (2016)
	Areas of Natural and Scientific Interest (ANSIs)				✓		✓	✓	LIO – ANSI (2016)
Population	Population density	✓							Census Canada, Carleton University GIS Library (2016)
Soils	Canada Land Inventory soil class			✓					F2R geodatabase, based on Soil Landscapes of Canada (2011)
Transportation	Roads	✓	✓						LIO – Ontario Road Network Road Net Element (2017)
Zoning	Aggregate sites		✓						LIO – Aggregate Site Authorized Active & Inactive (2016)

		Projects			Scenarios				
Data Type	**IDU Attributes**	**Urban expansion**	**Aggregate extraction**	**Habitat restoration**	**Status Quo**	**Growth Regulation**	**Landscape Regulation**	**Landscape Orientation**	**Data Sources**
Zoning (continued)	Population capacity	✓							F2R geodatabase – Ottawa Zoning (2016); City of Ottawa – Official Plan and Master Plans, Zoning By-Law (2016)
	Protected areas	✓							LIO – Crown Land Use Provincial (2016); Natural Heritage Values Area (2018)

D.2 Simulated Development Projects used in the Envision Model

Table 25 describes the three models created within Envision to simulate projects, representing potential land use changes.

Table 25. Development projects simulated in the Envision model

Project	Model Description
Urban expansion	Projected population growth rates for the three counties were the drivers of urban development projects. Population growth projections for 2017-2041[1] were used to determine linear rates of growth (1.42% for Ottawa, 0.58% for PR, and 0.08% for SDG). Within the City of Ottawa, new population was allocated to IDUs based on the population capacity associated with current zoning regulations, ranging from no capacity in areas zoned for leisure or industrial uses, to 6-12 people/ha in rural and rural residential areas, to 150-500 people/ha in higher density development zones[2]. Within the predominantly rural counties of PR and SDG, population was allocated to IDUs based on a simplified designation of IDUs into two categories, urban or rural. Urban IDUs were defined as those within a currently built-up area[3] and assigned a population capacity of 82 people/ha, while the remaining rural IDUs were assigned a population capacity of 6 people/ha[4]. Any IDU within a Provincial Park was automatically assigned a population capacity of zero, meaning it would be exempt from urban growth. New population allocations were soft-weighted towards existing roads, as it was assumed that housing would follow existing infrastructure. As the population of an IDU approached a density of 10 people/ha, the land use of that IDU would transition to an LULC B of “Built-pervious”; as population increased to a density of 50 people/ha[5], the land use again would transition to an LULC B of “Built-impervious”.
Aggregate mining	Aggregate extraction was driven by population growth and the associated requirement to build and maintain housing and infrastructure. For every 40,000 people in a given year, approximately 1 ha of land underlain by suitable deposits was required[6] and would transition to “Extraction”. Transition of an IDU to aggregate extraction was only proposed where land was zoned or licensed for extraction. Any new extraction areas were soft-weighted adjacent to existing extraction sites, in proximity to existing roads, and in proximity to population centres due to the high costs associated with aggregate transport.
Habitat restoration	There are several Conservation Authorities in Eastern Ontario working towards conservation and restoration of forests, grassland and wetlands. To simulate this activity in the model, targets of 30 ha of forest, 4 ha of wetland, and 2 ha of grassland[7] were proposed for restoration each year from marginal farmland.

Project	Model Description
[1]Ontario Population Projections by Census Division, 2017-2041 Reference Scenario (Ontario Ministry of Finance, 2018)	
[2]Population capacity was calculated using the average density targets in number of units per hectare for different land use zones, multiplied by the projected average household size (persons per unit). All data was obtained from the public City of Ottawa website and municipal planning documents and bylaws.	
[3]As per the SOLRIS definition of built-up area, which means an anthropogenic linear structure frequency of >4 per hectare.	
[4]Calculated using housing densities in the PR Official Plan available on the public PR website: 35 units/ha for urban policy areas and 2.5 units/ha for rural policy areas (based on minimum lot size).	
[5]Based on the approximate transition points between rural to low-density residential and low- to high-density residential, and the SOLRIS definitions of pervious (>80% green space per 0.5 ha) and impervious (<80% green space per 0.5 ha) development.	
[6]Calculated using an average of 12 tonnes/person per year of new (non-recycled) aggregate (OSSA, 2015), consisting of a 50/50 mix of sand-gravel and stone (TOARC, 2018) with an average density of 2.12 tonnes/m^3 (OGS, 1998), and assuming an average quarry depth of 20 m (MHBC Planning, 2009).	
[7]Averaged from numbers obtained from personal communication with Mississippi Valley Conservation Authority (6 September 2018), Rideau Valley Conservation Authority (20 September 2018), and South Nation Conservation Authority (20 September 2018).	

Appendix E Modelled Scenario Results by Indicator

E.1 Habitat Diversity

Habitat diversity was measured using Shannon's Diversity Index (SDI), which takes into account both the richness and evenness of habitat types (McGarigal and Marks, 1995). The LULC A level had only three possible broad habitat types: forest, grassland, and wetland. At the LULC B level there were a total of ten potential habitat types: four forest types, grassland, and five wetland types. SDI of the habitat types in the landscape increased from 2016 to 2055 but showed little variation between scenarios (Figure 13). Regional biodiversity tends to increase with increasing habitat diversity (Fahrig, 2001).

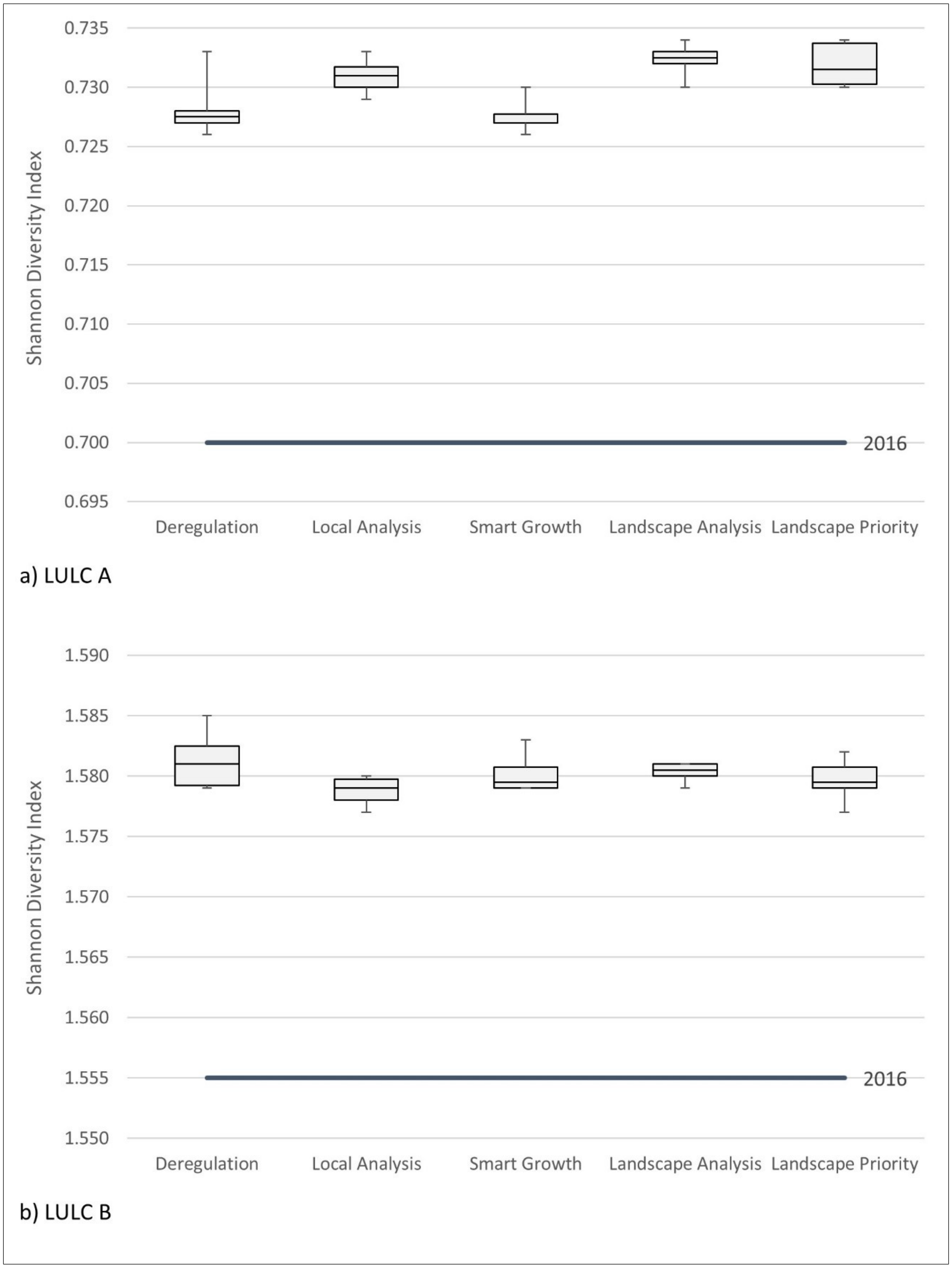

Figure 13. Boxplots comparing habitat diversity for the five scenarios

E.2 Patch Size

Mean patch size (MPS) of grassland, forest and wetland habitats were notably different between the Development-Based Scenarios and the Regulation-Based Scenarios at both coarse (LULC A) and finer (LULC B) habitat classifications. Larger MPS tends to indicate greater potential of a landscape to support regional biodiversity; it also tends to show a positive correlation with the overall amount of habitat in a landscape (Fahrig, 2003).

MPS of grassland habitat decreased in the Development-Based Scenarios and increased in the Regulation-Based Scenarios. Since grassland was defined the same way at both the LULC A and LULC B levels, a single boxplot is shown in Figure 14. Similarly, forest MPS increased in all scenarios but showed a greater increase in the Regulation-Based Scenarios (Figure 15). Interestingly, wetland MPS at a coarse habitat classification level increased in all scenarios, but decreased at a fine habitat classification level with a greater decrease shown in the Development-Based Scenarios (Figure 16).

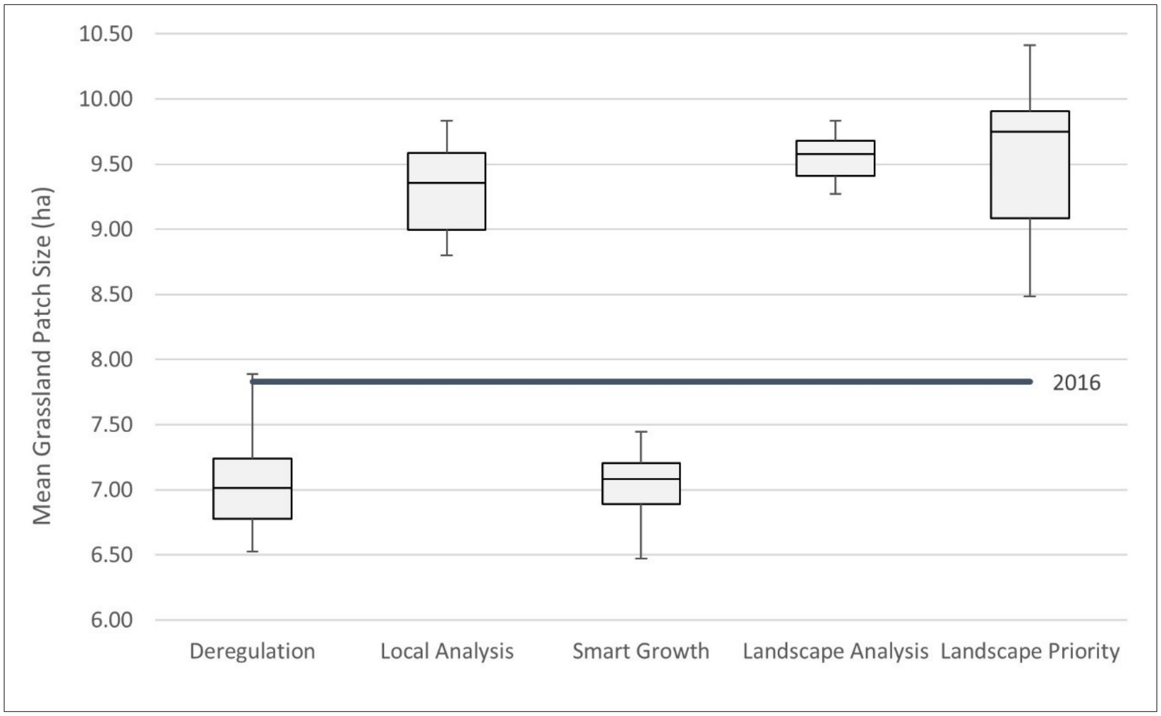

Figure 14. Boxplot comparing grassland patch size for the five scenarios

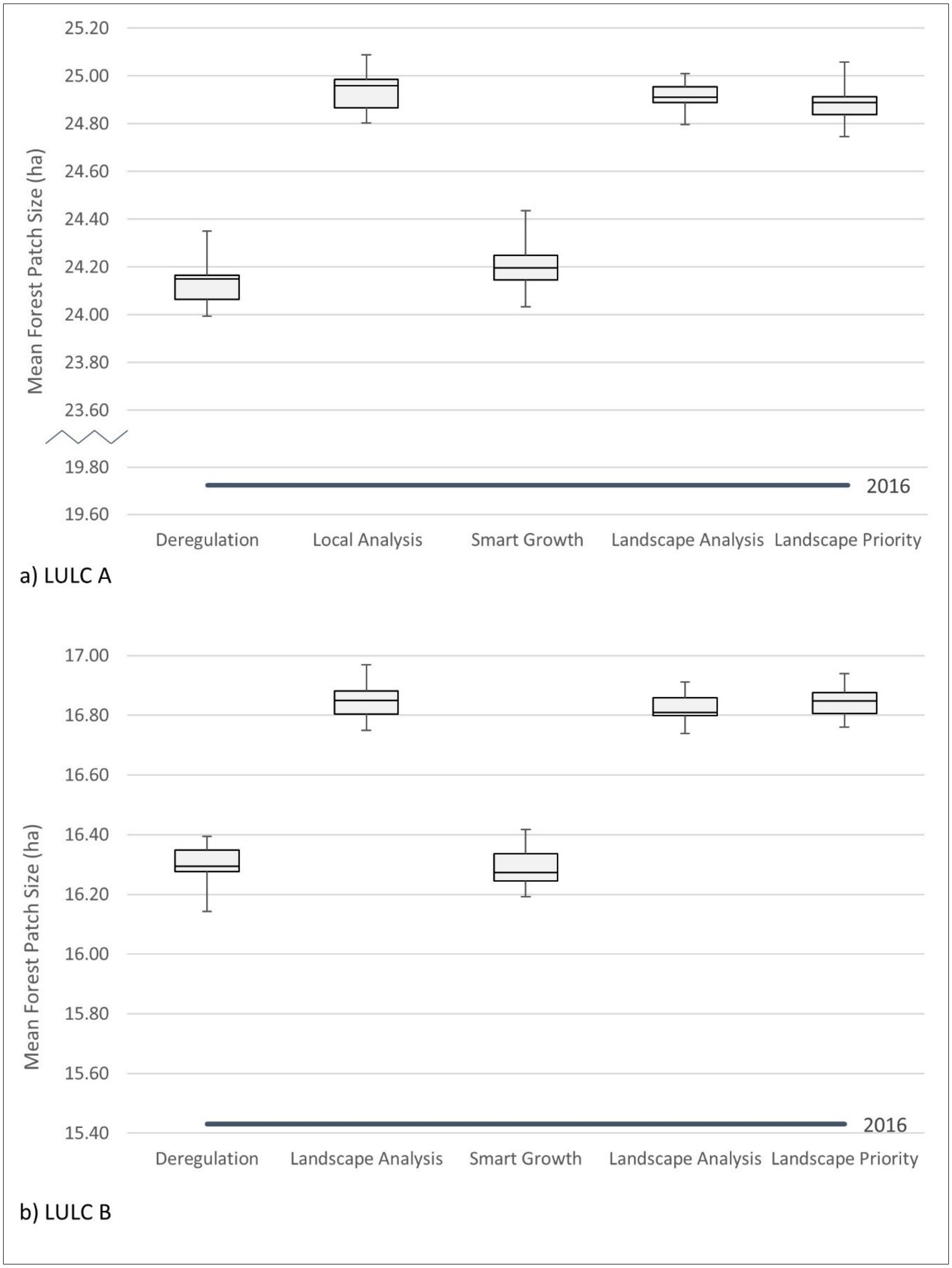

Figure 15. Boxplots comparing forest patch size for the five scenarios

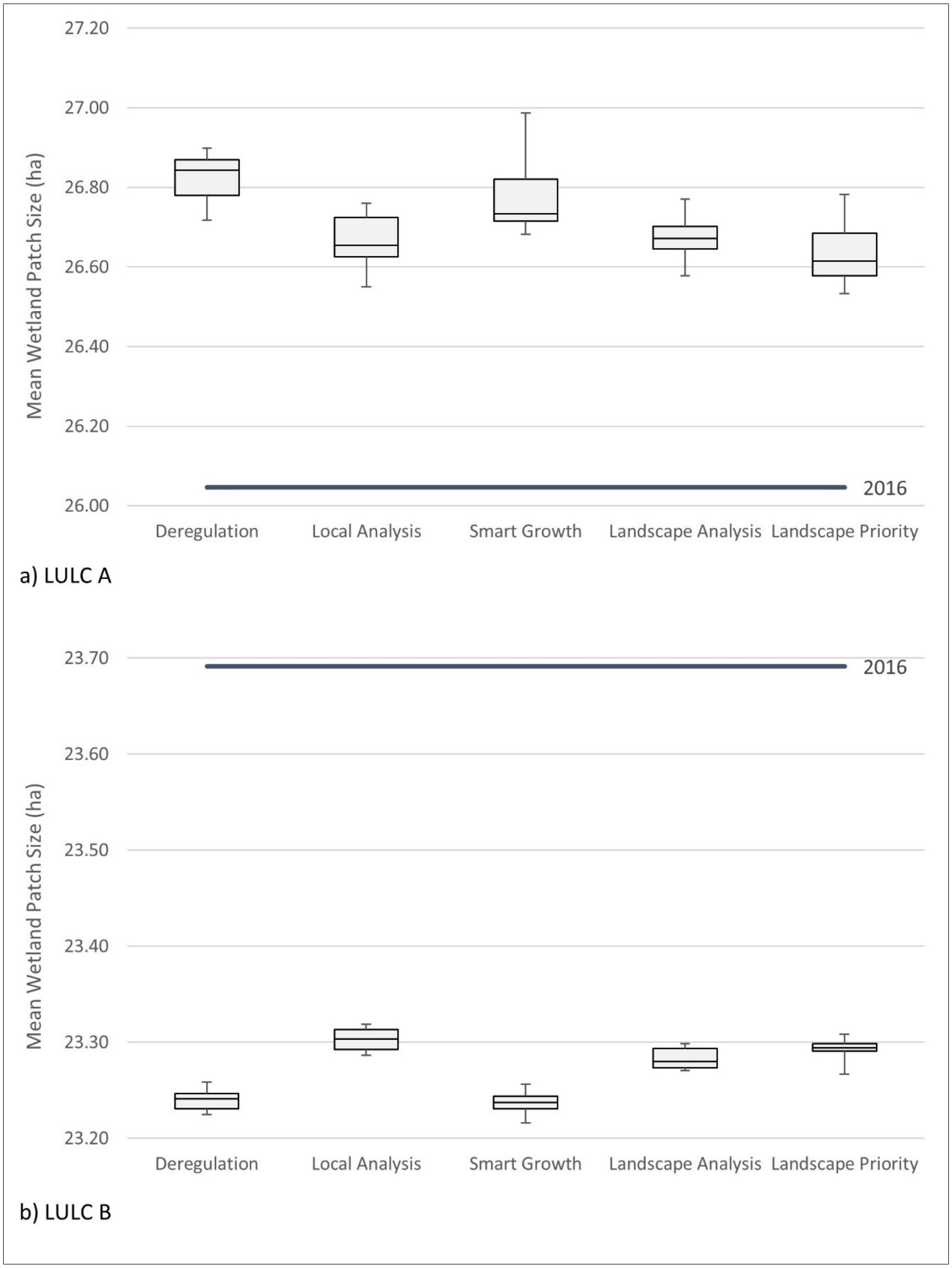

Figure 16. Boxplots comparing wetland patch size for the five scenarios

E.3 Shape and Edge

Mean shape index (MSI) was used as a metric for the shape and edge indicator. MSI of grassland (Figure 17) and forest (Figure 18) was larger in all scenarios but showed little difference between scenarios. Since a smaller MSI (closer to 1) indicates more regular average patch shape, with associated larger interior-to-edge habitat ratios, larger MSI values indicated greater amounts of edge relative to interior habitat with concomitant decreases in the potential of a landscape to support regional biodiversity (Lockhart and Koper, 2018; Morelli et al., 2018).

Wetland MSI depended on the level of habitat classification: at a coarse habitat classification (LULC A) it increased in the Development-Based Scenarios (indicated decreased potential of the landscape to support regional biodiversity) and showed no significant change from 2016 in the Regulation-Based Scenarios. At a fine habitat classification level (LULC B) wetland MSI decreased to a similar degree in all scenarios, indicating increased potential of the landscape to support biodiversity (Figure 19).

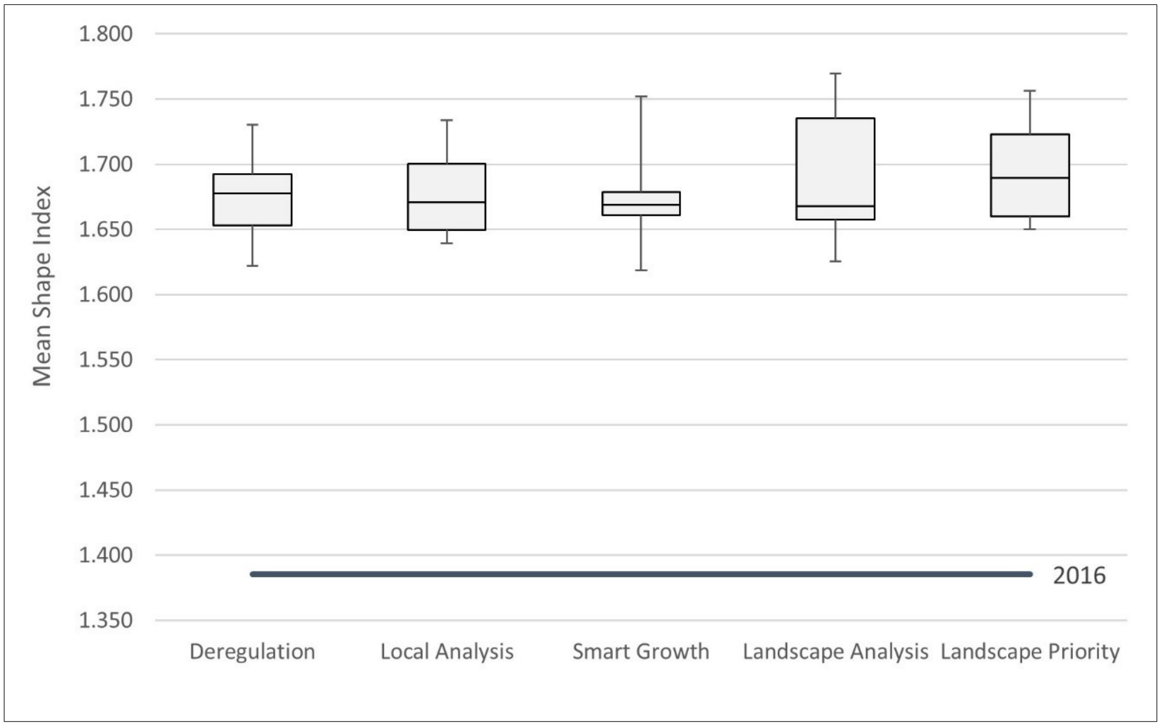

Figure 17. Boxplot comparing grassland shape and edge for the five scenarios

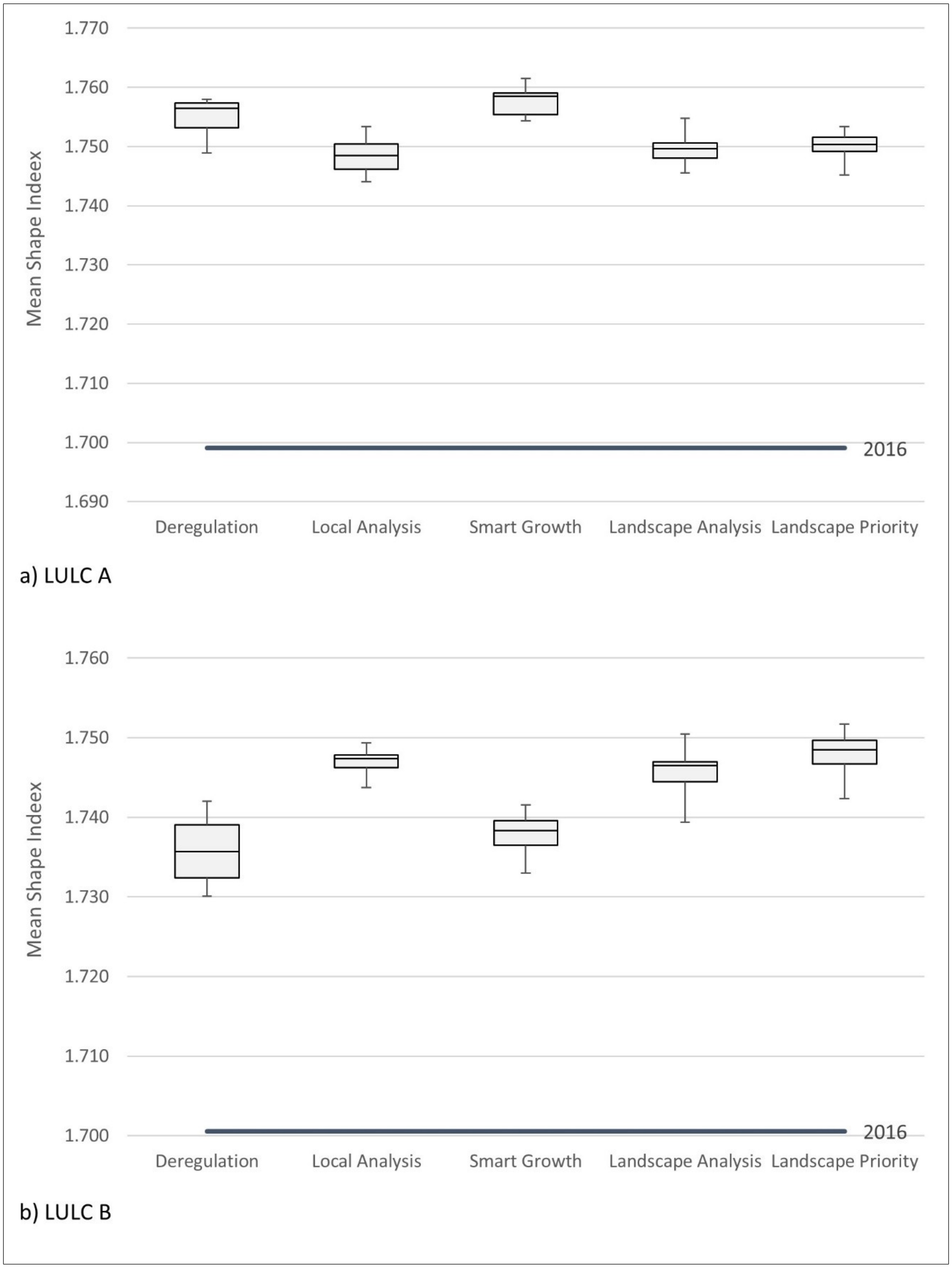

Figure 18. Boxplots comparing forest shape and edge for the five scenarios

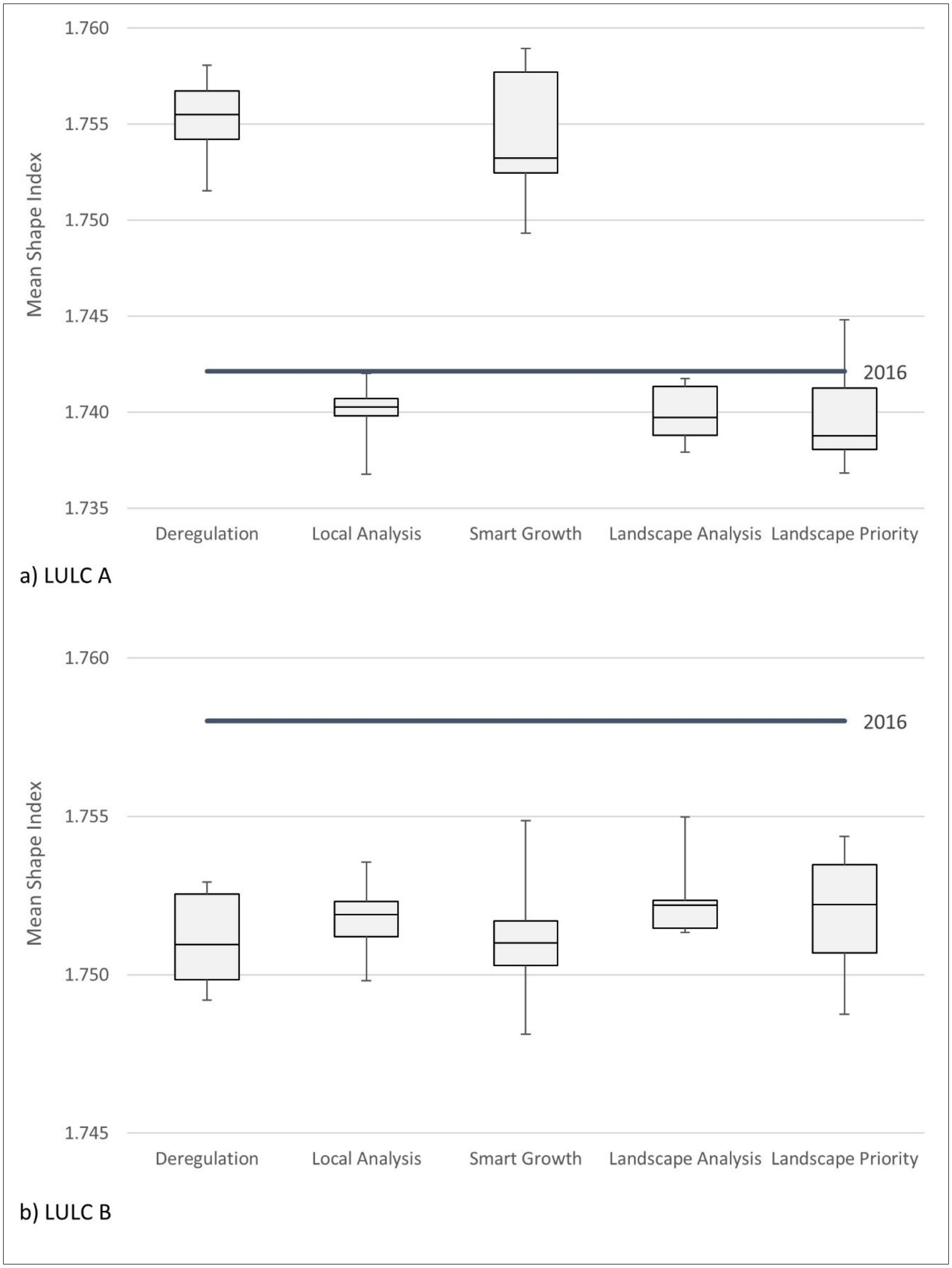

Figure 19. Boxplots comparing wetland shape and edge for the five scenarios

E.4 Connectivity

Connectivity was measured using effective mesh size (MESH) as a metric. Like MPS, MESH showed sensitivity in differentiating between scenarios. MESH of grassland increased in the Regulation-Based Scenarios, indicating a greater degree of habitat connectivity unfragmented by anthropogenic features and therefore increasing the potential of the landscape to support biodiversity (Di Giulio et al., 2009; Girvetz et al., 2007; Roedenbeck and Köhler, 2006). No significant differences in grassland connectivity were seen between 2016 and 2055 for the Development-Based Scenarios (Figure 20). Forest connectivity, on the other hand, increased in all scenarios, showing a greater increase in the Regulation-Based Scenarios (Figure 21). Connectivity of wetlands at a coarse (LULC A) habitat classification level also increased in the Regulation-Based Scenarios but showed no significant change from 2016 in the Development-Based Scenarios. At a fine (LULC B) habitat classification level, wetland connectivity decreased in all scenarios, showing a greater decrease in the Development-Based Scenarios (Figure 22).

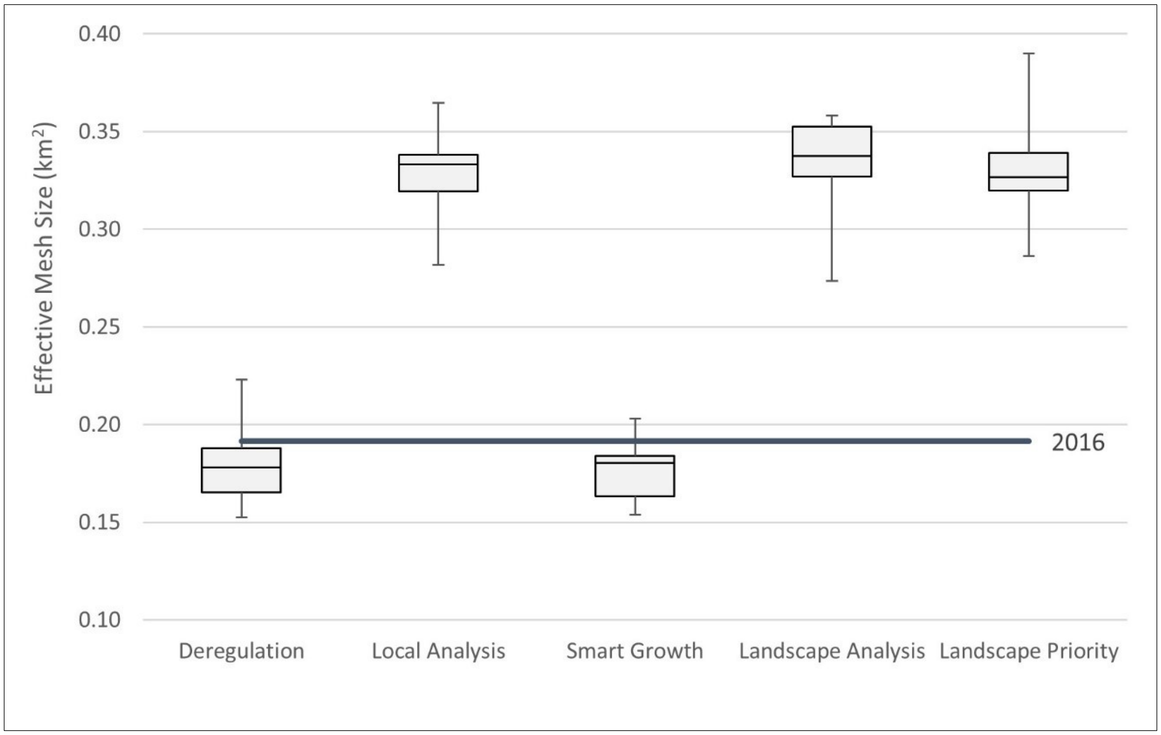

Figure 20. Boxplot comparing grassland connectivity for the five scenarios

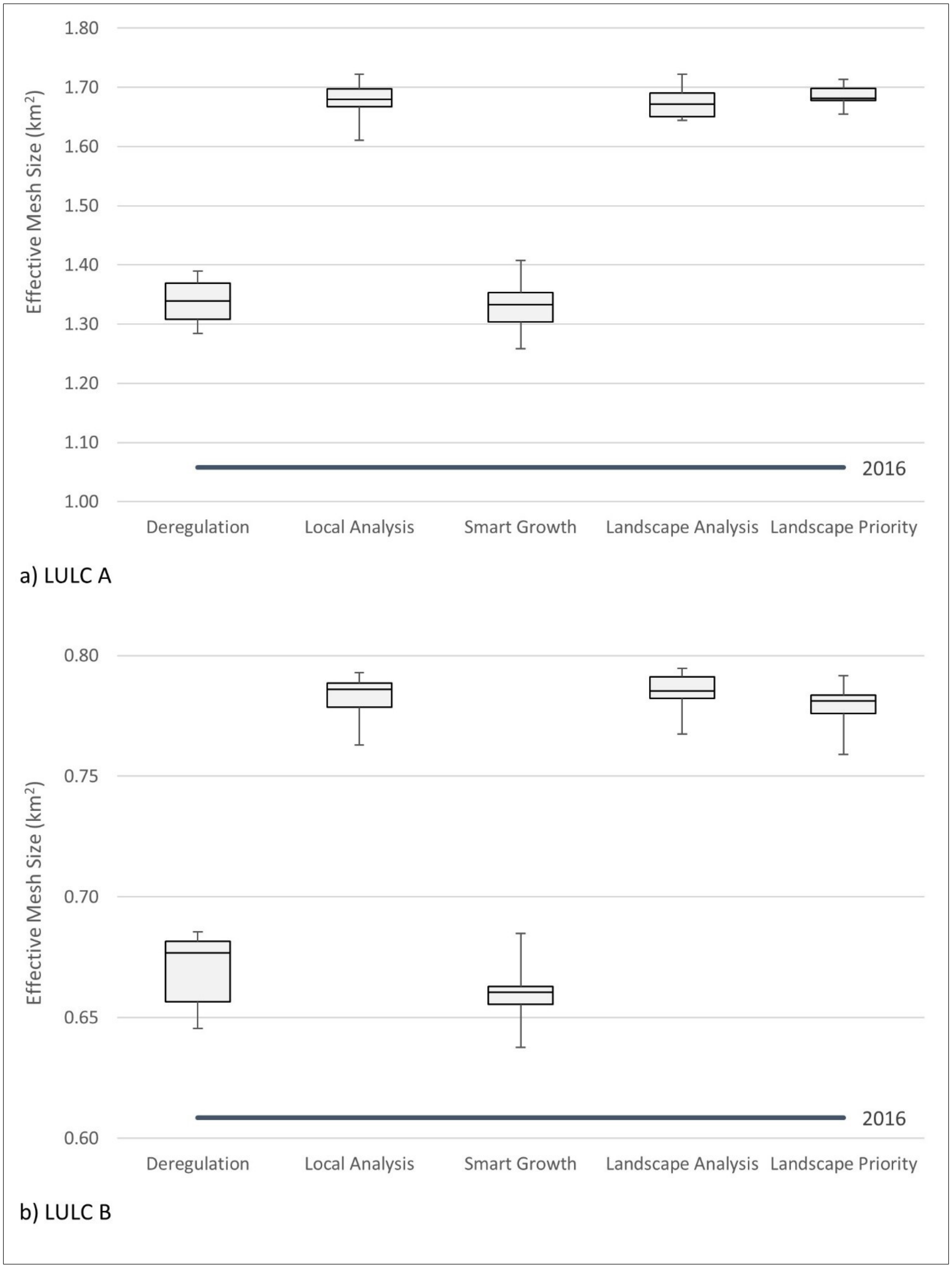

Figure 21. Boxplots comparing forest connectivity for the five scenarios

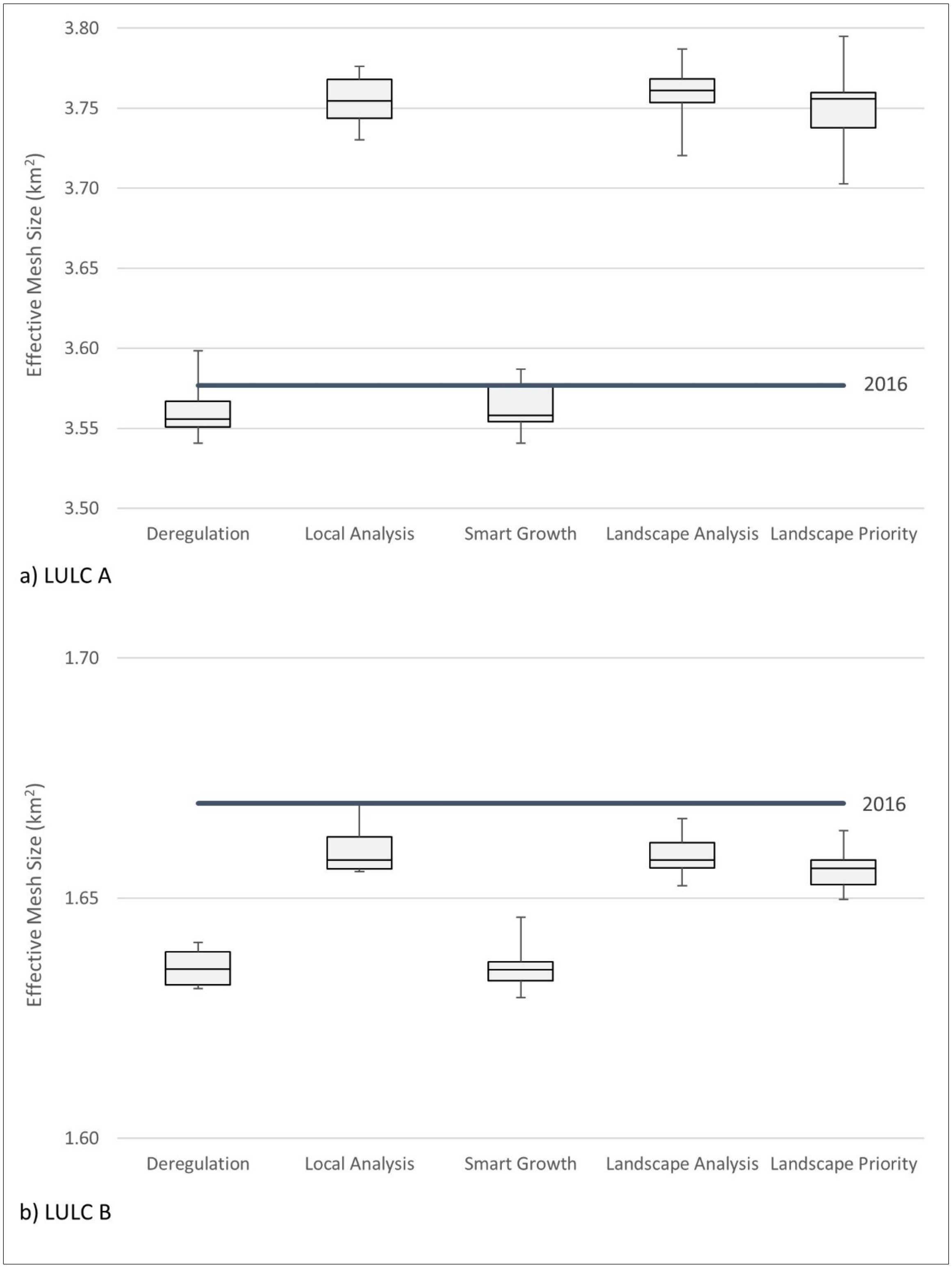

Figure 22. Boxplots comparing wetland connectivity for the five scenarios

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