Landscape Patterns Environmental Quality Analysis

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O2 PLANNING + DESIGN

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AENV – Alberta Environment

AESRD – Alberta Environment and Sustainable Resource Development

BCEAG – Bow Corridor Ecosystems Advisory Group

CAESA – Canada-Alberta Environmentally Sustainable Agriculture

CEC – Commission on Environmental Cooperation

EPA –Environmental Protection Agency (USA)

IBI – Index of Biotic Integrity

IS – Impervious Surface

NRV – Natural Range of Variability

USDA – United States Department of Agriculture

WPAC – Watershed Planning and Advisory Council

WSG – Watershed Stewardship Groups

Executive Summary

The cumulative impacts of human activities on the environment have driven extensive research to identify guiding metrics of environmental quality for the purposes of planning, monitoring, and resource management. Human land uses leading to habitat loss, fragmentation, and changes to watershed hydrology and water quality are of central concern in this effort. The quality of various ecosystem components, including land, water, and biodiversity have been studied across a wide range of landscapes and scales, however a comprehensive and widely accepted suite of metrics and targets for environmental quality have rarely been clearly defined.

The relationships between human patterns on the landscape and resulting environmental quality have been well documented in the disciplines of landscape planning, environmental planning, and landscape architecture. Landscape pattern analysis is based on the premise that there are indispensible patterns in any landscape that, if maintained, will conserve essential landscape processes. These landscape processes, in turn, strongly influence water quality, biodiversity, and other valued environmental components. Concise pattern-based indicators and targets for environmental quality can inform cumulative effects management and sustainable development by providing measurable criteria for how resource extraction and other human activities can be managed on the landscape in concert with ecosystem function.

The diversity of local conditions and the range of ecosystem components and associated indicators can be overwhelming, making clear assessments of environmental indicators challenging. Due to budget, time, and logistical constraints, it is virtually impossible to monitor all ecosystem components comprehensively, particularly on a regional scale. In addition, the multivariate and multi-scale nature of landscape function can make it difficult to demonstrate causation between specific actions and observed conditions. Few universal rules apply to assessments of landscape pattern and environmental function. However, information from individual landscape studies can be gathered and distilled into a body of landscape pattern indicators, thereby providing a more holistic approach to informing assessment and monitoring across various scales and ecosystem components.

With this in mind, landscape planning must draw from studies conducted under similar conditions in order to ensure that relationships identified in case studies are relevant and applicable to place-based decision making processes in western Canada and the coterminous United States. Land use planners must conduct an effective triage to identify which indicators are most relevant to assess and manage the impacts of land use decisions. The choice of indicators will depend on the scale of land-use planning, the intensity and nature of human land uses, and the environmental characteristics of the landscape.

Associated with this report, an accompanying searchable database provides users with an accessible interface through which specific findings from the 172 publications can be identified and applied in context. Importantly, the database has been made searchable by scale (mesoregional through site), location, and a broad range of keywords pertaining to the ecological process, taxa, or species in question. Formatted in this way, the database represents a collection of empirically based planning tools that may be applied to planning exercises at a variety of scales, and in many regional contexts.

This report aims to serve as a guide to understanding and harnessing the potential of landscape metrics as indicators of environmental quality. The goal therefore is to facilitate better integration of ecological knowledge into land use and land management decision making, by providing succinct and recognizable characterizations of landscape pattern/process relationships across a broad spectrum of North American environments. Accompanied by a database of findings from significant studies, the contents of this report can help provide land use managers with systematic, defensible tools intended to be applied in a wide range of planning projects, including:

- Regional cumulative effects planning and management in Alberta

- Sub-regional federal Crown land planning including the development of a Land Management Framework for CFB Suffield
- Trans-boundary regional planning (e.g., Crown of the Continent ecosystem)
- Multi-regional biodiversity conservation planning
- Basin-level integrated watershed management planning in Alberta for the Watershed Planning and Advisory Councils (WPACs)

1. Introduction and Concepts

This section provides a brief project overview, an introductory description of the need for this study, highlights the theoretical foundations of landscape ecology, and provides background information on landscape targets and thresholds.

1.1 Project Overview and Report Structure

This report summarizes findings from published literature identifying significant relationships between land use patterns and thresholds of environmental quality. In an effort to ensure applicability to landscape management in Western North America, the vast majority of publications were restricted to studies undertaken in Western Canada and the Western coterminous United States.

Titles and abstracts of over 650 publications were scanned to determine if they provide specific information on the relationships between landscape pattern and environmental quality within the geographic scope of the study. Of these papers, a total of 172 (26%) were chosen for closer examination. These selected papers are the foundation of this report and the accompanying landscape pattern database.

Intended users or audiences for this report include, but are not limited to:

- Provincial authorities and stakeholders undertaking regional cumulative effects planning and management in Alberta
- Watershed Planning and Advisory Councils (WPACs) undertaking basin-level Integrated Watershed Management Plans under the *Water for Life* strategy
- Watershed Stewardship Groups (WSGs)
- Sub-regional federal Crown land planners and managers (i.e., to assist with the development of the new Land Management Framework for CFB Suffield)
- Trans-boundary regional planning (e.g., Crown of the Continent ecosystem)
- Multi-regional biodiversity conservation planning`

This report is structured to provide 1) a foundational understanding of the principles and theories in landscape ecology and 2) a toolbox of ecological targets and thresholds relating to two major landscape indicators of environmental quality drawn from published literature. These indicators are:

- *Land cover types*
  - Biophysical aspects of the land's surface including vegetation communities, wetlands and riparian features, and human land uses
  - This indicator category assesses the amount of different land cover types as a proportion of the landscape and related influences on environmental quality
- *Landscape configuration*
  - The sizes, shapes, distribution, and spatial relationships of land cover types in a landscape mosaic

Part 1 of this report outlines basic landscape ecological principles, patterns, and models that establish a framework for understanding the empirical findings outlined in the Landscape Indicators section (Section 2). Much of this information is based on Richard Forman's work and others who have laid the groundwork for understanding the fundamentals of landscape ecology and landscape pattern. This half of the report first introduces the need for a landscape pattern-based approach to planning (1.2), followed by a brief overview of the foundations of landscape and regional ecology (1.3). The concept of scale is introduced (1.4) as an important precursor to understanding spatial relationships of land use and land cover patterns across a wide range of landscape settings. The differences between targets and thresholds (1.5), and their appropriate uses are also explained in this section in order to equip the reader with the necessary knowledge base to understand and apply the landscape indicator targets and thresholds discussed in Section 2. Lastly, part 1 briefly covers strategies for optimizing patterns for environmental quality (1.6), largely in terms of Forman's aggregate-with-outliers principle.

Part 2 of the report synthesizes the findings generated form a literature review of 172 publications related to landscape pattern and environmental quality. The methodology and approach to the literature review, as well as criteria for publication selection, are presented to provide insight into the overall process and intent driving this project.

The information generated from this review was classified into two broad categories of landscape indicators of environmental quality: land cover indicators, and landscape configuration indicators. Publications referring to relationships between the proportion of a certain land cover type, such as wetland cover, forest cover, grassland cover, etc., and environmental quality were classified and discussed under the land cover indicators section (2.2.1). Likewise, publications focused more on the spatial arrangement or composition of landscape features, such as fragmentation, edge effects, and linear disturbances, were classified and discussed under the landscape configuration indicators section (2.2.2).

Sections devoted to landscape indicators have been further divided into subsections focused on individual cover or configuration indicator types. Each subsection provides a brief overview of the indicator followed by general principles, metrics (if applicable), specific findings derived from the literature, and a table outlining conservation targets, thresholds, or key learnings drawn from empirical studies. Quantifiable targets, thresholds, and key learnings are presented in a series of tables to highlight critical findings from the literature in an accessible manner. The report provides a comprehensive base of knowledge and set of planning tools to ensure broad scale environmental quality across a diversity of landscapes in Western North America.

1.2 The Need for a Universal Pattern-based Approach to Planning

Human beings have vastly changed the shape, pattern, and functionality of almost every landscape on earth. In an effort to curb resulting environmental impacts, researchers, planners, and natural resource managers are increasingly seeking comprehensive ways to reconcile the relationships between human land use and environmental quality. Left unmanaged, human patterns of land use have implications for the quality of ecosystem components and the provision of ecosystem services.

Given the degree to which various components comprising ecosystems are interconnected, holistic approaches to characterizing environmental quality are currently lacking. However, over the past decade, an ecological understanding of the `big picture' has emerged based on a foundation of general patterns and principles in landscape ecology. This big picture approach is founded on the idea that there are certain indispensable patterns in the landscape that, if protected, will conserve the majority of important ecological functions (Forman 1995). While all or specific attributes of an ecosystem may not be protected by these measures, the most important assets will retain their integrity if the essential general patterns are maintained.

Analyses of landscape pattern are particularly useful in areas that are data poor. In addition, using measures that are relatively easy to communicate to planning agencies and understood by local operators is critical. Landscape configuration standards are far easier to describe spatially than habitat potential maps for individual species or groups of species.

1.3 Foundations of Landscape and Regional Ecology

A landscape can be defined as a mosaic where the mix of local ecosystems or land uses recurs in similar form (Forman 1995). Landscapes can range in size from thousands of square kilometers down to a few square kilometers. Regions occur over broader scales, typically greater than several thousand square kilometers, and include a common macroclimate and/or sphere of human interest (Forman 1995). Ecology is often defined as the study of interactions among organisms and their environment. Taken together, landscape ecology can be interpreted simply as the ecology of landscapes, and regional ecology as the ecology of regions (Forman 1995).

However, with ongoing advances in both ecological research and geomatics, the definition of landscape ecology has evolved to include more nuanced aspects of ecological processes and spatial dynamics.

1.3.1 Influential landscape patterns and models

The mosaic pattern of landscape—the spatial arrangement or structure of landscape elements—determines the movements and flows between local ecosystems. In turn, movements and flows of vertebrates, water, nutrients, and humans across the landscape determine the arrangement of mosaic patterns.

1.3.1.1 *Forman's patterns of landscape change*

Landscape ecologist Richard Forman identified five main ways in which humans alter landscapes spatially: perforation, dissection, fragmentation, shrinkage, and attrition (Figure 1). These changes result in different spatial patterning of landscape elements that can alter ecological processes and the population distributions of plants and animals (Forman 1995).

1.3.1.2 *The McIntyre and Hobbs model of landscape change*

Building on Forman's patterns of landscape change, McIntyre and Hobbs have suggested that landscape modification often increases through time. Four broad classes of landscape condition can therefore be identified along a continuum of increasing human landscape modification: intact, variegated, fragmented, and relictual (Figure 2).

Similar to Forman's model, the classes represented in the McIntyre and Hobbs model correspond to different spatial patterns in the landscape. Therefore, as the extent of human land use increases, the amount of intact habitat decreases and habitat degradation increases. Likewise, as land use extent increases further, fragmented or relictual landscapes become characterized by more sharply defined patch boundaries (McIntyre and Hobbs 1999).

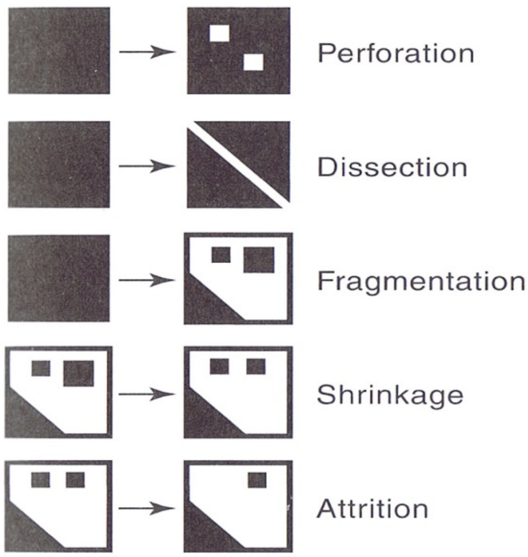

Figure 1. Five ways in which landscapes can be modified by humans *(Derived from Forman (1995) by Lindenmayer and Fischer (2006)*

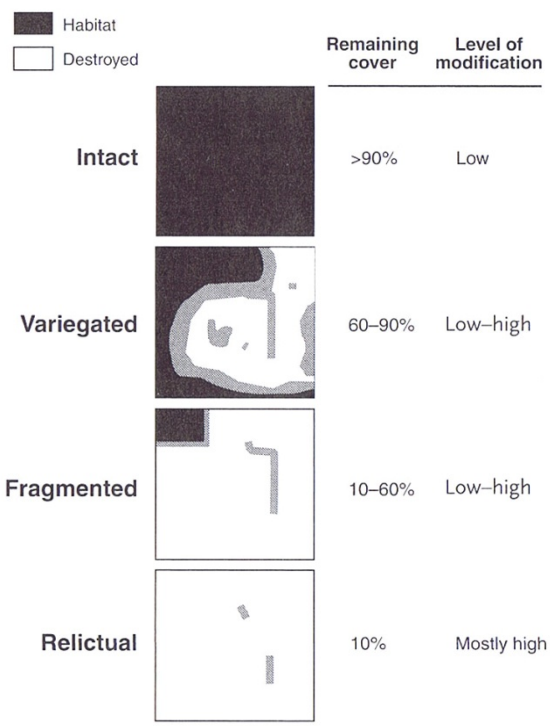

Figure 2. McIntyre and Hobbs model of landscape change *(Derived from McIntyre and Hobbs (1999) by Lindenmayer and Fischer (2006)*

1.3.1.3 *Pattern-based landscape models*

Three pattern-based landscape models are used frequently in applied landscape ecological research to broadly investigate the relationships between human-defined landscape patterns and ecosystem function. These include: the island model, the patch-corridor-matrix model, and the varigation model. Only one, the patch-corridor-matrix model, is explored here in detail because it has been so widely adopted in conservation biology (Lindenmayer and Fischer 2006).

The island model conceptualizes landscape as a collection of habitat islands surrounded by a sea of non-habitat. Its origins can be traced to *The Theory of Island Biogeography* (MacArthur and Wilson 1967). However, this model is limited in its ability to consider the influence of edge interactions with the surrounding environment—even true oceanic islands do not exist in isolation from their surrounding marine environment (Lindenmayer and Fischer 2006). In contrast, the variegation model recognizes that boundaries between landscape patch types are diffuse rather than sharp, accounting for gradual spatial changes in vegetation cover (McIntryre and Bartlett 1992).

The patch-matrix-corridor model put forth by Forman and Godron (1986) may be applied to any landscape at any scale. It describes landscapes as mosaics comprised of three principle components: patches, corridors, and a background matrix (Figure 3).

- Patches are “relatively homogenous non-linear areas that differ from their surroundings”
- Corridors are “strips of a particular patch type that differ from the adjacent land on both sides and connect two or more patches”
- The Matrix is “the dominant, most extensive and frequently most modified patch type in a landscape”, and exerts a major control over landscape and ecosystem dynamics
- Taken together as a whole, the configuration of these landscape features is referred to as a landscape mosaic

1.3.1.4 *Generalized Landscape Patterns (Indispensable Landscape Patterns)*

Indispensable Landscape Patterns are related to both configuration and connectivity and fragmentation (Figure 4). Forman (1995) suggests that the following are indispensable to provide an ecologically viable landscape:

- *Large patches of natural vegetation* that provide the benefits of species richness, habitat for interior species, and natural hydrological processes that maintain water quantity, timing, and quality downstream
- *Connectivity between large patches* in the form of wide corridors or clusters of smaller patches of natural vegetation
  - At least some of these corridors or clusters of patches should be large enough to provide interior habitat
- *Vegetated corridors along major streams and rivers* to provide for species movement, erosion control, water quality maintenance, and protection of fish habitat
  - In addition, headwater seepage areas and first order streams should receive protection in the form of near contiguous vegetative cover
- *Stepping stones of small natural vegetation patches* through altered landscapes to provide for benefits such as habitat for rare species and species movement through the matrix

Part 2 of this report synthesizes knowledge of these foundational models and concepts with empirical evidence from published studies pertaining to the landscapes of Western North America. The report aims to cohesively reflect the significant relationships, specific thresholds, and critical learnings drawn from empirical studies documented in the associated database and annotated bibliography. In this format, this report and its associated products provide an accessible means of understanding and applying pattern-based conservation targets that are supported by theory, but grounded in evidence.

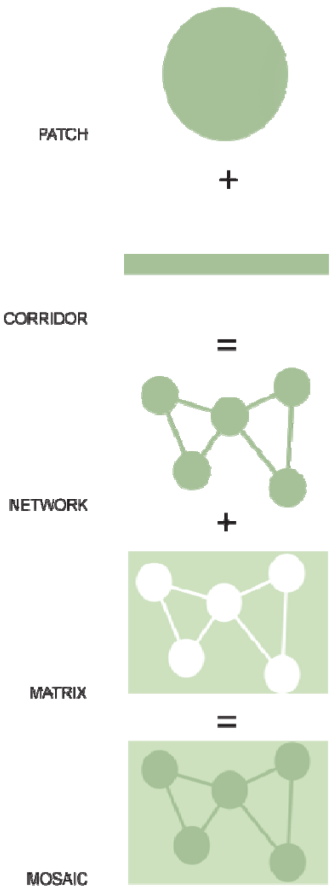

Figure 3. Patch-corridor-matrix-mosaic models *(Redrawn from Dramstad 1996)*

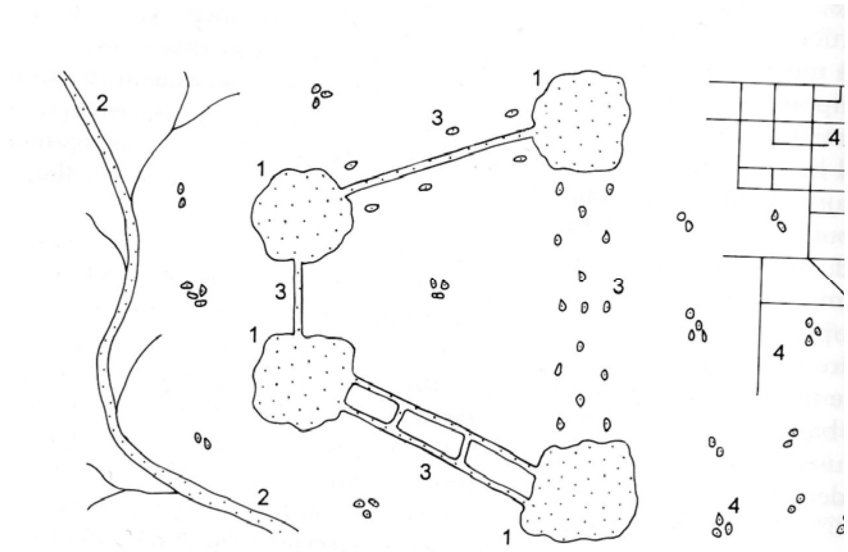

Figure 4. Indispensable landscape patterns.
1=a few large patches of natural vegetation, 2=major stream or river corridor, 3=connectivity with corridors and stepping stones, 4=heterogeneous bits of nature in the matrix *(From Forman 1995)*

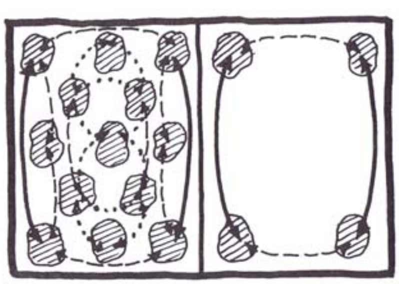

Figure 5. Animal perception of pattern and scale. A finely-fragmented landscape is perceived as continuous habitat by wide-ranging species (left). A more coarsely fragmented habitat is discontinuous to most all species, except the most wide-ranging large mammals *(From Dramstad 1996)*

1.4 The Importance of Spatial Scale

Scale refers to the spatial proportion of a mapped area. All species and ecological flows are affected at multiple scales (Lindenmayer and Fischer 2006). This section outlines the importance of various aspects of spatial scale in relation to landscape ecology.

1.4.1 Grain

Grain refers to the coarseness in texture or granularity of spatial elements composing a landscape (Forman 1995). This is often determined by the size of patches in a landscape. A fine-grained landscape is composed of small patches whereas a coarse-grained landscape is composed of larger patches. Different species perceive grain size in the landscape differently. In addition, the dynamics of ecological and watershed processes are also influenced by grain size. Therefore, planning and management must consider both the grain of the landscape and the grain-response of the ecological processes under investigation (see Section 1.4.3) (Forman 1995).

Figure 6. Example of a coarse grain landscape composed of large, regular patches of harvested forest blocks in a forest reserve west of Sundre, Alberta *(Image derived from Bing Maps, March 2013)*

1.4.2 Scale

The planet can be spatially subdivided into hierarchical categories encompassing human and ecological patterns, processes, and policies (Forman 1995). This report and associated products have drawn on mesoregional to site scale studies in an attempt to portray the influence of landscape patterns on environmental quality across many landscapes at many scales. The boundaries drawn in a hierarchy of scales can be based on many different criteria, including natural/ecological characteristics, watershed boundaries, land use patterns, or geopolitical administrative boundaries, or some combination of these. For the purposes of this project, the following common scale definitions were used for the purpose of interpreting and classifying the reviewed studies:

- ***Mesoregional** - A landscape area bigger than a region, but contained within a study area*
  - *Example: the Province of British Columbia or all the states and provinces included within the Yellowstone to Yukon region*

- ***Regional*** *- An area defined by distinct ecological , topographical characteristics occurring over broader scales, typically greater than several thousand square kilometers, and including a common macroclimate and/or sphere of human interest (Forman 1995)*
  - *Example: the Grassland Natural Region or the South Saskatchewan River Basin*
- ***Sub-regional -*** *An area at the scale of a component part of a region*
  - *Example: the Northern Fescue sub-region or the Oldman River basin*
- ***Local*** *- An area at the scale of a component or part of a sub-region*
  - *Example: the Drywood Creek watershed or the Rough Fescue-Needlegrass Plant Community Type*
- ***Site*** *- A confined study area normally restricted to the scale of a few hectares*

1.4.3 Species perspectives on scale

As with scale, different species perceive and respond to landscape patterns individualistically. For example, what may be considered a large patch with sufficient core area for a small generalist or multi-habitat species may not be sufficient for carnivores with large home ranges. Likewise, what one species perceives as a heterogeneous landscape may be perceived as fragmentation to another (Figure 5) (Tews et al. 2004).

A major question that has emerged in landscape ecology is whether to evaluate landscape change from an aggregated multi-species or single-species perspective. While it is certain that individual species respond uniquely to landscape change, it is not always practical to assess behavioural responses of all species in a given area. If the goal is to determine how the overall pattern of change affects larger assemblages of species, as is often useful from a management perspective, it is best to consider aggregate measures of multi-species occurrence (Lindenmayer and Fischer 2006).

1.4.4 The importance of watersheds as spatial planning units

Watersheds are topographically delineated areas that are drained by a stream or river system (Brooks 1991). Because watersheds have relatively well defined natural boundaries, analyzing landscape patterns and features at this level allows results to be compared across broad spatial scales, and related to stream or river water quality or quantity in a meaningful way. Multi-scale analysis can be performed by the aggregate of watersheds at several spatial scales.

1.5 Understanding Targets and Thresholds

Ecological *thresholds* represent a critical value of a stressor, ecosystem property, or landscape attribute at which species' rate of response to ecosystem change increases drastically. At this critical tipping point, there is often no turning back (O2 Planning + Design Inc. et al. 2007).

Conservation *targets* are parameters of biological health (often biotic indicators) used to assess biodiversity according to the threats and stresses brought to bear on it (Smith Fargey 2004, O2 Planning + Design Inc. et al. 2007). Conservation targets can include ecosystems, species, or groups of species. An indicator may or may not be a conservation target.

The relationships between ecological thresholds and landscape planning targets are not always clear or straightforward. Ideally, science would identify clear thresholds of landscape disturbance that should not be surpassed, and planning exercises would then set targets to ensure disturbances do not surpass the established thresholds. However, this is very difficult to achieve in practice for a variety of reasons as described below.

An ecological threshold can be defined as a critical value at which sudden, non-linear, and often irreversible change occurs. The particular appeal of ecological thresholds is the potential to identify quantitative values for indicators, beyond which irreversible changes to ecosystem structure, function, and service provision may occur. If thresholds for indicators are defined quantitatively, managers can set targets to avoid crossing these thresholds. Yet defining quantitative thresholds is a difficult task rarely achieved in practice (O2 Planning +

Design Inc. et al. 2002). The potential for sudden and irreversible change exists, but scientists and managers often struggle to quantify where thresholds lie in order to prescribe appropriate targets. Future research may reveal more information, but research on complex systems often reveals new layers of complexity and can lead to more questions than answers.

Planning exercises still require management targets to be set, even in the absence of knowledge on particular thresholds. In these cases, targets must be set by integrating existing knowledge, expert analysis, and socioeconomic considerations. Knowledge of the natural range of variability (NRV) is valuable for conditions with no easily defined threshold. In the absence of known thresholds, adaptive management frameworks are also useful in situations of complexity and uncertainty. In adaptive management, management targets are subject to explicit testing of assumptions and iterative analysis over time to refine or change targets as necessary.

Context is also particularly important when specifying desirable targets for indicators. There are no ‘right’ targets that can be applied across all landscapes. Landscapes and ecoregions all differ substantially from one another, and consequently require different targets. In addition, more pristine areas with intact natural assets require different targets than landscapes containing substantial urban, agricultural, or industrial activities. Finally, individual watersheds require different land use and land management approaches in order to work towards meeting defined instream flow needs and water quality objectives.

In many cases, existing insights on thresholds from the natural sciences must be integrated with “big picture” planning exercises, where indicators are linked to desirable outcomes based on social and biophysical criteria. A particularly relevant example for regional landscape planning is a scenario planning exercise conducted within the 600,000 ha New York/New Jersey Highlands area (O2 Planning + Design Inc. et al. 2008). Researchers established targets for various landscape indicators based on a review of the literature on the biophysical effects of land use change, combined with strategic objectives related to conserving ecosystem services such as natural water filtration, soil stabilization, groundwater recharge, and wildlife habitat support. They selected the following ‘unacceptable’ thresholds for application to scenario planning exercises: (i) >50% altered land, (ii) >10% impervious surface, (iii) >50% altered riparian zone, and (iv) <40% interior forest habitat (defined as greater than 90 m from forest edges). The particular strength of this approach is that the selected thresholds were based on “relationships between selected landscape indicators and independently measured environmental parameters”, and thus provide a scientifically defensible basis for environmental planning (O2 Planning + Design Inc. et al. 2008). A similarly rigorous approach was attempted here in screening publications relating landscape pattern indicators to measurable responses in the landscape.

1.6 Optimizing Pattern for Environmental Quality

In almost all human influenced landscapes, edge effects are increasing, making the task of preserving interior cores increasingly challenging. However, this balance may be accomplished by retaining large patches and by appropriate prescriptions for patch shapes (O2 Planning + Design Inc et al. 2002). In addition, considering Forman’s aggregate-with-outliers principle in any landscape planning process may assist in systematically optimizing landscape pattern and configuration to ensure the highest possible degree of environmental quality.

1.6.1 Forman’s aggregate-with-outliers principle

What is the optimum arrangement of land uses in a landscape? Forman’s aggregate-with-outliers principle states that land uses should be aggregated while allowing corridors and small patches of natural habitat to be maintained throughout developed areas. Outliers of human activity should also be spatially arranged along major boundaries in order to condense and minimize impacts to landscape ecological integrity (Figure 6).

According to Forman, five main landscape-ecological patterns can be incorporated into this principle:

- *Large patches* of natural vegetation protect aquifers and low order stream networks, provide habitat for large-home-range species, support viable population sizes for interior species, permit natural disturbance regimes tied to species persistence, and maintain a range of microhabitat proximities for multihabitat species.

- *Grain size*, or the average area of all patches in a landscape, affects a wide range of ecological components and processes. Coarse-grained landscapes provide large natural vegetation patches for specialist-interior species while safeguarding water quality. However, such large patches in coarse grained landscapes present movement challenges for multi-habitat species (including humans) due to the great distances one must travel across different parts of the mosaic. Fine grained landscapes predominantly support specialist species and are generally characterized by more degraded air and water quality overall. Variance in grain size between coarse and fine grain, is the most important configuration to aim for. Finer grain landscape elements are especially important near boundaries.
- *Boundary zones* are the transition areas between land uses, including the edge portions of adjacent large patches. The boundary zone is a suitable place to locate outliers of human activity, as they do not perforate or destroy the advantages of large patches in these locations.
- *Small patches of natural vegetation*, or outliers of natural vegetation, are valuable when dispersed throughout developed areas. As such, they serve as supplements to large patches by providing heterogeneity within the matrix and habitat for edge species with high population densities. They also act as stepping stones for migrating species.
- *Corridors* enhance important movements and flows in a landscape. Natural vegetation corridors foster ecological flows such as species migration and surface water movement. Corridors composed of fine scale land uses promote efficient human and multispecies movement among these land uses. Both corridor types concentrate and filter movement between large adjacent patches.

In action, the aggregate-with-outliers principle fosters landscape configurations that support genetic variation and high levels of biodiversity, as well as resiliency to disease and disturbance regimes (Collinge 2009). It can also be related to water quality, watershed health, and ecosystem services. The principle as a tool is formatted for flexibility to promote creative problem solving at the nexus of human and ecological dimensions of landscape

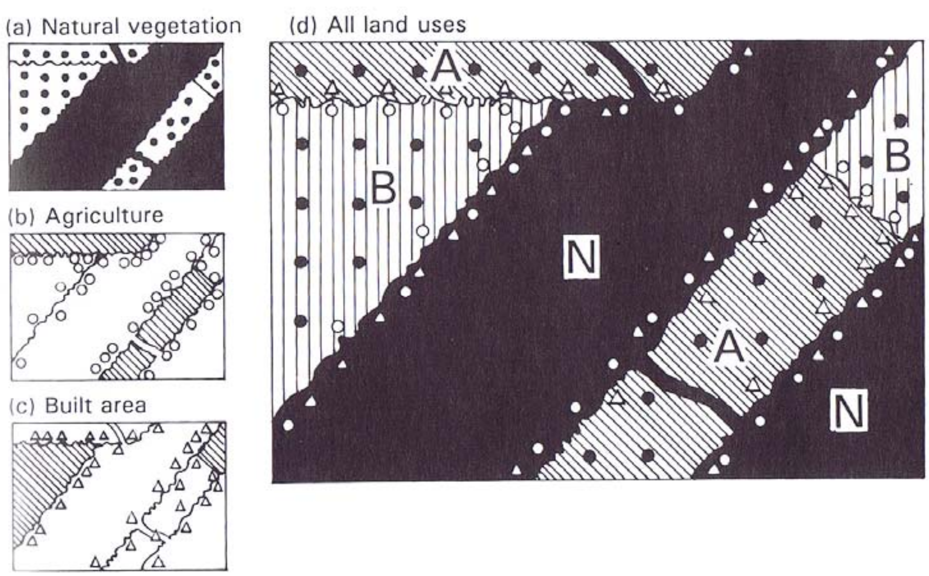

Figure 7. Arrangement of land uses based on Forman's aggregate-with-outliers principle. N = natural vegetation; A = agriculture; B = built area. Outliers of natural vegetation, agriculture, and built area are represented by small black dots in (a), circles in (b), and triangles in (c), respectively *(From Forman 1995).*

2. Methods

Because it is not logistically feasible to assess all organisms, landscapes, or local habitat features, various biodiversity 'indicators' are often established as surrogates to measure the effects of human activity on these features (Noss 1990, 1999). Traditionally, wildlife resource managers have used large mammals, game species, or species at risk as 'indicators'. However, such species often do not function well as indicators of land use change for monitoring purposes (O2 Planning + Design Inc et al. 2002). For example, it is not possible to have comprehensive water quality monitoring stations for multiple physical, chemical, and biological water quality parameters at high spatial densities throughout a watershed. Monitoring frequencies at individual water quality stations can also pose challenges, particularly in terms of capturing extreme events in the data records.

As a viable alternative, landscape pattern-based indicators can be harnessed to gain insight into the overall function and quality of an ecosystem. This can include landscape metrics such as the amount of forest cover in a given area, patch size, core area, intactness of riparian corridors, etc. described in Section 2.2 below, as well as indices of human influence such as road density and agricultural land cover. Pattern-based indicators provide a coarse filter approach to determining baseline thresholds for environmental quality, whereby landscape patterns are managed to achieve certain target levels of environmental quality.

While effective at a broader scale, a fine filter approach is also often required as a complementary tool to assess the outcome of coarse filter management, and determine if management goals are being reached (O2 Planning + Design Inc et al. 2002).

As a companion product to the landscape pattern database and annotated bibliography, this report has been designed to review, assess, and synthesize important findings identified in the literature review. This section outlines the assessment criteria used to narrow down the vast environmental literature in order to identify significant relationships, thresholds, and targets that would be potentially valuable to landscape planning efforts. Secondly, this section presents the rationale behind the standard formatting, organization, and decision making process that went into constructing the landscape pattern data base and annotated bibliography that are the cornerstones of this project. Lastly, this section presents the criteria used to assess the potential for each landscape pattern indicator outlined in Section 2.2 to function as a valid and useful metric of environmental quality.

2.1 Literature Review

A broad survey of academic, government and independent publications was conducted using combinations of the following major search terms. Several other search terms were deployed, however this list represents the key terms that generated the most fruitful results:

- habitat fragmentation
- pattern
- connectivity
- landscape structure
- landscape composition
- edge effects
- riparian buffers
- corridors
- ecological thresholds
- water quality
- watershed
- biodiversity
- air quality

- land use
- land cover
- disturbance
- environmental indicators

Following a comprehensive review of relevant literature totaling over 650 publications, 172 publications were selected that best represent the subject matter to date. The findings of these publications illuminate and quantify the impacts of landscape and land use pattern on a wide variety of valued environmental features. Publications containing quantitative information directly related to conservation thresholds were given particular attention. Review papers found in the grey literature (e.g., those produced by land management and regulatory agencies such as the US Bureau of Land Management) were also included when possible and applicable.

Each reviewed publication is assessed regarding the statistical rigour of the work, whether the study is correlative or mechanistic in its results, and summarized to identify the relevant factors which influence its applicability to landscapes of geographic relevance. The number of times a publication had been cited was also used as an important criterion in screening for the most influential work to date.

Publications were filtered hierarchically by the following criteria:

- Relevance to landscape pattern indicators and metrics referenced in keyword searches
- Geographic relevance (Western Canadian provinces and territories and Western States of the coterminous U.S.A.)
- Frequency of citation (to determine the most influential publications)
- Eco-regional applicability (prairie, boreal, and Rocky Mountain regions)
- Anthropogenic influence
- Empirical studies

2.2 Database format and organization

The way in which the information generated by this approach was organized and presented was carefully considered in order to maximize user accessibility. The landscape pattern database includes categorized information for each of the 172 reviewed publications on the topic, context, location, scale, and landscape indicators covered, as well as significant conclusions, learnings, and thresholds for each. The database has been made searchable by key words related to specific landscape processes, taxa or species (i.e., water quality, birds, bobolinks) in order to maximize searchability. The standard format applied to the annotated bibliography reflects many of these classifications. The following format was used to classify information in standardized way into a unified bibliographic source:

Citation: the bibliographic reference to the book, report, or paper

Link: url link to the report or paper

Synopsis: a brief summary of the key focus and findings of the book, report, or paper

Caveats: key limitations identified by the authors related to research methodology, data collection, or any other shortcoming that may provide additional insight into the results and conclusions.

Scale: the most appropriate scale category was chosen to classify each study (see Section 1.4.2 for definitions)

- Mesoregional
- Regional
- Sub-regional
- Local

- Site

Location: geographic setting of the study, including:

- Jurisdiction: e.g. Saskatchewan
- Ecoregion: according to the EPA level III CEC regions
- Basin and Sub-basin (where applicable in watershed studies)

Landscape Type/Pattern: dominant land uses (e.g., agriculture) and patterns (e.g., fragmentation) that define the landscape

Part of the Environment: the focal topic or species of focus recognized by the report or paper

2.3 Indicator assessment criteria

Each of the following landscape indicators in Section 2.2 have been assessed to determine its' applicability as a tool to maintain or improve environmental quality in Western North America. A given indicator should directly measure a pattern or condition that relates to an identified environmental conservation issue affecting landscapes within the geographic scope. The following criteria were used to determine the rigour of each potential indicator:

- *Relevance to ecological process*

  Each indicator was assessed to determine if it was related to either structural conditions or ecological function. The degree to which the indicator acts as a surrogate for important environmental processes or functions was also evaluated.

- *Measurability*

  Indicators should be relatively easy to measure and provide quantifiable information. Each indicator was assessed to determine if the information could be easily measured, and whether it would provide consistent and quantifiable information that could be compared over time and /or space.

- *Applicability to geographic scope*

  Vegetation and pattern characterization vary considerably across different landscapes and ecoregions. Each indicator was assessed to determine its relevance to the geographic scope and land uses of Western North America.

3. Synthesis of Indicators

There is a large body of scientific literature showing how indicators of environmental quality are associated with patterns of land use change, habitat loss, fragmentation, and decreasing landscape heterogeneity (Coppedge et al. 2001, Desrochers and Fortin 2000, Gelbard and Belnap 2003, Tews et al. 2004, Weins 1997, With and Crist 1995, Wu et al. 2002, O2 Planning + Design Inc. et al. 2009). The majority of published studies on landscape pattern examine how these patterns affect biodiversity and wildlife abundance. However there is an increasing body of literature beginning to examine how landscape patterns affect other ecosystem services, such as air and water quality (Moyle and Randall 1998, Johnston et al. 1990, Stewart et al. 1998, Ward 1998).

The following suite of landscape indicators were derived from the findings of 172 of the most influential published papers, grey literature, and books relating landscape pattern to changes in environmental quality. Common threads among significant findings were teased out and classified according to the assessment criteria described in Section 2.1.2.

It should be noted that the landscape indicators discussed below are often interrelated and linked across the landscape. Consider a landscape that is 20% forested. A forested landscape can consist of a few large, contiguous forest patches, or many smaller patches. Forest patterns may be dispersed or aggregated, highly fragmented or interconnected. Nuances in the interpretation of various landscape metrics depend on the spatial scale of the analysis in question and the scale-perspective of the taxa being examined (when applicable) (Figure 5, Section 1.5.3). It is also important to note that, because habitat requirements are species-specific, targets vary greatly across taxa.

Lastly, assessing many of the landscape pattern metrics identified in this report often requires specialized software. Based on this review and the experience of the authors of this report, using FRAGSTATS (McGarigal and Marks 1994) in conjunction with ArcGIS is recommended to assess and quantify landscape pattern components. In FRAGSTATS, metrics are calculated at the individual patch, class (all patches of the same type) and landscape level (the mosaic of patches) (O2 Planning + Design Inc. et al. 2002).

3.1 Land Cover Indicators

In addition to considering the size and configuration of landscape patches, land use planners must also consider the total amount of suitable habitat in a given landscape. Assessing different land cover types in a given landscape is the simplest broad-scale measure of environmental condition (O2 Planning + Design Inc. et al. 2009). Indicators described in this section refer to the amount and proportion of different land cover types in a landscape mosaic as coarse-filter determinants of environmental quality.

Indicator Overview

Land cover indicators refer to the area or percentage of natural vegetation and/or other land cover types in a landscape. Numerous studies have indicated that land cover and land use amount play important roles in determining stream water quality by influencing factors that control runoff, sediments, nutrients, flow, water temperature, and channel morphology (Omernik et al., 1981; Schlosser and Karr 1981; Lowrance et al. 1984, Osborne and Wiley1988; Roth et al. 1996; and Johnston et al. 1990). Land conversions and transformations that reduce the amount of natural land cover can also cause major alterations in hydrologic regimes, mineral and nutrient cycles, radiation balance, wind and dispersal patterns, and soil stability (Harris 1984 as cited in Collinge 1996; Hobbs 1993 *as cited in* Forman 1995).

The amount of natural habitat cover in a landscape is also closely tied to biological diversity (Tscharntke et al. 2012). Threshold amounts of land cover are often required to sustain certain populations and ecological processes. For example, species disappear in a landscape with the loss of a certain amount of habitat, and different species are extirpated at different thresholds of habitat loss (Fahrig 2002).

This section outlines general principles for various land cover indicators representing the dominant cover types in Western North America. These include: wetland cover, forest cover, grassland cover, impervious surface cover, and human land use covers (e.g., cropped agriculture, impervious areas, etc.). General principles and findings related to land cover amount are presented below, followed by specific findings derived from the literature for each land cover type. Information on each land cover is also accompanied by particular conservation thresholds, presented in Tables 1-5.

General Principles and Findings

- Proportions of suitable habitat range between 5% and 80% percent of the landscape depending on the species, geographic region, and parameters in question (Kennedy et al. 2003)
- Suitable habitat should comprise at least 50% of the total landscape (Kennedy et al. 2003)
- In landscapes that are highly fragmented—including most urban, suburban, and even rural areas with less than 30 percent of remaining suitable habitat—the spatial arrangement of habitat patches greatly affects species survival (Andrén 1994)
- The condition of the surrounding matrix in which habitat patches are embedded also influences the effective size of the remaining fragments and the degree to which the patches are isolated (Andrén 1994, Haynes and Cronin 2003)
- In one study of species persistence relative to landscape pattern, population size was largely determined by the proportion of habitat in a landscape. However, when habitat coverage dropped below 30-50%, population persistence reached a critical threshold and declined rapidly. After this point, habitat arrangement explained variation in population size more than habitat amount. When habitat coverage dropped below 30-50%, population persistence reached a critical threshold. Species persistence declined rapidly at this threshold range (50% for low degrees of aggregation, 40% for high and moderate degrees of aggregation) (Flather and Bevers 2002).

3.1.1 Wetland Cover

Wetlands provide diverse and valuable ecosystem services in any landscape (Costanza et al. 1997). However, many wetlands have been lost to drainage resulting from a multitude of human land uses. Remaining wetlands are thus increasingly critical for maintaining watershed health and water quality. Therefore, the proportion (%) of wetlands as a component of a watershed is a key indicator of environmental quality.

Specific Findings Related to Wetland Cover

Biodiversity:

- Habitat suitability for some species is related to local vegetation conditions within a wetland, while suitability for others is related to landscape structure at larger scales. Small wetlands are critical components of the surrounding landscape that influence habitat suitability of larger wetlands (Naugle et al. 2001).
- Species most vulnerable to small wetland loss are vagile species that exploit resources over broad spatial scales (Naugle et al. 2001)
- The fauna supported by a wetland depends highly on the size of the wetland and the home range size of the animal in relation to the wetland (Mitsch and Gosselink 2000)
- In a study of land use/cover as an effective predictor of stream integrity, stream biotic integrity and habitat quality positively correlated with extent of wetlands and forest, and negatively correlated with the extent of agriculture (Roth et al. 1996)

Water Quality:

- Wetlands are generally more efficient per unit area in nutrient removal than riparian buffers (Mitsch 1999)

- In a study investigating the relationship between watershed mosaics, water quality and flow output, wetland extent within a watershed correlated with decreased concentrations of chloride, lead, and specific conductance (Johnston et al. 1990)
- Wetlands were found to work best, in terms of providing ecosystem services, as spatially distributed systems (Mitsch and Gosselink 2000) (e.g., wetlands in a cultivated field provide very different ecosystem services than wetlands in a floodplain, but all contexts are important)
- Wetland value is highly dependent on its hydrogeomorphic position in the landscape relative to other landscape features and human settlements. For example, if a wetland is situated along a river, it will have a greater functional role in stream water quality. Likewise, wetlands function differently when situated at the headwaters of a stream as opposed to when situated further downstream (Mitsch and Gosselink 2000).
- In a study on the importance of continuity and width of riparian corridors in Wisconsin, streams with higher percentages of forested land and non-forested wetlands in the watershed had less organic and sediment pollution (Stewart et al. 2001)
- The proportion of wetlands in a watershed strongly affects the variability in dissolved organic carbon (DOC) in lakes and rivers. In a study in Wisconsin, the proportion of wetlands in the watershed always explained considerably more variability in DOC in rivers than the proportion of wetlands in the nearshore riparian areas. Watershed influence also varies seasonally in rivers, as the proportion of the watershed covered by wetlands explained more of the variability in DOC in the fall than in the spring (Gergel et al. 1999).
- In one study in Michigan (Zhang et al. 2012), upstream wetlands were shown to reduce phosphorus loads to lakes downstream, but also reduced water inflow to lakes and thus increased the phosphorus concentrations of inflows to lakes, demonstrating the importance of accounting for the spatial arrangement of ecosystem components and resulting effects on environmental quality
- In a study of the impacts of wetland loss between 1968 and 2005 in the Broughton's Creek watershed, Manitoba, over 21% of the total area of wetlands had been lost primarily due to agricultural drainage. This changed wetland cover in the watershed from 12% in 1968 to approximately 9.5% in 2005, resulting in the following changes to water quality (Yang et al. 2008):
  - Phosphorus loads in the watershed increased by 32%
  - Nitrogen loads in the watershed increased by 57%
  - Sediment loads in the watershed increased by 85%

Flood Control:

- In the Broughton Creek, Manitoba study (Yang et al. 2008), the following impacts of wetland loss from 1968-2005 on peak flows and water volume were calculated:
  - Peak flows (annual average) increased by 37%
  - Overall water flows increased by 62%
- Studies by Cobbaert et al. (2011) and O2 (2012) in Alberta, indicate that small wetlands, particularly at high landscape positions within watersheds, can cumulatively influence flood peak desynchronization and reduce flooding downstream
- Cedfeldt et al. (2000) have outlined the influence of surrounding watershed conditions and patterns on the relative influence of any individual wetland on flood control downstream. They considered the following variables: amount of upslope wetlands that may also be controlling flood peaks, total amount of wetlands in the watershed, the degree of impervious surfaces located upstream, soil infiltration rates, location of wetland in relation to intermittent or first-order streams, size of the wetland in question, and the degree of connection to the surface water network.

It is recommended that, due to the importance of wetlands and their historic losses in many watersheds, conservation targets for wetlands should be based on a "no net loss" principle and should include strong measures for avoidance, as well as a secondary focus on compensation for unavoidable impacts, complemented by wetland restoration where feasible. This requires wetlands inventories across specific areas, with conservation targets ideally based on existing conditions or higher. The targets listed in Table 1 below provide some indication of what others have come up with as potential targets, but do not by any means reflect appropriate, feasible, or "optimal" conservation targets for all situations, which require place-specific data.

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Water quality is positively correlated with wetland extent
- The functionality of a wetland depends on its position in a watershed
- Small wetlands in the surrounding landscape influence the habitat suitability of larger wetlands
- Habitat quality and stream biotic integrity are positively correlated with wetland extent

Table 1. Conservation Targets for Wetland Cover

Taxa or Process	Target wetland cover	Finding	Location	Citation
Water quality	3-7%	Wetlands should comprise at least 3-7% of temperate watersheds for improved water quality	Midwest USA	Mitsch and Gosselink 2000
Birds	Size >6.5 ha in heterogeneous landscapes; 15.4-32.6 ha in homogenous landscapes	Black terns required 6.5 ha of suitable wetland habitat for nesting and foraging in heterogeneous landscapes, but required 15.4-32.6 ha in homogenous landscapes	South Dakota	Naugle 1999
Water Quality	>15% of watershed area	Wetland cover should be maintained at >15% for watersheds with high potential for phosphorus loading & eutrophication	Michigan, USA	Wang and Mitsch (1998)
Flooding	7% of watershed area	A minimum of 7% of this watershed should be in wetland cover to adequately control flooding.	Mississippi	Hey and Philippi 1995
Water quality, biodiversity, etc.	>7.5% of watershed	Maintain or improve baseline conditions (>7.5%) for a range of watershed values	Red Deer River Basin, Alberta	O2 Planning + Design Inc. et al. 2013
Water quality, seasonal water distribution, biodiversity, etc.	>6% of the upper headwaters	Peatland cover (where applicable) should be maintained at >6% of the upper headwaters to maintain water quality	Red Deer River Basin, Alberta	O2 Planning + Design Inc. et al. 2013

These broader conclusions bring to light several management considerations that may be applied to landscapes in similar contexts. For example:

- Small wetlands can be acquired not only to consolidate suitable habitat within protected core areas, but also to ensure that core areas coalesce to preserve connectivity among regional wetland landscapes (Naugle et al. 2001)
- Wetlands and riparian zones should be strategically placed in watersheds to optimize nitrogen removal, as, for example, in tile-drained farmlands prone to high concentrations of nitrate (Mitsch 1999), in headwater areas for groundwater discharge and recharge as well as flood peak desynchronization, near floodplains for flood attenuation, and surrounding coastal areas to improve fish production corridors between large patches (O2 Planning + Design Inc. et al. 2008)
- Because the effects of adjacent land-use on wetland sediment and water quality can extend over comparatively large distances, effective wetland conservation will not be achieved merely through the creation of narrow buffer zones between wetlands and more intensive land-uses. Rather, sustaining high wetland water quality will require maintaining a heterogeneous regional landscape containing relatively large areas of natural forest and wetlands (Houlahan and Findlay 2004).

3.1.2 Forest Cover

The amount of forest cover in a landscape is a generally a good indicator of biological diversity and riparian health. Forest cover provides critical habitat to specialist interior species, and regulates essential ecosystem processes such as fire, flood, and drought. Forests also filter nutrients and sediment runoff from adjacent land uses, thereby protecting the integrity of both surface waters and aquifers. As demonstrated in several of the following studies, the amount of forest cover in a landscape is also directly related to the provision of important ecosystem services such as drinking water quality.

Specific findings on the importance of timber harvest, pine beetle infestation, and fire relative to forest cover and water quality have also been highlighted in this section. These land use changes and disturbance regimes have implications for the ways in which large intact forest patches in a watershed's headwaters ensure high downstream water quality and prevent sedimentation in reservoirs. In particular, forest fires can drastically alter the amount and proportion of forest cover, affecting erosion rates, nutrient flows, and water quality. However, severe fires can also triggers essential nutrient flushes to enrich ecosystem processes (Stephan et al. 2012), promote forest regeneration and succession, and create habitat conditions that support certain specialist species (Hutto 2008).

Specific Findings Related to Forest Cover

Biodiversity:

- As young forest stands increase in proportion to old forests, caribou population densities and survival rates decline as they become increasingly vulnerable to predation and extirpation (Whittmer et al. 2007)
- Caribou subpopulation persistence and landscape occupancy depends highly on the degree of forest cover, forest cover type (with the highest population densities in old cedar/hemlock and spruce/subalpine fir forests), and distance from human presence (Apps et al. 2006)

Water Quality:

- If there is more forest cover in a watershed, water treatment costs are generally lower. In one national study conducted for the United States as a whole, it was found that, for every 10% increase in forest cover in the source area, treatment and chemical costs decreased by about 20%. Treatment costs tend to level off when forest cover is between 70-100% (US Trust for Public Lands 2004).
- One New England study found statistically significant relationships among source water quality, percent land cover, and drinking water treatment cost. Higher percentages of agricultural and urban cover were significantly related to decreased water quality, while decreased forest land cover was significantly related to decreased water quality (Freeman et al. 1998).

- Watershed area and the percentage of a watershed that is covered by forest significantly influence watershed sensitivity to acidic deposition. Based on landscape pattern indicators, one can identify subregions where acid-sensitive streams are most abundant (Sullivan et al. 2007).

Timber Harvest and Stream Flow:

- Generally, timber harvest increases average annual local streamflow, while afforestation decreases average annual local streamflow (however, as a caveat it is not just the average effect on water yields that should be considered, but also influences on seasonal distributions, and effects during droughts and floods which are not always consistent with the average annual effect).
- A meta-analysis in Oregon found that when >25% of the watershed's forest cover is clearcut over a short period of several months, there is a measurable increase in annual streamflows from the watershed (Adams and Taratoot 2001).
- In general, as forest is removed, streamflow increases and evapotranspiration decreases. Threshold harvest areas required to produce a measurable increase in annual water yield have been identified at 15% for the Rocky Mountain/Inland Mountain area and 50% for the Central Plains region (Matheussen et al. 2000).

Timber Harvest and Water Quality:

- The greater the percentage of trees cut in a watershed, the greater will be impacts on stream water chemistry (Feller 2005).
- Streamwater temperatures will often increase where timber harvest or other practices remove vegetation; recovery of cool temperatures can occur when revegetation restores shade (Adams and Taratoot 2001).
- In a study of water quality in relation to forest clearcutting in Alberta, concentrations of refractory compounds (tannins and lignins) increased by a factor of about 4 after clear-cutting and persisted at the higher concentration for several years. Humic substances also increased but the effect only lasted about 2 years (Telang 1981).
- Forest harvesting impacts stream water chemistry by: increasing geological weathering rates due to exposing land surfaces to greater temperature, decreasing acidity of runoff, decreasing organic matter and litter inputs to streams, increasing anion exchange capacity of soils by lowering pH, etc. (Feller 2005).
- In a study investigating the effects of forest harvesting on watershed water quality in central Washington, no significance differences were found between pre-harvest and post-harvest chemical concentrations except for calcium which was 5 times higher, and sodium which was 20 times higher in the harvested watersheds. Concentrations declined over the 3 year post-harvest span (Fowler et al. 1988).
- Clearcutting only portions of a watershed reduces harvest impact on all nutrient outputs (Fowler et al. 1988).

Timber Harvest and Pine Beetle Infestation:

- In a study in Northern Alberta, pine bark beetle was most abundant prior to harvest in stands with many host trees (conifer dominated stands). In the first and second summers after harvest, pine beetle abundance increased exponentially with percent spruce cover and the number of spruce stumps in the stand. Beetles were likely attracted from a wide surrounding area because of the increase in host volatiles released from stumps. The results support the resource concentration hypothesis; that herbivorous insects congregate where hosts are abundant. In light of this apparent habitat cue, managers should strive to minimize the concentration of stumps and freshly dead trees in post-harvested conifer forests (Park and Reid 2007).

Forest Fire:

- The most significant difference between postfire and postharvest landscapes is the amount and orientation of residual live and dead trees. Postfire stands consist largely of standing dead trees whereas postharvest stands include primarily clumps of standing live trees. Reduction in the provision of snags in the landscape may have an immediate effect on specific bird populations. Retaining clusters of live trees may change forest composition in the longer term (Hobson and Sheik 1999).

Forest Fire and Water Quality:

- Severe fire regimes create essential habitat conditions for certain habitat specialists (Hutto 2008)
- Contaminant loading from burned landscapes can contribute substantially to the total annual downstream contaminant load (including metals and hydrocarbons from ash fallout) in the first several years following fires (Stein et al. 2012)
- Large fires that denude extensive areas of forest cover can significantly increase erosion and sedimentation rates, having negative impacts on downstream water quality. Smaller fire patches, either natural or successfully prescribed, would not have the same effects on water quality and sedimentation as larger more severe fires which take down more forest cover (Lavine et al. n.d).
- Wildfires can negatively affect water quality by altering watershed hydrology and increasing sediment and nutrient delivery to surface waters. In a study of fires in northern California, the burned urban sub-watershed was the largest source of nutrients and sediment contamination, whereas the wet meadow sub-watershed downstream of the burned area retained materials (Oliver et al. 2012).
- Large scale natural disturbances from wildfire and severe insect infestations can significantly impact water quality downstream of forested headwaters. Forest fires impact water quality due to sediment input of the ash and soot and by chemical changes to surface and groundwater (Emelko et al. 2012).
- Fire causes a flush of high dissolved organic nitrogen (DON) and total nitrogen concentrations in severely burned watersheds. These concentrations decline rapidly in the 3 years following the burn. Concentrations are most influenced by flow regimes, being most elevated during high discharge periods (Bladon et al. 2008).
- In a study of post-fire stream conditions at Lost Creek in Alberta, nitrate (NO_3^-), dissolved organic nitrogen (DON), and total nitrogen (TN) concentrations were 6.5, 4.1, and 5.3 times greater in severely burned watershed streams during the first year after the fire, respectively, than those in reference streams. Weaker effects were evident for concentrations of ammonium (NH_4^+; 1.5 times) and total particulate nitrogen (TPN; 3.0 times). A rapid decline in mean watershed concentrations and production of NO_3^-, DON, total dissolved nitrogen (TDN), and TN was observed from burned watersheds over the three seasons after the fire. Effects of the burn were strongly influenced by the regional flow regime, with the most elevated N concentrations and production occurring during higher discharge periods (Bladon et al. 2008).

Interpretation of Indicator Findings

Based on the findings from these selected publications, the following general conclusions can be drawn:

- Water quality in a watershed depends highly on the extent and proportion of forest land cover
- Water treatment costs decrease with higher percentages of forest cover in a watershed
- The proportion of a watershed cleared by timber harvest and/or forest fires (natural and prescribed) is significantly correlated with reduced water quality
- Forest fires can cause flushes of nutrients to streams, negatively impacting water quality, particularly if fires are large, widespread, and burn at high intensities in areas already subject to high nutrients from other sources
- Left unmanaged, areas partially harvested for timber can become more susceptible to pine beetle infestations

Table 2. Conservation Targets for Forest Cover

Taxa or Process	Target forest cover	Finding	Location	Citation
Water treatment cost	60%	For every 10% increase in forest cover in the source area, treatment and chemical costs decreased by about 20%, up to about 60% forest cover. Treatment costs level off when forest cover is between 70-100%.	USA	US Trust for Public Lands and the American Water Works Association 2004
Water quantity	<25%	When >25% of the watershed's forest cover is clearcut in a short period of time, there is a measurable increase in annual streamflows from the watershed.	Oregon	Adams and Taratoot 2001
Caribou	n/a	As young forest stands increase in proportion to old forests, caribou population densities and survival rates decline as they become increasingly vulnerable to predation and extirpation.	British Columbia	Whittmer et al. 2001
Water quality	>65%	Forest cover should be maintained at a minimum of 65% in order to effectively mitigate the impacts of urbanization and development on watersheds.	Washington	Booth 2000
Birds (northern spotted owl)	19-23%	Old forest must be maintained at 19-23% of the total area of a regional landscape to ensure the survival of northern spotted owls.	Washington, Oregon, California	Lande 1988
Fish Habitat (bull trout)	<35%	Timber harvest on up to 35% or more of individual subbasins is projected to result in the extirpation of bull trout from up to 43% of stream reaches, especially those that support high densities of bull trout.	Alberta	Ripley et al. 2005

These broader conclusions bring to light several management considerations that may be applied to forested landscapes in similar contexts. For example:

- Given that streamwater temperatures will often increase where timber harvest or other practices remove vegetation, prioritizing riparian buffer leave strips and/or revegetation along stream banks can restore shade and cooler temperatures (Adams and Taratoot 2001)
- Removing stumps and freshly dead trees in post-harvest conifer stands can reduce colonization by pine beetle (Park and Reid 2007)
- Wetland position in the landscape is important in determining the impacts of forest disturbance on water quality, as wetlands can act as filters mitigating water quality impacts (Oliver et al. 2012)
- Broad-scale fires that burn a large proportion of a watershed’s area can increase Total Suspended Solids (TSS), nitrogen and phosphorus export downstream, whereas smaller fires do not have much of an impact (Emelko et al. 2011; Bladon et al 2008)

- Even-aged stand structures that often occur in areas managed for forest timber values, combined with decades of suppressing natural fires, can lead to a higher risk of large fires occurring during drought in the future, with consequent greater risks posed to water quality.

3.1.3 Grassland Cover

Grasslands as a proportion of a landscape serve as indicators of species diversity, especially for ground nesting birds. Changes in the proportion of grassland also have implications for water quality, the spread of exotic species, predator/prey relationships and trophic cascades (Bergin et al. 2000, Crooks and Soule 1999).

Specific Findings Related to Grassland Cover

Biodiversity:

- Large areas of native grassland cover and regular fire regimes are essential to healthy grassland systems that many ground nesting birds depend on (Fitzgerald et al. 1999)
- The higher the percentage of native prairie in an area[1], the more suitable it is for burrowing owl habitat (Skiftun 2004)
- Swift foxes are typically found in open flat prairies, where visibility and prey availability are high (Downey 2004d)
- Native prairie is the most important and limiting factor for ferruginous hawks. Although hawks have been found in areas that were primarily under cultivation, their location was dependent on the proximity of nearby high quality prairie habitat (Taylor 2004)
- The more grassland available in an area, particularly in large unbroken blocks, the greater the number of area-sensitive grassland birds the area is able to support (USDA 1999)
- The amount of grassland cover in a given landscape can affect predation rates, especially when acting in conjunction with other landscape or land use patterns. For example, in one a study in Iowa, herbaceous grassland cover was negatively associated with predation in roadsides whereas the proximity of woody cover was positively associated with predation rates (Bergin et al. 2000)

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Many area sensitive bird and mammal species require high percentages of native grassland cover to meet their basic habitat needs
- Natural fire regimes are essential to maintain habitat conditions for certain specialist grassland species
- The amount and proportion of grassland in relation to other cover types can influence predation rates and trophic cascades

These broader conclusions bring to light several management considerations that may be applied to grassland landscapes in similar contexts. For example, landscape managers should bear in mind threshold amounts of grassland cover for certain taxa and groups of species when considering new land use plans. These numbers, while highly specific to species and location, can be useful for setting targets for conservation that benefit the ecosystem at large.

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[1]Burrowing owl are also known to nest in heavily grazed native pasture, and may feed in seeded pastures (e.g., tall brome), particularly during droughts. However, they also tend to require good opportunities to disperse into such habitats from nearby native prairie (Cleve Wershler, P.Biol, personal communications, 2011).

Table 3. Conservation Targets for Grassland Cover

Taxa or Process	Target grassland cover	Finding	Location	Citation
Birds	>5% tree cover; >20% shrub cover	Grassland bird species are affected when the amount of tree or shrub cover in the landscape exceeds 5% or 20%, respectively	Southern Alberta	O2 Planning + Design Inc. et al. 2008a
Birds	30-60%	When native grassland cover dropped below 60% at one site, and 30-40% at another site, the arrangement or habitat patches became more important to the survival of populations than habitat amount alone	Oklahoma	Coppedge et al 2001a
Birds (sharp-tailed grouse)	>75%	The ideal proportion of native grassland cover for sharp-tailed grouse is >75%	Southern Alberta	Jones 2004
Birds	>200 ha blocks	Contiguous grassland blocks of >200 ha provide the greatest habitat potential for most grassland bird species	US/Canada	USDA 1999
Birds (short-eared owl)	>100 ha	Short-eared owls and northern harriers require habitat patches of >100 ha	South Dakota, North Dakota, Montana, Saskatchewan, Alberta	Fitzgerald et al. 1999
Birds (prairie chicken)	>1500 m radius	Female greater prairie chickens require >1500m undisturbed radius of native prairie surrounding lek sites for nesting and foraging.	South Dakota, North Dakota, Montana, Saskatchewan, Alberta	Fitzgerald et al. 1999
Birds	<30 ha, >150 ha, 10-30 ha, >50 ha, and 30-100 ha	Specific area requirements for several grassland bird species include: <30 ha for sedge wrens, >150 ha for sprague's pipit, 10-30 ha for dickcissel, >50 ha for Baird's sparrow, 30-100 ha for grasshopper sparrow, <30 ha for LeConte's sparrow, and <30 ha for Bobolinks.	South Dakota, North Dakota, Montana, Saskatchewan, Alberta	Fitzgerald et al. 1999
Mammals (Richardson's ground squirrel)	>20%	A threshold amount of 20% graminoid coverage is the minimum suitable proportion for habitat suitability for Richardson's ground squirrel.	Southern Alberta	Downey 2004c

Taxa or Process	Target grassland cover	Finding	Location	Citation
Amphibians (Great Plains toad)	>75%	Great Plains toads thrive when >75% of the landscape is composed of native prairie components (i.e. shrubs, graminoids, riparian areas, lakes, wetlands, and trees)	Southern Alberta	Taylor 2004a
Microfauna	>20%	Beetle movements declined strongly when grass cover dropped below 20%	Colorado	Weins et al. 2007
Microfauna (grasshoppers)	>40%	Habitat generalists with good dispersal abilities aggregated (as a function of isolation) when <35% of the landscape consisted of suitable habitat, whereas generalist species with limited dispersal abilities aggregated in patchy distributions when suitable habitat constituted <20% of the landscape. Habitat specialists aggregated only when <40% of the landscape contained suitable habitat.	Colorado	With and Crist 1995
Mammals (Badgers)	>23%	Graminoid cover must be at least 23% in order to satisfy habitat requirements of the American badger.	Southern Alberta	Downey 2004b

3.1.4 Impervious Areas

The amount of impervious surface (IS) such as concrete, asphalt, and roofs reflects the intensity of urban, ex-urban, and industrial development in a watershed. IS is an inverse indicator of watershed integrity since increasing it is strongly associated with high peak storm water discharges and pollutant loadings from non-point sources (O2 Planning + Design Inc. et al. 2009). Imperviousness can be used as a general indicator of potential development impacts on water resources when making land use decisions (Arnold and Gibbons 1996).

Specific Findings Related to Impervious Surface Cover

- The amount of upstream impervious area affects downstream fish habitat quality, channel stability, and water quality. The use of riparian buffers can reduce the magnitude of urban impacts, however, they cannot fully mitigate the impacts of upstream development in the watershed. In Washington State, threshold percentages of impervious areas , as well as the percentage of forest cover in a watershed appear to be the two most effective indicators of watershed health (Booth 2000).
- As impervious surfaces in the watershed increase, linear increases in aquatic nitrogen pollution are observed (Arnold et al. 1996; Booth 2000)
- Watersheds are impacted considerably when IS >10%, with increasing channel instability, lower water quality, and lower stream biodiversity (O2 Planning + Design Inc. et al. 2008; Leitao et al. 2006; Brabec et al. 2002)

- Watersheds with IS >25-30% provide very low ecosystem services, and are characterized by highly unstable channels, typically poor water quality, and poor stream biodiversity (O2 Planning + Design Inc. et al. 2008; Leitao et al. 2006; Brabec et al. 2002)
- However, lower levels of imperviousness can also have watershed impacts as well; for example, a recently published study in Vermont found that stream stability and biodiversity decreased rapidly in watersheds with >5% impervious area (Fitzgerald et al. 2012)

Table 4. Conservation Targets for Impervious Surface Cover

Process	Target impervious cover	Finding	**Location**	**Citation**
Water quality	<10% of watershed	Impervious areas should be kept at or below 10% of a watershed in order to effectively mitigate the impacts of urbanization and development on watersheds.	Washington	Booth 2000
Water quality	<25%	Impervious cover should be maintained at or below 25% in heavily urbanizing watersheds	Multiple	Leitao et al. 2006; Brabec et al. 2002; Arnold et al. 1996
Stream health	<10% = protected; 10%-30% = impacted; > 30% = degraded	Generalized threshold values of imperviousness on overall stream health include: <10% = protected; 10%-30% = impacted; > 30% = degraded	USA	Arnold and Gibbons 1996
Stream stability and biodiversity	<5%	Stream stability and biodiversity decreased rapidly in watersheds with >5% impervious area	Vermont	Fitzgerald et al. 2012

Interpretation of Indicator Findings

Based on the findings from these selected publications, the following general conclusions can be drawn:

- The amount of impervious surface area in a watershed is significantly negatively correlated with lower water quality, increased channel instability, and lower stream biodiversity
- Examining *effective* impervious area may be more useful then impervious area alone; effective impervious area also accounts for how connected impervious areas are to the drainage network, and can account for site-specific LID practices such as grassed swales, rain gardens, etc., etc.
- Where the proportion of imperviousness in a given watershed exceeds 10%, watershed health is expected to be significantly impacted
- Where the proportion of imperviousness in a given watershed exceeds 25-30%, watershed health is expected to be highly degraded and characterized by very poor water quality, high channel instability, and poor stream biodiversity
- However, there is no threshold of *no* effect, and ideally, to maintain watershed health, impervious areas should be kept as low as possible
- For individual small “sensitive” watersheds, it may be appropriate to specify low levels of imperviousness as a target (e.g., <5% or <10%)
- However, in an urban or peri-urban context, low imperviousness targets applied at the municipal, community, or parcel scales are inappropriate and can lead to perverse outcomes at broad scales by encouraging sprawl and higher cumulative impacts over broader scales. At broader scales, it is more

effective to encourage higher density in smaller targeted areas than to potentially encourage sprawl due to misguided imperviousness targets.

- In urban contexts a nuanced approach that considers multiple scales, local watershed contexts, and regional and municipal planning issues is required, and should include flexible development process controls that can be applied to all developments.

3.1.5 Agriculture

Agricultural land cover is also generally an inverse indicator of water quality and biodiversity. The proportion and density of human settlements also has a significant impact on the occurrence of certain wildlife populations within areas dominated by human land use.

Specific findings Related to Agricultural Land Cover

Pests and Pollination:

- Landscape simplification resulting from agricultural intensification often leads to increased insect pest pressure, and thus an increased need for insecticides. The proportion of harvested cropland treated with insecticides can increase with the proportion of cropland and decrease with the proportion of semi-natural habitat in a county (Meehan et al. 2011).
- In a study of how native bee populations responded to patterns of land cover and land use in California, pollination services from native bees were significantly, positively related to the proportion of upland natural habitat in the vicinity of farm sites. The scale of this relationship matched bee foraging ranges. Stability and predictability of pollination services also increased with increasing natural habitat area (Kremen et al. 2002).
- In another study of native bee populations relative to land use, agricultural intensification diminished pollination services by roughly 3- to 6-fold. The decline of native bee pollination services with agricultural intensification resulted in significant reductions in both diversity and total abundance of native bees (Kremen et al. 2004).
- Agricultural fields with at least 15% pastureland within an 800m of fields had more bumble bees and other wild bees than fields with <6% pasture nearby. Nearly 95% of the variation in bumble bee abundance in fields was explained by variation in the amount of pastureland nearby (Morandin 2007).

Biodiversity/Biotic Integrity:

- In a study conducted in a predominantly agricultural landscape in Michigan, stream biotic integrity and habitat quality were found to be negatively correlated with the extent of agriculture and positively correlated with extent of wetlands and forest (Roth et al. 1996)
- In a study in an agricultural region of Saskatchewan, burrowing owls avoided agricultural lands (due to prey availability), used grass-forb areas for foraging, and avoided croplands and grazed pasture (Haug and Oliphant 1990)

Water Quality:

- Conversion of forested lands to agriculture (or urban/residential areas) has been associated with declines in stream and lake water quality (Houlahan and Findlay 2004)
- The Canada-Alberta Environmentally Sustainable Agriculture (CAESA) water quality monitoring study found that water quality depends strongly on the amount and distribution of land under cultivation; more specific findings included (Lorenz et al. 2008):
    - Generally, streams draining watersheds with high proportions of agricultural land had higher concentrations of nutrients, bacteria, and pesticides (Lorenz et al. 2008)

    - Pesticide detection frequency, total pesticide concentrations, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high (Lorenz et al. 2008)

- In Michigan, upstream regional land use, including agriculture and other human-dominated land uses, were found to be the primary determinant of stream conditions, able to overwhelm the ability of local site vegetation to support high-quality habitat and biotic communities (Roth et al. 1996)
- Increased percent agriculture (and urban land cover) were significantly related to decreased water quality, while decreased forest land cover was significantly related to decreased water quality and higher treatment costs (Freeman et al. 2008)
- The impacts of agricultural activities on water quality depend strongly on the amount and distribution of land under cultivation (Lorenz et al. 2008)
- Generally, streams draining watersheds with higher proportions of agricultural land cover had higher concentrations of nutrients, bacteria, and pesticides (Lorenz et al. 2008).
- Pesticide detection frequency, total pesticide concentrations, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high (Lorenz et al. 2008).
- Conversion of forested lands to agriculture or urban/residential areas has been associated with declines in stream and lake water quality (Houlahan and Findlay 2004)
- The impacts of agricultural activities on water quality depend strongly on the amount and distribution of land under cultivation. Generally, streams draining watersheds with more agriculture had higher concentrations of nutrients, bacteria, and pesticides (Lorenz et al. 2008).
- In the same study mentioned above (Roth et al. 1996), upstream regional land use was found to be the primary determinant of stream conditions, able to overwhelm the ability of local site vegetation to support high-quality habitat and biotic communities
- Increased percent agricultural land use was significantly related to decreased water quality, while decreased forest land cover was significantly related to decreased water quality and higher treatment costs (Freeman et al. 2008)

Table 5. Conservation Targets for Agricultural Land Use

Taxa or Process	Target cover/other measure	Finding	Location	Citation
Pollination	>30% uncultivated	Yield and profit could be maximized with 30% of land uncultivated within 750 m of field edges	Northern Alberta	Morandin 2006
Birds	<50% upland landscape in tilled agriculture	Numerous wetland bird species were more likely to inhabit wetlands in landscapes where <50% of the upland matrix was tilled	South Dakota	Naugle et al. 2001

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Biotic integrity is negatively correlated with the extent and proportion of agricultural land cover
- Rates of pollination by native bees increase with the amount and proximity of nearby natural habitat
- The amount, distribution, and intensity of agricultural land use correlates negatively with water quality and stream health
- Upstream land uses are the primary determinant of downstream water quality

These broader conclusions bring to light several management considerations that may be applied to agricultural and other human dominated landscapes in similar contexts. For example:

- In areas where upstream regional land use is the primary determinant of stream conditions, the ability of local site vegetation to support high-quality habitat and biotic communities may be overwhelmed by upstream conditions (Roth et al. 1996). In these cases, it is best to focus management effort at a broader scale rather than striving to improve stream quality through localized mitigation efforts.
- Conservation and restoration of bee habitat are potentially viable economic alternatives for reducing dependence on managed honey bees. Because crop pollinating species are often generalists that pollinate many native plants, restoring pollination services for agriculture could also benefit wild plants and thereby promote conservation biodiversity across the agro-natural landscape (Kremen et al. 2004).
- In a study linking landscape simplification, pest pressure, and insecticide use, it was estimated that, across a seven-state region in 2007, landscape simplification was associated with insecticide application to 1.4 million hectares and an increase in direct costs totaling between $34 and $103 million. Both the direct and indirect environmental costs of landscape simplification should be considered in design of land use policy that balances multiple ecosystem goods and services (Meehan et al. 2011).

3.1.6 Other Human Land Uses

The literature search turned up several studies on “human settlements” and relationships to biodiversity. However, very few studies were found focusing specifically on other human land uses, such as energy development, mining, and hydroelectric development. This may be a function of the difficulty in both studying and making generalizations at a landscape scale for these types of industrial activities. Another explanation is that there may be additional research on these topics, but a broader net and different search terms may need to be applied to dig into these topics in greater detail. Most likely it is a combination of both of these factors. In any case, the timing and scope of this study did not allow for a more detailed look at additional information on industrial and other human land uses. However, it is recommended that this be an area of future expansion of the study to help address these themes more comprehensively.

Notwithstanding these limitations, the following limited information on other human land uses was included in the study:

- In a study of ovenbirds responses to noise associated with every development, there was a significant reduction in ovenbird pairing success at compressor sites (77%) compared with noiseless well pads (92%). These differences were apparent regardless of territory quality or individual male quality. Noise interferes with a male's song, such that females may not hear the male's song at greater distances and/or females may perceive males to be of lower quality because of distortion of song characteristics (Habib et al. 2007).
- In general, watersheds with low indices of biotic integrity (IBI) have been heavily developed by hydroelectric dams, as well as mining and agricultural activities. The most influential factors contributing to low IBIs were the presence of large dams, introduced fish, and road density. Dams at low to middle elevations had the greatest effect on IBI (Moyle and Randall 1998).
- In Michigan, human-dominated land uses were found to be the primary determinant of stream conditions, able to overwhelm the ability of local site vegetation to support high-quality habitat and biotic communities (Roth et al. 1996)
- Conversion of forested lands to urban and/or country residential areas has been associated with declines in stream and lake water quality (Houlahan and Findlay 2004)
- In a study of grizzly bears in Western North American, females grizzly bears reduced their movement rates drastically when settlement increased to >20% of a given area. In highly settled areas (>50% settlement), both sexes demonstrated similar reductions in movement (Proctor et al. 2012).

Table 6. Conservation Targets for Other Human Land Uses

Taxa or Process	Target cover/other measure	Finding	Location	Citation
Stream biotic diversity	Locate dams at higher elevations	Dams at low to middle elevations had the greatest effect on IBI.	California	Moyle and Randall 1998
Mammals (cougars)	<250-500 people per month	Male and female cougars avoided areas of high human use and where human use levels exceeded 250-500 users per month.	Western Alberta	BCEAG 1999
Mammals (grizzly bears)	<20% settlement	Females grizzlies reduced their movement rates drastically when settlement increased to >20% of a given area. In highly settled areas (>50% settlement), both sexes demonstrated similar reductions in movement.	Wyoming, Montana, Alberta, British Columbia	Proctor et al. 2012

3.2 Landscape Configuration Indicators

Landscape configuration refers to the diversity in pattern, spatial arrangement, and types of land uses and vegetation communities in a landscape. Landscape mosaics are spatially heterogeneous, forming distinct boundaries between different landscape components, or acting as a gradient across which change occurs gradually. Each component can generally be recognized as a patch, corridor or background matrix.

Landscapes differ structurally in distribution of species, energy, and materials among landscape components and therefore differ in the flows of species, energy and materials throughout. Therefore, the configuration of various landscape elements can significantly affect ecosystem processes and function. For example, the position of a wetland in a watershed can have a substantial influence on the amount of sediment and nutrients affecting water quality, by virtue of its location in relation to both contaminant sources and receiving environments. Likewise, landscape characteristics have been known to affect water chemistry patterns (Buffam et al. 2008).

This section outlines general principles for various landscape configuration indicators including fragmentation and connectivity (2.2.2.1), regional corridors (2.2.2.2), patch size (2.2.2.3), patch shape, core area, and edge (2.2.2.4), and landscape heterogeneity (2.2.2.5). These indicator sections include discussions on specific types of configuration and disturbance patterns as examples of these broader indicator themes on the landscape. For example, road disturbances are discussed as a particularly significant linear disturbance pattern within the broader theme of corridor systems.

Overall, this section examines each indicator in relation to several aspects of environmental quality and biodiversity, cites specific findings derived from the literature, and presents particular conservation thresholds associated with each indicator type.

3.2.1 Natural Habitat Fragmentation and Connectivity Indices

Natural habitat fragmentation and connectivity refer to the degree to which vegetation communities are broken apart into smaller isolated sections within a landscape. This section outlines the causes and implications of natural habitat fragmentation on ecosystem function and processes.

Note that fragmentation effects are difficult to translate directly into management rules-of-thumb for several reasons. They tend to be highly specific to the taxa, spatial scales, and ecological processes which vary from landscape to landscape. Secondly, fragmentation effects vary according to the landscape type and its structure. Finally, the influence of fragmentation on species distribution and abundance may be obscured by local effects such as habitat degradation (Kennedy et al. 2003). In light of these limitations, threshold values and ranges presented in this document must be interpreted carefully. As with all other conservation thresholds presented elsewhere in this report, these values are intended to serve as guidelines to be tailored to unique circumstances and geographic settings.

Indicator Overview

Destruction of natural habitats involves three factors, often acting in concert: (1) habitat loss, (2) area and edge effects, and (3) habitat isolation. The last two factors are termed habitat fragmentation (Andren 1994, Fahrig 2002). Fragmentation can occur when habitat is divided by roads, railroads, drainage ditches, dams, power lines, fences or other barriers that prohibit free movement and migration of plant and animal species (Forman 1995).

Habitat fragmentation often works in tandem with habitat loss. When habitat is destroyed, a patchwork of habitat fragments is left behind, often resulting in patches that are isolated from one another in a modified and inhospitable landscape matrix. Fragmentation is often considered to be inevitable following habitat loss, although the relationship between the two can vary. They may be independent, such that habitat loss has no effect on fragmentation, or habitat loss may cause fragmentation to increase or decrease, depending on the original spatial distribution of habitat patches and the spatial pattern of habitat loss (Figure 7) (Weins 1997, With and Crist 1995). It is important to distinguish between pure habitat loss and true fragmentation effects when assessing population responses, because land management recommendations may differ depending on the resulting landscape composition.

Related to fragmentation, connectivity is a contiguity condition of the landscape in which patch elements flow uninterrupted across a landscape. As an indicator, it is related to certain metrics of landscape heterogeneity (Section 2.2.2.5), notably isolation and contagion—the degree to which land cover types occur in clumped distribution rather than dispersed smaller fragments. Importantly, connectivity and fragmentation influence ecological flows and the interaction between various landscape elements, affecting the overall health and functionality of entire landscapes.

General Principles

- Habitat loss also implies a corresponding increase in other landscape elements, which may affect ecological function and processes in the remaining, original habitat (Weins 1997)
- When habitat is lost from the landscape, individuals are also lost, resulting in species population declines (With and Crist 1995)
- Fragmentation effects, including decreases in patch size and increases in the amount of edge and in patch isolation, can compound the effects of pure habitat loss (With and Crist 1995)
- Large numbers of remaining fragments in a landscape can provide:
  - Microhabitat proximity for multi-habitat species
  - Buffers against local extinction during environmental change
- Several smaller patches can facilitate connectivity by acting as:
  - Stepping stones to facilitate species movement through the matrix
  - Supplemental habitat for species fleeing local extinction
  - A surrogate habitat in place of a large patch, when grouped
- Connectivity is particularly related to wildlife and species movements, but also to fire and other disturbance mechanisms, as well as watershed protection (particularly with respect to riparian area

connectivity and connectivity within the headwaters) (Leach and Givnish 1996, O2 Planning + Design Inc et al. 2002)

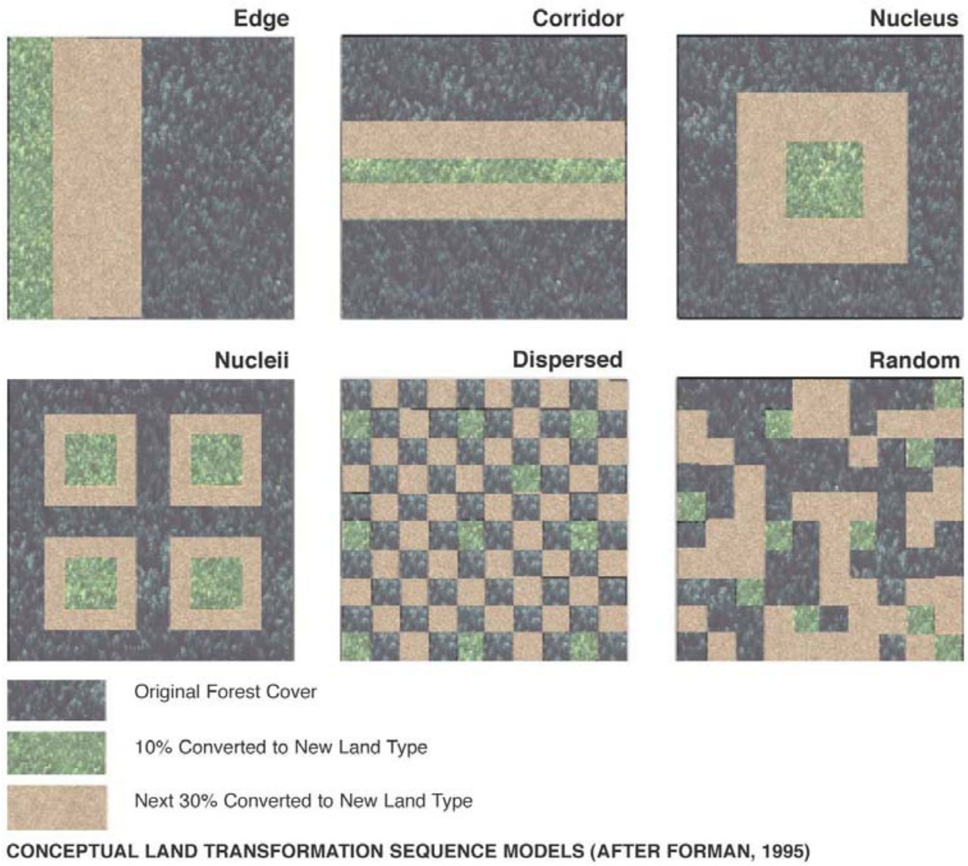

Figure 8. Conceptual land transformation sequence. Original forest amount remains the same; only configuration changes. *(O2 Planning + Design Inc et al. 2002 after Forman 1995)*

Specific Findings Related to Fragmentation

Biodiversity:

- Habitat fragmentation results in demographic changes in plant populations associated with increased extinction risk. In a study of trillium populations in forest remnants, researchers found that within 65m of forest clear-cut edges there was almost no recruitment of young plants (Jules 1998).
- In a study of fragmentation responses of American martens, martens appeared to respond negatively to low levels of habitat fragmentation, even with remaining patches of connectivity. Marten capture rates were negatively correlated with increasing proximity of open areas and increasing extent of high-contrast edges (Hargis et al. 1999).
- In general, sage-grouse populations depend on large expanses of interconnected sage-brush habitat. While sagebrush habitats and sage-grouse populations were once continuous across much of Montana, Wyoming, Nevada, Utah, Oregon, Washington, Alberta, and Saskatchewan, they are now fragmented by agriculture, urbanization and energy development. These fragmentation disturbances result in direct habitat loss and noise disturbances that disrupt sage-grouse breeding and nesting activities (Connelly et al. 2004).
- In a study on the importance of continuity and width of riparian corridors in Wisconsin, biotic integrity declined as riparian vegetation became more fragmented (Stewart et al. 2001)

Water Quality:

- Small streams are the most important at regulating water chemistry in large drainages, because their large surface-to-volume ratios favor rapid nitrogen uptake and processing. Yet small streams are often the most vulnerable to diversion, channelization, and elimination in urban and agricultural environments (Peterson 2001).
- The most rapid uptake and transformation of inorganic nitrogen tends to occur in the smallest streams of a watershed, which are the most prone to fragmentation. In a mesoregional scale study of N uptake by small streams, ammonium entering these streams was removed within a few tens to hundreds of meters, primarily through assimilation by microorganisms, sorption to sediments, and nitrification. Nitrate was also removed from stream water but traveled a distance 5 to 10 times as long, on average, as ammonium. Nitrate was removed by biological assimilation and denitrification processes. During seasons of high biological activity, the reaches of headwater streams retain and transform important amounts of inorganic N, frequently more than 50% of the inputs from their watersheds (Peterson 2001).

Specific findings Related to Connectivity

- In a study of bird movement relative to forest clearcutting in Quebec, researchers found that birds strongly preferred forested corridors to open areas during the post-fledging phase of dispersal, taking significant detours through these corridors in order to avoid crossing open areas (Desrochers and Hannon 1997)
- Because bark beetles are relatively poor dispersers, connectivity of suitable habitat is highly correlated with dispersal. Localized habitat fragmentation can predispose stands to attack, alter water flow, and uncouple predator-prey tracking (Raffa et al. 2008)

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Landscape fragmentation results in demographic changes in plant and animal populations, as well as the possible risk of extinction
- Many area-sensitive species are reluctant to cross gaps and require high levels of landscape connectivity to satisfy basic movement-related habitat needs
- Connectivity of suitable habitat is highly correlated with pine beetle dispersal
- Small streams, and the water quality provisioning ecosystem services they provide, are most vulnerable to fragmentation via diversion, channelization, and elimination in fragmented urban and agricultural environments

These broader conclusions bring to light several management considerations that may be applied to fragmented landscapes in similar contexts. For example:

- Since small streams are the most important for regulating water chemistry in large drainages, but are most vulnerable to fragmentation, restoration and preservation of small stream ecosystems should be a central focus of management strategies to ensure maximum N processing in watersheds. Ensuring that these ecosystems are protected can in turn improve the quality of water delivered to downstream aquatic systems (Peterson 2001).
- Forest management for pine beetle, involving the removal of all colonized trees, can significantly reduce the spread of pine beetle by reducing connectivity between host trees (Trzcinski and Reid 2008)
- Since the spatial pattern of open areas determines the amount of forest interior habitat in a landscape, it is also recommended that timber cuts are made progressively from a single cleared patch in order to retain the largest amount of forest interior habitat as possible (Hargis et al. 1999)

Table 7. Conservation targets for connectivity

Taxa or Process	Connectivity index	Findings	Location	Citation
Mammals (American Martens)	<100m gaps; <25% open	Forested landscapes were unsuitable for martens when the average nearest-neighbour distance between open, non-forested patches was <100m. Timber harvests and natural openings should not constitute more than 25% of a landscape greater than 9km^2 to ensure marten population persistence.	Northern Utah	Hargis et al. 1999
Birds	Movement confined within 75m of forest edge	Chickadee flocks moved parallel to forest boundaries within up to 75m of forest edge	Northern Alberta	Desrochers and Fortin 2000
Birds	<50 m gaps	Forest dwelling birds are reluctant to cross gaps in forest cover greater than 50 meters.	Quebec	Desrochers and Hannon 1997
Birds (Greater sage-grouse)	1600m	Dispersal corridors for should be preserved between blocks of habitats useful to greater sage-grouse at widths of at least 1600m to reduce predator concentrations.	Wyoming	Braun 2006
Pollination	1000-2500m between farm and natural habitat	Crop pollination services provided by native bee communities in California strongly depended on the proportion of natural upland habitat within 1000–2500m of the farm site, a spatial scale that accords well with maximal foraging distances for similar bee species.	California	Kremen et al. 2002
Pollination	750m	Bee abundance was greatest in canola fields that had more uncultivated land within 750 m of field edges. Yield and profit could be maximized with 30% of land uncultivated within 750 m of field edges.	Northern Alberta	Morandin 2006
Connectivity	<400m gaps	Small patches (<40 ha) should be interconnected by vegetated hedgerows and/or shelterbelts, or be located within 400m of each other	Southern Alberta	O2 Planning + Design Inc et al. 2008a
Connectivity	<100m gaps	Medium (40-500 ha) and large (500 ha or larger) patches should be interconnected by forested corridors >100 m in width	Southern Alberta	O2 Planning + Design Inc et al. 2008a

3.2.2 Corridor Systems

This section covers three types of corridor systems that represent important indicators for landscape connectivity and fragmentation. These indicators include: riparian corridors, shelterbelts, and linear disturbance corridors (i.e., road density and road avoidance). These linear landscape pattern indicators have important implications for water quality, air quality, and regional biodiversity.

Indicator Overview

Corridors can occur across a wide range of scales, including local, regional, and even continental. The Yellowstone to Yukon project is an example of a subcontinental corridor which aims to provide a continuous wildlife corridor connecting the Rocky Mountains from Wyoming to the Yukon and Alaska (Y2Y 2010). However, for the purposes of land use planning, a more typical scale for assessing corridors is at the regional scale. General principles for corridor systems are outlined below, followed by additional principles, specific findings, and conservation targets and thresholds derived from the literature for each indicator type.

General Principles

- The larger the focal species, the wider the corridor will need to be to facilitate movement and provide potential habitat
- As the length of the corridor increases, so should the width
- A corridor will generally need to be wider in landscapes that provide limited habitat or that are dominated by human use
- Corridors that need to function for decades or centuries should be wider.
- Some functions that require significant time include dispersal for slow-moving organisms, gene flow, and changes to range distributions due to climate change
- Wide corridors or clusters of smaller patches of natural vegetation can provide interior habitat for specialist species and can facilitate species' dispersal between large patches

3.2.2.1 *Riparian Corridors*

Riparian corridors, or buffers, are vegetated zones or bands of permanent vegetation located between aquatic resources and adjacent areas subject to human land use. Because riparian buffers have proven so effective in protecting water quality and wildlife habitat, at least 15 states and seven local jurisdictions in the United States have adopted riparian buffer regulations, protecting widths ranging from six meters to over 300 meters in size (Kennedy et al. 2003).

For a regional corridor encompassing a riparian buffer, the entire topographic gradient and habitat spectrum from river to ridge top should be considered (Noss 1990). It should also include a strip of upland interior habitat free from the edge effects of adjacent land uses to facilitate dispersal of species that depend on upland habitat types (Forman 1995). By including a wide diversity of habitats, including riverbank, floodplain, hill slope, upland interior, and upland edge habitats, a wide range of species with different habitat requirements can move through a regional corridor (Figure 8) (Forman 1995).

It is difficult to define an "optimum" corridor width, as suitable corridor widths are driven by local topography and habitat, and depend on the ecological processes and/or species of interest. In most cases the width of a regional corridor will vary considerably along a valley due to asymmetric and convoluted margins on opposite sides (Forman 1995). Generally, mimimum buffer widths may help maintain natural physical and chemical characteristics of resources whereas greater buffer widths may be required to maintain biological components of many wetlands and streams. A variable width buffer (one which varies in response to topography) is generally more desirable than a 'fixed width' buffer (a single specified distance from the water's edge), as this allows a more nuanced definition which better reflects the true extent of the riparian area. Fixed width buffers do not consider site-specific conditions, and therefore may not adequately buffer aquatic resources. However, variable width buffers tend to require greater site specific data and may be difficult to consistently implement across a wide area. There is a trade off to consider between a more site specific and ecologically representative definition and a more easily specified and consistent definition (Castelle and Connolly 1994). The former may prove more effective at maintaining the ecological function of the landscape, while the latter may be more consistently and predictably applied during the landscape planning process.

Riparian areas provide important water quality improvements to the river system. Buffers of various vegetation types have been shown to be equally effective at removing nitrogen but buffers composed of herbaceous and forest/herbaceous vegetation were more effective when wider. Wide buffers (>50 m) more consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0-25 m) (Mayer et al. 2007).

When riparian vegetation is maintained in areas of intensive agriculture, suspended solids levels are generally lower due to reduced in-stream organic production. Sediment deposition in near stream areas and stream bank scour are also reduced when riparian vegetation is present (Schlosser and Karr 1981).

Riparian areas provide important habitat with important effects across the broader landscape. Riparian vegetation provide refugia and may act as stepping stones to dispersing species, maintaining connectivity between natural patches in otherwise heavily disturbed landscapes.

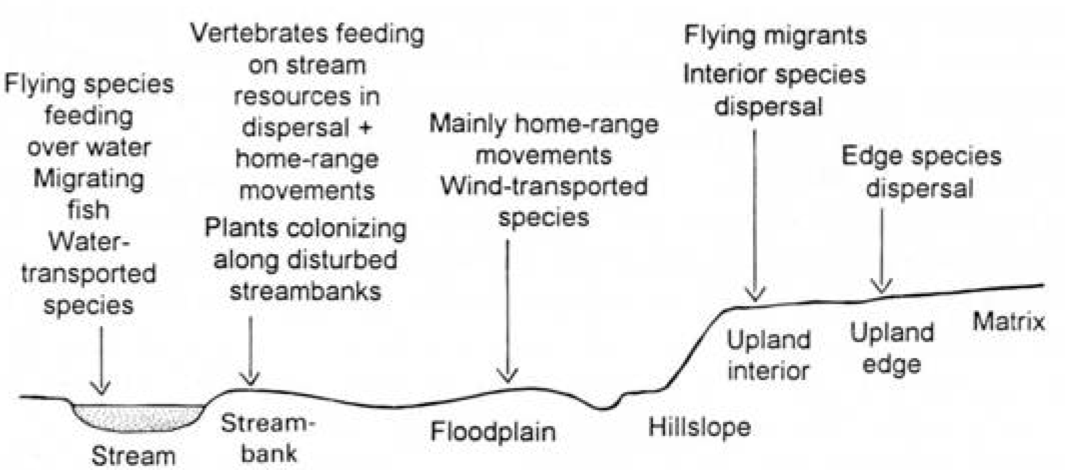

Figure 9. Regional corridors should include a wide diversity of habitats to accommodate a wide range of biodiversity *(AENV 2000)*

General Principles

- Headwater streams as well as all floodplains should be the primary focus areas for riparian corridor restoration or establishment
- Headwater streams and downstream floodplains generally encompass less than 10 percent of total landmass, representing a feasible protection goal (Naiman et al. 1993)
- Vegetated corridors along major streams and rivers provide erosion control, thereby protecting regional water quality
- Riparian buffers protect fish habitat
- Riparian vegetation provides habitats along river corridors that are often very distinct from the surrounding landscape

Metrics

- Degree of variable width riparian area in natural land cover[2]
- Vegetation extent
- Vegetation diversity

[2]In Alberta, DEM-derived variable width lotic riparian GIS polygons are now available province-wide, and can be intersected with the best local land cover maps

- Topographic complexity
- Degree of Bank modification
- Slope
- Anthropogenic footprint
- Stream Order

Specific Findings Related to Riparian Corridors

- The ideal size for a riparian buffer varies considerably based on the specific management goal. In general, buffers should be wider if the goal is to provide wildlife habitat, but do not need to be quite as wide if the goal is to protect water quality. As with other conservation thresholds, the literature does not support an ideal buffer width applicable in all circumstances (Kennedy et al. 2003). However, based on the majority of findings from empirical studies, buffer strips should be maintained at the following widths relative to the associated conservation target:
  - > 25 meters to provide nutrient and pollutant removal
  - > 30 meters to provide temperature and microclimate regulation and sediment removal
  - > 50 meters to provide detrital input and bank stabilization
  - > 100 meters to provide for wildlife habitat functions (Kennedy et al. 2003)
- Buffers less than 5-10m provide little protection of aquatic resources under most conditions (Castelle and Connolly 1994)
- Generally, minimum buffer widths (15m-30m) may help maintain natural physical and chemical characteristics of resources, but significantly wider buffers (>100m) may be required to maintain biological components of many wetlands and streams (Castelle and Connolly 1994; Kennedy et al. 2004)
- In areas with no riparian vegetation, both in-stream algal production and seasonal low flows appeared to be major determinants of suspended solids, turbidity, and phosphorus concentrations (Schlosser and Karr 1981)
- When riparian vegetation is maintained in areas of intensive agriculture, suspended solids levels are generally lower due to reduced in-stream organic production (Schlosser and Karr 1981)
- Variability in buffer width reduces total buffer retention, due to transport of contaminants through areas of below-average buffer width, especially through gap areas (Weller et al. 1998)
- In a study on the importance of continuity and width of riparian corridors in Wisconsin, streams with forested land within a 10 m buffer had less organic and sediment pollution (Stewart et al. 2001)
- Buffer width is an important consideration in managing nitrogen in watersheds (Mayer et al. 2007)

Table 8. Conservation Targets for Riparian Corridors

Taxa or Process	Target buffer width	Findings	Location	Citation
Water quality/ecosystem health	15-30 m	Stream buffers should be a minimum of 15 to 30 m in width to be effective in protecting the ecological integrity of wetlands and streams.	World-wide (literature review)	Castelle and Connolly 1994
Water quality/ecosystem health	5-10m	Buffers less than 5-10m provide little protection of aquatic resources under most conditions	World-wide (literature review)	Castelle and Connolly 1994
Water quality	3.4% of river basin	Restoring 10 million hectares of riparian zones and wetlands, representing 3.4% of the Mississippi River basin, would reduce nitrogen in the Mississippi River Basin and its tributaries by an average of 40%	Mississippi	Mitsch et al. 1999
Fish habitat/ aquatic health	30m	High percentages of forest cover within a 30m riparian buffer were related to healthy fish communities and water quality. Fish density increased with increase in the average length of riparian vegetation without gaps (>30m).	Wisconsin	Stewart et al. 2001
Water quality	>50m	Wide buffers (>50 m) more consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0-25 m).	World-wide (literature review)	Mayer et al. 2007
Water quality, aquatic health, fish habitat	30m width; 30m length	High percentages of forest cover within a 30m riparian buffer were related to healthy fish communities and water quality. Fish density increased with increase in the average length of riparian vegetation without gaps (>30m).	Wisconsin	Stewart et al. 2001

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- The ideal size for a riparian buffer varies considerably depending on management goals. In general, buffers should be wider if the goal is to provide wildlife habitat, and can be narrower if the goal is solely to protect water quality
- Buffers less than 5-10m provide little protection of aquatic resources under most conditions
- Continuous riparian buffers correlate with higher overall watershed water quality and aquatic diversity
- Riparian buffers play an important role in managing nitrogen uptake in watersheds
- For major river valley systems, an appropriate buffer should encompass more than just the area strictly considered “riparian” to include the entire river valley systems as well as an adjacent strip of upland interior habitat

These broader conclusions bring to light several management considerations that may be applied to riparian landscapes in similar contexts. For example:

- Fixed width buffers do not consider site-specific conditions, and therefore may not adequately buffer aquatic resources. Variable width buffers are derived from a combination of criteria based on site-specific conditions. They may be adjusted accordingly to protect valuable resources. However, variable width buffers also require greater expenditure of resources and more training for agency staff, while offering less predictability for land use planning. However, site-specific conditions may indicate the need for substantially larger buffers or for somewhat smaller buffers than the guidelines provided (Castelle and Connolly 1994).
- Protection efforts should prioritize the establishment of continuous buffer strips along the maximum reach of stream, rather than focusing on widening existing buffer fragments (Weller et al. 1998)
- Efforts to improve water quality in agricultural watersheds during base flow should emphasize riparian vegetation maintenance, as well as stable flow conditions (Schlosser and Karr 1981)
- Nonpoint pollution control strategies should consider the influence of small upland streams; protection of downstream riparian zones alone is insufficient to protect water quality (Dodds and Oakes 2008)

3.2.2.2 *Shelter Belts*

Shelterbelts are important linear landscape features composed of lines of trees or other vegetation used to control erosion in agricultural landscapes, thereby safeguarding regional air and water quality. Shelterbelts generally fall into one of four categories: 1) tree and shrub windbreaks, 2) annual and perennial vegetative barriers, 3) strip cropping and trap strips, and 4) crop residues and cover crops. In essence, shelterbelts control erosion by establishing more isolated and protected field conditions (Ticknor et al. 1988). Windbreaks and wind barriers contribute to wind erosion control by reducing windspeed on their leeward side and by decreasing field length in the erosive wind direction (Tibke 1988). Shelterbelts can also function as filters to ameliorate livestock odour by impeding and diffusing the movement of particulates (Tyndall and Colletti 2007).

The effectiveness of shelterbelts is determined partially by its external structure including its height, length, orientation, continuity, width, and cross-sectional shape. Effectiveness is also determined by its internal structure including the amount and distribution of solid and open portions, vegetative surface area, and shape of individual plant element (Brandle et al. 2004).

General Principles

- At the farm scale, shelter belts help control erosion and trap blowing snow, improve animal health and survival under winter conditions, reduce energy consumption of the farmstead, and enhance habitat diversity. At a landscape scale, they reduce windblown erosion and provide habitat for various types of wildlife (Brandle et al. 2004)
- Shelterbelts must be oriented as perpendicular as possible to the prevailing wind direction (Brandle et al. 2004)
- Windbreak height is the most important external structural element that determines the extent of wind protection (Brandle et al. 2004)
- As a general rule, the area completely protected by windbreaks is assumed to be a distance 10 times the height of the barrier downwind from the barrier along the prevailing wind direction (Ticknor et al. 1988)

Specific Findings Related to Shelter Belts

- Shelterbelts placed around livestock production facilities may effectively reduce the movement of odours emitted by manure to neighbouring properties (Leuty 2004)
- Because the odour source is near the ground and the tendency of livestock odour is to travel along the ground, shelterbelts of modest heights (6-10m) may be ideal for odour interception, disruption, and dilution (Tyndall and Colletti 2007)

- If trees are used as a windbreak, single row plantings are common and are as effective and use less land than multiple row plantings (Tibke1988)
- Measurements of air pressure upwind and downwind of a windbreak show that the pressure increases as the wind approaches the windbreak, drops as wind passes through the barrier, and then gradually returns to the original condition at or beyond 10 times the height of the windbreak (Brandle et al. 2004)

Table 9. Conservation targets for shelter belts

Taxa or Process	Shelter belt dimension	Findings	Location	Citation
Air quality	6-10m high	Shelterbelts of 6-10 meters high serve as an adequate buffer to reduce odours from nearby animal operations	North America	Tyndall and Colletti 2007
Erosion protection	Area protected = distance 10 times the height trees	Erosion protection is thought to extend to a distance 10 times the height of the tree species used as a windbreak	North America	Ticknor 1988
Erosion protection	Single row	Single row plantings are common and are as effective and use less land than multiple row plantings.	North America	Tibke 1988
Erosion protection	<9m between perennial grass barriers	The maximum distance of 9m should be maintained between perennial grass barriers when oriented perpendicular to the erosive wind force	North America	Tibke 1988

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Shelterbelts can be effective in controlling erosion and filtering odours at both the farm and landscape scale as a means of safeguarding regional air
- Shelterbelts must be oriented as perpendicular as possible to the prevailing wind direction
- For erosion control, the area completely protected by windbreaks is assumed to be a distance 10 times the height of the barrier downwind from the barrier along the prevailing wind direction
- Shelterbelts of 6-10 meters high serve as an adequate buffer to reduce odours from nearby animal operations

These broader conclusions bring to light management considerations that may be applied to agricultural or other landscapes characterized by shelterbelts in similar contexts. For example, perennial grass barriers can also be effective for controlling wind erosion, trapping snow and reducing evaporation on dryland cropping areas (Tibke 1988).

3.2.2.3 *Linear Disturbances*

While other types of linear disturbances exist, such as pipelines and seismic lines, roads are the predominant linear disturbance patterns that affect many ecological processes in landscapes all over the world (Forman 1995). For example, roads provide a direct source of mortality for slow-moving terrestrial vertebrates such as amphibians, while also providing the means by which human activities and land uses spread throughout the landscape (McGarigal et al. 2001). As linear landscape features that can create high-contrast edges when bisecting a patch, roads represent significant mechanisms of fragmentation and habitat loss, especially when used to facilitate logging activities (Tinker et al. 1997).

The literature revealed two main ways in which road disturbances are quantified in a landscape:

- As measures of road density in a landscape
- As critical distances at which wildlife avoid roads and pipelines

The relationship between road avoidance and density is a matter of scale and species perception. If an animal avoids roads at a certain distance, and the density of roads (i.e. ratio of road length to land area) is very high, an animal may be pushed out of a landscape completely depending on its threshold for avoidance and habitat area requirements. Conversely, some predators use road edges as travel corridors, altering the predator/prey balance of a landscape. For example, in a study of caribou mortality in relation to roads and wolf populations, caribou deaths were largely attributed to wolf predation closer to a road corridor, indicating that linear disturbance corridors may enhance wolf predation efficiency (James and Stewart-Smith 2000).

General Principles

As linear disturbances in the landscape, roads often serve as:

- Conduits for the movements of predators
- Vectors for encroachment of invasive weeds into patch interiors
- Barriers or filters, preventing or impeding the movement of sensitive species

Roads also affect ecological flows and the provision of ecosystem services, including:

- Increases in soil erosion and sedimentation rates, thereby affecting water quality
- Fire regimes by being a source of ignition resulting from human activities along the travel corridor (Franklin and Forman 1987)
- Fire suppression by serving as physical barriers to fire movement and providing increased accessibility for firefighting activities (McGarigal et al. 2001)

Specific Findings Related to Linear Disturbances

Roads and Biodiversity:

- As a component of a guide to consistent reporting for Alberta's State of the Watershed Reports, road density thresholds for bull trout were reported as follows: 0.0-0.1 km/km2 = low risk; 0.1-0.2 km/km2 = moderate risk; 0.2-0.6 km/km2 = high risk; 0.6-1.0 km/km2 = very high risk; >1.0 km/km2 = extirpation (AESRD 2012).
- In a study of IBI among fish in the Battle River of Alberta, the biotic integrity of fish assemblages were noticeably impaired at road densities as low as 0.7km/km^2 (Stevens and Council, n.d).
- Of 14 possible extinction-risk correlates for mammals, fishes, and birds throughout Canada, risk is positively and strongly correlated with road density and age at maturity for land animals. For birds, road density is the dominant correlate of risk (Anderson et al. 2011)
- In one study in Colorado, roads were found to have had a greater impact on landscape structure than logging. A three-fold increase in road density between 1950 and 1993 accounted for most of the changes in landscape configuration including mean patch size, edge density, and core area. Change in landscape structure varied as a function of landscape extent (McGarigal et al. 2001)
- Width of roadside verges is strongly positively correlated with exotic species richness and cover. Roads influenced both exotic and native species richness in interior communities 50 m beyond the edge of the road, suggests that roads affect the distribution of both exotic and native species in lands beyond the influence of roadside disturbance. In a study conducted on exotic species persistence in relation to road disturbance, sites isolated (>1000m) from roads tended to contain fewer exotic species than sites near (<50m) roads (Gelbard and Belnap 2003)

- In general, habitat further away from main roads which contain ground squirrels and open grassland is the most beneficial for badgers. The degree to roads affected badger populations depended upon the road type (Downey 2004b)
- In a study of elk habitat requirements, elk use was highest in summer in areas characterized by diverse habitats and at distances >2.8 km away from major roads. High use areas during winter were similar, although elk tended to use areas slightly closer to roads (>2.1 km away), which is largely attributed to reduced human activity on roads in winter (Sawyer and Neilson 2005)
- In a study of grizzly bear responses to road proximity, grizzlies strongly avoided roads regardless of traffic volume, suggesting that even a few vehicles can displace bears from adjacent habitats (Carroll et al. 2003)
- Grizzly bear population fragmentation corresponded to the presence of settled mountain valleys and major highways. In these disturbed areas, the inter-area movements of female bears was affected more than for male bears. Without landscape connectivity suitable for female bears, small subpopulations of grizzly bears are not viable over the long term (Proctor et al. 2012)
- In a study examining the spatial patterns and factors influencing small terrestrial vertebrate road-kill aggregations in the Bow River Valley of Alberta, Canada, mammal and bird road-kill indices were consistently higher on low volume parkway roads than on the high-speed, high volume highways (Clevenger et al. 2003)
- Forest-dwelling birds are more vulnerable to collisions than mammals on highways. Since they are generally reluctant to cross large un-forested gaps, the increased road-kill rate on divided sections of road may be explained by a greater propensity for birds to cross the narrower gaps. Highway sections with forested medians are less significant barriers to forest birds than open grassy medians (Clevenger et al. 2003)
- Low volume parkway road-kills are less likely to occur on raised sections of road, and tend to occur close to vegetative cover far from wildlife passages and culverts (Clevenger et al. 2003)

Roads and Water Quality:

- In a study of the effects of logging on watershed water quality in central Washington, turbidity and suspended sediment were measured adjacent to a logging road construction site. These measures increased with road construction but declined rapidly to nearly background levels after 2 years (Fowler et al. 1988)
- Roads can lead to increased erosion and suspended solids downstream, particularly as a result of unpaved surfaces, and potential erosion surrounding culverts, as well as from increased streambank erosion rates due to localized higher flows due to impermeable road surfaces (Forman et al., 2003)
- Road maintenance activities such as salting, de-icing, dust suppression, and pesticide application for weed control can result in salt-laden runoff and other localized water quality impacts
- Road wear and vehicle wear can lead to a wide range of chemicals to be gradually washed into creeks, rivers and lakes. Asphalt contains a mixture of condensed polycylic aromatic hydrocarbons, sulfur, and many heavy metals including nickel, vanadium, lead, chromium, mercury, arsenic, and selenium. Stress, deformation, and cracks over time can allow slow leaching of small amounts of these chemicals into surrounding ecosystems. Most of the chemicals found on and adjacent to roads originate from vehicles due to gradual wear, leaks, and emissions. This includes oil, grease, and hydraulic fluids, as well as a wide range of heavy metals and other chemicals released gradually due to wear and tear on car parts (Forman et al., 2003).
- Traffic accidents may also result in impacts to water quality particularly if contaminants such as gasoline, diesel fuels, or other dangerous cargo are spilled during an accident.
- Roads are also an organizing element for nearly all human activity, providing access to remote areas for people engaged in a wide range of activities such as off-highway vehicle use. Many industrial, recreational, and other activities associated with roaded access also represent potential water quality hazards.

Energy Development:

- Increasing seismic line density from 0 to 8 km/km2 resulted in a 38% decline and an 82% decline in bird abundance when individuals used lines as territory boundaries or avoided edges by 50 m, respectively. Ovenbirds declined with seismic line density when a threshold seismic line density of 8.5 km/km^2 was reached. Above the threshold, ovenbirds declined 19% for each 1 km/km^2 increase in seismic line density (Bayne et al. 2005)
- Sage-grouse leks are frequently abandoned once road use associated with mining and gas/oil development increased in close proximity (< 1 km) to leks and nesting habitat (Braun 2006)

Table 10. Road Density Thresholds

Taxa or Process	Target density	Findings	Location	Citation
Elk	1.5 km/km^2	Road density threshold at which elk could still occur in high numbers: 1.5 km/km^2	Oregon	Rowland et al. 2000
Elk	0.62 km/km^2	Road density threshold for elk in Alberta: 0.62 km/km^2	Alberta	AESRD 2012
Snakes (Prairie rattlesnake)	1.6km per 1/4 section	Road densities greater than 1.6 km per 1/4 section are unsuitable for prairie rattle snakes	Alberta	Kissner 2004
Grizzly bears	0.4 km/km^2	Road density threshold for grizzly bears in Alberta: 0.4 km/km^2	Alberta	AESRD 2012
Female Grizzly bears	<20% settlement	Females grizzlies reduced their movement rates drastically when settlement increased to >20% of a given area. In highly settled areas (>50% settlement), both sexes demonstrated similar reductions in movement.	Wyoming, Montana, Alberta, British Columbia	Proctor et al. 2012
Black bears	1.25 km/km^2	Road density threshold for black bears in Alberta: 1.25 km/km^2	Alberta	AESRD 2012
Fish	0.7km/km^2	Impaired integrity of fish assemblages was detectable at road densities as low as 0.7km/km^2	Alberta	Stevens and Council (n.d.)
Bull trout	0.0-0.1 km/km^2 = low risk; 0.1-0.2 km/km^2 = moderate risk; 0.2-0.6 km/km^2 = high risk; 0.6-1.0 km/km^2 = very high risk; >1.0 = extirpation	Road density thresholds for bull trout population persistence range from <0.1 km/km^2 (low risk) to >1.0 (species extirpation)	Alberta	AESRD 2012
Watershed health	2 km/km^2 = good; 2-3 km/km^2 = fair; and >3 km/km^2 = poor	General road density threshold indicators for watershed health include: <2 km/km^2 = good; 2-3 km/km^2 = fair; and >3 km/km^2 = poor[3]	Alberta	AESRD 2012
Bird Abundance	<8.5 km/km^2 seismic line density	Ovenbirds declined with seismic line density when a threshold seismic line density of 8.5 km/km^2 was reached. Above the threshold, ovenbirds declined 19% for each 1 km/km^2 increase in seismic line density (Bayne et al. 2005).	Northern Alberta	Bayne et al. 2005

[3] These general thresholds for watershed health have been documented in several recent state of the watershed reports produced by watershed groups in Alberta. However, they may not be appropriate in all watershed or sub-watersheds. Groups undertaking these assessments should seriously consider watershed specific characteristics and objectives, and seek expert advice to assist with selecting measures and thresholds.

Table 11. Road Avoidance Thresholds

Taxa or Process	Buffer width	Findings	Location	Citation
Birds	1,500 m for >10,000 vehicles/day; 2,800 m for >60,000 vehicles/day	In a study of grassland birds (bobolinks and meadowlarks), effect distances ranged from 50-1,500 m at 10,000 vehicles/day and increased to 70-2,800 m at 60,000 vehicles/day. Similar effect distances were found for woodland species.	Netherlands; Boston USA	Kaseloo 2005
Species dwelling near roads	1,000m	Species occupancy near roads is severely affected at a threshold traffic volume of 30,000 vehicles per day. Avoidance zones extend up to 1000 m from the road. Roads with 50,000 vehicles per day can result in an average effect-distance of 800 m for woodland species and more than 900 m for grassland species.	Multiple (literature review)	Kociolek and Clevenger 2011
Mammals (Elk)	>2800m	Elk use was highest in summer in areas characterized by diverse habitats and >2800m away from major roads	Wyoming	Sawyer and Neilson 2005
Mammals (Caribou)	1250m for active roads; 750m for derelict roads	The threshold distance at which caribou avoid roads is 1250m for active roads and 750m from derelict roads.	Quebec	Leblond et al. 2011
Mammals (Grizzly Bears)	100m	Grizzlies strongly avoided areas within 100m of all roads	Alberta	McLellen and Shackleton 1988
Invasive species	>1000m	Sites isolated (>1000m) from roads tend to contain fewer exotic species than sites near (<50m) roads	Utah	Gelbard and Belnap 2003

Interpretation of the Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- In general, most mammals, fish, and birds are significantly negatively affected by increasing road density in a given landscape
- Birds are more vulnerable to roadkill than mammals on divided highways with forested medians due to their willingness to cross narrow gaps. On highways with no median, many birds will judge the gap to be too large, and will not cross
- Roads can serve as vectors for the spread of invasive plant species, especially up to 1000m from the road
- Roads can affect male and female members of a species differentially, having cascading implications for the survival of populations when females of a species are disproportionately impacted
- Road avoidance among mammals varies seasonally, with greater avoidance during the summer months when human use is higher
- Road construction can increase turbidity and suspended sediment loads in nearby streams
- Noise associated with road traffic and energy development can significantly negatively affect bird breeding success

These broader conclusions bring to light management considerations that may be applied to landscapes characterized by roads in similar contexts. For example, the risk of landslides and erosion when constructing roads on steep terrain can be greatly reduced with improved road location, design, and maintenance (Adams and Taratoot 2001).

3.2.3 Patch Size

Large patches of natural vegetation provide ecological services that cannot be duplicated by other elements. For example, large patches of natural vegetation are the only structures in a landscape that protect a wide area of interconnected stream networks (Dramstad 1996). In this sense, patch size is one of the most important indicators of water quality and watershed health (US Trust for Public Land 2004).

However, when considering requirements for biodiversity conservation, targets for patch sizes are highly species-specific (Figure 9) and can range from 0.0004 ha (for some invertebrates) up to 220 000 ha for wide ranging mammals such as bears and cougars (O2 Planning + Design Inc. et al. 2008).

The size of a give patch is linked to its carrying capacity in terms of species diversity. Large patches have the capacity to support larger species with expansive home ranges, or area-sensitive bird species with specific core area requirements, whereas smaller patches support more generalist and edge species. Patch size can also affect predation rates, trophic cascades, and species diversity at a landscape level. One study in Southern California demonstrated that fragment size correlates with coyote abundance, which in turn influences the abundance of meso-predators that prey on scrub-breeding birds. Therefore, in this case, fragment area and age were the strongest determinants of bird diversity (Crooks and Soule 1999).

This section outlines general principles of patch size in relation to several aspects of environmental quality and biodiversity, lists metrics for quantifying patch size, cites specific findings derived from the literature, and presents conservation thresholds associated with patch size as a landscape indicator.

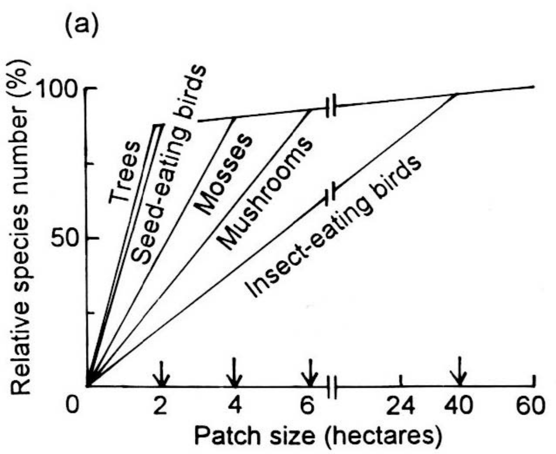

Figure 10. Sensitivity of different species groups to patch size *(From Forman 1995)*

General Principles

- In forested and mountainous ecoregions, desirable target patch sizes should be larger in order to protect headwaters, preserve interior habitat, and maintain wilderness recreation experiences (O2 Planning + Design Inc. et al. 2008)

Large patches provide:

- Connectivity for overland wildlife movement
- Habitat to sustain populations of patch interior species
- Core habitat for large roaming mammals

- Source of species dispersing to smaller patches throughout the matrix
- Unequivocal protection for aquifers and lakes by filtering nutrient runoff and reducing stream sedimentation

Metrics

- Total area of each patch type (class area)
- Percentage of cover of each patch type
- Number of patches of each type
- Patch density
- Variation in patch size
    - Patch size class distribution
    - Patch size standard deviation
- Mean and median patch size

Specific Findings Related to Patch Size

- Depending on the species or habitat in question, minimum critical patch size ranges from as little as 0.0004 hectares (based on the needs of certain invertebrates) up to 220,000 hectares (based on the needs of certain mammals) to sustain target species or communities (Kennedy et al. 2003)
- The amount of habitat necessary to maintain healthy wildlife populations varies according to differences in taxonomic group, body size, foraging and resource requirements, and species dispersal patterns (Bender et al. 1998)
- Taxonomic groups, such invertebrates and plants, which have smaller dispersal ranges and tend to respond to their environment at smaller spatial scales, require smaller habitat areas of less than 10 hectares (McGarigal and Cushman 2002)
- Breeding bird species richness patterns significantly increased with fragment size (Herkert 1994).
- In general, where large blocks of undisturbed grassland occur, grassland birds are able to fulfill most of their requirements during the nesting season. The more grassland available in an area, particularly in large unbroken blocks, the greater the number of area-sensitive grassland birds the area is able to support (USDA 1999)
- When isolated, larger patch size correlates with higher species density and occurrence in area-sensitive grassland birds (Johnson and Igl 2001)
- Larger bodied vertebrates and wide-ranging predators tend to require larger territories to meet resource and reproductive needs (Kennedy et al. 2003)
- Minimum habitat area is greater for large predators, with recommended patch sizes of > 2,800 hectares for bears and >220,000 ha for cougars (Mace et al. 1996 and Beier 1993, respectively)
- Wide-ranging predators or particularly sensitive interior bird species require habitat patches greater than 2,500 hectares (Kennedy et al. 2003)
- As a general rule, land use planners should strive to protect and maintain habitat patches larger than 55 hectares (Kennedy et al. 2003)

Table 12. Conservation Targets for Patch Size

Taxa	Target patch size	Finding	Location	Citation
Birds	5-55ha	Area-sensitive bird species required patches of suitable habitat at least 5-55 ha in size, and regularly avoided smaller grassland fragments even when they were composed of suitable habitat	Illinois	Herkert 1994
Birds	50 ha	Minimum habitat requirements for birds ranges from 1 to 2,500 hectares, however most studies cited area requirements under 50 hectares (Kennedy et al. 2003)	USA	Kennedy et al. 2003
Birds	>6.5 ha, 15.4-32.6 ha	Black tern required 6.5 ha in heterogeneous landscapes, but required 15.4-32.6 ha in homogenous landscapes	South Dakota	Naugle et al. 1999
Mammals (grizzly bears)	>900 ha	More than 80% of bear sitings occurred in blocks of undisturbed habitat >900 ha		Mace et al. 1996
Butterflies	2 ha	Patch areas of >2ha are required to sustain many populations of prairie butterflies	Alberta	O2 Planning + Design Inc. et al. 2008
Birds	>200 ha	Contiguous grassland blocks of >200 ha provide the greatest habitat potential for most grassland bird species	USA, Canada	USDA 1999
Fish (bull trout)	>2500 ha	In watersheds above 1600m in elevation, the probability of bull trout occurrence is significantly greater (predicted probability of occurrence is 0.5) in patches >2500 ha	Idaho	Rieman and McIntyre 1995

Interpretation of the Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Ideal patch size varies depending on the taxonomic group and associated dispersal patterns in question.
- In general, species with smaller dispersal ranges, such as plants and invertebrates, require smaller patches of <10 ha
- Large vertebrates, wide-ranging predators, and area-sensitive birds require larger patches of >2,500 ha
- When isolated, large patch size correlates with higher species density and occurrence, especially in area-sensitive birds.

These broader conclusions bring to light management considerations that may be applied to landscapes in similar contexts. For example:

- As a general rule, land use planners should strive to protect and maintain habitat patches larger than 55 hectares (Kennedy et al. 2003).
- Large forested patches should be maintained in the upper headwaters region of watersheds in order to safeguard water quality

3.2.4 Patch shape, core area, and edge

The following sections describe the influence of patch shape, core area, and edge width on ecological function. Although these are highly correlated with other landscape fragmentation and heterogeneity indicators, these are important to discuss as potential independent indicators as well.

Indicator Overview

The relationship between edge and core area and several ecological processes has been established in many studies (Holloran and Anderson 2005, Braun 2006, Gignac and Dale 2005). Patch shape affects edge conditions and subsequently the amount and quality of patch core area (i.e. circles and squares vs. elongated or highly convoluted shapes).

3.2.4.1 *Patch shape*

Patch shape is indicated by the approximate form of a two-dimensional area, which is calculated from the variation in the area's margin and border area (Forman 1995). Patch shape appears to be of significant ecological importance, particularly related to ecological flows and movement, although empirical correlation studies are not common in the literature. However, there have been studies of the cause and formation of shapes, their measurement, as well as the effect on ecological flows (O2 Planning + Design Inc. et al. 2002).

3.2.4.2 *Core area and edge*

The influence of matrix conditions on the edge of a patch give rise to vegetation structure that is different from that of the patch interior. Ecologically, the core area represents the interior or central portion of a patch that is a given distance from the edge. It is highly influenced by patch shape and size as well as edge width. The width of the edge may be variable and depends upon adjacent conditions as well as orientation. Wind direction, sun direction and internal edge structure all combine to determine the edge width and its effect on amount of core area.

Edge width varies depending on patch size and shape and the process or species under investigation. A single patch may have two or more disjunct core areas. These are formed when the narrow portions of the patch become completely edge dominated and core areas within the patch become discontiguous.

Groups of organisms respond differently to varying proportions of patch edge versus interior. While some generalist species, such as white tailed deer, may thrive under high edge conditions, other species—often rare species and habitat specialists—are negatively affected. Species that depend upon high proportions of forest interior, native prairie, wetlands, or other natural habitats will be absent from landscapes that lack sufficient natural areas containing true core habitat (Kennedy et al. 2003).

This section outlines general principles for patch shape, core area, and edge as landscape indicators of environmental quality and lists specific metrics used to quantify these indicators. Because the literature review generated very few specific or quantifiable findings on patch shape, specific findings and targets derived from the literature are presented here only for core area and edge.

General Principles

- Species diversity and foraging efficiency are generally higher in patches that have greater percentages of interior core area
- Large multi-habitat, wide-ranging species have a greater advantage in very large core areas; bear habitat security, for example, is often increased in larger undisturbed cores
- There are fewer barriers to wildlife in larger core areas
- Large core areas have less interaction with the surrounding matrix leading to reduced probability of invasive species spreading to the interior
- The probability of a species being locally extirpated decreases in patches with larger core areas

- Edges with higher structural diversity lead to more species likely to use the area as habitat
- Edges facilitate inter-patch flows, particularly species movement, fire, and other natural disturbances
- Edge shape facilitates different forms of species movement:
    - Straight edges promote movement parallel to the edge
    - Curvilinear edges promote permeability, or movement into the patch
- Edges functions as filters, buffering against the effects of adjacent land uses
- Edges occur where a habitat—such as a forest, prairie, or wetland—meets a road, clearcut, housing development, or some other natural or artificial transition or boundary (Kennedy et al. 2003). Changes in energy, nutrient, or species flows result from increased amounts of edge and reduced interior habitat, and has been termed the “edge effect”.

Metrics

- Patch shape
    - Mean patch fractal dimensions (grain)
    - Area weighted mean patch fractal dimension
    - Area weighted mean shape index
    - Mean shape index
- Core Area
    - Total core area
    - Mean core area index
    - Mean area per disjunct core
    - Disjunct core area standard deviation
    - Core as a percentage of landscape
- Edge
    - Total length of edge
    - Edge density (km/km2)
    - Contrasted weighted edge density

Specific Findings Related to Core Area and Edge

- A 5 km buffer around sage-grouse leks encompassed the majority (64%) of sage-grouse nests (Holloran and Anderson 2005)
- Sage-grouse numbers on leks within 1.6 km (1 mile) of coal bed methane (CBM) compressor stations were lower than on leks unaffected by this disturbance (Braun 2006)
- Mammalian predators (e.g., raccoons, foxes, coyotes, feral cats), egg-eating birds (e.g., crows and blue jays), and brood parasitizers (e.g., brown-headed cowbirds) concentrate their hunting along forest edges, thus, increasing the intensities of predation on native species (Patten et al. 2006)
- Based on the response of birds to edge environments, edge effects may penetrate into a habitat patch from about 16 meters up to almost 700 meters (Kennedy et al. 2003)
- Mammals may avoid edge environments from 45 meters up to 900 meters (Kennedy et al. 2003)
- Microclimate changes may extend from 8 meters up to 240 meters into habitat (Gignac and Dale 2005)

- Roads, trails, and other development should be placed at least 300 meters away from interior habitat to minimize impact (Kennedy et al. 2003)
- Bird and medium sized mammal population densities were affected by the arrangement and density of exurban housing developments, with both species groups avoiding developments up to 180 away (Odell and Knight 2001)

Table 13. Conservation Targets for Core Area and Edge

Taxa or Process	Target Edge Length	Finding	Location	Citation
Water quality	2250m for N and P; 4000m for sediment P	Nitrogen and phosphorous concentrations were negatively correlated with forest cover at 2250 meters from the wetland edge. Sediment and phosphorus levels were negatively correlated with wetland size and forest cover at 4000 meters from the wetland edge, and positively correlated with the proportion of land within 4000 meters of the wetland.	Ontario	Houlahan and Findley 2004
Amphibian species richness	2000m	Species richness increases with the percentage of forest within 2000m of a wetland	Iowa and Wisconsin	Knutson et al. 1999
Flora	65m	Trillium populations in forest remnants within 65m of forest clear-cut edges have almost no recruitment of young plants	Oregon	Jules 1998
Birds (chickadees)	75m	Chickadee flocks moved parallel to forest boundaries within up to 75m of forest edge	Alberta	Desrochers and Fortin 2000
Birds (burrowing owl)	600m	A 600 meter radius should be maintained around burrowing owl nests in order to ensure the survival of burrowing owls	Saskatchewan	Haug and Oliphant 1990
Birds (sage-grouse)	5000m	A 5000m buffer around sage-grouse leks encompassed the majority (64%) of sage-grouse nests.	Wyoming	Holloran and Anderson 2005
Birds (sage-grouse)	5500m	All drilling activities for gas and oil development should be prohibited within 5500m of active sage-grouse leks and their associated nesting areas (Braun 2006)	Alberta	Braun 2006
Flora	15m	Temperature and light intensity decreased, and humidity increased up to 15m from the edge of fragments, affecting bryophyte and lichen species richness	Alberta, Saskatchewan, Manitoba	Gignac and Dale 2005
Invasive species	>1000m	Sites isolated (>1000m) from roads tended to contain fewer exotic species than sites near (<50m) roads	Utah	Gelbard and Belnap 2003

Interpretation of Indicator Findings

Based on the findings from these selected publications, we are able to draw the following general conclusions:

- Species diversity is generally higher in patches with greater percentages of interior core area
- Larger core areas have less interaction with the surrounding matrix, resulting in reduced probability of exotic species invasion
- Edges with higher structural diversity generally have higher habitat value
- The shape of edges facilitate different movement patterns among mammals and birds, either directing movement parallel to hard edges of promoting passage through softer curvilinear edges
- Edges can act as both filters, buffering against adjacent land uses
- In general, mammals avoid edges between 45 and 900m in width
- Predation rates may be greater at habitat edges

These broader conclusions bring to light management considerations that may be applied to landscapes in similar contexts. For example, edge shape can be managed to promote movement and connectivity amongst birds and mammals that may be reluctant to cross hard edges.

3.2.5 Landscape Heterogeneity

This section provides information on land cover heterogeneity and its relationship to various aspects of environmental quality. Heterogeneity is not a single indicator but rather a series of configuration measures at a spatial level that lie between landscape and local ecosystem components (O2 Planning + Design Inc. et al. 2002).

Generally speaking, structurally complex, heterogeneous landscapes support more species and robust ecological processes than simple, more homogenous landscapes (Tscharntke et al. 2012). Heterogeneity is highly scale dependent, and differs according to species perception (Tews et al. 2004). As such, the reviewed literature generated very few specific targets associated with heterogeneity as a landscape indicator. Therefore, this section highlights metrics for quantifying landscape heterogeneity that may be useful for assessing variation across individual study areas.

Indicator Overview

The quantification of the diversity of land cover types found with any given region is often referred to as landscape heterogeneity. Heterogeneity may have a strong effect on ecological functioning, however the effects of heterogeneity per se are often difficult to quantify, and are strongly dependent on the nature of the land cover types found within any given landscape, and the species which make use of them. The distinction must be made between the diversity of natural land cover (which provides an increased range of habitats for species to occupy or otherwise interact with), and the diversity of anthropogenic land cover (which, while it may provide habitat to a select set of species, is often associated with habitat disturbance, individual mortality and loss of unique habitat types). Land cover heterogeneity is often perceived as fragmentation by certain species depending on the spatial scale at which they perceive the landscape (Tews et al. 2004). Other species may select habitat based on the close proximity of a number of disparate land cover types, and so require an assessment of the spatial configuration of the landscape in order to effectively evaluate the quality of habitat.

Structurally complex landscapes support more species than simple landscapes, implying that habitat patches in complex landscapes receive a higher diversity of potential colonists from the overall species pool than do patches of the same size and quality in less complex landscapes (Tscharntke et al. 2012). Due to a combination of spatial heterogeneity in landscape characteristics (presence of wetlands and lakes, underlying geology, etc.) and scale-related processes, boreal catchments can be expected to experience high spatial variability in water chemistry (Buffam et al. 2008).

As the nature of landscape heterogeneity differs greatly across landscapes, and is heavily influenced by data resolution and classification methodology, general thresholds are often difficult to establish. What constitutes a different land cover may vary substantially between species, and studies which attempt to assess the effect of differing land cover types may be influenced by the methods used to delimit disparate land cover. The classification of the landscape from a continuously varying surface of environmental conditions into a discrete set of classes has practical significance when conducting surveys and managing the land, but it is fundamentally an artificial distinction. A poorly conducted classification will introduce bias into the perceived environmental patterning of the landscape, and may skew or obscure relevant signals when assessing the environmental functioning of the landscape. A variety of factors influence the land cover classification and the resulting assessment of landscape heterogeneity: the resolution and extent of the raw data, the intended purpose of the land cover product, and the classification methodology used to detect discrete classes from the raw, continuous data inputs. Most land-cover analyses tend to treat the landscape as a 2-dimensional surface, and therefore may not adequately represent the true 3-dimensional structural complexity of a particular area. Subdividing land-cover into age-classes is often used in forested landscapes to represent this facet, but these classifications often necessitate a broad-brush assessment when conducted across a wide extent.

For these reasons, the effect of increasing land cover heterogeneity is often inconsistent when comparing between landscapes, depending on the aspects of the environment under study, and proscriptive universal targets or thresholds are often difficult to establish. However, changes to land cover heterogeneity have been shown to affect a wide variety of ecological components (regardless of the direction or magnitude of that effect), and so must be considered and evaluated when assessing the ecological condition of any particular area. It is especially useful when comparing the condition or functioning of subsets of a single landscape, as these subsets are likely to contain similar sets of species and environmental conditions, and are therefore more likely to respond in a similar fashion to changes to heterogeneity.

General Principles

- *Biotic diversity principle*- landscape heterogeneity decreases the abundance of rare interior species, increases the abundance of edge species and animals requiring two or more landscape elements, and enhances the potential species coexistence.
- *Species flow principle*- the expansion and contraction of species among landscape elements has both a major effect on and is controlled by landscape heterogeneity.
- *Energy flow principle*- the flows of energy and biomass across boundaries separating the patches, corridors and matrix of a landscape increase with increasing landscape heterogeneity.
- *Landscape change principle*- when undisturbed, horizontal landscape structure tends progressively toward homogeneity; moderate disturbance rapidly increases heterogeneity, and severe disturbance may increase or decrease heterogeneity.

Specific Findings Related to Heterogeneity

- Pine beetle eruptions occur when key thresholds are surpassed, prior constraints cease to exert influence, and positive feedbacks amplify across scales. The structure of the greater landscape critically influences pine beetle eruptions. Landscape-scale management and land-use activities can reduce forest heterogeneity, a major constraint against populations surpassing the eruptive threshold (Raffa et al. 2008).

Metrics

- Simpson’s diversity index
- Patch density
- Index of juxtaposition and interspersion
- Contagion index

3.2.5.1 *Simpson's Diversity Index*

The diversity of natural land cover types plays an important role in the ecological functioning of the landscape. Increasing cover diversity is associated with increases in the range of ecological spaces available to species, which tends to increase the overall biodiversity of the region. For example, frogs and toad species have been shown to be more abundant and diverse where habitat patch diversity was high (Knutson et al. 1999).

Simpson's diversity index is a useful metric for assessing the diversity of land cover types across the region, as it provides an easily interpretable index of diversity. Although there are a number of alternative formulations of the index itself, fundamentally the question answered by the index is 'what is the likelihood that any two randomly selected units in the landscape are of the same cover type?'. As this probability increases, the landscape is said to be dominated by that cover type. As the probability decreases, the landscape is said to contain an even distribution of land cover types. Landscapes dominated by a single land cover type tend towards lower structural complexity, and a reduced biodiversity, as the range of spaces that may be occupied by different species is reduced. Dominant cover types may be more susceptible to large scale disturbance, such as fire or pest outbreak, as once the conditions are met for disturbance of that cover type, wholesale landscape disturbance may more easily occur. Again, it comes down to the nature of the cover types under investigation. If the classification does not adequately represent the critical components of the landscape, then assessments of heterogeneity may not provide a clear signal.

3.2.5.2 *Patch Density*

Natural cover in close proximity may provide a greater functional contribution to ecological function than the same total area of natural cover spread farther apart. For this reason, patch density may be a useful indicator when assessing and comparing the relative value of habitat in particular areas. Natural patch complexes, identified as a set of smaller patches located within a species-specific threshold distance (based on local daily movement distances, for example) may be as important to the ecological functioning of the landscape as single large patches.

3.2.5.3 *Contagion*

The contagion index has been widely used in landscape ecology because it seems to be an effective summary of overall clumpiness on categorical maps. The contagion index is based on the probability of finding a cell of type i next to a cell of type j, and identifies which cover types are spatially associated with each other on a scale equivalent to the resolution of the land cover data. Contagion indices may be very useful for identifying small-scale structural differences across the landscape, when probabilities are calculated over broad subsets of the landscape. Certain areas may have very similar proportions of different cover types, the contagion index can be used to evaluate whether the spatial structure of these cover types is similar. 'Salt and pepper' configurations may result in decreased habitat quality due to edge effects.

3.2.5.4 *Juxtaposition and Interspersion*

The juxtaposition or interspersion of patches plays an important role in defining the quality of habitat in the landscape. Many species require a range of types of habitat within the landscape in order to meet their life history needs. The interspersion and juxtaposition index is based on patch adjacencies, not single-cell adjacencies like the contagion index. As such, it does not provide a measure of class aggregation like the contagion index, but rather assesses the interspersion or intermixing of patch types. This metric is an important one for assessing the quality of the landscape for species which are dependent on a variety of habitat types for different stages of their life-history, or those which require different cover types for foraging than they do for nesting. For example, habitat for western small-footed myotis bats is ideally located within 1 km of water, to provide access to high densities of insects during foraging without straying far from shelter. Habitat located >3km from water is deemed unsuitable (Landry 2004a). Other species may require a buffer between their optimal habitat cover and anthropogenic cover types, as avian densities have been shown to be altered up to 180 m away from homes on the perimeter of ex-urban developments (Odell and Knight 2001). Other species may require substantially different conditions as the seasons change. Habitat associations of prairie rattlesnakes appear to differ depending on whether snakes are hibernating, foraging, or reproducing. Most rattlesnake hibernacula occur within 4 km of a major river, drainage, or coulee, on relatively gentle slopes, but they migrate as far as 25 km away from dens in summer (Kissner 2004).

3.2.5.5 *Isolation*

Isolation may be quantified as the distance between habitat patches in the landscape, calculated as the average distance for a given patch, or the average distance between patches across the entire landscape. This metric is highly dependent on the methods used to identify and delimit these patches, and threshold values will be strongly influenced by the movement and behavioural regime of the species in question. For example, marten capture rates were negatively correlated with increasing proximity of open areas and increasing extent of high-contrast edges. Forested landscapes were unsuitable for martens when the average nearest-neighbour distance between open, non-forested patches was <100m (Hargis et al. 2009). Species with strong associations to particular cover types tend to show the greatest effect of patch isolation, but this may be simply because the identification of habitat for these species is more clear cut or consistent. Depending on the ease and extent of movement of the species in question, the impacts of isolation begin to be detectable only after substantial habitat loss. The negative effects of patch size and isolation on species may not occur until the landscape consists of less than 10% suitable habitat for birds, and 30% suitable habitat for mammals. Isolation in space was also a significant factor in determining the degree of species richness in a grassland landscape (Bruun 2000).

Interpretation of Indicator Findings

Based on the findings from selected publications, we are able to draw the following general conclusions:

- Structurally complex, heterogeneous landscapes support more species and robust ecological processes than simple, more homogenous landscapes (Tscharntke et al. 2012)
- Land cover heterogeneity is often perceived as fragmentation by certain species depending on the spatial scale at which they perceive the landscape (Tews et al. 2004)
- Landscape heterogeneity decreases the abundance of rare interior species, increases the abundance of edge species and animals requiring two or more landscape elements, and enhances the potential species coexistence (Kennedy et al. 2003)
- The flows of energy and biomass across boundaries separating the patches, corridors and matrix of a landscape increase with increasing landscape heterogeneity (Kennedy et al. 2003)

3.3 Conclusions

The functioning of the environment is strongly dependent on the spatial patterning of natural habitat, and human disturbances. The specific nature of this dependence varies substantially depending on the environmental component under investigation, and the approaches used to identify and describe the patterns across the landscape. This synthesis cast a wide net in order to document and distill essential findings and principles found in 172 of the most influential publications in landscape ecology. In doing so, it forms the basis for an effective cross-media, coarse filter approach to assuring environmental quality across various scales and landscapes in Western North America. The resulting reference database must be bolstered and extended over time, to ensure that recent learnings are documented as they come to light.

Each of the 172 papers selected for this literature review shed light on the ways in which patterns of land use and land cover influence ecological flows of water, nutrients, animals, and plants across a landscape. While many papers were generalized studies of mechanisms affecting biodiversity and ecological processes, several studies focused on localized effects of land cover amount or configuration on a specific taxa, species, or impacts to water quality. The vast majority of papers were based in empirical studies, supported by a minority of prominent studies based on modelling or literature surveys.

Efforts were made to cast a wide net in order to capture papers touching on all aspects of environmental quality. However, by nature of the spread and focus of available literature, a large portion of papers reviewed for this report were biodiversity related studies (43%) while the second largest portion focused on water quality and quantity (25%). Of the biodiversity studies, 23 % focused on birds and 16% focused on mammals. The other 4% were model based biodiversity studies. Of the water quality and quantity studies, the strongest association found is that between vegetation cover (forest cover and riparian extent) and water quality.

Other particularly significant or overarching conclusions that can be drawn from this review include:

- The patterns which we perceive on the landscape are fundamentally influenced by the categories and classifications used to describe the features in the landscape
- There are consistent benefits to maintaining *indispensible patterns* (Forman 1995) in the landscape that are key to maintaining robust ecological function and species diversity. As such, land managers should strive to protect the following heterogeneous combination of landscape features:
  - Large patches of natural vegetation
  - Connectivity between large patches
  - Continuously vegetated riparian corridors
  - Stepping stones of natural habitat distributed throughout the matrix
- Land cover and the configuration of landscape features are related, and relative importance of each fluctuates at certain thresholds of landscape cover
- Proportion of native land cover in a landscape is a good indicator or environmental quality, species diversity, riparian and watershed health
- Proportion of impervious surface and agricultural land cover are inverse indicators of environmental quality, species diversity, riparian and watershed health
- Large patches of forest or other natural vegetation provide ecological services that cannot be duplicated by other elements
- Linear corridors of vegetation can provide habitat connectivity and erosion control in an otherwise fragmented landscape

The information and conclusions summarized in this report are fairly robust and are recommended for utilization in a wide range of planning and environmental management exercises. However, the literature on this interdisciplinary subject is vast, complex, and is expanding rapidly. Consequently, additional and ongoing efforts devoted to synthesizing and honing our understanding is highly recommended. To help facilitate this endeavour, the database associated with this report can be expanded over time to include additional research.

In addition, whenever users are applying concepts, targets, and thresholds within case-specific applications, supplementary research should also be conducted to address the place-specific nature of the area under consideration. As such, the information and guidelines provided in this report may be applied over broad areas in the absence of species-specific information. While landscape scale analyses may not be appropriate for all assessments of ecological condition, this report and its associated tools represent powerful first steps in broadening the horizons of applied ecological research.

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ANNOTATED BIBLIOGRAPHY

1. **Citation:** Sullivan, TJ, JR Webb, KU Snyder, AT Herlihy, and BJ Cosby. "Spatial distribution of acid sensitive and acid-impacted streams in relation to watershed features in the Southern Appalachian Mountains." *Water, Air and Soil Pollution* 182 (2007): 57-71.

   Link: swas.evsc.virginia.edu/VTSSS-2010/.../Sullivan_et_al_WASP07.pdf

   Synopsis: Hypotheses relating to watershed sensitivity to acidic deposition were tested using a geologic classification scheme and available regional data for the Southern Appalachian Mountains region. Landscape characteristics including lithology, elevation, elevational gradients, landscape position, and forest cover were used in the geologic classification scheme. Acid neutralizing capacity (ANC) was used as the stratifying variable for evaluating streamwater acid-base chemistry. The geologic scheme was able to explain the location of all known streams that have low ANC or that are acidic in the Southern Appalachian Mountains Initiative (SAMI). Results from the study indicate that acidic and low-ANC streams are strongly associated with watershed lithology. Other important variables that influence acid-sensitivity include elevation, percent forested watershed and watershed area. The relationships based on these parameters have allowed identification of sub-regions where acid-sensitive streams are most abundant.

   Keywords: Acid neutralizing capacity, acidification, Appalachian Mountains, geology, streamwater, watershed

   Scale: Meso-regional

   Location:
   Jurisdiction: West Virginia, Kentucky, Tennessee, Alabama, Georgia, South Carolina, North Carolina, Virginia
   Ecoregion: Ozark, Ouachita-Appalachian Forests

   Landscape Type/Pattern:
   Land Use: protected area, settlement
   Landscape pattern: percent native

   Part of the Environment: Water quality

2. **Citation**: Scott, KA, B Wissel, JJ Gibson, and SJ Birks. "Chemical characteristics and acid sensitivity of boreal headwater lakes in northwest Saskatchewan." *Journal of Limnology* 69, no. 1 (2010): 33-44.

   Link: http://www.jlimnol.it/index.php/jlimnol/article/view/jlimnol.2010.s1.33

   Synopsis: This study evaluates the acid sensitivity of lakes in Saskatchewan within ~300km of Fort McMurray. The study area is downwind of atmospheric emissions sources from regional oil sands mining operations and there is concern that the lakes may be threatened by acidification. A helicopter sampling program was implemented in late September 2007 and 2008 to measure 16 chemical variables (e.g., Ca, Mg, Na, pH) and 15 environmental variables (e.g., latitude, elevation, slope, percent bog, percent fen) for 259 headwater lakes. Acid neutralizing capacity (ANC) was used as an index of the extent of surface water acidification and sensitivity to acidification. A high degree of acid sensitivity was found among the lakes: 60% were sensitive and 8% were highly sensitive. The remaining 32% of the lakes were well buffered to acid deposition.

   Keywords: acidification, lake chemistry, land cover, critical load, SSWC model, Canada

   Scale: Regional

   Location:
   Jurisdiction: Saskatchewan
   Ecoregion: Coppermine River and Tazin Lake Uplands, Athabasca Plain and Churchill River Upland, Mid-Boreal Lowland and Interlake Plain

Landscape Type/Pattern:
Land Use: Protected area, forest, settlement
Landscape pattern: percent native, connectivity

Part of the Environment: Water quality

3. **Citation**: Hargis, Christina D, John A Bissonette, and David L Turner. "The influence of forest fragmentation and landscape pattern on American martens." *Journal of Applied Ecology* 36, no.1 (1999): 157-172.

   Link: http://www.jstor.org/stable/2655704

   Synopsis: This study aimed to determine whether American marten abundance changed with incremental increases in habitat fragmentation caused by the combined effects of natural openings and timber clearcuts. Researchers evaluated differences in marten capture rates in 18 study sites with different levels of fragmentation. Martens appeared to respond negatively to low levels of habitat fragmentation, even with remaining patches of connectivity. Marten capture rates were negatively correlated with increasing proximity of open areas and increasing extent of high-contrast edges. Forested landscapes were unsuitable for martens when the average nearest-neighbor distance between open, non-forested patches was <100m. Therefore, it is recommended that the combination of timber harvests and natural openings constitute no more than 25% of a landscape greater than 9km^2. Since the spatial pattern of open areas determines the amount of forest interior habitat in a landscape, it is also recommended that timber cuts are made progressively from a single cleared patch in order to retain the largest amount of forest interior habitat as possible.

   Keywords: Edge density, habitat fragmentation, *Martes americana*, proximity index, timber harvest

   Caveats: 1) R^2 values associated with all significant relationships were low. It may be unrealistic to expect high R^2 values in a study design where landscapes are the units of replication. 2) The size chosen for study areas was small relative to marten home range scale. 3) Marten capture rates represent relative, not absolute, marten numbers. Sites with no marten captures may have contained martens but at densities too low to detect during the 6-night trapping period. 4) Researchers were unable to determine whether martens in our samples were residents or transients. This is an important consideration because high numbers of transients could indicate a population sink. 5) Martens in the study sites may have exhibited a stronger response to low levels of fragmentation than would be expected in geographical areas with less harsh conditions. The clearcuts in our sites provided no habitat for martens because cut areas generally were stripped of both vegetation and logging slash after timber harvest.

   Scale: site/local (replicated 9 km^2 study areas)

   Location:
   Jurisdiction: Utah
   Ecoregion: Wasatch and Uinta Mountains

   Landscape Type/Pattern:
   Land Use: managed forest, timber harvest
   Landscape pattern: fragmentation, percent native, edge

   Part of the Environment: Terrestrial mammals

4. **Citation**: Knutson, Melinda G, John R Saur, Douglas A Olsen, Michael J Mossman, Lisa M Hemesath, and Michael J Lannoo. "Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, USA." *Conservation Biology*13, no.6 (1999): 1437-1446.

   Link: http://www.jstor.org/stable/2641967

Synopsis: This study examined landscape-level relationships for frogs and toads by measuring associations between relative abundance and species richness based on survey data derived from anuran calls and features of land cover maps for Iowa and Wisconsin. Relative abundances correlated positively with metrics such as the length of edge between forest and wetland, and negatively with the presence of agricultural and urban land. Remnant forest patches in agricultural landscapes provided refuge for some frog and toad species. In summary, predicting amphibian habitat use based on landscape features can be helpful in conservation efforts, however water quality and vegetation information collected from individual wetlands may be needed to strengthen those predictions.

Keywords: Species richness, relative abundance, anuran calls, landscape metrics, wetlands, water quality

Scale: Meso-regional (Iowa and Wisconsin)

Location:
Jurisdiction: Iowa and Wisconsin
Ecoregion: Western corn-belt plains, Driftless area, North-central hardwood forest, Southeastern Wisconsin till plains, Northern lakes and forests.

Landscape Type/Pattern:
Land Use: agriculture, urban, forested
Landscape pattern: fragmentation

Part of the Environment: Riparian systems, biodiversity indices

5. **Citation**: Taylor, Brad N. "Great Plains Toad." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 99-105. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division. 2004a.

   Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

   Synopsis: In Alberta, Great Plains toads are found in the dry mixed grass of the southeastern corner of the province. Typical breeding habitat tends to be in shallow ponds with relatively fresh, clear water in sandy soil. In this report habitat suitability was evaluated for the Great Plains toad according to the parameters of soil order, soil texture, and native prairie class. Great plains toads are primarily found in soil orders that are primarily chernozemic and secondarily solonetzic in the Milk River Basin. However, these sites are adjacent to regosolic soils. Chernozemic/solonetzic soil orders accommodate the toads breeding requirements by allowing ponds to last longer due to the poor drainage attributed to solonetzic type soils. Sandy soils are indicated in the literature as one of the primary habitat suitability factors. Moderately coarse and coarse soil textures are important for burrowing habitat. Native Prairie Class (NPC) is derived from the Native Prairie Vegetation Baseline Inventory developed by Alberta Environment. Class 1 is comprised of greater than 75% native prairie components (i.e. shrubs, graminoids, riparian areas, lakes, wetlands, and trees), Class 2 is 50 - 75%, Class 3 is 25 - 50%, Class 4 is 1- 25%, and Class 5 is no native prairie components. HSI values were 1 for Class 1 sites, decreasing in value as Class increased.

   Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Great Plains toad

   Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

   Scale: Sub-regional (Milk River Basin)

   Location:
   Jurisdiction: Alberta, Saskatchewan
   Ecoregion: Northwestern Glaciated Plains

   Landscape Type/Pattern:

Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, amphibians, species-at-risk

6. **Citation**: Landry, Julie P. "Western Small-footed Myotis." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 90-98. Edmonton, AB.: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004a.

   Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

   Synopsis: Areas for roosting are likely the most limiting factor for the Western Small-footed Myotis. Unlike various other bats, this myotis does not roost in trees, but rather under rocks, and in holes and crevices found in rock outcrops within cliffs and coulees. Summer roosts can be found in cavities within cliffs, boulders, vertical banks, the ground, and talus slopes. Preferred roosting sites are in small, protected, and dry and hot (27-33°C) crevices. Although human disturbance may be of limited concern for the western small-footed myotis, activities such as the damming of rivers may flood their roosting habitat. Terrain slope, distance to water, as well as the proportion of rock outcrops and exposed soil were considered in an evaluation of habitat suitability. Steep river valley coulees and cliff areas have significantly higher bat activity than areas of more gradual topography. Steeper terrain areas can be used for foraging and may contain rock outcrops for roosting. Consequently, habitat suitability increases as steepness of terrain increases. For the purposes of this study, rock outcrops and exposed soil areas were considered preferred roosting habitat for bats. Lastly, distance to water was a significant factor affecting habitat suitability. Distances of 0 -1 km from water received the highest HSI value of 1, while distances of 3 km and over were deemed unsuitable and therefore assigned an HSI value of 0.

   Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Western Small-footed Myotis

   Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

   Scale: Sub-regional (Milk River Basin)

   Location:
   Jurisdiction: Alberta, Saskatchewan
   Ecoregion: Northwestern Glaciated Plains

   Landscape Type/Pattern:
   Land Use: Native Prairie
   Landscape Pattern: Percent native

   Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, terrestrial mammals, species-at-risk

7. **Citation**: Weins, John A, Robert L Schooley, and Ronald D Weeks. "Patchy landscapes and animal movement: do beetles percolate?" *Oikos* 78 (1997): 257-264.

   Link:http://ezproxy.lib.ucalgary.ca/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=8226014&site=ehost-live

   Synopsis: This study used beetles to empirically test the reliability of neutral percolation models to predict critical thresholds of landscape connectivity. Beetle movements declined sharply when grass cover dropped below 20% of the experimental plot. The findings of this study differed from what was predicted by the model, indicating that landscape connectivity is not dependent on spatial pattern alone, but is also highly dependent how individual organisms move within and among patches depending on the amount of cover. The results suggest that assessments of metapopulation structure must consider landscape pattern, but also the non-linear responses of organisms to such patterns.

Keywords: patch, landscape connectivity, landscape pattern, neutral percolation models.

Scale: Site scale, but applicable to entire region (short-grass prairie of north-central Colorado, USA)

Location:
Jurisdiction: Colorado
Ecoregion: High Plains

Landscape Type/Pattern:
Land Use: protected area, rangeland
Landscape Pattern: patchiness, fragmentation, connectivity

Part of the Environment: Terrestrial micro-fauna, ecosystem intactness

8. **Citation**: Tscharntke, Teja, et al. "Landscape moderation of biodiversity." *Biological Reviews* 87, no. 3 (2012): 661-685.

   Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1469-185X.2011.00216.x/pdf

   Synopsis: Structurally complex landscapes support more species than simple landscapes, implying that habitat patches in complex landscapes receive a higher diversity of potential colonists from the overall species pool than do patches of the same size and quality in less complex landscapes. Movement across habitats is a common phenomenon in many species and the spillover of organisms from natural habitats to agroecosystems has been well documented in human dominated landscapes. The authors propose a variety of hypotheses which explain how landscape structure moderates local to landscape biodiversity patterns and how such structure influences population, community and ecosystem processes. The authors organize the eight hypotheses into four sections. Section A on 'landscape moderation of biodiversity patterns' focuses on the dependence of local (alpha) biodiversity on the landscape-wide species pool and whether there is a dominant role of landscape-wide beta diversity for determining landscape biodiversity. Section B on 'landscape moderation of population dynamics' addresses landscape moderated spillover across habitats and the transient dilution or concentration of populations in dynamic landscapes. Section C addresses the 'landscape moderation of functional trait selection' driving the functional role of communities and their insurance effect in changing landscapes. The applied focus of Section D, 'landscape constraints on conservation management,' deals with landscape-dependent effectiveness of conservation management and the different measures needed for the enhancement of endangered species versus ecosystem services.

   Keywords: Landscape, biodiversity, pattern, process, beta diversity, mechanism

   Caveats: This is a review and synthesis paper, which contains excellent proposed mechanisms, but is not reflective of direct research efforts.

   Scale: Meso-regional

   Location:
   Jurisdiction: n/a
   Ecoregion: n/a

   Landscape Type/Pattern:
   Land Use: managed ecosystems
   Landscape Pattern: Percent cover, connectivity

Part of the Environment: Ecosystem health, functionality/intactness, biodiversity indices, species-at-risk

9. **Citation**: O2 Planning + Design Inc. NAESI Biodiversity Prairie Synthesis. Environment Canada, 2008a.

Link: http://www.o2design.com/solutions/working-landscapes/habitat-based-biodiversity-standards-for-agricultural-landscapes

Synopsis: This report synthesizes the work completed to date on habitat-based biodiversity standards specific to the prairie ecozone. The intent of this report is to contribute to the delivery of habitat-based biodiversity standards in the Prairie region via landscape-level indicators and targets. Examples of key landscape targets for prairie landscapes that were identified included:

- A minimum of 3 to 7% (<10%) of each major watershed should be in wetland habitat to provide adequate flood control and water quality values for the landscape.
- Rehabilitation of wetlands should take place in key locations such as headwater areas for groundwater discharge and recharge, floodplains for flood attenuation and coastal wetlands for fish production corridors between large patches
- Streams should have a minimum riparian habitat width of 100m on both sides of the stream
- Seventy-five percent of 1st and 2nd order streams should be vegetated
- Small patches (<40 ha) should be interconnected by vegetated hedgerows and/or shelterbelts, or be located within 400 m of each other
- Medium (40-500 ha) and large (500 ha or larger) patches should be interconnected by forested corridors >100 m in width

Keywords: Agriculture, biodiversity, prairie ecozone

Scale: Regional (Southern Alberta)

Location:
Jurisdiction: Alberta
Ecoregion: Northwest glaciated plains, northern glaciated plains

Landscape Type/Pattern:
Land Use: agriculture, settlement
Landscape Pattern: fragmentation, linear disturbance, connectivity

Part of the Environment: Ecosystem services, biodiversity indices, ecosystem function

10. **Citation**: Kadoya, Taku, and Izumi Washitan. "The Satoyama Index: A biodiversity indicator for agricultural landscapes." *Agriculture, Ecosystems and Environment 140* , 2011: 20–26.

Link: http://www.sciencedirect.com/science/article/pii/S0167880910002963

Synopsis: The most critical of the issues faced in addressing the targets of the Convention of Biological Diversity are ‘biodiversity conservation under agricultural development’ and ‘the sustainable use of natural resources and/or land’. Therefore, appropriate indicators for the status of biodiversity and the pressures placed on biodiversity in relation to the intensification of agriculture are needed. Agricultural development has had major impacts on biodiversity and the abandonment of traditional land use to meet rapidly growing demands for food and biofuel. Habitat diversity is one of the most important factors influencing biodiversity in agricultural landscapes. An ecological index of ecosystem or habitat diversity in agricultural landscapes is proposed – the Satoyama Index (SI) – that is discernible under appropriate spatial units (e.g., 6km×6km) from 1 km×1 km gridded land-cover data available from an open-access web site. A high SI value is an indicator of high habitat diversity, which is characteristic of traditional agricultural systems, including Japanese satoyama landscapes, while a low value indicates a habitat condition typical of extensive monoculture landscapes. The index correlated well with the spatial patterns of occurrence of a bird of prey (Butastur indicus) and species richness of amphibians and damselflies in Japan. The values of the SI also corresponded well to the spatial patterns of typical traditional agricultural landscapes with high conservation value in other countries, for example, the dehesas of the Iberian Peninsula and shade coffee landscapes in Central America. Globally, the pattern of East/South-East Asian paddy belts with their high index values contrasts markedly with the low values of the Eurasian, American, and Australian wheat or corn belts. The SI, which correlates landscapes with biodiversity through potential habitat availability, is highly promising for assessing and monitoring the status of biodiversity irrespective of scale.

Keywords: Amphibian species richness, Butastur indicus, Convention on Biological Diversity, Countryside biodiversity, Damselfly species richness, Landscape heterogeneity

Caveats: A land-use category revision may be required to apply the index to finer scales.

Scale: world-wide

Location:
Jurisdiction: agricultural areas (globally)
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: tilled agriculture
Landscape pattern: connectivity

Part of the Environment: biodiversity indices; bird; ecosystem functionality/intactness

11. **Citation**: British Columbia Ministry of Water, Land, and Air Protection. Environmental Trends in British Columbia. State of the Environment Report, Victoria, BC: Government of British Columbia, 2002.

Link: http://www.env.gov.bc.ca/soe/archive/reports/et02/ET2002_report.pdf

Synopsis: This document represents British Columbia's third environmental indicators report, including 16 key indicators incorporating 64 separate measures highlighting the status and trends in environmental issues. The information is grouped into six theme areas: biodiversity, water, stewardship, human health and the environment, toxic contaminants, and climate change. Individual sections report current conditions and action plans to address key issues, which often include thresholds and targets associated with environmental factors that give precision and shape to planning goals.

Keywords: Environmental indicators, biodiversity, water quality, climate change, environmental quality

Caveats: Examples of road density thresholds are not applicable to all areas of the province because the impact of roads also depends on the amount and type of traffic.

Scale: Meso-regional

Location:
Jurisdiction: British Columbia
Ecoregion: Boreal Cordillera, Marine West Coastal Forest, Thompson-Okanogan Plateau

Landscape Type/Pattern:
Land Use: agriculture, timber harvest, urban and rural settlements, energy development, roads, protected areas
Landscape pattern: percent native, fragmentation, linear disturbance, edge, connectivity

Part of the Environment: Air quality, water quantity and quality, biodiversity indices, riparian systems, terrestrial mammals, species at risk, ecosystem services

12. **Citation**: Schmiegelow, Fiona KA, Craig S Machtans, and Susan J Hannon. "Are boreal birds resilient to forest fragmentation? an experimental study of short-term community responses." *Ecology*78, no. 6 (1997) : 1914-1932.

    Link: http://www.jstor.org/stable/2266112

    Synopsis: This study examined the effects of forest fragmentation on the richness, diversity, turnover, and abundance of breeding bird communities in old boreal mixed-wood forest by creating experimental forest fragments of 1, 10, 40, and 100 ha. Connected fragments were linked by 100 m wide buffer strips. The study detected no significant change in species richness as a result of forest harvesting, except in the 1 ha connected fragments where the number of species increased during the two years after isolation. The population increase in the connected fragments indicates that these areas were being populated by transient species that used the connecting buffer strips as movement corridors. In isolated fragments, diversity was dependent on the area of the fragment after cutting. The number of Neotropical migrant species declined in both the connected and isolated fragments, and resident species declined in the isolated fragments, largely due to their preference for older forest and interior areas. In contrast, the abundance of short-distance migrants, most of which are habitat generalists, did not change following landscape modification. In summary, although there was not a detectable decrease in species richness resulting from fragmentation, community structure was altered, and maintaining connections between fragments significantly mitigated these effects.

    Keywords: Boreal mixed-woodforest, connectivity, experimental fragmentation, Neotropical migrants, regional forests, songbird communities

    Caveats: These results are short-term and address only broad-scale community responses based on species richness and relative abundance. Secondly, the study area was embedded in a landscape where large areas of old, mixed forest are still available, potentially dampening any local-scale impacts of fragmentation.

    Scale: regional

    Location:
    Jurisdiction: Alberta
    Ecoregion: Mid-boreal uplands and Peace-Wabaska lowlands

    Landscape Type/Pattern:
    Land Use: Managed forest, experimental forest cutting
    Landscape pattern: fragmentation, connectivity

    Part of the Environment: Birds, biodiversity indices

13. **Citation**: Desrochers, Andre, and Marie-Josee Fortin. "Understanding avian responses to forest boundaries: a case study with chickadee winter flocks." *Oikos* 91 (2000): 376-384.

    Link: http://www.jstor.org/stable/3547558

    Synopsis: During a two-year study of chickadee flocks in a fragmented agricultural landscape near Edmonton, Alberta, researchers tested the degree to which flocks responded to forest boundaries based on changes in vegetation, foraging sites, and edge structure near these boundaries. The results indicate that sharp forest boundaries (edges) acted strongly as movement corridors for birds, encouraging flocks to move parallel (within 75 m) to forest edges.

    Keywords: Forest boundary, edge effects, movement corridor, avian response, fragmentation

    Scale: Study conducted at the local scale (Meanook Biological Research Station), but applicable to larger ecoregion (regional scale).

    Location:
    Jurisdiction: Alberta (54°37 N, 113°20 W)
    Ecoregion: Aspen Parkland/North Glaciated Plains

Landscape Type/Pattern:
Land Use: Deciduous aspen forest, agriculture
Landscape Pattern: edge, fragmentation, connectivity

Part of the Environment: Birds, ecosystem intactness

14. **Citation**: Norton, Michael R, Susan J Hannon, and Fiona KA Schmiegelow. "Fragments are not islands: patch vs landscape perspectives on songbird presence and abundance in a harvested boreal forest." *Ecography* 23 (2000): 209-223.

    Link: http://www.jstor.org/stable/3683023

    Synopsis: This study investigates the degree to which species respond differently to logging across different scales in Alberta's boreal mixed-wood forests. Researchers tracked changes in the composition and abundance of songbirds at the patch-level and landscape level, finding significant variation between the two spatial scales. The results suggest that predictions of organism response based on the island biogeographic model are limited, and that—while responses varied across species—songbirds demonstrated "habitat compensation" by moving into different adjacent habitats across a fragmented landscape.

    Keywords: Forest fragmentation, boreal forest, island biogeography, logging, spatial scale, songbird abundance

    Caveats: Logging patterns and vegetation were different at the two study sites. These differences patterns may have had some effect on responses to forest loss.

    Scale: Local/site (representing larger boreal mixed-wood forests stretching across Alberta, Saskatchewan, and Manitoba)

    Location:
    Jurisdiction: Alberta
    Ecoregion: Mid-boreal uplands

    Landscape Type/Pattern:
    Land Use: forest clear cutting
    Landscape Pattern: fragmentation, connectivity, percent native, perforation

    Part of the Environment: Birds, biodiversity indices, ecosystem intactness

15. **Citation**: Bayne, Erin M, Steve L Van Wilgenburg, Stan Boutin, and Keith A Hobson. "Modeling and field-testing of Ovenbird (Seiurus aurocapillus) responses to boreal forest dissection by energy sector development at multiple spatial scales." *Landscape Ecology* 20 (2005): 203-216.

    Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-004-2265-9

    Synopsis: In the boreal plains of Alberta, Canada, energy sector exploration has resulted in extensive dissection of the landscape through 8 m wide seismic lines. This study developed a spatially explicit model to test how bird abundance might change in response to increasing seismic line density if individuals use seismic lines as territory boundaries or actively avoid these edges. Increasing seismic line density from 0 to 8 km/km2 resulted in a 38% decline and an 82% decline in bird abundance when individuals used lines as territory boundaries or avoided edges by 50 m, respectively. When tested with Ovenbirds, all crossed seismic lines at some point during the breeding season. However, male Ovenbirds showed a distinct use of one side of the seismic line, suggesting lines acted as territory boundaries. Ovenbirds declined with seismic line density at the level of the individual point-count station (12 ha scale), but only when a threshold seismic line density of 8.5 km/km2 was reached. Above the threshold, Ovenbirds declined 19% for each 1 km/km2 increase in seismic line density. While we found little evidence that Ovenbird numbers have declined at current seismic line densities, the behavior of Ovenbirds around seismic lines and the reduced density of birds at point locations with extreme linear densities suggests there is the potential for population level effects. As energy sector development proceeds in Alberta, seismic line density could increase to an average value of greater than 8 km/km2. This will mean that 50% of landscapes will have seismic line densities greater than this value.

Under the precautionary principle, we recommend energy sector companies use new advances in seismic exploration technology that allow for significantly narrower line widths (2 m). In mature 214 forests, these new low-impact technologies can avoid felling trees, resulting in disturbance to the understory only. Energy companies might further reduce their impacts by maximizing the angle at which seismic lines converge.

Keywords: Energy sector, seismic lines, bird abundance, Ovenbird, *Seiurus aurocapillus,* landscape dissection, edge effects

Caveats: It is possible that the impact of seismic lines may be more substantial in areas of the landscape with multiple human disturbances such as the convergence of seismic lines in forestry leave blocks or the combined impacts of seismic lines and forestry roads.

Scale: Regional

Location:
Jurisdiction: Northern Alberta
Ecoregion: Northern Glaciated Plains

Landscape Type/Pattern:
Land Use: Energy development/exploration
Landscape pattern: Linear disturbance, edge

Part of the Environment: Birds, ecosystem intactness

16. Citation: Habib, Lucas, Erin M Bayne, and Stan Boutin. "Chrinic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla." *Journal of Applied Ecology* 44 (2007): 176-184.

Link: http://www.jstor.org/stable/4123836

Synopsis: Anthropogenic noise is rapidly increasing in wilderness areas as a result of industrial expansion. This study assessed pairing success and age distribution of male ovenbirds, *Seiurus aurocapilla,* in the boreal forest of Alberta, Canada, in areas around noise-generating compressor stations compared with areas around habitat-disturbed, but noiseless, wellpads. The study found a significant reduction in ovenbird pairing success at compressor sites (77%) compared with noiseless wellpads (92%). These differences were apparent regardless of territory quality or individual male quality. Significantly more inexperienced birds breeding for the first time were found near noise-generating compressor stations than noiseless wellpads (48% vs. 30%). Noise interferes with a male's song, such that females may not hear the male's song at greater distances and/or females may perceive males to be of lower quality because of distortion of song characteristics

Keywords: Age structure, compressor stations, industrial impacts, noise, ovenbird, pairing success

Scale: Regional

Location:
Jurisdiction: Northern Alberta
Ecoregion: Northern Glaciated Plains

Landscape Type/Pattern:
Land Use: Energy development
Landscape pattern: Fragmentation, perforation

Part of the Environment: Birds

17. **Citation:** Johnson, Douglas H, and Lawrence D Igl. "Area requirements of grassland birds: a regional perspective." *The American Ornithologists Union* 118, no. 1 (2001): 24-34.

    Link:
    http://www.fws.gov/southwest/es/documents/R2ES/LitCited/LPC_2012/Johnson_and_Igl_2001.pdf

    Synopsis: This paper examines the influence of landscape fragmentation and isolation of Conservation Reserve Program (CRP) grasslands on grassland breeding bird populations in the northern Great Plains states. The study explores the relationship between species occurrence and density, and patch size by tracking 15 bird species on 303 restored grassland areas. Locating CRP grassland fields near existing grasslands, or establishing one large CRP field rather than several small fields, benefits area-sensitive grassland bird species.

    Keywords: Area-sensitive, Conservation Reserve Program, fragmentation, grassland birds, Great Plains, grassland restoration.

    Caveats: Inconsistent findings in area sensitivity may be attributable to the following causes:

    - Differences in study designs and analytic methods among studies result in inconsistencies
    - Species may respond differently in different portions of their breeding range
    - Variable responses to patch size are likely in landscapes with different amounts of suitable habitat variation in the abundance of species in the region

    Scale: Meso-Regional (Northern Great Plains states, USA)

    Location:
    Jurisdiction: Montana, North Dakota, South Dakota, Minnesota
    Ecoregion: Northern Glaciated Plains, Northwestern Glaciated Plains, Northwestern Great Plains, Lake Agassiz Plain

    Landscape Type/Pattern:
    Land Use: agricultural land enrolled in the Conservation Reserve Program for grassland restoration
    Landscape Pattern: percent native, fragmentation, edge

    Part of the Environment: Birds, biodiversity indices, ecosystem functionality/intactness

18. **Citation**: Kociolek, A, and A Clevenger. Effects of paved roads on birds: a literature review and recommendations for the Yellowstone to Yukon Ecoregion. Technical Report #8, Canmore, Alberta: Yellowstone to Yukon Initiative, 2011.

    Link: http://www.westerntransportationinstitute.org/documents/reports/4W2380_Final_Report.pdf

    Synopsis: This report is synthesizes and summarizes major findings from literature relating to the direct and indirect ecological impacts of paved highways on birds. It represents a meta-analysis of contributing factors of road mortality, effects of roadway lighting, traffic noise, traffic volume, and roadway contaminants on bird populations, which may help guide conservation efforts within the Yellowstone to Yukon ecoregion. Traffic volume and noise are believed to be the most important factors affecting breeding bird population densities near roads. The number of affected species increases with traffic volume but the relationship appears to reach threshold at an average daily traffic volume of 30,000 vehicles a day. In addition, traffic can influence occupancy levels and create avoidance zones that extend as far as 1000 m or more from the road itself. In general, roads with 50,000 vehicles per day can result in an effect-distance of ~800 m for woodland species and more than 900 m for grassland species. While birds do not appear to perceive roads as barriers to movement, their willingness to fl y over roads puts them at risk for collision. Birds are more likely to be road-killed in relatively open or low-growing habitats than forested habitats. Likewise, density-depressing effect distances tend to be larger in open versus closed habitats. Urban development and roads in forested areas can be associated with increased rates of brood parasitism by Brown-headed Cowbirds. In the grassland setting, rates of brood parasitism are strongly associated with the presence of trees and shrubs planted along roadcuts.

However, clearing remnant native vegetation along roadsides in agricultural areas can result in reduced species richness and abundance.

Keywords: bird mortality, roads, highways, road-kills, vehicle-collisions, noise effect distances, species richness and abundance.

Caveats: Spatial heterogeneity, diurnal variation of noise levels, and vertical reflective surfaces should also be considered in studies of noise effects on birds.

Scale: Meso-regional

Location:
Jurisdiction: Yellowstone to Yukon region
Ecoregion: applicable to Western Cordillera (Yellowstone to Yukon ecoregion)

Landscape Type/Pattern:
Land Use: roads
Landscape pattern: linear disturbance, edge, connectivity

Part of the Environment: Birds

19. **Citation**: Hobson, Keith A, and Jim Schieck. "Changes in bird communities in boreal mixedwood forest: harvest and wildfire effects over 30 years." *Ecological Applications* 9, no.3 (1999): 849-863.

Link: http://www.jstor.org/stable/2641334

Synopsis: The study examined the effects of forest harvest practices that approximate natural disturbance processes to evaluate whether these practices help conserve biodiversity. Past research has shown that management practices that mimic natural disturbance events such as forest fires is a successful habitat conservation strategy, particularly for boreal forest bird communities. The study investigated how bird communities differed between postharvest and postfire stands in the mid-boreal region of Alberta. The research found that the most significant difference between postfire and postharvest landscapes is the amount and orientation of residual live and dead trees. Postfire stands consist largely of standing dead trees whereas postharvest stands include primarily clumps of standing live trees.

The results suggest two primary landscape differences with distinct temporal effects. The first is that differences in bird communities are evident immediately following the disturbance. This is a concern for bird species requiring high snag densities typically found in standing dead trees in postfire stands. These bird species are of specific management concern as industrial harvesting practices can't be modified to replicate snags. The second is that over time, the landscape may become increasingly modified by harvest and less disturbed by fire. The effect on habitat is changing stand structure, allowing for the growth of large live trees, especially in clumps, that may produce forest structures and microclimates that otherwise would not be present in landscapes. One potential management solution is to burn or otherwise kill clumps of residual trees in postharvest stands. If managers wish to pattern harvest in the boreal forest based on a natural disturbance regime, then strategies to compensate for these initial differences must be developed and implemented.

Keywords: Avian communities, boreal forest management, fire salvage, forest harvest practices, natural disturbance

Caveats: The study did not directly compare species richness among age or treatment categories, which may have lent more insight to the results.

Scale: Regional

Location:
Jurisdiction: Alberta
Ecoregion: Mid-Boreal Uplands and Peace-Wabaska Lowlands

Landscape Type/Pattern:
Land Use: forest
Landscape pattern: patch, percent native

Part of the Environment: Birds

20. **Citation**: Coppedge, BR, DM Engle, SD Fuhlendorf, and RE Masters. "Landscape cover type and pattern dynamics in fragmented southern Great Plains grasslands." *Landscape Ecology* 16 (2001a): 677-690.

    Link: http://www.jstor.org.ezproxy.lib.ucalgary.ca/stable/pdfplus/3061054.pdf?acceptTC=true

    Synopsis: Avian community structure shifted along gradients of increasing woody plant cover and grassland fragmentation in northwestern Oklahoma. Open-habitat generalists, woodland, and successional shrub species generally increased along these gradients, whereas many grassland species decreased. Most grassland bird species demonstrated consistent declines related to the influx of woody vegetation and landscape changes associated with fragmentation. Two thresholds for native grassland cover were identified in the paper. When native grassland cover dropped below 60% at one site, and 30-40% at another site, the arrangement or habitat patches became more important to the survival of populations than habitat amount alone.

    Keywords: Agriculture, Breeding Bird Survey, canonical correspondence analysis, Conservation Reserve Program, fragmentation, grassland birds, Great Plains, landscape structure.

    Caveats: No consensus exists as to which indices of landscape pattern best describe particular ecological phenomena. Therefore, this study chose to follow two widely used spatial configuration indices: mean patch size and mean patch core size.

    Scale: Sub-regional (Bird Breeding Survey Routes, northwestern Oklahoma mixed-grass prairie, USA)

    Location:
    Jurisdiction: Oklahoma
    Ecoregion: Central Great Plains

    Landscape Type/Pattern:
    Land Use: agriculture, managed grassland
    Landscape Pattern: Percent native, fragmentation, edge

    Part of the Environment: Birds, biodiversity indices, ecosystem functionality/intactness

21. **Citation**: Machtans, Craig S, Marc-Andre Villard, and Susan J Hannon. "Use of riparian buffer strips as movement corridors by forest birds." *Conservation Biologist* 10, no. 5 (1996): 1366-1379.

    Link: http://www.jstor.org/stable/2386911

    Synopsis: This study empirically tests whether songbirds used riparian buffer strips as corridors connecting forest reserves more frequently than crossing adjacent clearcut areas to access the same areas. The field experiment measured frequency of bird movement through riparian buffer strips before and after clearcutting of the adjacent forest. Capture rates increased significantly from pre to post harvest for juveniles, indicating that buffer strips acted as corridors enhancing the movement of juveniles. The same buffers maintained movement rates for adults. There is a threshold distance between reserves below which birds do not mind crossing clear cuts, making corridors more important as clear-cut area and distance between forest reserves expands.

    Keywords: corridors, isolation, forest clearing, riparian buffers, fragmentation, movement barriers.

    Caveats: The study design was admittedly less than perfect in several ways:

- Because the result of the experiment was not replicated, the researchers cannot conclusively argue that juvenile movement of songbirds will increase in all buffer strips after adjacent habitats are disturbed.
- In terms of the experimental design, the researchers were only able to establish one before and after treatment site, which may have biased results.
- The configuration of the control site near lakes was different, which may have skewed results.
- More replication would be helpful, but would be unmanageably large and expensive.

Scale: Sub-regional (boreal mixed-wood forests of Alberta)

Location:
Jurisdiction: Alberta
Ecoregion: Mid-boreal uplands

Landscape Type/Pattern:
Land Use: forest clear cutting
Landscape Pattern: Edge, fragmentation, connectivity, percent cover

Part of the Environment: Flora, biodiversity indices, ecosystem functionality/intactness

22. Citation: Fletcher, Robert J. "Multiple edge effects and their implications in fragmented landscapes ." *Journal of Animal Ecology* 74, no. 2 (2005): 342-352.

Link: http://www.jstor.org/stable/3505623

Synopsis: This paper examined how multiple edges within fragments intensify edge responses by looking at spatial distributions of the bobolink, an area-sensitive songbird that breeds in temperate grasslands of North America. The study tested the degree to which bobolinks avoid edges and whether avoidance is stronger near two edges (experimental double edge plots) than near only one edge (experimental single edge plots). Bobolink distributions were subsequently linked to landscape maps representing variation in the amount of habitat and degree of fragmentation in order to explore some potential implications of multiple edges on patch-and landscape-level distributions. Multiple edges appeared to influence the magnitude of observed edge effects, in which the probability of bobolink occurrence was four times lower in double edged plots and two times lower in single edged plots than in the interior of grasslands. Within single-edge plots, the probability of occurrence increased with increasing distance from edge. Within double-edge plots, the probability of occurrence increased as a function of the nearest and next-nearest distances from edges. Multiple edges also appeared to increase the extent of edge effects, or distance of edge influence. In summary, the results of this study indicate that edge effects are intensified when multiple edges collide.

Keywords: Bobolink, *Dolichonyxo ryzivorus*, edge effects, habitat edge, patch-size effects, multiple edge effects.

Caveats: This study only modelled effects arising from two edges within patches because bobolink data were limited to information on two edges. While the distances to the two nearest edges captured most variation in edge configurations, edge effects could be stronger in extremely fragmented landscapes if more than two edges are incorporated into the modelling process.

Scale: Sub-regional

Location:
Jurisdiction: Northern Iowa
Ecoregion: Western Cornbelt Plains

Landscape Type/Pattern:
Land Use: agriculture, roads
Landscape pattern: Edge, fragmentation, linear disturbance

Part of the Environment: Birds (bobolink)

23. **Citation**: Odell, Eric A, and Richard L Knight. "Songbirds and medium size mammal communities associated with exurban development in Pitkin County, Colorado." *Conservation Biology*15, no. 4 (2001): 1143-1150.

    Link: http://www.jstor.org/stable/3061333

    Synopsis: In this paper, songbirds and medium-sized mammals were surveyed at 30, 180, and 330 m away from 40 homes into undeveloped land in an exurban development in Colorado. The study aimed to examine the effect of housing along a distance gradient and housing density on species occurrence in this type of development. For both songbirds and mammals, densities of individual species were statistically different between 30 and 180 m sites. Avian densities were altered up to 180 m away from homes on the perimeter of exurban developments. Six bird species were present in higher densities in developed areas, while eight species were present in higher densities in undeveloped areas. For mammalian species, dogs and cats were detected more frequently in high-density developments and red foxes and coyotes were detected more frequently in undeveloped land areas. In summary, these trends and consequences suggest that the composition of native wildlife will be altered in the vicinity of exurban housing developments. It is preferable to arrange houses in clusters in order to leave undeveloped areas intact, as opposed to dispersing houses widely across the entire landscape.

    Keywords: Exurban development, songbird densities, mammalian densities, fragmentation

    Caveats: Areas that are undeveloped may not all be productive habitat. When development borders wild or undisturbed lands, a buffer of up to 180 m around the development should be considered affected habitat.

    Scale: local/site

    Location:
    Jurisdiction: Pitkin County, Western Colorado (39°13'N, long 106°55'W)
    Ecoregion: Southern Rockies, Colorado Plateau

    Landscape Type/Pattern:
    Land Use: Exurban development
    Landscape pattern: Fragmentation

    Part of the Environment: Terrestrial mammals, birds, biodiversity indices, ecosystem intactness

24. **Citation**: Downey, Brandy L. "Long-Billed Curlew." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 36-41. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004.

    Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

    Synopsis: The purpose of this model is to indicate potential nesting and foraging habitat for the long-billed curlew (Numenius americanus) within the Milk River Basin of Alberta and Saskatchewan. The following habitat types and factors were reviewed for suitability: native prairie, shrub coverage, and topography. Native prairie was found to be the most suitable habitat for long-billed curlew. Agriculture lands, while considered to be undesirable, are still utilized by the long-billed curlew and were included in this model at a lower value than native prairie. While the long-billed curlew makes use of large open areas for breeding, areas of high shrub coverage are considered unsuitable as habitat. Based on the data available and the overall shrub coverage in the Milk River Basin, areas of greater than 1-10% shrub coverage are considered undesirable for the long-billed curlew. The long-billed curlew is usually found in areas of flat to rolling topography; steeps slopes are avoided due to a lack of nesting habitat and high visibility of the birds to predators. Any slope over 25 degrees is considered unsuitable habitat and receives a rating of zero.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, birds, Long-billed curlew

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

25. **Citation**: Landry, Julie P. "Sprague's Pipit." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 55-63. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division. 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: The Sprague's pipit tends to occupy native grassland habitats containing very little or no woody vegetation, with non-native areas populated to a significantly lower extent. The following land cover categories were evaluated for habitat suitability for the Sprague's pipit:

Percent Native Grass: Areas comprised of 25% or more native grass were considered very suitable, so were assigned a suitability value of 1. Since non-native areas are not completely devoid of Sprague's pipits, zero percent native grass areas did not receive a habitat suitability value of zero but received a low suitability of 0.1. As native grassland percent cover increases from zero, the suitability increases.

Percent Trees and Shrubs: To satisfy nesting and foraging requirements, Sprague's pipits require open grasslands with little or no amounts of woody vegetation. If woody vegetation increases above 15%, the habitat is no longer considered suitable.

Distance from Riparian Areas: To further satisfy the Sprague's pipit's preference for open grasslands, riparian areas, which potentially contain woody vegetation, were considered unsuitable habitat.

Grass Height: There was no available database containing information on grass heights. This variable would have been useful in selecting more specific nesting areas for Sprague's pipits.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Sprague's Pipit

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

26. **Citation**: Jones, Paul F. "Sharp-tailed grouse." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 47-54. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004.

    Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

    Synopsis: This report evaluated habitat suitability requirements for the sharp-tailed grouse according to native prairie cover and percent shrub cover. Native grass and shrub cover are critical habitat components for maintaining viable sharp tailed grouse populations. These cover classes represent suitable conditions for hiding, nesting, brood rearing, and winter habitat.

    Native Prairie cover classes are used to evaluate the relative intactness of native prairie in the area. Native prairie cover class 1 was given the highest suitability score of 1. Class 1 is comprised of greater than 75% native prairie components (i.e. shrubs, graminoids, riparian areas, lakes, wetlands, and trees). Native prairie cover class 5, which represents 0% native prairie or agricultural land, was given an HSI score of O. The remaining three classes were scaled between these two extremes.

    An HSI value of 1 is given to the range of 5% to 15% shrub cover and then the value decreases until shrub cover reaches > 20% at which point the HSI value is 0. With the model not focusing on any specific life requisite it can be applied across the entire study area and likely the Grassland Natural region.

    Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, sharp-tailed grouse

    Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

    Scale: Sub-regional (Milk River Basin)

    Location:
    Jurisdiction: Alberta, Saskatchewan
    Ecoregion: Northwestern Glaciated Plains

    Landscape Type/Pattern:
    Land Use: Native Prairie
    Landscape Pattern: Percent native, connectivity

    Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

27. **Citation**: Tewksbury, Joshua J, Sallie J Hejl, and Thomas E Martin. "Breeding productivity does not decline with increasing fragmentation in a western landscape ." *Ecology* 79, no. 8 (1998): 2890-2903.

    Link: http://www.jstor.org/stable/176524 .

    Synopsis: This paper illuminates how the relationship of predation rates and landscape fragmentation differ in western landscapes of the United States as opposed to studies conducted in the eastern North America and Scandinavia. While studies from the Midwestern United States suggest that predation rates increase rapidly with diminishing forest cover and increasing agricultural land use, this study found the opposite: nest predation was greater in predominantly forested landscapes than in fragmented agricultural areas. This pattern probably reflects the importance of forest predators in these landscapes. For example, in this study in a riparian area in western Montana, red squirrels were much more abundant in forested landscapes and declined quickly with decreasing forest cover. Predators that typically increase in fragmented landscapes in the Midwest (such as corvids) increased only at very high levels of fragmentation. Brood parasitism by brown-headed cowbirds decreased with increasing forest cover, and increased with the abundance of human development. Results suggest that the effects of landscape fragmentation depend on habitat structure, landscape context, the predator community, and the impact of parasitism. Because these factors differ substantially in western ecosystem compared to eastern forest ecosystems, it is difficult to make universal generalizations about the effects of landscape fragmentation on ecosystem processes and wildlife dynamics.

Keywords: American robin, brood parasitism, brown-headed cowbird, cedar waxwing, fragmentation, landscape, nest predation, riparian birds, warbling vireo, yellow warbler

Scale: sub-regional

Location:
Jurisdiction: Montana
Ecoregion: Middle Rockies
Basin: Bitterroot River Basin
Sub-basin: Bitterroot River Sub-basin

Landscape Type/Pattern:
Land Use: agriculture, grazing

Landscape pattern: fragmentation, percent native, connectivity

Part of the Environment: Birds, biodiversity indices

28. Citation: Hutto, Richard L. "The ecological importance of severe wildfires: some like it hot." *Ecological Applications* 18, no. 8 (2008): 1827-1834.

Link: http://www.jstor.org/stable/27645904

Synopsis: Using data on the pattern and distribution of the black-backed woodpecker (Picoides arcticus) derived from 16,465 sample locations in western Montana, the author demonstrates that this bird species is extremely specialized on severely burned forests. The findings of this study indicate that severe fire provided an important ecological backdrop for fire specialists species. The presence and importance of severe fire in maintaining critical ecosystem processes must be accounted for in land management and planning.

Keywords: Black-backed woodpecker, fire history, fire regime, mixed-conifer forest, severe fire

Scale: meso-regional

Location:
Jurisdiction: Montana
Ecoregion: Middle Rockies, Columbia Mountains/Northern Rockies, Idaho Batholith

Landscape Type/Pattern:
Land Use: Managed forest (prescribed burn, fire suppression)
Landscape pattern: fragmentation

Part of the Environment: Birds, ecosystem functionality/intactness

29. Citation: Schmiegelow, Fiona K, and Monkkonen. "Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest." *Ecological Applications* 12, no. 2 (2002): 375-389.

Link: http://www.jstor.org/stable/3060949

Synopsis: This study aimed to evaluate the application of theoretical fragmentation paradigms, based largely on studies of temperate forests in agricultural mosaics, to managed boreal forests. Researchers constructed simple empirical models of benchmark communities in boreal forests of Finland and Canada based on species composition, species abundance distribution, and habitat requirements, in order to identify features of bird species sensitive to the loss of older forests. The results indicated that system and species-specific considerations are important when assessing the potential outcome of habitat loss and fragmentation on regional biota.

Keywords: Boreal birds, boreal forest, Canada, dynamic landscapes, Finland, forest harvesting, habitat fragmentation, habitat loss, random sample hypothesis

Scale: meso-regional (circumpolar boreal forests of Canada and Finland)

Location:
Jurisdiction: Northern Canada and Finland
Ecoregion: Southern Arctic and Boreal plains ecoregions

Landscape Type/Pattern:
Land Use: timber harvest
Landscape pattern: percent native, fragmentation

Part of the Environment: Ecosystem intactness, biodiversity indices

30. **Citation:** Herkert, James R. "Effects of habitat fragmetation on Midwestern grassland bird communities." *Ecological Applications* 4, no.3 (1994): 461-471.

Link: http://www.jstor.org/stable/1941950 .

Synopsis: This paper examines the influence of area and vegetation structure on breeding bird communities in Midwestern grasslands fragmented by agriculture. The study documents the effects of habitat fragmentation on species richness, highlighting the relative importance of patch size versus vegetation structure for each species studied. Results indicate that breeding bird species richness patterns significantly increased with fragment size. Eight of the 15 (53%) most common bird species demonstrated distributions among fragments that were significantly influenced by habitat area, whereas 6 species (40%) had distributions among fragments that were significantly influenced by vegetation structure only. Only one species, the dickcissel, was not significantly influenced by either habitat area or vegetation structure. Based on statistical analysis of the results, birds were grouped into four categories based on habitat preference: area sensitive species (5 species), edge species (3 species), vegetation-restricted species (6 species), and the dickcissel. Area-sensitive species required patches of suitable habitat at least 5-55 ha in size, and regularly avoided smaller grassland fragments even when they were composed of suitable habitat. As for edge and vegetation-restricted species, overall loss of habitat is likely a stronger driver or regional population declines than reductions in average patch size.

Keywords: bird population declines, habitat fragmentation, habitat selection, midwestern grassland birds, species-area relationships

Scale: Regional

Location:
Jurisdiction: Illinois
Ecoregion: Central Cornbelt Plains

Landscape Type/Pattern:
Land Use: Agriculture
Landscape pattern: percent native, fragmentation

Part of the Environment: Birds, biodiversity indices, species at risk

31. **Citation:** Patten, Michael A, Eyal Shochat, Dan L Reinking, Donald H Wolfe, and Steve K Sherrod. "Habitat edge, land management, and rates of brood parasitism in tallgrass prairie." *Ecological Applications* 16, no. 2 (2006): 687-695.

Link: http://www.jstor.org/stable/40061688 .

Synopsis: This study analyzed a five-year set of nest data to test how management and landscape patterns in an Oklahoma tallgrass prairie affected rates of brood parasitism by the brown-headed cowbird among grassland birds. Researchers examined seven landscape features that may have been associated with parasitism: presence of edge, burning, grazing, and distance of the nest from woody vegetation, water, roads, and fences. All five birds species included in the analysis exhibited evidence of an edge effect. Edges in this landscape were defined as narrow strips of woody vegetation occurring along roadsides cut through tallgrass prairie. Sparrows avoided nesting along these woody edges, but the other three species experienced significantly higher (2-5 times higher) rates of parasitism along edges than prairie. In general, this paper found that increased rates of parasitism correlated with decreased distance from woody vegetation. In grazed plots, rates of parasitism were even higher (2.5-10 times higher), particularly in those burned in spring to increase forage, than in undisturbed prairie. In summary, rates of brood parasitism are strongly associated with relatively recent roads and grazing due to the influx of woody vegetation tied to these disturbances.

Keywords: Brood parasitism, burning, edge effects, grazing, land management, Oklahoma, regression trees, tallgrass prairie

Scale: sub-regional

Location:
Jurisdiction: Oklahoma
Ecoregion: Central irregular plains

Landscape Type/Pattern:
Land Use: grazing, roads
Landscape pattern: linear disturbance, edge effects, fragmentation

Part of the Environment: Birds

32. **Citation:** Gignac, Denis L, and Mark LT Dale. "Effects of fragment size and habitat heterogeneity on cryptogram diversity in the low-boreal forest of western Canada." *The Bryologist* 108, no. 1 (2005): 50-66.

Link: http://www.bioone.org/doi/full/10.1639/0007-2745%282005%29108%5B50%3AEOFSAH

%5D2.0.CO%3B2

Synopsis: This study aims to determine the importance of size and shape of forest fragments compared to habitat heterogeneity (number of microhabitats) on lichen and bryophyte diversity in remnants of sub-humid low-boreal forest. The results indicate that the distance from the patch edge and habitat heterogeneity were the most important variables affecting bryophyte and lichen species richness. Temperature and light intensity decreased, and humidity increased up to 15m from the edge of fragments in the study, affecting the viability of bryophyte and lichen species.

Keywords: Agro-environments, edge effects, forest fragmentation, habitat heterogeneity, indicator species, microclimate, microhabitat

Scale: Meso-regional

Location:
Jurisdiction: Alberta, Saskatchewan, Manitoba
Ecoregion: Northwestern glaciated plains, aspen parkland/northern glaciated plains, mid-boreal uplands

Landscape Type/Pattern:
Land Use: low-boreal forest, agriculture
Landscape Pattern: edge, fragmentation

Part of the Environment: Flora, biodiversity indices, ecosystem functionality or intactness

33. Citation: Ripley, Travis, Garry Scrimgeour, and Mark S Boyce. "Bull trout (Salvelinus confluentus) occurance and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed." *Canadian Journal of Fisheries and Aquatic Science*s 62, no. 11 (2005): 2431-2442.

Link: http://search.proquest.com.ezproxy.lib.ucalgary.ca/docview/219326553?accountid=9838

Synopsis: This study investigated the relationship between cumulative levels of forest harvesting and road density on the occurrence and abundance of bull trout in the Kakwa River Basin, Alberta. The occurrence of bull trout was positively related to stream width and negatively related to the area of the subbasin that is harvested for timber. Occurrence was also negatively related to road density within the subbasin. Bull trout abundance was positively related to elevation, and negatively related to stream width, slope, and levels of forest harvesting. Study results forecast that forest harvesting within the Kakwa River Basin will result in the local extirpation of bull trout from 24-43% of stream reaches over the next 20 years.

Keywords: road density, forest harvesting, bull trout, species abundance, species occurrence, fragmentation

Caveats: Correlative studies such as this one provide only insights into the underlying mechanisms through which industrial activities influence bull trout. Additional studies that identify causal mechanisms underlying negative relations between forest harvesting and road density on the occurrence of bull trout in boreal ecosystems are needed to provide further insight.

Scale: Sub-regional

Location:
Jurisdiction:
Ecoregion: Mid-boreal uplands and Peace-Wabaska lowlands
Basin: Peace River Basin
Subbasin: Kakwa River subbasin

Landscape Type/Pattern:
Land Use: Oil and gas development, logging, roads
Landscape pattern: Fragmentation, linear disturbance

Part of the Environment: Riparian systems, biodiversity indices, ecosystem intactness, water quality

34. Citation: Haug, Elizabeth A, and Lynne W Oliphant. "Activity patterns and habitat use of burrowing owls in Saskatchewan." *Journal of Wildlife Management* 54, no.1 (1990): 27-35.

Link: http://www.jstor.org/stable/3808896

Syopnsis: This paper documents the breeding ecology and behavioral patterns of burrowing owls (*Athene cunicularia*) in central Saskatchewan. Researchers radio-tagged six adult male owls to determine their home range, activity patterns, and habitat selection patterns. Results indicate that owls avoided agricultural lands (due to prey availability) and used grass-forb areas for foraging and avoided croplands and grazed pasture. Mean home-range size was 2.41 km2 and 95% of all movements occurred within 600 meters of the nest burrows. These findings indicate that, at a minimum, a 600 meter radius should be maintained around burrowing owl nests in order to ensure the survival of burrowing owls.

Keywords: burrowing owls, habitat use, activity patters, Saskatchewan

Scale: regional

Location:
Jurisdiction: Saskatchewan

Ecoregion: Northwestern glaciated plain

Landscape Type/Pattern:
Land Use: grazing, cereal agriculture
Landscape pattern: percent native, fragmentation

Part of the Environment: Birds, biodiversity indices

35. Citation: Skiftun, Corey L. "Burrowing Owl." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 13-17. Edmonton, AB.: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: This report provides information on the habitat suitability requirements of the burrowing owl. Due to limited available data, the model that this report is based upon can only be used as a general habitat model. The habitat variables chosen for this model were native prairie coverage, soil texture, shrub/tree coverage, and distance from linear disturbances (roads):

- Native Prairie Coverage: Because burrowing owls require short grass habitat for nesting and subsequent reproduction, native prairie coverage was considered the most critical variable in determining the most suitable habitat. The higher the percentage of native prairie, the more suitable it is for burrowing owl habitat.
- Soil texture: Soil texture affects burrow stability and therefore can be used to predict and assess possible nest and satellite burrows (burrows that are used other than their nest burrows.) in a given area. Medium and Moderately Coarse soils are given maximum value, Fine and Coarse soils are given lowest value.
- Shrub/Tree Coverage: The amount of shrub/tree cover affects burrowing owls by limiting their line of sight, making them more susceptible to predators. Increased shrub/tree coverage can also provide perch sites for raptors that utilize burrowing owls as prey. For these reasons, the HSI value has maximum value at 0% coverage, and reaches 0 at a threshold of 25% coverage.
- Distance from linear disturbances: Burrowing owls will use right of ways to forage, making them susceptible to road mortality. For the purposes of this model, habitat suitability increases as the distance from linear disturbances (roadways) increases, given that owl/vehicle interactions would be less likely. HSI reached maximum values at over 800m from roads.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, birds, Burrowing owl

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity, linear disturbance

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

36. Citation: Ries, Leslie, and Diane M Debinski. "Butterfly responses to habitat edges in highly fragmented prairies of central Iowa." *Journal of Animal Ecology* 70 (2001): 804-852.

Link: http://www.jstor.org/stable/2693467

Synopsis: The behavior of two butterfly species, one habitat specialist and one habitat generalist, were tracked at four prairie edges to determine the extent to which edge structure affects emigration. The specialist species responded strongly to all edges, and was particularly affected by edge density. The generalist species responded strongly only to high contrast edges. Emigration rates are closely tied to edge structure. Therefore, promoting low contrast edges in conservation planning may positively influence edge permeability and species richness in highly fragmented landscapes.

Keywords: edge permeability, habitat fragmentation

Caveats: Due to the limited number of large native prairie remnants in the area, two reconstructed prairies were included in the study to increase the number of study sites. Also due to the limited number of larger remnants, some sites contained only two plots as opposed to three, and plots with treeline boundaries (high contract edges) were established in only two sites.

Scale: Sub-regional

Location:
Jurisdiction: Iowa, USA
Ecoregion: Western corn-belt plains

Landscape Type/Pattern:
Land Use: agriculture, protected and reconstructed prairie
Landscape Pattern: fragmentation, linear disturbance

Part of the Environment: Terrestrial micro-fauna

37. Citation: Ricketts, Taylor H. "The matrix matters: effective isolation in fragmented landscapes." *The American Naturalist* 158, no. 1 (2001): 87-99.

Link: http://www.jstor.org/stable/10.1086/320863

Synopsis: This study challenges traditional assumptions about the uniform nature of the matrix, and the reliance on distance alone as an indicator of patch isolation, by testing whether the type of inter-patch matrix contributes significantly to patch isolation in butterfly populations. The author tracked the movement of six butterfly species between patches of meadow habitat through two natural matrix types (conifer forest and willow thicket). All taxa of butterflies studied responded similarly to different matrix types with two exceptions. Lycaenini butterflies were reluctant to leave patches regardless of surrounding matrix type whereas Argynnini butterflies moved without discretion, perceiving very few barriers to movement in the landscape mosaic. The results indicate that the heterogeneous nature of the surrounding matrix contributes significantly to the degree of patch isolation, highlighting the importance of matrix modification to improve habitat connectivity and genetic distribution in fragmented landscapes.

Keywords: Fragmentation, landscape ecology, matrix, dispersal, butterflies, maximum likelihood

Scale: Sub-regional (Copper Creek Valley, Colorado)

Location:
Jurisdiction: Colorado
Ecoregion: Southern Rockies

Landscape Type/Pattern:
Land Use: forest, meadow
Landscape Pattern: percent native, fragmentation, connectivity

Part of the Environment: Terrestrial micro-fauna (butterflies), ecosystem intactness

38. Citation: Taylor, Brad N. "Weidemeyer's Admiral." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 131-135. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004b.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: Two variables were selected to model potential habitat for the butterfly species, Weidemeyer's Admiral. Topographical features derived from the Agricultural Region of Alberta Soils Inventory Database (AGRASID) and percent shrub cover derived from the Native Prairie Vegetation Baseline Inventory developed by Alberta Environment were used to model habitat suitability. The results indicate that valleys are the only areas capable of sustaining sufficient habitat for the Weidemeyer's Admiral. Consequently, all other areas (i.e. plains, uplands, benches, escarpments, plateaus) received an HSI value of 0. Areas devoid of shrub cover did not meet the habitat requirements of this specialized species.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, butterflies, Weidemeyer's Admiral

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, micro-fauna, species-at-risk

39. Citation: Klein, David R. "Caribou in the Changing North." *Applied Animal Behavior Science* 29 (1991): 279-291.

Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/0168-1591(91)90254-U

Synopsis: This study documented the behavioural reactions of caribou to oil development in the circumpolar regions of the northern hemisphere. Researchers observed patterns of avoidance near linear features such as pipelines, roads, and other oil field structures. Female caribou, especially those accompanied by calves avoided these areas in particular. Male caribou were more apt to occupy areas influenced by oil field structures and activity. In summary, the patterns oil field development on the landscape resulted in seasonal fracturing of caribou populations, and delayed movement to and from ecosystems that herds seasonally depend on for insect-relief and foraging.

Keywords: Caribou, population fragmentation, oil field development, Prudhoe Bay

Caveats: Due to the absence of historical knowledge of abundance and extent of caribou herd range use, one cannot make conclusive statements about the cause and effect relationships between oil development and herd population dynamics.

Scale: Meso-regional

Location:
Jurisdiction: Northern Alaska, Canada, Russia, and Scandinavia
Ecoregion: Tundra, Alaskan Tundra, Northern Arctic, Southern Arctic, Taiga Plain, Taiga Shield

Landscape Type/Pattern:
Land Use: oil field development
Landscape Pattern: fragmentation

Part of the Environment: Terrestrial Mammals

40. Citation: Apps, Clayton D, and Bruce N Mclellen. "Factors influencing the dispersion and fragmentation of endangered mountain caribou populations." *Biological Conservation* 130 (2006): 84-97.

Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.biocon.2005.12.004

Synopsis: This study evaluates factors influencing the persistence and landscape occupancy of caribou subpopulations in southern British Columbia. Data from 235 radio-collared caribou across 13 subpopulations were used to derive a landscape occupancy index. The index was analyzed against 33 landscape variables including, land cover, terrain, climate, and human influence. At the metapopulation level, the persistence of subpopulations correlated with the extent of wet climate conditions and the distribution of old forests and alpine areas. Distance from human presence and low road densities were also important factors. At the subpopulation level, the intensity of caribou landscape occupancy was correlated with the distribution of old cedar/hemlock and spruce/subalpine fir forests and the lack of deciduous forest cover. Non-forested areas, highways, road networks, and hydro-reservoirs were also noted as factors impeding population contiguity.

Keywords: British Columbia, mountain caribou, extirpation, fragmentation, habitat, human influence, persistence, population, spatial modeling

Caveats: Interpreting model output as an objective means to evaluate the need for

population translocation should be tempered with some caution given that the probability of species persistence does not increase linearly with habitat amount and quality.

Scale: Regional (southeast British Columbia)

Location:
Jurisdiction: British Columbia
Ecoregion: Columbia Mountains/Northern Rockies

Landscape Type/Pattern:
Land Use: Forest, settlement (road density)
Landscape Pattern: Fragmentation, connectivity, percent native

Part of the Environment: Terrestrial mammals, ecosystem functionality and intactness

41. Citation: James, Adam RC, and Kari A Stuart-Smith. "Distribution of caribou and wolves in relation to linear corridors." *Journal of Wildlife Management* 64, no.1 (2000): 154-159.

Link: http://www.jstor.org/stable/3802985

Synopsis: This study tested the hypothesis that linear corridors affect caribou and wolf activities by examining the distribution of telemetry locations of caribou and wolves, as well as locations of caribou mortality and caribou predation by wolves relative to linear corridors caused by roads, seismic lines, power lines, and pipeline rights-of-way. Caribou mortalities attributed to wolf predation were generally closer to a corridor, indicating that linear corridors may enhance wolf predation efficiency by increasing their search rate and may provide greater access into caribou range. Therefore, caribou existing closer to linear corridors are at a higher risk of depredation than those farther from corridors.

Keywords: Alberta, human disturbance, hunting, linear corridors, mortality, pipelines, predation, caribou, seismic lines, wolves, woodland caribou

Scale: sub-regional

Location:
Jurisdiction: Alberta
Ecoregion: Mid-boreal uplands and Peace-Wabaska lowlands

Landscape Type/Pattern:
Land Use: Industrial, roads, pipelines
Landscape pattern: linear disturbance

Part of the Environment: Terrestrial mammals

42. **Citation:** Whittmer, Heiko U, Bruce N Mclellen, Robert Serrouya, and Clayton Apps. "Changes in landscape composition influence the decline of a threatened woodland caribou population." *Journal of Animal Ecology*76 (2007): 568-579.

    Link: http://www.jstor.org.ezproxy.lib.ucalgary.ca/stable/4539159

    Synopsis: Timber harvesting in areas of Mountain Caribou habitat have created landscapes of early seral forests. Such habitat changes have altered the predator–prey balance resulting in asymmetric predation in which predators are maintained by alternative prey (i.e. apparent competition). This study estimates survival probabilities for the threatened arboreal lichen-feeding ecotype of woodland caribou in British Columbia, Canada, at two different spatial scales. At the broader scale, observed variation in adult female survival rates among 10 distinct populations was explained by variation in the amount of early seral stands within population ranges and population density. At the finer scale, home ranges of caribou killed by predators had lower proportions of old forest and more mid-aged forest as compared with multi-annual home ranges where caribou were alive. The study concludes that apparent competition can cause rapid population declines and even extinction where changes in species composition occur following large scale habitat change.

    Keywords: Apparent competition, caribou, extirpation, habitat loss, population dynamics, predation, survival analysis

    Scale: Meso-regional (Mountain caribou range of North America, covering southern BC and the northwestern US just below the US-Canada border)

    Location:
    Jurisdiction: British Columbia and bordering US states
    Ecoregion: Columbia Mountains/Northern Rockies, Canadian Rockies

    Landscape Type/Pattern:
    Land Use: Forest, public land, logging
    Landscape Pattern: Percent native

    Part of the Environment: Species at risk, ecosystem intactness

43. **Citation**: Kennedy, C, J Wilkinson, and J Balch. Conservation Thresholds for Land Use Planners. Planning Guide, Washington, DC: Environmental Law Institute, 2003.

    Link: http://www.elistore.org/reports_detail.asp?ID=10839

    Synopsis: This report summarizes findings from a review of literature intended to identify critical thresholds for conservation based in empirical studies of landscape fragmentation. In presenting a conceptual overview of landscape fragmentation and habitat loss, as well as guidelines and thresholds relating to landscape indicators such as patch size, habitat amount, edge effects, riparian buffers, and habitat connectivity, the report serves as a platform for guiding sound environmental planning and policy. The review also identifies gaps in existing knowledge in order to help guide further in-depth ecological research applicable to land use planning.

    Keywords: Thresholds, patch size, habitat amount, edge effects, riparian buffers, connectivity

Caveats: The effects of landscape fragmentation are difficult to translate into management rules-of-thumb for a number of reasons. They tend to be highly specific to the taxa, spatial scales, and ecological processes considered. They also vary according to landscape type and structure. Lastly, their influence on species distribution and abundance may be obscured by local effects such as changes to certain microhabitat features. Therefore, conservation thresholds presented in this study should be interpreted carefully and tailored to the unique circumstances and geographic settings to which they are applied.

Scale: literature review

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: Roads, power lines, seismic lines, agriculture, grazing, settlement, resource extraction, dams, etc.
Landscape pattern: fragmentation, linear disturbance, percent native, edge, connectivity

Part of the Environment: Ecosystem functionality/intactness, terrestrial mammals, birds, ecosystem services, water quality

44. **Citation**: Harig, Amy L, and Kurt D Fausch. "Minimum habitat requirements for establishing translocated cutthroat trout populations." *Ecological Applications* 12, no. 2 (2002): 535-551.

Link: http://www.jstor.org/stable/3060961

Synopsis: This study aimed to identify stream-scale and basin-scale macrohabitat attributes limiting successful translocation and persistence of native cutthroat trout populations in fragmented landscapes along the Rio Grande. The study developed models of habitat attributes measured at two scales to best predict the probability of translocation success. Study results indicate that, in fragmented watersheds, measurements recorded at the patch scale were far more effective in predicting translocation success than measurements taken at the landscape scale. Furthermore, fine spatial scales do not capture the spatial heterogeneity and connectivity of habitat patches needed to maintain persistent cutthroat trout populations. As a course filter indicator of cutthroat trout translocation success, the study found that translocations have a greater than 50% chance of fruitful establishment in watershed >14.7km2 in area.

Keywords: cutthroat trout, greenback cutthroat trout, habitat fragmentation, information-theoretic approach, landscape scale, patch scale, polytomous logistic regression, restoration, translocation

Scale: meso-regional

Location:
Jurisdiction: Colorado and New Mexico
Ecoregion: Southern Rockies, Arizona/New Mexico plateau, Arizona/New Mexico mountains.
Basin: Rio Grande

Landscape Type/Pattern:
Land Use: rangeland, settlement, protected area along the Rio Grande
Landscape pattern: fragmentation

Part of the Environment: Water quality, riparian systems, biodiversity indices

45. **Citation**: Wofford, John E.B, Robert E Gresswell, and Michael A. Banks. "Influences of barriers to movement on within-watershed genetic variation of coastal cutthroat trout." *Ecological Applictions* 15, no. 2 (2005): 628-637.

Link: http://www.jstor.org/stable/4543380

Synopsis: This study aimed to determine if coastal cutthroat trout were genetically structured within streams and to assess the effects of habitat fragmentation on coastal cutthroat trout genetic variation.

Habitat fragmented by roads and other human disturbances acted as dispersal barriers, which strongly influenced coastal cutthroat trout genetic structure, diversity, and differentiation. At range-wide spatial scales, fragmentation potentially contributes to coastal cutthroat trout genetic diversity, and it is not recommended that natural barriers be modified for fish passage. However, at small spatial scales, where extirpation risks are high, fragmentation will likely have long-term negative consequences on the genetic variation of individual assemblages of coastal cutthroat trout.

Keywords: conservation genetics, dispersal barriers, habitat fragmentation, headwater streams, isolation, cutthroat trout

Scale: sub-regional (river basin)

Location:
Jurisdiction: Oregon
Ecoregion: Coastal range

Landscape Type/Pattern:
Land Use: Managed forest
Landscape pattern: linear disturbance

Part of the Environment: Ecosystem intactness, biodiversity indices, riparian systems

46. **Citation**: Gergel, Sarah E, Monica G Turner, James R Miller, John M Melack, and Emily H Stanley. "Landscape indictors of human impacts to riverine systems." *Aquatic Sciences* 64, no. 2 (2002): 118-128.

Link: http://www.esajournals.org/doi/abs/10.1890/1051-0761%281999%29009%5B1377%3ADOCAAI%5D2.0.CO%3B2?journalCode=ecap

Synopsis: This study quantifies how the proportion of wetlands in the watershed at different scales affects dissolved organic carbon (DOC) concentrations in downstream lakes and rivers. Whether the watershed influence varies with season or hydrologic type of lake was also examined. The scaling and modelling approach used offered a useful way to examine heterogeneity of land cover types within the watershed and spatial arrangements, while allowing generality of conclusions with a large sample size. Zones of increasing distance from the lake shore were created around each lake at 25, 50, 100, 200, through to 1500 m until the direct drainage watershed boundary was reached. The concentric scales were overlain with digital wetlands data, and the proportion of wetlands in each zone was calculated. Regression analysis was used to determine which independent variables (proportion of wetlands at different scales) explained the most variability in DOC.

For lakes, the proportion of wetlands in the entire watershed often explained most of the variability in DOC if stepwise regression was used. However, the proportion of wetlands in near-shore riparian areas (25-100 m) was only slightly less powerful in explaining variability in DOC. For rivers, the proportion of wetlands in the watershed always explained considerably more variability in DOC than the proportion of wetlands in the nearshore riparian areas. A summary of the results for rivers is shown in Figure 6 of the paper. The watershed influence also varied seasonally in rivers, as the proportion of the watershed covered by wetlands explained more of the variability in DOC in the fall than in the spring. Overall, the proportion of wetlands in the landscape explained much more of the variability in DOC concentrations in rivers than in lakes. The variability of DOC values was also used to discuss landscape “predictability” as a function of the scale of influence and the type of aquatic system (seepage lakes, drainage lakes, rivers).

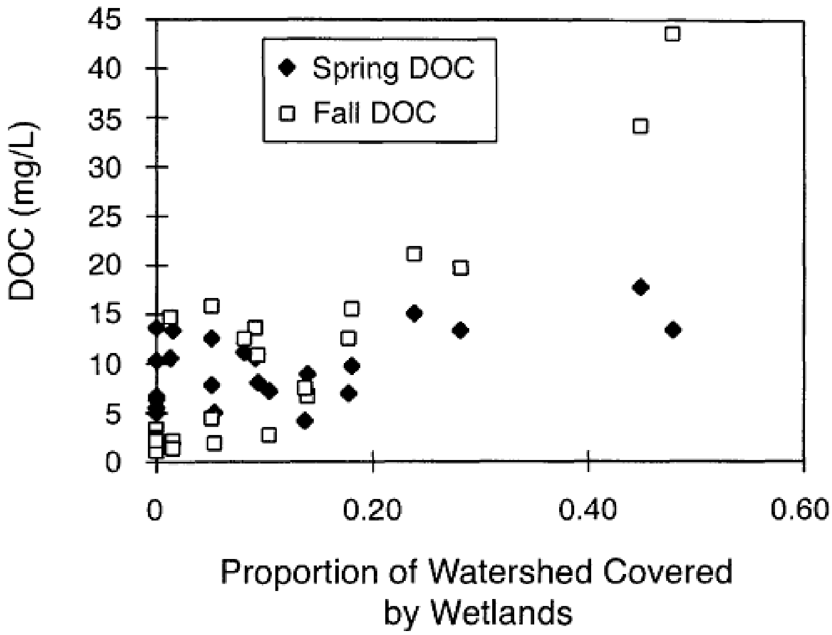


FIG. 6. Relationship between DOC and percentage of wetlands in the watershed for rivers during different seasons.

Keywords: dissolved organic carbon, land cover, land use, spatial scale, watersheds, wetlands

Caveats: The results indicate that for lakes, topographic watershed boundaries may not always be the most useful and accurate way to define the contributing area for lakes, as they generally do not accurately reflect groundwater contributing areas.

Scale: local watersheds (~3 km2 to 50 km2 for lakes, and 20 km2 to 400 km2 for rivers studied)

Location:
Jurisdiction: Wisconsin, USA
Ecoregion: Northern Lakes and Forests (Mixed Wood), 8.2.1

Landscape Type/Pattern:
Land Use: agriculture, forest
Landscape pattern: percent wetland cover, location of wetlands in relation to water bodies

Part of the Environment: Water quality

47. **Citation:** Stephan, Kirsten, Kathleen L Kavanaugh, and Akihiro Koyama. "Effects of spring prescribed burning and wildfires on watershed nitrogen dynamics of central Idaho headwater areas." *Forest Ecology and Management* 263 (2012): 240-252.

Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.foreco.2011.09.013

Synopsis: This study aimed to compare the short-term effects of spring prescribed burns and wildfires on Nitrogen cycling dynamics in headwater watersheds of central Idaho. Fire affected N dynamics in both terrestrial and aquatic components of the watershed ecosystem after wildfires but were limited to the terrestrial ecosystem after prescribed burns. Streamwater NO3 concentrations were affected significantly by wildfires but not prescribed burns due to their much lower burn intensity. Fire effects tended to be strongest and statistically significant in the first growing season after fire in the terrestrial ecosystem. In the headwater streams, effects of wildfire persisted through the first three growing seasons after fire. Streamwater NO_3^- concentrations were one order of magnitude higher in wildfire-burned watersheds than in unburned watersheds. Prescribed burns did not supply the low nutrient stream ecosystems in this region with potentially important nutrient pulses that are often observed after wildfires. Prescribing higher severity burns would enhance N cycling in productivity in N-limited headwater watersheds.

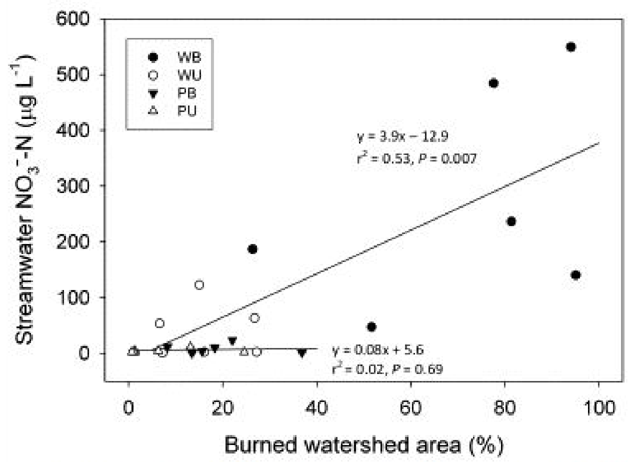


Fig. 4. Relationship between the proportion of watersheds classified as "burned" based on delta Normalized Burn Ratio (dNBR) and streamwater NO_3^-–N concentrations in wildfire-burned (WB) watersheds, prescription-burned (PB) watersheds, and their corresponding unburned (U) watersheds in late May of 2004. The proportion of "burned" watershed area was positively correlated with streamwater NO_3^-–N concentrations in wildfire sites but not in prescribed burn sites.

Keywords: Nitrogen cycling, prescribed burning, watershed ecosystem, wildfire

Caveats: In this region of low-nutrient headwater streams, peak stream nitrate concentrations in wildfire-burned watersheds are an order of magnitude below national drinking water standards. By implication, in other watershed contexts where higher nutrients pose concerns of eutrophication downstream, lower severity burns may be preferable from a water quality perspective to prevent high nitrate concentrations.

Scale: sub-regional (watershed), burned patches ranged from 180 ha to 2670 ha

Location:
Jurisdiction: Idaho
Ecoregion: Idaho Batholith
Basin: Salmon River, Payette River
Subbasin: Danskin Creek, Sixbit, Parks-Eiguren, Canyon Creek, Hall, South Fork

Landscape Type/Pattern:
Land Use: US Forest Service managed- recreation, protected area, timber harvest, prescribed burn
Landscape pattern: fire patches, percent burned, perforation

Part of the Environment: ecosystem health/function, riparian systems

48. Citation: Fiedler, Anna K, Doug A Landis, and Steve D Wratten. "Maximizing ecosystem services from conservation biological control: The role of habitat management." *Biological Control* 45 (2008): 254–271.

Link:
http://www.landislab.ent.msu.edu/pdf/Landis%20PDF%20Collection/7.Fiedler.Landis.Wratten.2008.Maximizing%20ecosystem%20services.pdf

Synopsis: The intentional provision of flowering plants and plant communities in managed landscapes to enhance natural enemies is termed habitat management and is a relatively new but growing aspect of conservation biology. The focus of most habitat management research has been on understanding the role of these plant-provided resources on natural enemy biology, ecology, and their ability to enhance suppression of pest populations. Far less attention has been paid to additional ecosystem services that habitat management practices could provide in managed landscapes. The analysis of past habitat management studies indicates that four plant species have been tested in the majority of field evaluations, while plants native to the test area and perennial plants are particularly underrepresented. Synergies among biodiversity conservation, ecological restoration, human cultural values, tourism, biological control and other ecosystem services have largely been overlooked in past habitat management research. These potential ecosystem services should be evaluated and enhanced. Two case studies are reviewed in which broader ecosystem services were explicitly addressed in terms of plant selection criteria. One case study demonstrates that native plants useful in restoration of rare ecosystems can increase natural enemy abundance as much as widely recommended non-natives. The second case study addresses additional ecosystem services provided by habitat management in New Zealand vineyards. Addressing ‘stacked’ ecosystem services with multiple ecosystem service goals can decrease agriculture’s dependence on ‘substitution’ methods such as the current reliance on oil-based agro-chemical inputs. This publication provides a synopsis of ecosystem services with examples of publications relating to provision of these services from habitat management.

Keywords: Native plants, ecological restoration, biodiversity conservation, biological control, ecosystem services, habitat management

Scale: Study conducted at sub-regional level, but results applicable to national scale.

Location:
Jurisdiction: Michigan (case study)
Ecoregion: Michigan/N. Indiana Drift Plains

Landscape Type/Pattern:
Land Use: agriculture, grazing
Landscape pattern: connectivity

Part of the Environment: Micro-fauna (arthropods), biodiversity indices, Ecosystem services (arthropod-mediated), ecosystem health

49. **Citation**: O2 Planning and Design Inc. Ecosystem Goods and Services Southern Alberta Assessment of Natural Asset Condition. Environmental Assessment Report, Calgary: Environment Alberta, 2008.

Link: http://www.environment.gov.ab.ca/info/library/8374.pdf

Synopsis: This report develops a framework for assessing the condition of Southern Alberta’s natural assets and their resulting ability to provide ecosystem goods and services. The report explains and summarizes relationships between natural asset condition, and the type, quantity and quality of services provided. Measurable indicators of ecosystem services, including landscape indicators, were also distilled from a wide-ranging literature review.

A discussion of potential thresholds and targets at both broad and fine scales were also identified and discussed. Broad-scale indicators focused on relationships between landscape composition, landscape patterns, and ecosystem services. Fine-scale indicators of ecosystem services were focused on site-specific conditions for different natural land cover types (e.g., forests, grasslands, riparian areas, lakes, wetlands, etc.). At the fine scale, one of the key focuses was to link existing site sampling programs in Alberta with an ecosystem services concept and framework.

Examples of potential targets for indicators of ecosystem service distilled from the literature included:

- Wetland cover should be maintained at >15% for watersheds with high potential for phosphorus loading & eutrophication
- Impervious cover should be maintained at or below 25% in heavily urbanizing watersheds

Keywords: Ecosystem services, anthropogenic footprint, natural assets, Southern Alberta

Scale: Regional (Southern Alberta)

Location:
Jurisdiction: Alberta
Ecoregion: Northwest glaciated plains, northern glaciated plains

Landscape Type/Pattern:
Land Use: agriculture, settlement, forest, and prairie
Landscape Pattern: fragmentation, linear disturbance, connectivity

Part of the Environment: Ecosystem services

50. Citation: Rowland, Mary M, Michael J Wisdom, Bruce K Johnson, and John G Kie. "Elk distribution and modeling in relation to roads." *Journal of Wildlife Management* 64, no. 3 (2001): 672-684.

Link: http://www.jstor.org/stable/3802737

Synopsis: This study tested 3 aspects of an elk road density model to determine patterns of elk behavior relative to road density and configuration. The study compared model predictions with observed values of elk habitat selection at varying levels of road density. It also compared the effect of different spatial patterns of roads on model predictions. Habitat selection ratios increased with increasing distance from open roads, but varied seasonally with more selection away from roads during spring and summer. Habitat selection also varied significantly in response to road pattern, which is not accounted for in the elk road density model. Regularly spaced roads had the greatest influence on habitat selection whereas a clumped pattern of roads supported larger blocks of road-free habitat. Road density threshold at which elk could still occur in high numbers: 1.5 km/km^2.

Keywords: disturbance, elk, forest management, habitat effectiveness models, Oregon, radiotelemetry, roads, road density

Caveats: Due to the rarity of locations located far from roads, precisely defining the distance at which road effects dissipated was infeasible in this study.

Scale: sub-regional (USFS Starkey Experimental Forest and Range)

Location:
Jurisdiction: Oregon
Ecoregion: Blue Mountains

Landscape Type/Pattern:
Land Use: managed forest and rangeland; grazing
Landscape pattern: linear disturbance

Part of the Environment: Terrestrial mammals

51. Citation: Sawyer, H, and R Nielson. *Seasonal distribution and habitat use patterns of elk in the Jack Morrow Hills Planning Area.* Technical Report, Cheyenne, Wyoming: Western Ecosystems Technology, Inc., 2005.

Link: http://west-inc.com/reports/big_game/Sawyer%20and%20Nielson%202005.pdf

Synopsis: This study indentifies and describes the distribution and habitat selection patterns of the Steamboat elk herd in the Jack Morrow Hills of southwestern Wyoming. The document provides baseline information on elk herd behavioral patterns in response to landscape cover and pattern prior to oil and gas development, which may be used as a point of reference for monitoring the effects of development on elk populations if and when it occurs. Seasonal distribution patterns of the elk herd were identified by plotting individual elk locations. Resource selection analysis was performed based on vegetation cover type, distance to cover, distance to roads, slope, aspect, elevation, and tree cover. Elk consistently selected for big basin sagebrush, greasewood, and tree cover; and consistently selected against Wyoming sagebrush, mixed shrub, and bare ground/sand. Selection patterns were similar during the winter, except big basin sagebrush and mixed shrubs were selected in proportion to their availability. Elk tend to prefer areas characterized by edge habitat where quality forage and cover habitats are in close proximity to one another. Elk use was highest in summer in areas characterized by diverse habitats and >2.8 km away from major roads. High use areas during winter were similar, although elk tended to use areas slightly closer to roads (>2.1 km away), which is largely attributed to reduced human activity on roads in winter.

Keywords: Steamboat elk herd, habitat selection patterns, seasonal distribution, vegetation cover, Jack Morrow Hills, Wyoming

Scale: sub-regional

Location: Jurisdiction: Wyoming
Ecoregion: Wyoming Basin

Landscape Type/Pattern:
Land Use: energy development, roads, protected public land
Landscape pattern: percent native, linear disturbance, edge

Part of the Environment: Terrestrial mammals, biodiversity indices, species at risk

52. Citation: Taylor, Brad N. "Ferruginous Hawk." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 20-27. Edmonton, AB.: Alberta Sustainable Resource Management, Fish and Wildlife Division, 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: This model is based around Native Prairie Cover types, and Soil Texture. Native Prairie Class (NPC) is derived from the Native Prairie Vegetation Baseline Inventory developed by AlbertaEnvironment. Class I is comprised of greater than 75% native prairie components (i.e. shrubs, graminoids, riparian areas, lakes, wetlands, and trees), Class 2 is 50 - 75%, Class 3 is 25 - 50%, Class 4 is 1 - 25%, and Class 5 is no native prairie components. Native prairie is probably the most important and limiting factor for ferruginous hawks. Although hawks have been found in areas that were primarily under cultivation), they were in close proximity to prairie in good condition. Overall NPC was selected over its individual components (i.e. percent graminoids) because it is more indicative of undisturbed prairie and consequently, nesting habitat.

Most burrowing mammals require medium to moderately coarse textured soils for burrows. Texture data contained in the Agricultural Region of Alberta Soils Inventory Database (AGRASID) was used to provide an indication of potential ground squirrel sites or ferruginous hawk foraging areas.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, birds, Ferruginous hawk

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

53. Citation: Lavine, A. et al. A Five Year Record of Sedimentation in the Los Alamos Reservoir, New Mexico, Following the Cerro Grande Fire. Los Alamos Technical Publication LA-UR-05-7526.

Link: http://www.fws.gov/fire/ifcc/Esr/Library/LARsedimentaton.pdf

Synopsis: The effects of the 17,400 ha Cerro Grande fire patch in New Mexico on erosion and sedimentation processes were analyzed by this study, located in the Jemez Mountains upstream of the Los Alamos Reservoir, New Mexico. This study provides a unique data set demonstrating post-fire erosion rates relative to pre-fire conditions. The fire affected a large fraction of the watershed, with 32% of the basin experiencing a moderate to high severity burn, including some of the steepest mountainous portions of the basin. Average sediment deposition was 150 m3/year prior to the fire, equivalent to an average basin-wide denudation rate of 0.009 mm/year. The year after the fire, over 21,800 m3 of sediment accumulated in one year, equivalent to an average basin-wide denudation rate of 1.3 mm/year or 140 times higher than the average pre-fire rate. Assuming that all the sediment was derived from the high and moderate severity burn area, the average denudation rate for those areas was 4.0 mm/year or 450 times higher than the pre-fire rate. Erosion and sediment delivery into the reservoir were highest in the first year after the fire, accounting for about half the total sedimentation in the first five years, despite the occurrence of below average summer precipitation and relatively low-intensity storms (<1 year return interval). Sedimentation rates gradually dropped off in the second, third, fourth, and fifth years after the fire (Figure 1). Prior to the fire, the reservoir received very minor amounts of sediment and had never been dredged, preserving a 57-year record of sedimentation.

<u>O2 Interpretation in study context</u>: This study illustrates the importance of ensuring large intact forest patches in a watershed’s headwaters, due to the role of forests in providing high quality water downstream and preventing sedimentation in reservoirs. It also illustrates the dangers associated with historical and current fire suppression, which began in this area in the late 19th century and ultimately led to fuel buildup, and large, uncontrollable, hot fires. This case study in particular also raises interesting questions regarding forest management and prescribed burns. The fire actually began as a prescribed burn that quickly went out of control and burned a very large area much hotter than intended. Smaller fire patches, either natural or successfully prescribed, would not have the same effects on water quality and sedimentation.

Keywords: Forest fire, headwaters, sedimentation, erosion

Caveats: Many of the coarse sediments that were eroded may still remain in long-term storage upstream from the reservoir, and in the short term may continue to be a major source of sediment reaching the reservoir.

Scale: Local watershed

Location:
Jurisdiction: New Mexico (Los Alamos County)
Ecoregion: Southern Rockies
Basin: Upper Rio Grande
Subbasin: Los Alamos Canyon drainage basin (16.6 km2)

Landscape Type/Pattern:
Land Use: Forested Protected Area
Landscape pattern: Fire patch size

Part of the Environment: Ecosystem services (water supply), water quality, water quantity

54. Citation: Oliver, A.A., Reuter, JE, Heyvaert, AC, Dahlgren, RA. "Water quality response to the Angora Fire, Lake Tahoe, California". Biogeochemistry 111, no.1-3 (2012): 361-376

Link: http://download.springer.com/static/pdf/828/art%253A10.1007%252Fs10533-011-9657-0.pdf?auth66=1364059800_7ca3ff22bdb28e33dba1eb4408f10bd3&ext=.pdf

Synopsis: Wildfires can negatively affect water quality by altering watershed hydrology and increasing sediment and nutrient delivery to surface waters. The Angora Fire (summer of 2007) was the largest and most severe wildfire in recent history within the Lake Tahoe basin of the Sierra Nevada. The fire burned 839 ha within the watershed (56% of the total watershed area), with 22% of the watershed affected by a high severity burn. To determine the watershed response to fire and assess the potential for downstream impacts of nutrient and sediment delivery to Lake Tahoe, the post-fire hydrology and stream water chemistry was monitored for 2 years at four locations along the length of Angora Creek, a perennial stream draining the burned watershed. When compared with unburned streams, the hydrology of Angora Creek indicated an earlier and faster melting of the spring snowpack. Peak stream water concentrations of total N (TN) and ammonium occurred within the burned area, whereas peak concentrations of nitrate (NO3-), total P, soluble reactive P, total suspended solids, turbidity, electrical conductivity (EC), and dissolved organic C occurred below the burned area. In comparison to pre-fire data, TN, NO3-, TP, total dissolved P, EC, and turbidity increased significantly following the fire, particularly in the wetter second year. Nitrate showed the largest increase. Overall, a large and catastrophic response was not observed; however, given the relatively small overall size of the watershed, steep slopes, and the considerable extent that burned under high severity, a major rainfall event would have been predicted to elicit a much larger watershed response.

Yields for sub-watershed areas suggest that the burned urban sub-watershed was the largest source of nutrients and sediments, whereas the wet meadow sub-watershed downstream of the burned area retained materials. The existence of a wet meadow below the burned watershed (among other factors) likely reduced the negative impacts that would have been expected from such a severe wildfire.

Keywords: wetland, wildfire, water quality, streams, watershed response nutrients

Caveats: The magnitude of the effects of wildfire on watershed dynamics is influenced by multiple factors including fire severity, precipitation, climate, topography, soil type, vegetation, and land use, which make the prediction of watershed response complex and challenging. The absence of a potentially severe watershed response may be attributed, in part, to the timing, magnitude, and form of precipitation during the first 2 years following the fire. For example, in contrast the Gondola Fire that occurred near Lake Tahoe in 2002 was followed by a large rain event within weeks resulting in massive erosion, higher nutrient export, and a much greater watershed responses due to the timing and magnitude of precipitation, despite the fact that the Gondola Fire was neither as severe nor as large as the Angora Fire.

Scale: Local watershed (Angora Creek)

Location:
Jurisdiction: Lake Tahoe, California
Ecoregion: Sierra Nevada

Landscape Type/Pattern:
Land Use: forested
Landscape pattern: forest fire patches

Part of the Environment: Water quality, wetlands

55. Citation: Emelko, MB, U Silins, KD Bladon, and M Stone. "Implications of land disturbance on drinking water treatability in a changing climate: Demonstrating the need for "source water supply and protection" strategies." *Water Research* 45, no. 2 (2011): 461-472.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20951401

Synopsis: Large scale natural disturbances from wildfire and severe insect infestations can significantly impact water quality downstream of forested headwaters. Forest fires impact water quality due to sediment input of the ash and soot and by chemical changes to surface and groundwater. This has recently been extensively studied in southwestern Alberta, after the “Lost Creek” wildfire of 2003. Four years of comprehensive hydrology and water quality data from seven watersheds were evaluated and synthesized to assess the implications of wildfire and post-fire intervention (salvage logging) on downstream drinking water treatment. Burned and unburned reference watersheds were examined by the authors.

Far more contaminants of concern were exported downstream from burned watersheds than from unburned watersheds, while burned watersheds subsequently salvage logged had the highest rates of contaminant export. Some highlights included:

- Turbidity (NTU) measured in streams (95th percentile):
– 5.1 NTU for unburned watersheds
– 15.3 NTU in burned watersheds (3x higher)
– 18.8 NTU in burned watershed subsequently salvage logged (>3.5 x higher)
- Over 6.5x as much nitrate (NO3-) exported downstream from burned watersheds in the first year
- Over 4.1x as much dissolved organic nitrogen (DON) exported downstream in the first year
- Observed increases in contaminants such as nutrients and heavy metals (mercury)
- Increases were particularly elevated during snowmelt freshet as well as during storm flows
- A rapid decline in mean concentrations of many nutrients three years after the fire, although high contaminant loads were still exported during the snowmelt freshet and following precipitation events
- Much higher peak concentrations for many parameters during extreme events were observed in burned and burned + salvage logged watersheds (Figure2, Figure 4)

There were persistent increases in sediment and other contaminants such as nutrients, heavy metals, and chlorophyll-a in discharge from burned and salvage-logged watersheds present important economic and operational challenges for water treatment processes. This is particularly the case for any “extreme” values which often dictate drinking water infrastructure and chemical consumption requirements. Many traditional source water protection strategies would fail to adequately identify and evaluate many of the significant wildfire- and post-fire management-associated implications to drinking water "treatability"; accordingly, it is proposed that "source water supply and protection strategies" should be developed to consider a suppliers' ability to provide adequate quantities of potable water to meet demand by addressing all aspects of drinking water "supply" (i.e., quantity, timing of availability, and quality) and their relationship to "treatability" in response to land disturbance. In addition, large scale wildfire and insect infestations have become more likely due to climate change.

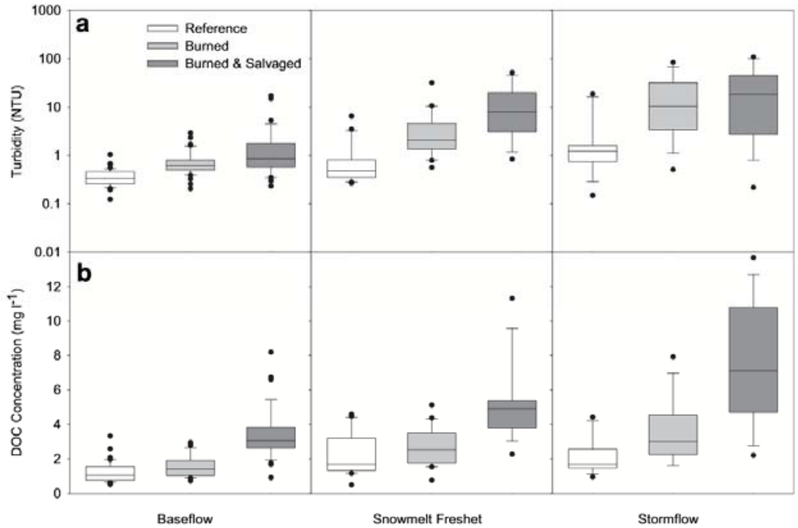


Fig. 2 – Boxplot of (a) turbidity and (b) dissolved organic carbon (DOC) concentration (2004–2007) in streams draining reference, burned, and salvage-logged watersheds during baseflow, snowmelt, and stormflow. Turbidity data obtained using manual and daily composite sampling only.

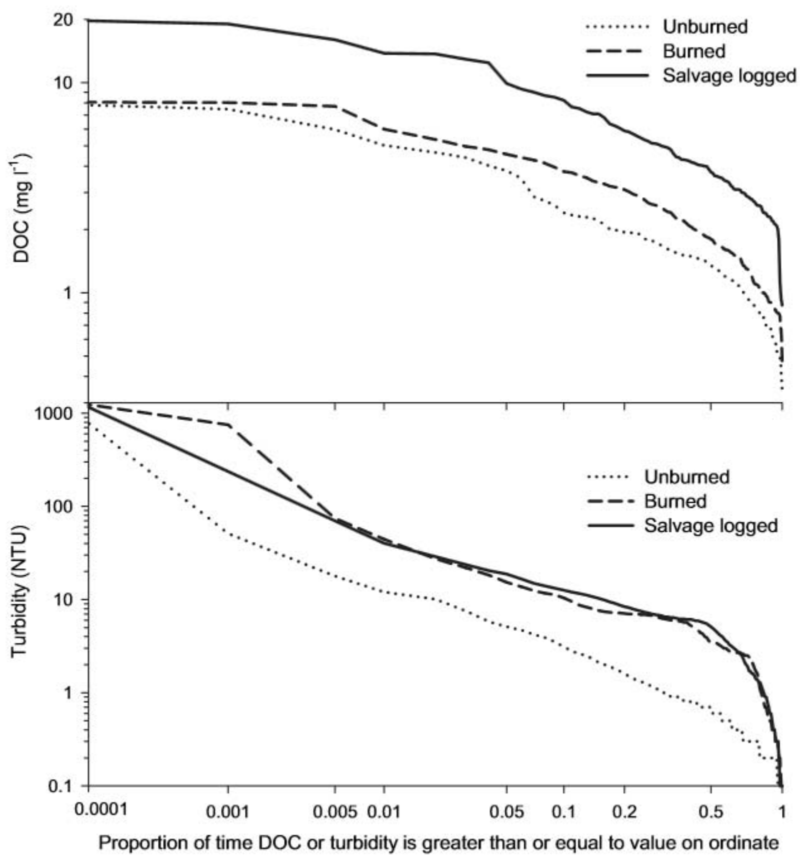


Fig. 4 – Residual DOC and turbidity exceedance curves for water in reference, burned, and salvage-logged watersheds during four post-fire years ($n = 105$ per series). Turbidity data are based on manual samples, daily composite samples, and 10-min interval data obtained using calibrated multiparameter sondes.

Keywords: forest fire, water quality, salvage logging, natural disturbance,

Caveats: The importance of the scale of fire disturbances should be considered, since for small fires, effects such as local nutrient inputs and stimulation of microscopic organism growth may occur, but major water quality impacts are generally insignificant at broader scales. However, large-scale fires that burn a large proportion of a watershed's area can result in increases in Total Suspended Solids (TSS), nitrogen and phosphorus export downstream, whereas smaller fires do not have much of an impact. Consequently, the proportion of a watershed burned is really a key indicator.

The "recovery" of water quality parameters to levels observed prior to disturbances must be carefully interpreted because "recovery" is a matter of perspective. Much of the published literature considers recovery from watershed hydrology and ecological perspectives in which "rapid recovery" may occur over time frames of years. In contrast, "rapid recovery" during water treatment requires returns to baseline values within hours, days, or weeks, depending on available water storage capacity. Accordingly, when "rapid recovery" is not possible, robust design and operation of treatment processes is particularly critical.

In other situations, typically reported watershed-scale data obtained at greater time intervals (e.g., weekly, monthly, etc.) or at conditions that are not representative of periods of greatest treatment challenge (e.g., samples that do not represent extreme values of parameters such as turbidity or DOC), must be interpreted with caution because they are less relevant to water treatment design and practice. Detailed data collection regarding extreme values is necessary for evaluating water "treatability".

Scale: Local watersheds were studied, but conclusions generally extrapolated to sub-regional or even regional scale

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies
Basin: Oldman River Watershed
Subbasin: Lost Creek

Landscape Type/Pattern:
Land Use: forested
Landscape pattern: forest fire patches, salvage logging

Part of the Environment: Water quality, ecosystem services (water supply provisioning)

56. Citation: Hey, DL, and NS Philippi. "Flood reduction through wetand restoration: the Upper Mississippi River Basin as a case history." *Restoration Ecology* 3 (1995): 4-17.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1111/j.1526-100X.1995.tb00070.x/abstract

Synopsis: This article outlines how wetlands can significantly reduce flooding in the Upper Mississippi watershed. The authors first provide a historical context by estimating the original and lost wetland storage capacities of the Upper Mississippi and Missouri River Basins. Historically, about 10% of the basin would have been classified as wetland in 1780. By 1980, wetland acreage had been reduced to only 4% of the basin, representing about 26 million acres of wetlands eliminated since 1780. The area of wetland restoration required to reduce the risk of future flooding adequately was estimated based on the total amount of excess floodwater beyond bank-full discharge that passed through the City of St. Louis during the major flood event of 1993. Next, the approximate area of upstream wetlands that could have accommodated an equivalent volume of water was estimated. The authors conclude that by restoring 13 million acres of upstream wetlands within the watershed (approximate depth=1m), flooding would be adequately controlled. The authors therefore recommend that 7% of this watershed should be in wetland cover to provide adequately control flooding. Related water quality benefits of this amount, including lower turbidity, excess nutrients, and toxic substances were also described, as supported by research at the Des Plaines River Wetlands Demonstration Project, Illinois.

Keywords: wetlands, flooding, restoration
Caveats: In addition to wetland restoration, the authors also recommend restoring a prairie-forest matrix-at least in part-to intercept and hold precipitation where it falls, and to increase the water-holding capacity of the soil by replenishing organic matter throughout the watershed.

Scale: Meso-Regional

Location:
Jurisdiction: Multiple States (Missouri, Illinois, Wisconsin, Minnesota, Iowa, Kansas, Nebraska, South Dakota, North Dakota, Wyoming, Montana)
Ecoregion: Multiple
Basin: Upper Mississipi River

Landscape Type/Pattern:
Land Use: agriculture, rural and urban settlement, managed forest and prairie, protected area, roads, oil and gas development, recreation
Landscape pattern: percent native, fragmentation, connectivity, linear disturbance, edge

Part of the Environment: Water quantity, water quality

57. **Citation**: Withers, Mark A., Michael W. Palmer, Gary L. Wade, Peter S. White, and Paul R. Neal. "Changing Patterns in the Number of Species in North American Floras." In Perspectives of Land Use History in North America: A context for understanding our changing environment, by T.D. Sisk, editor, 104. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-1998-0003 (Revised September 1999), 1998.

Link: http://landcover.usgs.gov/luhna/chap4.php

Synopsis: One of the most important trends in biodiversity is the increase in the number of species as the land area increases. Botanists call this trend the species-area relationship, and it is one of the most dependable rules in biology. Many human activities on the landscape, influence species directly by disrupting their habitat, by removing other organisms upon which they may depend, or by injuring or killing them. Less direct, but in many cases equally as disruptive to the native species of an area, is the introduction of exotic species.

In this study, data from published studies on flora over the last two centuries was used to produce contour maps of flora size and percentage of exotic species in North America for two specified unit areas (1,000 and 1,000,000 ha) and two specified years (1900 and 1996). Flora size decreases toward higher latitudes and is greatest in the southeastern United States. The number of species decreases from east to west. This decrease may result from drier environments, which have been linked to reduced diversity, and to a less thoroughly documented flora. Increases in the size of floras since 1900 probably do not reflect increased plant biodiversity but rather suggest that plant life has been more thoroughly documented. The average size of floras in parts of the eastern United States has decreased since 1900, but this decrease may be a result of increased botanical interest in unusual, but relatively depauperate, environments. Proportions of exotic species are greatest in the northeastern United States. The west coast also has relatively high proportions of exotic species. The proportion of exotic species lowest in the mountain West and in the far northern latitudes of Canada and Alaska. Despite the lack of complete or consistent scientific data, it can be concluded that floras represent a valuable data source to assess biodiversity. The resulting understanding of trends in the geographical distribution of biological diversity will be essential in developing strategies to best conserve it and to benefit from it.

Keywords: Biodiversity, patterns, flora, exotic plants, ecosystem services, conservation

Caveats:

- Plants living in any given area that have not been identified and described and some floras are more complete than others. Floras were compiled by different researchers with different methods and different standards.

- Floras differ in the area covered, from less than 1 ha to millions of hectares, creating difficulties in interpreting differences in diversity.
- Inconsistency in reporting, imprecise definition of study area or collection methods, inconsistency in the definitions of species, and the use of different nomenclature
- Variation in reported numbers of species may represent differences in definition rather than differences in biological variability
- The regression equations used to estimate diversity of a given region produce erroneous estimates when there are extreme values or some range of values with few observations.
- Contour mapping is based on further estimating the value of the mapped phenomenon between known points. Errors are greatest where known data points are sparsely distributed. In addition, errors arise when the mapped value has great variation, since in that case it is more difficult to estimate values for locations between known values.

Scale: Meso-regional/continental

Location:
Jurisdiction: North America
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: protected area, forest, agriculture (till cropping - dryland/irrigated, rangeland- native/seeded), settlement (urban, country residential, industrial)
Landscape pattern:

Part of the Environment: Biodiversity indices, ecosystem services (biodiversity), ecosystem health

58. **Citation**: Matheussen, Bernt, Kirschbaum, Robin L, Iris A Goodman, Greg M O'Donnell, and Dennis P Lettenmaier. "Effects of land cover change on streamflow in the interior Columbia River Basin (USA and Canada)." *Hydrological Processes* 14 (2000): 867-885.

Link:
http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1002/(SICI)10991085(20000415)14:5%3C867::AID-HYP975%3E3.0.CO;2-5/pdf

Synopsis: This study analyzed the effects of vegetation change on hydrological fluctuations in the Columbia River basin over the last century using two land cover scenarios. The first scenario was a reconstruction of historical land cover vegetation, c. 1900. The second scenario was more recent land cover as estimated from remote sensing data for 1990. The results show that, hydrologically, the most important vegetation-related change has been a general tendency towards decreased vegetation maturity in the forested areas of the basin. This general trend represents a balance between the effects of logging and fire suppression. In those areas where forest maturity has been reduced as a result of logging, wintertime maximum snow accumulations, and hence snow available for runoff during the spring melt season, have tended to increase, and evapotranspiration has decreased. The reverse has occurred in areas where fire suppression has tended to increase vegetation maturity, although the logging effect appears to dominate for most of the sub-basins evaluated. The study provides a broad-scale framework for assessing the vulnerability of watersheds to altered streamflow regimes attributable to changes in land cover that occur over large geographical areas and long time-frames. Threshold harvest areas required to produce a measurable increase in annual water yield: 15% for the Rocky Mtn/Inland Mtn area, 50% for the Central Plains region.

Keywords: Vegetation change, streamflow, evapotranspiration, snow processes

Scale: Meso-regional (Columbia River basin)

Location:
Jurisdiction: Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, and British Columbia

Ecoregion: Blue Mountains, Columbia Plateau, North Cascades, Columbia Mountains/North Rockies, Idaho batholiths, Snake River plain, Middle Rockies, Northern Basin and Range, Central Basin and Range

Landscape Type/Pattern:
Land Use: agriculture, timber harvest, managed forest, settlement
Landscape pattern: percent native

Part of the Environment: Water quantity, ecosystem functionality

59. **Citation**: Leblond, Mathieu, Jacqueline Frair, Daniel Fortin, Christian Dussault, Jean-Pierre Ouellet, and Rehaume Courtois. "Assessing the influence of resource co-variates at multiple spatial scales: an application to forest-dwelling caribou faced with intensive human activity." *Landscape Ecology* 26, no. 10 (2011): 1433-1446.

    Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-011-9647-6

    Synopsis: Using multi-scale seasonal models, this study explored how broad scale landscape context and local resource heterogeneity influenced local resource selection among threatened forest-dwelling woodland caribou in southern Quebec. Caribou consistently avoided roads, however researchers identified thresholds in road proximity effects. The threshold distance at which caribou avoid roads is 1.25 km for active roads and 0.75 km from derelict roads. Open lichen woodlands were an important cover type for caribou during winter and spring, whereas deciduous forests, wetlands, and even young disturbed stands became important during calving and summer. Landscape cover type and amount explained more variation in habitat selection by caribou at the landscape-level than other landscape pattern variables.

    Keywords: Forest-dwelling woodland caribou, landscape context, multi-scale habitat selection, caribou, resource selection function, spatial extent, threshold

    Scale: sub-regional

    Location:
    Jurisdiction: Quebec (Parc des Grands Jardins)
    Ecoregion: Algonquin/Southern Laurentians

    Landscape Type/Pattern:
    Land Use: Managed forest
    Landscape pattern: linear disturbance, percent native, fragmentation

    Part of the Environment: Terrestrial mammals, biodiversity indices, species at risk

    Seasonality: The scale of habitat selection for a given resource varies according to season

60. **Citation**: Heilman, Gerald E, James R Strittholt, and Nicholas C, Dellasala, Dominick A Slosser. "Forest fragmentation of the coterminous United States: assessing forest intactness through road density and spatial characteristics." *Bioscience* 52, no. 5 (2002): 411-422.

    Link:
    http://www.jstor.org/stable/10.1641/00063568%282002%29052%5B0411%3AFFOTCU%5D2.0.CO%3B2

    Synopsis: This study attempts to build a forest fragmentation database for the conterminous United States by utilizing high-resolution NLCD data, roads, and a series of fragmentation indices that quantify forest landscape patterns. The paper outlines a methodology for assessing forest fragmentation and provides a comprehensive data set to be used as a base for further investigation at smaller scales.

    Keywords: forest fragmentation, national database, fragmentation indices, road density, coterminous United States.

Caveats: Because of the limits of the input data, it was not possible to differentiate in this study between natural and anthropogenic disturbance.

Scale: Meso-regional

Location:
Jurisdiction: Coterminous USA
Ecoregion: Forested ecozones

Landscape Type/Pattern:
Land Use: Forests: protected, managed, grazing, recreation, transportation, settlement
Landscape pattern: fragmentation

Part of the Environment: Ecosystem functionality/intactness

61. **Citation**: Desrochers, Andre, and Susan J Hannon. "Gap crossing decisions by forest songbirds during the post-fledgling period." *Conservation Biology* 11, no. 5 (1997): 1204-1210.

    Link: http://www.jstor.org/stable/2387402 .

    Synopsis: This study examined the reluctance of different birds species to cross habitat gaps in a fragmented forest landscape. Researchers induced birds in the post-fledging period to cross gaps of varying widths and to choose between routes through woodland or across open areas by attracting them with recorded chickadee mobbing calls. Overall, birds were twice as likely to travel through 50 m of woodland than they were to travel through 50 m of open gap areas to reach the recording. When given a choice of traveling through woodland or across a gap, the majority of birds preferred woodland routes, even when they were three times longer than shortcuts in the open. Birds did not just use movement corridors, but strongly preferred them to open areas during the post-fledging phase of dispersal. Moving individuals will take significant detours to avoid open areas. However, species differed greatly in their response to gaps. The results indicate that woodland links significantly facilitate movements of birds across fragmented landscapes.

    Keywords: fragmentation, songbirds, gap crossing

    Caveats: It is possible that the recorded mobbing calls may have caused birds to behave more cautiously than usual, thereby skewing results.

    Scale: Local/site

    Location:
    Jurisdiction: Quebec
    Ecoregion: Algonquin/Southern Laurentians

    Landscape Type/Pattern:
    Land Use: protected and managed forest
    Landscape pattern: fragmentation

    Part of the Environment: Birds

62. **Citation**: Cushman, Samuel L, Andrew Shirk, and Erin L Landguth. "Separating the effects of habitat area, fragmentation, and matrix resistance on genetic differentation in complex landscapes ." *Landscape Ecology* 8 (2012): 369-380.

    Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-011-9693-0

    Synopsis: This paper aimed to quantify the relative importance of habitat area and configuration, as well as the contrast in resistance between habitat and non-habitat, on genetic differentiation patterns. Using spatially explicit, individual-based simulation modeling, researchers found that habitat configuration had stronger relationships with genetic differentiation than did habitat area. The pattern of habitat in a landscape will affect the distribution of the population and the degree of connectivity across it, resulting in differential patterns of gene flow. Researchers also evaluated the predictive ability of six widely used landscape metrics and found that patch cohesion and correlation length of habitat are among the strongest individual predictors of genetic differentiation.

Keywords: Landscape genetics, area, configuration, fragmentation, limiting factors, simulation, thresholds

Caveats: Even when using neutral landscape models, it is impossible to fully separate the effects of habitat area and configuration. As a result, our analysis shows a high degree of confounding between habitat area and configuration.

Scale: n/a; model based

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: n/a
Landscape pattern: percent native, fragmentation, linear disturbance

Part of the Environment: Biodiversity indices, ecosystem functionality/intactness

63. Citation: With, Kimberly A, and Thomas O Crist. "Critical thresholds in species responses to landscape structure." *Ecology*76, no. 8 (1995): 2446-2459.

Link: http://www.jstor.org.ezproxy.lib.ucalgary.ca/stable/pdfplus/2265819.pdf

Synopsis: A simulation model, modified from percolation theory, was empirically tested to determine if population distribution patterns correlated with different landscape patterns, for different species across a landscape. Using two grasshopper species in a short-grass prairie of north-central Colorado, the experiment found that the threshold for population aggregation (random to clumped distribution) was differentially affected by dispersal ranges and habitat specialization for habitat generalists and habitat specialists, respectively. Habitat generalists aggregated differentially depending on dispersal abilities. Generalist species with good dispersal abilities aggregated when <35% of the landscape consisted of suitable habitat, whereas generalist species with limited dispersal abilities aggregated in patchy distributions when suitable habitat constituted <20% of the landscape. Habitat specialists aggregated only when <40% of the landscape contained suitable habitat.

Keywords: critical thresholds, habitat fragmentation, landscape ecology, neutral models, percolation theory, population distributions, simulation modeling.

Caveats: For the sake of simplicity and clarity, organism movement is presumed to exist within a binary landscape—it is constrained within suitable habitat and unable to access the matrix.

Scale: Sub-regional (short-grass prairie of north-central Colorado, USA)

Location:
Jurisdiction: Colorado
Ecoregion: High Plains

Landscape Type/Pattern:
Land Use: protected area, rangeland
Landscape Pattern: percent native, fragmentation, connectivity

Part of the Environment: Terrestrial micro-fauna (grasshoppers, Orthoptera: Acrididae), ecosystem functionality/intactness

64. Citation: Kaseloo, Paul A. "Synthesis of noise effects on wildlife populations." Proceedings of the 2005 International Conference on Ecology and Transportation. Raleigh, North Carolina: North Carolina State University, 2005. 33-35

Link: http://www.escholarship.org/uc/item/9fz3s9x0

Synopsis: This paper summarizes significant findings from literature related to the effect of noise on wildlife, emphasizing the effects of road traffic noise on birds. Many studies from the United States and the Netherlands indicate that road noise has a negative effect on bird populations, particularly during breeding season in a variety of species. In this paper, 'effect distances'—distances at which bird density decreases—are reported at a range of two to three thousand meters from the road. Effect distances tend to increase with traffic density, being the greatest near large, multilane highways. In a study of woodland species, 26 of 43 (60%) were found to show a decrease in population densities with effect distances that also increased with the amount of traffic. Based on cumulative results, sound levels above 50 dB could be considered detrimental to many bird species. Findings that illuminate the relationship between reduced population density in some species and traffic density support the idea that noise has a significant effect on these species. However, the effect is not universal and needs to be considered in terms of the surrounding habitat as well as species in question.

Keywords: Road disturbance, noise effects, wildlife, traffic density

Caveats: No multi-species study has found all species to be sensitive. In several studies that cover a wide range of habitat types it has been shown that while some species become less common near the road, others show the opposite effect. One central question that has yet to be resolved is whether noise in isolation is sufficient to cause this effect. Further study is needed to verify the isolated effects of noise on species population abundance.

Scale: Regional

Location:
Jurisdiction: Netherlands and Boston, Massachusetts USA
Ecoregion: Northeastern coastal zone and equivalent

Landscape Type/Pattern:
Land Use: roads, settlement
Landscape pattern: linear disturbance, edge

Part of the Environment: Birds, biodiversity indices

65. Citation: Forman, Richard T, Bjorn Reineking, and Anna M Hersperger. "Road traffic and nearby grassland bird patterns in a suburbanizing landscape ." *Environmental Management* 29, no. 6 (2002): 782-800.

Link: http://search.proquest.com.ezproxy.lib.ucalgary.ca/docview/17284271?accountid=9838

Synopsis: The study examined the effects of road networks on suburbanizing ecosystems, using grassland bird distribution to explore the relative ecological importance of variables relative to linear disturbances and the effect of road traffic volumes. The study found that roads primarily affect ecological variables for 1) distance from road and 2) habitat patch size. The study also found that road traffic volumes are correlated to avian distribution, suggesting that traffic volumes have an ecological effect. The research suggests that traffic noise is the primary ecological effect of roads and that roads with higher traffic volumes extend the road effect zone outwards of 100 m and up to 1,200 m.

Given the ecological variables that are affected by roads, the study recommends that transportation facilities with high road volumes such as highways should be located away from natural resource areas and that open patches with quality microhabitats should be maintained away from highways. Mitigation of these effects should include efforts to reduce traffic volumes and decrease roadway noise through roadway and vehicular design measures. Further, broader process solutions are required at the transportation and regional planning levels that consider the road-effect zone in all planning projects such that mobility and ecological objectives can be achieved.

Keywords: Linear disturbance, road ecology, road network, traffic volumes, grassland birds, patch size, landscape ecology, transportation planning

Caveats: Species richness was not analyzed since 90% of the bird records were of two species (bobolinks and eastern meadowlarks)

Scale: Local/site

Location:
Jurisdiction: Boston
Ecoregion: Northeastern Coastal Zone

Landscape Type/Pattern:
Land Use: Settlement
Landscape pattern: Linear disturbance

Part of the Environment: Birds, ecosystem health

66. Citation: USDA. *Grassland Birds.* 1999. United States Department of Agriculture, Fish and Wildlife Management Leaflet No.8, Natural Resources Conservation Service, Wildlife Habitat Management Institute, Madison, WI and Wildlife Habitat Council, Silver Springs, MD.

Link: http://www.mn.nrcs.usda.gov/technical/ecs/wild/gnb.pdf

Synopsis: Reviews information on grassland bird habitat requirements including a focus on the importance of grassland cover, size of contiguous patches, and other landscape factors. Some species require large blocks of unbroken grassland habitat for nesting. In general, where large blocks of undisturbed grassland occur, grassland birds are able to fulfill most of their requirements during the nesting season. For many bird species, these habitats provide winter and migration cover as well. The more grassland available in an area, particularly in large unbroken blocks, the greater the number of area-sensitive grassland birds the area is able to support. Pastures and crop fields also often provide attractive cover to many grassland birds, although farming practices may impact nests and adults. Habitat value for grassland birds is greatly affected by the condition of the landscape in the area and surrounding land uses. Small, isolated parcels of grasslands in landscapes that are heavily wooded have limited potential to support grassland birds. On the other hand, blocks of grassland habitat that occur within landscapes dominated by open grass cover are much more likely to attract and support grassland birds. Interspersion of various types of grassland can maximize habitat quality for some species.

In order to support an array of grassland-nesting bird species within an area, the report recommends contiguous grassland blocks of at least 500 acres (>200 ha) to provide the greatest potential. However, smaller grassland blocks provide viable habitat patches for many grassland bird species. A general rule may be to maximize the size and interconnectedness of grassland habitat patches available, while conducting management actions that maximize the habitat quality within these habitat patches. A range of recommended grassland and rangeland management practices to maintain or enhance bird habitat are also outlined in the paper, including rotational mowing, prescribed grazing, prescribed burning, nesting cover, food requirements, and interspersion of habitat components, minimum habitat sizes, and hedgerow planting.

Keywords: Grassland birds, habitat requirements, patch sizes, rangeland management

Caveats: Estimates of the minimum size of suitable nesting and breeding habitat required to support breeding populations of grassland birds vary greatly among species. Species-specific area requirements may also vary among geographic regions and landscape characteristics. For example, the size of habitat patches needed to attract individuals of a given species may be smaller in landscapes that contain a large amount of grassland and open habitats compared to areas with little grassland habitat.

Scale: Regional

Location:
Jurisdiction: United States, Canada
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Rangeland, grassland
Landscape pattern: natural patch size, habitat interspersion, connectivity, fragmentation

Part of the Environment: Birds, ecosystem intactness

67. **Citation**: Thurber, Joanne M, Rolf O Peterson, Thomas D Drummer, and Scott A Thomasma. "Gray wolf response to refuge boundaries and roads in Alaska." *Wildlife Society Bulletin* 22, no. 1 (1994): 61-68.

    Link: http://www.jstor.org/stable/3783224

    Synopsis: In an attempt to better characterize the influence of human settlement patterns on wolf distribution, this paper examined how radio-collared gray wolves responded to different road types and human presence at the boundaries of Kenai National Wildlife Refuge in south-central Alaska. Wolves tended to avoid oilfield access roads that were open to the public, but were attracted to gated pipeline access roads and secondary gravel roads with limited human use. The low use access and secondary roads likely provided an easy travel corridor for wolves. Prior to intensive trapping and hunting from 1978-1979, wolves demonstrated little territorial adjustment in response to a heavily used highway. However, only after wolf populations declines from this intensive year of hunting and trapping did wolves adjust their territory to avoid the highway, forming separate packs on each side of the highway. In summary, road type and density influence the spatial organization of packs.

    Keywords: Alaska, behavior, Canis lupus, gray wolf, Kenai Peninsula, refuge boundaries, roads

    Caveats: Data used in this study originated primarily in winter, when human activity in wolf hab- itats was at a seasonal minimum. Wolf responses might be different at other times of year, such as the firearm hunting season, when human activity is greatly modified.

    Scale: sub-regional

    Location:
    Jurisdiction: Kenai Peninsula (60ºN, 150ºW) in south-central Alaska
    Ecoregion: Coastal western hemlock, Cook Inlet

    Landscape Type/Pattern:
    Land Use: settlement, oil and gas development, roads, protected area (national wildlife refuge)
    Landscape pattern: linear disturbance, connectivity

    Part of the Environment: Terrestrial mammals, ecosystem intactness

68. **Citation**: Jenkins, Christopher L, and Charles R Peterson. Linking landscape disturbance to the population ecology of Great Basin rattlesnakes (Crotalus oreganus lutosus) in the Upper Snake River Plain.

    Link: http://www.gsseser.com/Newsletter/Jenkins_Tech_Bull.pdf

    Synopsis: This study investigates the relationships of landscape disturbance, altered prey resources, and rattlesnake populations in the Upper Snake River Plain of southeastern. Researchers used radio telemetry to track rattlesnakes while concurrently conducting habitat sampling and small mammal trapping in areas used by snakes and in random locations. Disturbed areas (by grazing and/or burning) were characterized by lower biological crust cover, shrub cover, shrub height, and shrub dispersion, as well as higher grass and bare soil cover. Disturbed areas were also characterized by lower proportions of small animal biomass, abundance, and large prey species (such as chipmunks), while the proportions of small prey species (such as pocket mice) were higher at disturbed sites. As such, snakes preferred the habitat characteristics of undisturbed sites, with the exception of areas with lower biological soils crust cover. Study results suggest that land cover disturbance in sagebrush steppe ecosystems may cause a series of interactions that result in lower energy acquisitions by top predators, such as the Great Basin rattlesnake, that are particularly sensitive to landscape change. Landscape disturbance may therefore have implications for ecosystem wide trophic cascades.

Keywords: Disturbance, land cover, trophic interactions, Great Basin rattlesnakes, sagebrush steppe, Idaho

Scale: Sub-regional

Location:
Jurisdiction: Idaho
Ecoregion: Snake River Plain
Basin: Upper Snake River Basin

Landscape Type/Pattern:
Land Use: Grazing
Landscape pattern: percent suitable habitat cover, fragmentation

Part of the Environment: Reptiles, biodiversity indices, ecosystem health and functionality, species at risk

69. Citation: Braun, Clait E. *A blueprint for sage-grouse conservation and recovery.* Technical Report, Tucson, Arizona: Bureau of Land Management, 2006.

Link: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/revdr-comments/eg.Par.34919.File.dat/02Bio-attach5.pdf

Synopsis: This technical report by the Bureau of Land Management outlines strategies to improve sagebrush habitats that can, in turn, increase greater sage-grouse abundance and distribution in Wyoming. The goal of the report is to set forth guidelines for increasing greater sage-grouse abundance by at least 33% by 2015, and overall distribution of greater sage-grouse by at least 20% by 2030. In summary, the guidelines presented include steps for improving vegetation management to 1) restore degraded habitat, followed by 2) steps to reduce habitat fragmentation. For example, the report recommends restoring degraded areas at the following proportions of native vegetation cover in order to promote viable habitat for greater sage-grouse: sagebrush comprising 10 to 25% of the vegetative canopy cover, grasses at 30-40%, and forbs comprising 15 to 20% of the ground cover. These enhancements to land-cover and spatial arrangement have the greatest potential for maintaining and enhancing viable populations of greater sage grouse.

Keywords: Greater sage-grouse, sagebrush habitat, Wyoming, restoration guidelines, fragmentation

Caveats: Reaching targeted abundances of greater sage-grouse using the recommendations presented in this document is achievable; however meeting distribution goals will be more difficult.

Scale: Regional

Location:
Jurisdiction: Wyoming
Ecoregion: Wyoming basin

Landscape Type/Pattern:
Land Use: livestock grazing, oil and gas development, roads
Landscape pattern: percent native, fragmentation, linear disturbance

Part of the Environment: Birds, biodiversity indices, ecosystem intactness, species at risk

70. **Citation**: Connelly, JW, ST Knick, MA Schroeder, and SJ Stiver. Conservation Assessment of Greater Sage-Grouse and Sagebrush Habitats. Unpublished report, Cheyenne: Western Association of Fish and Wildlife Agencies, 2004.
Link: http://sagemap.wr.usgs.gov/docs/Greater_Sagegrouse_Conservation_Assessment_060404.pdf

Synopsis: This report identifies regional patterns of habitat disturbance, land use practices, and population trends relative to greater sage-grouse. In general, sage-grouse populations depend on large expanses of interconnected sage-brush habitat. While sagebrush habitats and sage-grouse populations were once continuous across much of Montana, Wyoming, Nevada, Utah, Oregon, Washington, Alberta, and Saskatchewan, they are now fragmented by agriculture, urbanization and development. Oil and gas development is prevalent on public lands that coincide with sagebrush habitat. These types of energy development result in direct habitat loss and noise disturbances that disrupt sage-grouse breeding and nesting activities. Fences associated with grazing operations also create barriers across the landscape, inhibiting sage-grouse movement and resource access. Roads, power lines, railroads, and other linear disturbances act as conduits for the invasion of exotic plants, create travel corridors for predators, and facilitate human access into sage-grouse habitats.

In general, the most important landscape characteristics influencing sage-grouse populations are the proximity of leks (areas in which males perform to nesting habitat for and The report examined findings from studies that indicate several area and distance specific conservation thresholds for maintaining viable sage-grouse habitat. These include:

- <5% of existing sagebrush habitat is located >2.5km from a mapped road
- Average proximity of lek to nest is 4.6 km
- Lek areas range from 0.04-36 ha.
- 36 ha was the average lek size for the 4 largest leks studied in central Washington
- Male sage-grouse prefer sod-forming grasses or bare ground for leks
- Female sage-grouse prefer dense sagebrush stands surrounding leks for nesting
- Gentle terrain characterized by <10% slope
- Breeding grounds must be <2000 m from a water source
- Average canopy cover for breeding areas is 7.3%, with an average vegetation height of 5.3cm.
- During breeding season, male sage-grouse travel <2.1km from a lek for foraging.
- Minimum core day-use by males is $0.25 km^2$

Keywords: Greater-sage-grouse, leks, breeding area, habitat requirements, population trends, habitat fragmentation, disturbance, land use, sagebrush habitat

Caveats: Appropriate patch size needed for winter and breeding habitats is uncertain. It is likely not a fixed amount, but depends on various factors such as migration patterns and productivity of habitats.

Scale: Meso-regional

Location:
Jurisdiction: Montana, Wyoming, Nevada, Utah, Oregon, Washington, Alberta, and Saskatchewan
Ecoregion: Wyoming Basin, Northwest Glaciated Plains, Colorado Plateaus, Central Basin and Range, Northern Basin and Range, Snake River Plain

Landscape Type/Pattern:
Land Use: Managed sagebrush steppe/grassland, grazing, oil and gas development, roads
Landscape pattern: fragmentation, linear disturbance, percent native, connectivity

Part of the Environment: Birds, biodiversity indices, ecosystem intactness

71. Citation: Holloran, Matthew J, and Stanley H Anderson. "Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats." *Condor* 107, no. 4 (2005): 742-752.

Link: http://www.jstor.org/stable/4096476 .

Synopsis: This study used radio-telemetry to determine nesting patterns of Greater Sage-Grouse relative to leks in a relatively contiguous sagebrush habitat in Wyoming. The proportion of nests located within 3 vs 5 km suggested that a 5 km buffer around a lek encompassed the majority of nests. The results indicate that land managers should strive to maintain a 5 km buffer around known sage-grouse lek locations in order to ensure sage-grouse breeding success.

Keywords: Greater Sage-Grouse, lek-to-nest distance, nest distribution, nest spacing, Wyoming

Caveats: Nest distribution patterns may change as a result of habitat alteration and fragmentation, thus a 5-km buffer should be considered relevant only within contiguous sagebrush habitats

Scale: Sub-regional

Location:
Jurisdiction: Wyoming
Ecoregion: Wyoming basin

Landscape Type/Pattern:
Land Use: grazing, natural resource development
Landscape pattern: percent habitat cover

Part of the Environment: Birds, biodiversity indices, species at risk

72. Citation: Carroll, Carlos, Michael K Phillips, Nathan H Schumaker, and Douglas W Smith. "Impacts of landscape change on wolf restoration success: planning a reintroduction program based on static and dynamic spatial models." *Conservation Biology* 17, no. 2 (2003): 536-548.

Link:
http://ezproxy.lib.ucalgary.ca/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=9377942&site=ehost-live

Synopsis: This study employed two types of spatial models to evaluate the potential of wolf reintroduction in the southern Rocky Mountain region. A multiple logistic regression was used to develop a resource-selection function relating wolf distribution in the Greater Yellowstone region with regional-scale habitat variables. Researchers also used a spatially explicit population model to predict wolf distribution and viability at several potential reintroduction sites within the region under current and future landscape change scenarios. The dynamic model predicted similar population distribution under current conditions but suggested that development trends over the next 25 years may result in the loss of one of four potential regional subpopulations and increase isolation of the remaining areas. An overall reduction in landscape carrying capacity for wolf population distribution and viability depends largely on the degree of road development on public lands.

Keywords: Dynamic models, spatial distribution, population viability, grey wolf, spatially explicit population model, wolf reintroduction, southern Rocky Mountains

Caveats: The model's sensitivity to errors in poorly known parameters such as dispersal rate made it difficult to predict the probability of natural recolonization from distant sources.

Scale: Meso-regional (Southern Rocky Mountain region encompassing parts of Wyoming, Colorado and northern New Mexico.

Location:
Jurisdiction: Wyoming, Colorado, and New Mexico USA
Ecoregion: Southern Rocky Mountains

Landscape Type/Pattern:

Land Use: Protected area, public lands, settlement (road density)
Landscape Pattern: Fragmentation, connectivity

Part of the Environment: Terrestrial mammals, ecosystem functionality and intactness

73. **Citation:** Proctor, Michael F, et al. "Population fragmentation and inter-ecosystem movements of grizzly bears in western Canada and the northern United States." *Wildlife Monographs* 180 (2012): 1-46.

Link:
http://www.swetswise.com.ezproxy.lib.ucalgary.ca/eAccess/viewToc.do?titleID=216038&yevoID=3449970

Synopsis: Researchers studied the current state and potential causes of population fragmentation in grizzly bears over western Canada, the Greater Yellowstone region of the United States, and southeast Alaska. In less settled northern regions, the study found that spatial genetic patterns of isolation-by-distance (IBD) are caused largely by natural fragmentation from the rugged glaciated terrain. These results contrasted with spatial patterns of fragmentation found in the southern parts of the study area. Near the US-Canada border, population fragmentation corresponded to the presence of settled mountain valleys and major highways. In these disturbed areas, most inter-area movements were recorded in male bears. North-south movements within mountain ranges were more common that east-west movements across settled mountain valleys. In Alberta, fragmentation corresponded to east-west highways. Both males and females demonstrated reduced movement rates with increasing settlement and traffic, however females reduced their movement rates drastically when settlement increased to >20% of the fracture zone. In highly settled areas (>50%), both sexes demonstrated similar reductions in movement. The results of this study indicate that, without female connectivity, small subpopulations of grizzly bears are not viable over the long term. Enhancing female connectivity among fractured areas by securing linkage-zone habitat appropriate for female dispersal is key to guaranteeing the persistence of fragmented metapopulations.

Keywords: Demographic fragmentation, DNA, gene flow, grizzly bear, microsatellites, population assignment,population fragmentation, radio telemetry, *Ursus arctos,* climate change

Caveats: Measuring natal dispersal and inter-population movements is challenging, especially for wide-ranging, long-lived species that occur at low densities. Radiotelemetry is often used to measure movement in large mammals that can carry transmitters, but the capacity of this technology is limited because collars are seldom worn during natal dispersal.

Scale: Meso-regional (all grizzly bear ranges in North America, including British Columbia, Western Alberta, southeast Alaska and the Greater Yellowstone Region).

Location:
Jurisdiction: BC, Alberta, Montana and Wyoming
Ecoregion: Middle Rockies, Columbia Mountains/Northern Rockies, Canadian Rockies, Chilcotin Ranges and Fraser Plateau, Skeena-Omineca-Central Canadian Rocky Mountains, Coastal Western Hemlock, Sitka Spruce Forests. Yukon-Stikine Highlands/Boreal Mountains and Plateaus, Watson Highlands, Mackenzie and Selwyn Mountains, Peel River and Nahanni Plateaus, Clear Hills and Western Alberta Upland

Landscape Type/Pattern:
Land Use: Mountain conifer forests, boreal uplands, public lands, settlement, roads
Landscape Pattern: percent native, fragmentation, linear disturbance

Part of the Environment: Terrestrial Mammals, biodiversity indices, ecosystem intactness

74. **Citation:** McLellen, BR, and BM Shackleton. "Grizzly bears and resource extraction industries: effects of road on behavior, habitat use, and demography." *Journal of Applied Ecology*25, no. 2 (1988): 451-460.

Link: http://www.jstor.org/stable/2403836

Synopsis: This study aimed to determine whether grizzly bears were displaced by roads associated with resource extraction industries in the Rocky Mountains. Since many habitats close to roads contained important bear foods, researchers expected bears to frequent these roads, despite the presence of human activity. However, study results indicated that grizzlies strongly avoided roads regardless of traffic volume, suggesting that even a few vehicles can displace bears from adjacent habitats. Roads were used by bears more at night than during the day. In general, roads increased access for legal and illegal hunters, which are a major source of adult grizzly mortality. Roads often follow valley bottoms and pass through riparian area, which are important habitats for grizzly bears. When roads do displace bears, increased pressure is placed on similar adjacent habitats in undisturbed regions.

Keywords: Grizzly bears, human disturbance, road avoidance, habitat displacement

Scale: Regional

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies

Landscape Type/Pattern:
Land Use: Road construction associated with resource extraction
Landscape pattern: linear disturbance

Part of the Environment: Terrestrial mammals, biodiversity indices, ecosystem intactness

75. **Citation:** Chruszcz, Bryan, Anthony P Clevenger, Kari E Gunson, and Michael L Gibeau. "Relationships among grizzly bears, highways, and habitat in Banff-Bow Valley, Alberta, Canada." *Canadian Journal of Zoology* 81, no.8 (2003): 1378-1391.

Link: http://search.proquest.com.ezproxy.lib.ucalgary.ca/docview/220487450?accountid=9838

Synopsis: The study examined the relationships among grizzly bears, their habitats and roads in Banff National Park, a protected area characterized by a major transportation corridor. This corridor is comprised of the Trans-Canada Highway and other low-volume roads that provide visitor access to the park. Corridors such as this one constitute a significant linear disturbance in the landscape which are known to significantly affect landscape connectivity, habitat, movement patterns and increased species mortality, leading to decreased populations and species viability for grizzly bear populations.

Three main analyses were undertaken as part of the research and included the spatial distribution of grizzly bears relative to roads, road crossing attributes and road crossing indices. The study took into consideration the quality of habitat for grizzly bears in the lower elevation montane ecozone located in the study area. The study identified two main patterns: grizzly bear avoidance of high volume roads (25,000 vehicles/day) and the importance of high quality habitat in determining movement decisions relative to roads. Specifically, grizzly bears avoided crossing high volume roads; however, were more likely make the crossing to access high-quality habitat. Further, the research found that grizzly bears used areas close to roads more than expected, in particular low-volume roads (10,000 vehicles/day).

The findings suggest that the cumulative effects of linear disturbances within the transportation corridor can limit access to important habitats and negatively affect grizzly bears in the Banff National Park ecosystem. The study recommends that land managers and transportation planners in the Bow Valley prevent loss of habitat connectivity with the following mitigation: maintain high-quality habitat adjacent to roads, install continuous highway fencing and create wildlife passages. Mitigation should seek to address effects of traffic volume and road-crossing decisions and recommendations were informed by research findings and a review of mitigation literature.

Keywords: Grizzly bears, major transportation corridor, roads, traffic volume, habitat connectivity, linear disturbance, road crossing behaviour, protected area, permeability, road ecology

Scale: Sub-regional

Location:
Jurisdiction: Banff-Bow Valley corridor, Alberta, Canada
Ecoregion: Canadian Rockies

Landscape Type/Pattern:
Land Use: Protected area, settlement
Landscape pattern: Linear disturbance, connectivity

Part of the Environment: Terrestrial mammals, species-at-risk

Seasonality: Stratified by season when sample size was large enough.

76. **Citation:** Linke, Julia, Steven E Franklin, Falk Huettmann, and Gordon, B Stenhouse. "Seismic cutlines, changing landscape metrics, and grizzly bear landscape use in Alberta". *Landscape Ecology* 20 (2005): 811-826.

    Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-005-0066-4

    Synopsis: This study assessed seismic cutline effects on landscape structure and grizzly bear use during early summer. Landscape use was related to landscape metrics using a Generalized Linear Model (GLM). The study found that seismic cutline proportion did not explain landscape use by grizzly bears; however secondary effects of cutlines on landscape structure did. Declining use was mainly associated with increasing proportions of closed forest, and increasing variation of inter-patch distances, while use was mainly increasing with increasing mean patch size.
    The study suggests that the investigated grizzly bear population does not respond to seismic cutline densities in early summer, but to the habitat structure they create. Bears appear to use areas more when landscape patches tend to be larger, and mean patch size is generally reduced with additional seismic cutlines. Also, bears appear to use areas more when landscape patches are consistently spaced, and the spacing between landscape patches becomes more variable with additional seismic cutlines.

    Keywords: Binning, Generalized linear models (GLM), GPS locations, Landscape configuration, Landscape ecology, Landscape structure, Satellite imagery, Seismic cutlines, *Ursus arctos*

    Caveats: A female bias in the analyzed population existed and within the female group, some individuals were represented by more GPS locations than others. The analysis was also subject to potential influences of GPS-collar bias, which dealt less with the spatial inaccuracy due to the 30 m habitat mapping resolution, but with missing data in the form of failed location attempts.

    Scale: Sub-regional (FRM Grizzly Bear Research Project Area)

    Location:
    Jurisdiction: West, Central Alberta
    Ecoregion: Canadian Rockies

    Landscape Type/Pattern:
    Land Use: energy exploration (seismic cutlines)
    Landscape pattern: Fragmentation, linear disturbance, edge

    Part of the Environment: Terrestrial Mammals

77. **Citation:** Mace, Richard D, John S Waller, Timothy L Manly, Jack L Lyon, and Hans Zuuring. "Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana." *Journal of Applied Ecology* 33 (1996): 1395-1404.

    Link: http://www.jstor.org/stable/2404779

    Synopsis: The study examined the relationships between grizzly bears, habitat and roads in the Swan Mountains, Montana. The study showed complex spatial and temporal relationships between grizzly bears and habitat resources. Resource selection was expressed relative to strength and association of road and habitat parameters and relationships varied by landscape scale, level of selection, season and individual. Selection was greatest for unroaded cover types and declined as road densities increased. Grizzly bears were found to tolerate habitat resources proximate to roads when roads are either closed or limited to less than 10 vehicles per day, particularly in the spring near cutting units and chutes that terminate proximate to roads. Few bears exhibited selection for habitat near roads having greater than 60 vehicles per day. These findings are consistent with findings related to the conservation values of unroaded habitats for other species, elsewhere. The study is significant as there is minimal research on grizzly bear habitat selection in roaded, multiple-use environments.

The results suggest that grizzly bears can use roaded habitats, but spatial avoidance will increase and survival will decrease as traffic levels, road densities and human settlement increases. The study notes that land tenure appears to influence mortality as habituation and mortality levels are higher on or adjacent to private lands. The study recommends that road density standards and road closure programmes should be developed and that these programmes incorporate seasonal habitat requirements of grizzly bears.

Keywords: grizzly bear, roads, linear disturbance, road ecology

Scale: Sub-regional

Location:
Jurisdiction: Montana
Ecoregion: Canadian Rockies

Landscape Type/Pattern:
Land Use: forest
Landscape pattern: Linear disturbance

Part of the Environment: Terrestrial mammals, species-at-risk

Seasonality: The study observed positive selection for chutes during spring as well as increased use of cutting units and shrub lands in the low temperate and temperate zones in the summer and autumn. In direct relationship to roads, the study observed positive selection for habitat near roads in the spring likely because of grizzly bear preference for cutting units or chutes and these often terminate near roads.

78. Citation: Bergin, Timothy M, Louis B Best, Katherine E Freemark, and Kenneth J Koehler. "Effects of landscape structure on nest predation on roadsides of a mid-western agroecosystem: a multi-scale analysis." *Landscape Ecology* 15 (2000): 131-143.

Link:
http://download.springer.com/static/pdf/189/art%253A10.1023%252FA%253A1008112825655.pdf?auth66=1363104786_4931950ac3526c71e032def9229347dc&ext=.pdf

Synopsis: This study evaluated the influence of habitat structure and spatial configuration on nest predation in central Iowa. In a multi-scale analysis of 10 artificial ground nests along 136 roadsides across six watersheds, researchers found that predation was affected by the surrounding landscape mosaic. Nest predators with different home-range sizes and habitat affinities responded to landscape configuration in different ways. In general wooded landscapes were associated with greater nest-predation whereas herbaceous habitats were associated with less. Wooded roadsides functioned as important travel corridors for predators, increasing their likelihood of encountering nests. Different landscape variables were important at different spatial scales. Woodlands with continuous forest cover were important at all scales while agricultural fields were important only at large scales. Roadsides were important at small scales, but wooded roadsides were important at all scales. Most landscape metrics, such as patch size and edge density, were important at large scales.

Keywords: Agricultural landscapes, artificial nests, landscape structure, multi-scale analysis, nest predation, roadsides, spatial scale.

Caveats: The explanatory power of the study was weak (R2 value was generally below 30%), suggesting that some associations between nest predation and landscape structure were weak or that some significant variables were not measured. Secondly, identifying specific predators from evidence left at nest sites was difficult. Therefore, the study cannot accurately correlated predator home-range size and landscape composition.

Scale: Sub-regional (watershed scale)

Location: Jurisdiction: Iowa
Ecoregion: Western corn-belt plains

Landscape Type/Pattern:
Land Use: Agriculture
Landscape Pattern: fragmentation, linear disturbance

Part of the Environment: Birds, biodiversity indices

79. Citation: Downey, Brad A. "Richardson's Ground Squirrel." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 76-81. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004c.
Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis:
Ground squirrels, once the most abundant terrestrial mammal, are widespread across the prairies and play an essential role in the biodiversity of the prairie ecosystem, particularly as prey species and by providing underground refuges for native prairie species. This report evaluated habitat suitability requirements for the Richardson’s ground squirrel according to parameters of graminoid cover, tree and shrub cover, slope, and soil texture. Richardson's ground squirrels prefer short grass native prairie/ pasture but can also occupy small isolated islands within cropland. A threshold amount of 20% graminoid coverage is the minimum suitable proportion for habitat suitability. These squirrels prefer open prairies and tend to select against heavily forested areas. Areas with less than 20% forest/shrub cover were given maximum value, while those greater than 40% were given an HSI value score of 0. Richardson's ground squirrels prefer flat, open habitat and would probably not be found in 1/4 sections with slopes greater than 25 degrees.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Richardson’s ground squirrel

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, terrestrial mammals, species-at-risk

80. Citation: Andren, H. "Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review." *Oikos*, 71, no. 3 (1994): 355-366.

Link: http://www.jstor.org/stable/3545823

Synopsis: This study involved a review of studies on birds and mammals in habitat patches in landscapes with different proportions of suitable habitat. The findings demonstrate that there exists a threshold in proportion of suitable habitat in the landscape, above which fragmentation becomes pure habitat loss. The threshold is 10% of suitable habitat for birds and 30% suitable habitat for mammals. The negative effects of patch size and isolation on the original species may not occur until the landscape consists of less than these threshold amounts of suitable habitat. For mobile organisms, the effects of isolation may appear only in landscapes with very fragmented habitat. In landscapes with highly fragmented habitat, a further reduction in habitat results in an exponential increase in distances between patches. Thus, in landscapes with highly fragmented habitat, the spatial arrangement of habitat patches is very important. Moreover, the effect of patch size and isolation will not only depend on the proportion of original habitat in the landscape, but also on the suitability of the surrounding habitats. Beta diversity, may increase when new patches of habitat are created within a continuous habitat, because new species may be found there, even if the new patches are human-made. The beta diversity in the landscape will probably be highest when two habitats occur in about equal proportions

Keywords: habitat loss, fragmentation, patch, birds, mammals, random sample hypothesis, species diversity

Caveats: Almost all the studies in the review were performed during one or two seasons. Thus, most studies are snap-shots that do not consider spatio-temporal dynamics. In addition, human-caused habitat fragmentation observed in the paper is often the result of very recent disturbance activities. Therefore, habitat patches might be overcrowded and the decline in population size has not yet occurred. There is a need for more long-term studies to address this issue.

Scale: literature review; many scales

Location:
Jurisdiction: World-wide
Ecoregion: Many

Landscape Type/Pattern:
Land Use: agriculture, settlement, managed land, grazing, recreation, roads
Landscape pattern: percent native, fragmentation

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices.

81. Citation: Leitner, Lawrence A., Dunn, Christopher P., Guntenspergen, Glenn R., Stearns, Forest, Sharpe, David M. Effects of site, landscape features, and fire regime on vegetation patterns in presettlement southern Wisconsin. Landscape Ecology 5, no. 4 (1991): 203-217.

Link: http://www.chicagobotanic.org/downloads/staff/dunn/LandscapeEcology.pdf

Synopsis: Disturbance is considered to be a major factor influencing landscape pattern and vegetation composition. However, the presettlement vegetation composition of three Ohio (U.S.A) counties was controlled largely by soil texture, soil drainage, and topography. In most cases, both disturbance regime and local site conditions can explain presettlement landscape pattern. This study examines the roles of edaphic conditions landscape features such as topography, and fire in contributing to (1) the abundance, spatial distribution, and size structure of forest trees and to (2) vegetation pattern in a presettlement southern Wisconsin landscape. The presettlement tree cover of 3 townships in a southern Wisconsin landscape was analyzed using original survey records. Four forest types were identified: closed forest, open forest, savanna, and prairie. Comparisons of vegetation types and landscape pattern were made between the east and west sides of the Pecatonica River, which bisects the landscape and may have acted as a natural fire barrier. West of the river, presettlement tree species richness and diversity were lower and trees were smaller in diameter and less dense than to the east. The major vegetation types to the west were prairie (42% of landscape) and savanna (40%), both fire-susceptible types. Prairie was more common on gentle slopes than on other landforms. To the east, the landscape was 70% forested (closed plus open forest). Here, prairie was more frequent on steep dry sites.

These vegetation differences, including the contrasting landscape placement of prairie, are attributed to distinct site characteristics and to disturbance (fire) regimes, with the west likely having more frequent fires. In terms of the four vegetation types, the east landscape was more homogeneous, being dominated by closed forest (50%). West of the Pecatonica River, the landscape was more heterogeneous because of the high proportion of both prairie and savanna; however, in terms of flammability of vegetation, the west was essentially homogeneous (82% prairie plus savanna). In southern Wisconsin, the legacy of this interaction between disturbance, topography, and vegetation can be found in the scattered woodlots of today. Successional changes resulting from a legacy of fire suppression and other agricultural and access disturbances have created the current heterogeneous landscape mosaic.

Keywords: disturbance, fire, heterogeneity, landscape pattern, topography, Wisconsin

Scale: Sub-regional

Location:
Jurisdiction: Wisconsin, Cadiz Township
Ecoregion: Southeast Wisconsin Till Plains
Basin: Pecatonica River Valley

Landscape Type/Pattern:
Land Use: agriculture
Landscape pattern: fragmentation, connectivity

Part of the Environment: Ecosystem functionality and intactness

82. **Citation:** Booth, Derek B, and Rhett C Jackson. "Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation." *Journal of the American Water Resources Association* , 33, no. 5 (1997): 1077-1090.

Link: http://your.kingcounty.gov/ddes/cao/PDFs04ExecProp/BAS-AppendixB-04.pdf

Synopsis: This paper articulates and summarizes relationships between (i) forest cover and (ii) impervious surface area as watershed indicators. These indicators strongly influence hydrology, stream channel stability, bank erosion, sedimentation, water quality, fish and other aquatic habitats. The area of focus in King County, western Washington State, has experienced rapid development. The paper provides an excellent background on technical principles, empirical monitoring results, and models applied to study these issues.

Key empirical results summarized include the relationships between upstream impervious area and fish habitat quality (Figure 6), and channel stability, peak flows and land use (Figure 9). One key finding was that less empirical data are available on the direct correlations between forest cover and stream conditions than for watershed imperviousness and stream conditions. The “evidence” with regards to forest cover has been primarily based on observed correlations of channel instability to modelled hydrologic analyses exploring relationships between peak flows and forest cover.

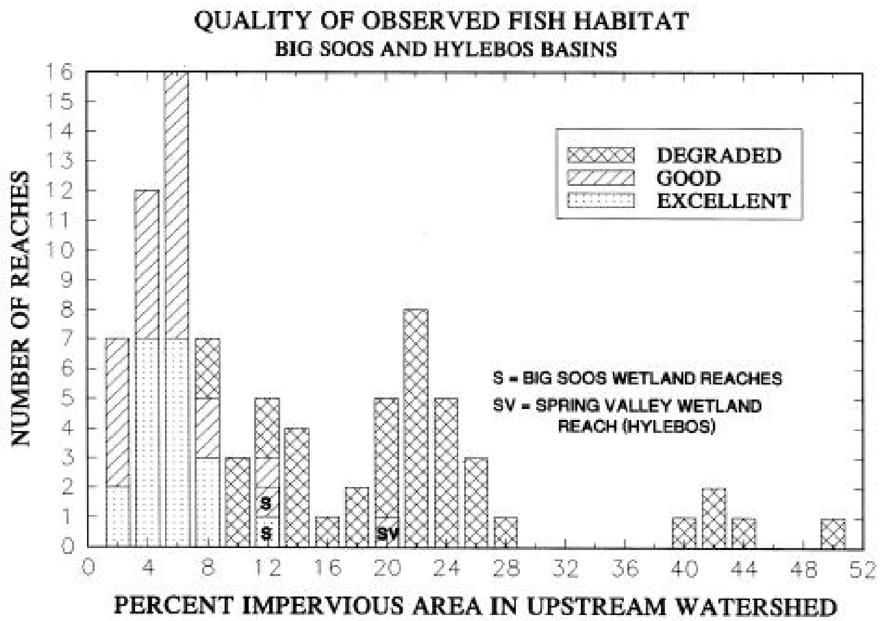


Figure 6. Observed fish habitat quality as a function of effective impervious area in the contributing watershed, based on more than 80 individually inventoried channel segments in south King County (From Booth and Jackson, 1997; data from King County 1990a,c). "EXCELLENT" reaches show little or no habitat degradation; "GOOD" reaches show some damage to habitat but still maintain good biological function; and "DEGRADED" reaches contain aquatic habitat that has been clearly and extensively damaged, typically from bank erosion, channel incision, and sedimentation.

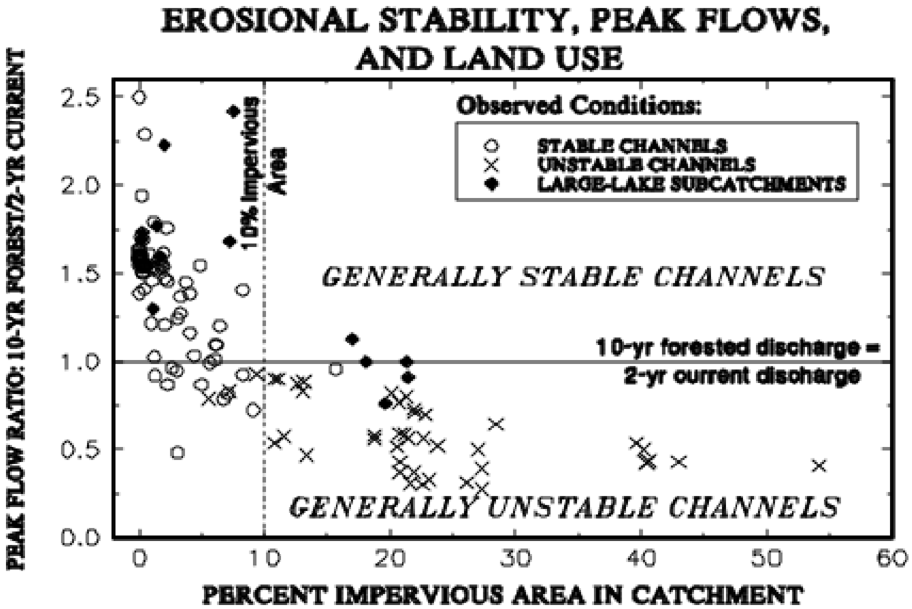


Figure 9. Observed stable ("O") and unstable ("X") channels, plotted by percent effective impervious area (EIA) in the upstream watershed (horizontal scale) and ratio of modeled 10-year forested and 2-year current (i.e. urbanized) discharges (vertical scale). Apparent thresholds relating channel stability with either 10-percent EIA or $Q_{2\text{-cur}} = Q_{10\text{-for}}$ are consistently met, except for the few catchments containing large lakes.

The analyses, including extensive empirical studies spanning 20 years, were used to support limiting effective impervious areas in high quality watersheds to at or below 10%, *and* to maintain forest cover at a minimum of 65%, in order to effectively mitigate the impacts of urbanization and development on watersheds. These thresholds mark an observed transition to degraded stream conditions.

Another key finding was that riparian buffers can also reduce the magnitude of urban impacts; however, these cannot fully mitigate the impacts of upstream development in the watershed.

Keywords: Impervious area, stream stability, forest cover, fish habitat, thresholds

Caveats: Some degree of measurable resource degradation can be seen at virtually any level of human development. At lower levels of human disturbance below the identified thresholds, aquatic system damage may range from slight to severe. “Thresholds of effect,” identified in some literature, often exist largely as a function of measurement precision.

Scale: Sub-regional

Location:
Jurisdiction: King County, Washington
Ecoregion: Strait of Georgia/Puget Lowland, and North Cascades
Basin: Central Puget Sound Watershed
Sub-basins: Sammamish Watershed, Snoqualmie-Skykomish River, Cedar River-Lake Washington, Green-Duwamish River, White River

Landscape Type/Pattern:
Land Use: Forested, rural, suburban, urban, and exurban settlement
Landscape pattern: Percent Forested, Percent Impervious

Part of the Environment: Water quantity, water quality, riparian systems, aquatic fish habitat, ecosystem health

83. Citation: Stevens, Cam, and Trevor Council. A fish-based index of biological integrity for assessing river condition in Central Alberta. Technical Report, Lethbridge, Alberta: Alberta Conservation Association, n.d.
Link: http://www.ab-conservation.com/go/default/index.cfm/publications/conservation reports/report-series/details/?reportID=2E0C40F9-BCD6-BFDD-58ABBE7FE8D87DBC

Synopsis: Report describes the development of a multi-metric, fish-based Index of Biological Integrity (IBI) to assess the health of aquatic ecosystems on the Battle River, Alberta. The IBI was highly sensitive to cumulative anthropogenic disturbance. Impaired integrity of fish assemblages was detectable at road densities as low as 0.7km/km2.

Keywords: Index of Biological Integrity (IBI), prairie-parkland ecosystem, Battle River, Alberta, aquatic health, fish-based index, road density

Caveats: Additional research on ecological functions and requirements of species in northern systems is recommended to strengthen the basic foundation of guild-based bio-assessment methods in Alberta.

Scale: Sub-regional

Location:
Jurisdiction: Alberta (Central)
Ecoregion: Aspen Parkland/Northern Glaciated Plain
Basin: South Saskatchewan
Subbasin: Battle River

Landscape Type/Pattern:
Land Use: Settlement, agriculture, energy development, roads
Landscape pattern: Fragmentation, linear disturbance

Part of the Environment: Fish, riparian systems, aquatic health

84. Citation: Moyle, Peter B, and Paul J Randall. "Evaluating the biotic integrity of watersheds in the Sierra Nevada, California." *Conservation Biology* 12, no. 6 (1998): 1318-1326.

Link: http://www.jstor.org/stable/2989851

Keywords: Researchers developed a watershed index of biotic integrity to evaluate the biological health of 100 watersheds in the Sierra Nevada of California. In general, watersheds with low indices of biotic integrity (IBI) have been heavily developed by hydraulic mining, agriculture, and hydroelectric dams. The biggest factors contributing to low IBIs were the presence of large dams, introduced fish, and road density. Dams at low to middle elevations had the greatest effect on IBI.

Caveats: Analysis on such a large scale tends to overlook the importance of smaller watersheds. Detailed surveys within watersheds are needed to identify special, unusual, or undisturbed aquatic systems at a smaller scale for protection or remediation.

Scale: Meso-regional

Location:
Jurisdiction: California
Ecoregion: Sierra Nevada

Landscape Type/Pattern:
Land Use: Agriculture, hydroelectric dams, mining
Landscape pattern: fragmentation, connectivity

Part of the Environment: Biodiversity indices

85. Citation: Rooney, Rebecca R, Suzanne E Bayley, Irena F Creed, and Matthew J Wilson. "The accuracy of land cover-based wetland assessments is influenced by landscape extent." *Landscape Ecology* 27, no. 9 (2012): 1321-1325.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-012-9784-6

Synopsis: In an effort to establish a cost-effective evaluation of wetlands throughout whole regions, this study aimed to determine if cover data could be used to estimate the biotic integrity of wetlands in Alberta's Beaverhills Watershed. Biotic integrity was measured using both plant- and bird-based indices of biotic integrity (IBIs) in 45 wetlands. Land cover data were extracted from seven nested landscape extents (100–3,000 m radii) and used to model IBI scores. The results offer support for the use of land cover as an indicator of biotic integrity estimated by both vegetation and bird communities. Strong, significant predictions of IBI scores were achieved using land cover data from every spatial extent. Plant-based IBI scores were best predicted using data from 100 m buffers and bird-based IBI scores were best predicted using data extracted from 500 m buffers. Road density and measures of the proportion of disturbed land were consistent predictors of IBI score, suggesting their universal importance to plant and bird communities.

Keywords: Wetland assessment, regional assessment, buffer, land cover, index of biotic integrity, birds, vegetation, North Saskatchewan watershed, Canada, spatial autocorrelation

Scale: Local/site (45 individual watersheds)

Location:
Jurisdiction: Alberta (53.54° N latitude and113.50° W longitude_
Ecoregion: Aspen Parkland

Landscape Type/Pattern:
Land Use: protected, agriculture, settlement
Landscape pattern: percent native (land cover extent)

Part of the Environment: Riparian systems, biodiversity indices

86. Citation: Park, Jane, and Mary L Reid. "Distribution of bark beetle, Trypodendron lineatum in a harvested landscape." Forest Ecology and Management 242 (2007): 236-242.
Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.foreco.2007.01.042

Synopsis: This study monitored the response of a species of pine bark beetle, *Trypodendron lineatum,* to direct and indirect measures of habitat availability in a forest subjected to various levels of harvest intensities. Four stand types (conifer dominated, mixed, deciduous dominated, and deciduous dominated with conifer understory) were treated with four levels of harvest intensity (unharvested, 50%, 80%, and 90% harvested). Prior to harvest, the pine bark beetle was most abundant in stands with many host trees (conifer dominated stands). In the first and second summers after harvest, pine beetle abundance increased exponentially with percent spruce cover and the number of spruce stumps in the stand. Beetles were likely attracted from a wide surrounding area because of the increase in host volatiles released from stumps. The results support the resource concentration hypothesis; that herbivorous insects congregate where hosts are abundant. In light of this apparent habitat cue, managers should strive to minimize the concentration of stumps and freshly dead trees in post-harvested conifer forests.

Keywords: Pine bark beetle, *Trypodendron lineatum*, resource concentration hypothesis.

Scale: sub-regional

Location:
Jurisdiction: Northern Alberta

Ecoregion: Mid-boreal uplands, Peace/Wabaska lowlands

Landscape Type/Pattern:
Land Use: boreal forest, timber harvest
Landscape pattern: perforation, percent cover

Part of the Environment: Terrestrial micro-fauna, ecosystem intactness

87. **Citation**: Trzcinski, Kurtis M, and Mary L Reid. "Effect of management on spatial spread of mountain pine beetle (Dendroctonus ponderosae) in Banff National Park." Forest Ecology and Management 256 (2008): 1418-1426.
Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.foreco.2008.07.003

Synopsis: This study evaluated the effects of landscape management on the spread of mountain pine beetle colonization in Banff National Park, Alberta, Canada. Researchers used annual aerial survey data and geo-referenced locations of colonized trees that were cut and removed to assess if the area colonized and the spatial extent of pine beetles differed between monitoring and management zones. Pine beetles were allowed to follow their natural course in the monitoring zone, while an extensive eradication program involving cutting and burning colonized trees was established in the management zone. Management resulted in no detectable effect on the scale of the zone. However, at the sub-zone scale, the area affected within the management zone had stabilized more than the monitoring zone. Therefore, the management program appeared to have reduced the success of long-distance movement by pine beetles, thereby reducing the risk of infestation.

Keywords: Bark beetle, lodgepole pine, aerial survey, landscape management, direct control

Caveats: Even under the favorable conditions of the study, researchers could not be strongly conclusive about management effectiveness, likely due in part to data limitations. In order to improve data collection, future evaluations should involve conducting a comprehensive survey of vegetation age structure and spatial variation in tree growth rates (habitat modeling).

Scale: Sub-regional (Banff National Park)

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies

Landscape Type/Pattern:
Land Use: Protected and managed forest (pine beetle eradication/control)
Landscape pattern: fragmentation, connectivity

Part of the Environment: Terrestrial micro-fauna, ecosystem intactness

88. **Citation**: Raffa, Kenneth F, et al. "Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions." Bioscience 58, no. 6 (2008): 502-517.
Link: http://www.jstor.org/stable/10.1641/B580607 .

Synopsis: Because recent bark beetle population eruptions have exceeded the frequencies, impacts, and ranges documented during the previous 125 years, researchers have been prompted to determine what factors trigger broad scale outbreaks, and how do these factors interact? How do human activities, such as forest management, alter these interactions, and thus the frequency, extent, severity, and synchrony of outbreaks? Extensive host tree abundance and susceptibility, concentrated beetle density, favorable weather, optimal symbiotic associations, and escape from natural enemies must occur jointly for beetles to surpass a series of thresholds and exert widespread disturbance. Eruptions occur when key thresholds are surpassed, prior constraints cease to exert influence, and positive feedbacks amplify across scales.

The structure of the greater landscape critically influences pine beetle eruptions. Because bark beetles are relatively poor dispersers, connectivity of suitable habitat is highly correlated with dispersal.

Temperature, drought, and processes that homogenize forest age, genetic, or species structure, such as stand-replacing disturbances or widespread management activities, may synchronize spatially disjunct populations. Localized habitat fragmentation can predispose stands to attack, alter water flow, and uncouple predator-prey tracking. Landscape-scale management and land-use activities can reduce forest heterogeneity, a major constraint against populations surpassing the eruptive threshold. Additionally, transport by humans poses an ever-present risk of introducing invasive bark beetles.

Management practices in some regions have also increased the abundance of susceptible hosts. Because of aggressive fire suppression, the annual burned area declined from about 100,000 ha to less than 1000 ha over the last five decades (Taylor and Car- roll 2004). This reduced rate of disturbance yielded forests in which nearly 70% of lodgepole pine was more than 80 years old, therefore resulting in an overall threefold increase in the amount of susceptible pine from 1910 to 1990.

Keywords: Thresholds, plant-insect interactions, landscape disturbance, forest management, anthropogenic change

Caveats: Future research should determine precise thresholds at which pine beetle eruptions take place, in order to help pin-point specific management tactics.

Scale: Meso-regional

Location:
Jurisdiction: Alaska, Alberta, British Columbia, Washington, Oregon, Montana, Idaho, South Dakota, Wyoming, Colorado, Utah, California, Nevada, Arizona, New Mexico
Ecoregion: multiple

Landscape Type/Pattern:
Land Use: Protected and managed forest
Landscape pattern: fragmentation, connectivity

Part of the Environment: Terrestrial micro-fauna, ecosystem intactness

89. Citation: O2 Planning + Design Inc. *Integrated Land Management Tools Compendium.* Planning Compedium, Government of Alberta, 2012. Prepared for: Alberta Sustainable Resource Development.

Link: http://srd.alberta.ca/LandsForests/IntegratedLandManagement/ILMToolbox.aspx

Synopsis: Synthesizes information on a range of tools for reducing the footprint of human use, with an intended focus on public lands and associated natural resources. Implementation considerations and links to other resources are provided. Many tools are related either directly or indirectly to landscape patterns. For example, the section on “Disturbance Standards, Limits, or Thresholds” provides guidance and case study examples of pattern-based threshold establishment and implementation considerations in Alberta, California, and Australia.

Many other Integrated Land Management tools outlined also relate directly or indirectly to landscape patterns and techniques for their management. Selected examples under the key organizing themes of the report included:

- Integrated Planning:
- – Industrial Access Management Plan
- – Integrated Shoreline Management Plan
- Technologies:
- – Low Impact Seismic Exploration
- – Multi-Pad Directional Drilling to minimize surface footprint
- Coordination of Multiple Activities:

- Siting to Avoid Valued Features
- Joint Road Development
- Coordinating FireSmart Engineering with Land UseAccess and Corrridor Management (e.g., Multi-Use Corridors), and Reclamation.
- Access and Corridor Management
- Multi-Use Corridors
- Coordinated Physical Access Controls
- Reclamation
- Road Deactivation
- Conservation Offsets and Mitigaiton Banking
- Progressive Reclamation

Keywords: Integrated Land Management, implementation considerations, thresholds, spatial patterns, planning

Scale: Meso-regional

Location:
Jurisdiction: Alberta
Ecoregion: Northwest glaciated plains, northern glaciated plains, mixed boreal uplands, Canadian Rockies, Western Alberta upland, Hay and Slave River lowlands

Landscape Type/Pattern: Land use: agriculture, settlement, forest, protected area, and prairie
Landscape Pattern: fragmentation, linear disturbance, connectivity

Part of the Environment: Terrestrial mammals, biodiversity indices, water quality

90. Citation: Turner, Monica G, Robert H Gardner, and Robert V O'Neill. Landscape Ecology in Theory and Practice: Pattern and Process. Washington, DC: Springer, 2001.

Link: http://www.springer.com/life+sciences/ecology/book/978-0-387-95122-5

Synopsis: This book provides a comprehensive introduction to the principles and theories in landscape ecology. Early chapters introduce basic concepts and terminology that build a foundation for understanding more complex issues such as landscape disturbance dynamics, formulas and metrics for quantifying landscape patterns, and predictive models of landscape change.

Keywords: landscape pattern, landscape ecology, landscape metrics, disturbance dynamics

Scale: multiple

Location: Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: multiple
Landscape pattern: multiple

Part of the Environment: Ecosystem function/intactness

91. Citation: Lindenmayer, David B, and Joern Fischer. *Habitat Fragmentation and Landscape Change.* Washington, DC: Island Press, 2006.

Link: http://er.uwpress.org/content/26/2/162.refs

Synopsis: This book provides important foundational concepts in landscape ecology, with a particular focus on the effects of land use and landscape fragmentation. Building on Forman's patterns of landscape change, the book cites the McIntyre and Hobbs model of landscape change, which suggests that landscape modification often increases through time. Four broad classes of landscape condition can therefore be identified along a continuum of increasing human landscape modification: intact, variegated, fragmented, and relictual (figure 3). Similarly to Forman's model, these classes represented correspond to different spatial patterns in the landscape. Therefore, as the extent of human land use increases, the amount of intact habitat decreases and habitat degradation increases. Likewise, as land use extent increases further, fragmented or relictual landscapes become characterized by more sharply defined patch boundaries.

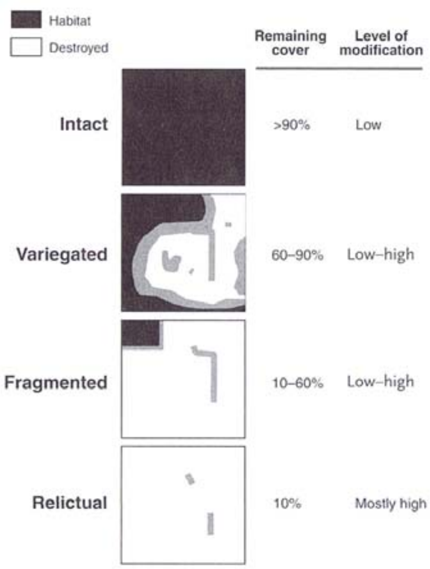


Figure 3. McIntyre and Hobbs model of landscape change (Derived from McIntyre and Hobbs (1999) by Lindenmayer and Fischer (2006**).**

The book also discusses how landscape change differentially affects organisms. Different species perceive and respond to landscape patterns individualistically, which presents the dilemma of how to best evaluate landscape change: from a single species perspective or from an aggregated multi-species perspective. While it is certain that individual species respond uniquely to landscape change, it is not always practical to assess behavioral responses of all species in a given area. If the goal is to determine how the overall pattern of change affects larger assemblages of species, as is often useful from a management perspective, it is often best to consider aggregate measures of multi-species occurrence.

Keywords: landscape change, fragmentation, land use, spatial patterns

Scale: multiple

Location:
Jurisdiction: n/a
Ecoregion: n/a
Basin: n/a
Landscape Type/Pattern:

Land Use: multiple
Landscape pattern: percent native, linear disturbance, edge, connectivity, intactness, variegated, fragmentation, relictual (multiple).

Part of the Environment: Ecosystem functionality/intactness

92. Citation: Forman, Richard T, and Michel Godron. *Landscape Ecology.* Minneapolis, MN: Wiley, 1986.

Link: http://books.google.ca/books/about/Landscape_ecology.html?id=ZvNEVs2MWqcC&redir_esc=y

Synopsis: This foundational text focuses on the distribution patterns of landscape elements that affect flows of animals, plants, energy, mineral nutrients and water in an ecosystem. The book also discusses the ecological implications of landscape change over time. The book introduces the important and well documented concepts of patches, corridors, and a background matrix and the building blocks of landscape (figure 4). The patch-corridor-matrix model is thus comprised of these three principle components which, together, constitute a landscape mosaic:

- Patches are “relatively homogenous non-linear areas that differ from their surroundings”.
- Corridors are “strips of a particular patch type that differ from the adjacent land on both sides and connect two or more patches”.
- The Matrix is “the dominant, most extensive and frequently most modified patch type in a landscape” The matrix exerts a major control over landscape and ecosystem dynamics.
- Taken together as a whole, the configuration of these landscape feature is referred to as a landscape mosaic

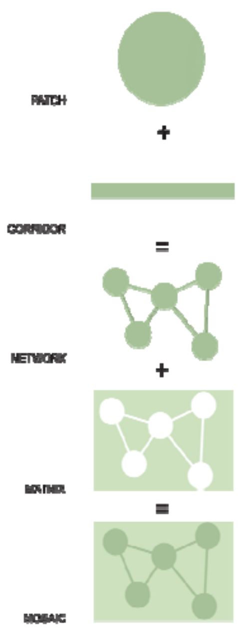


Figure 4. Patch-corridor-matrix-mosaic models. Redrawn from Dramstad 1996

Keywords: landscape ecology, landscape pattern, patch-corridor-matrix model

Scale: multiple

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: multiple

Landscape pattern: multiple

Part of the Environment: Ecosystem function/intactness

93. Citation: Forman, Richard T. *Land Mosaics: the ecology of landscapes and regions.* Cambridge: Cambridge University Press, 1995.

Link: http://www.cambridge.org/gb/knowledge/isbn/item5708031/?site_locale=en_GB

Synopsis: This book is the foundational text for understanding landscape ecology in terms of pattern/process relationships. Forman introduces the concept of "indispensible patterns" of habitat and habitat linkages that, if protected, can conserve the majority of important ecological function in a landscape. While all or specific attributes of an ecosystem may not be protected by these measures, the most important assets will retain their integrity if the essential general patterns are maintained.

Forman's Indispensable Landscape Patterns are related to both configuration and connectivity and fragmentation (figure 1). Forman suggests that the following patterns are indispensable in maintaining an ecologically viable landscape:

Large patches of natural vegetation that provide the benefits of species richness, habitat for interior species, and natural hydrological processes that maintain water quantity, timing, and quality downstream.

Connectivity between large patches in the form of wide corridors or clusters of smaller patches of natural vegetation. At least some of these corridors or clusters of patches should be large enough to provide interior habitat.

Vegetated corridors along major streams and rivers to provide for species movement, erosion control, water quality maintenance, and protection of fish habitat. In addition, headwater seepage areas and first order streams should receive protection in the form of near contiguous vegetative cover.

Stepping stones of small natural vegetation patches through altered landscapes to provide for such benefits as rare species habitats and species movement.

Furthermore, Forman identifies five main ways in which humans alter landscapes spatially: perforation, dissection, fragmentation, shrinkage, and attrition (figure 2). These changes result in different spatial patterning of landscape elements that can alter ecological processes and the population distributions of plants and animals. The concepts and principles underlying this seminal work on landscape pattern serve as important land use planning tools for conserving natural landscapes.

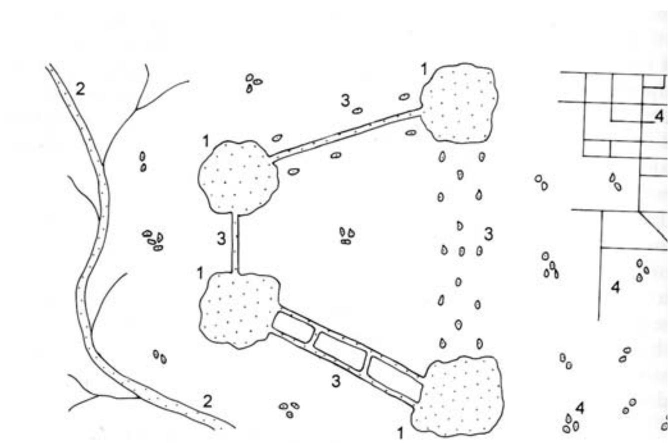


Figure 1. Indispensable landscape patterns (Forman 1995)
1=a few large patches of natural vegetation, 2=major stream or river corridor, 3=connectivity with corridors and stepping stones,
4=heterogeneous bits of nature in the matrix

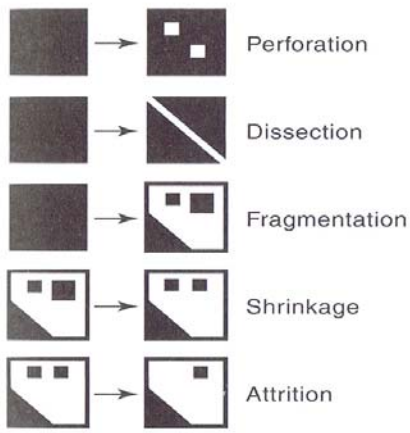


Figure 2. Five ways in which landscapes can be modified by humans (Derived from Forman (1995) by Lindenmayer and Fischer (2006).

Keywords: indispensible landscape patterns, patch, connectivity, habitat, spatial pattern, landscape ecology

Scale: multiple

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: multiple
Landscape pattern: multiple

Part of the Environment: Ecosystem function/intactness

94. Citation: O2 Planning + Design Inc. *Landscape, Biodiversity, and Indicator Review and Assessment.* Assessment report, Wood Buffalo: CEMA Landscape and Biodiversity Subgroup, 2002.

Link: http://www.o2design.com/solutions/working-landscapes/CEMA-landscape-biodiversity-and-watershed-indicator-review-and-assessment

Synopsis: Recognizing that natural and human disturbances cause significant changes to landscape composition and ecosystem function, this report aims to identify and describe key indicators of environmental sustainability, categorized by vegetation, biodiversity, and watershed characteristics. Measurable indicators of environmental sustainability, including landscape indicators summarized in the vegetation indicators category, were distilled from a wide-ranging literature review. These indicators are intended to serve as metrics of environmental quality that assist land use planners in determining if management goals have been reached. As such, the report provides an overview, assessment, and recommended uses for broad-scale and fine scale landscape indicators. Broad-scale vegetation indicators focus on landscape metrics such as cover type and amount, patch shape, core area and edge metrics, the distribution and juxtaposition of patches, and landscape fragmentation and connectivity. Fine-scale vegetation indicators include information on tree species, forest canopy cover, and the amounts of dead wood and vascular understory cover in relation to ecosystem processes and function.

Keywords: Landscape indicator, environmental quality, watershed, biodiversity, disturbance, metrics

Scale: Regional (Northern Alberta)

Location:

Jurisdiction: Alberta
Ecoregion: Kazan River and Selwyn Lake Uplands; Coppermine River and Tazin Lake Uplands; Athabasca Plain and Churchill River Upland
Basin: Buffalo River Basin and Peace/Slave River Basin

Landscape Type/Pattern:
Land Use: Logging, oil and gas development, protected area, roads, rural and urban development
Landscape pattern: percent native, fragmentation, connectivity, linear disturbance, edge

Part of the Environment: Ecosystem health and functionality/intactness, water quality, biodiversity indices.

95. Citation: McGarigal, Kevin, and Samuel A Cushman. "Comparative evaluation of experimental approaches to the study of habitat fragmentation effects." Ecological Applications 12, no. 2 (2002): 335-345.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1023/A%3A1011185409347

Synopsis: This study investigated the magnitude of change in landscape structure resulting from road and logging since the onset of timber harvesting in 1950. Overall, roads were found to have had a greater impact on landscape structure than logging. A three-fold increase in road density between 1950 and 1993 accounted for most of the changes in landscape configuration including mean patch size, edge density, and core area. Change in landscape structure varied as a function of landscape extent. At a large scale of 228,000 ha, change in landscape change over time was trivial, suggesting that the landscape is capable of incorporating disturbances with minimal impact. At intermediate scales of 1000-10,000 ha, change in landscape structure was very evident, suggesting that there is an optimal range of scales for detecting changes in landscape structure in the study area.

Keywords: landscape structure, timber harvest, roads

Caveats: Without a framework within which to interpret landscape structure (i.e. a range of expected values for landscape structure variability), it was difficult to interpret the findings of this study in a meaningful way.

Scale: Regional

Location:
Jurisdiction: Colorado (San Juan Mountains, CO)
Ecoregion: Colorado Plateau

Landscape Type/Pattern:
Land Use: managed forest, timber harvest, prescribed burn, recreation, grazing
Landscape pattern: fragmentation

Part of the Environment: Ecosystem intactness

96. Citation: Tinker, Daniel B, Catherine A.C Resor, Gary P Beauvais, Kurt F Kipfmueller, Charles I Fernandes, and William L Baker. "Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest." *Landscape Ecology* 13 (1998): 149-165.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1023/A%3A1007919023983

Synopsis: Remotely sensed data and GIS were used to compare the effects of clear-cutting and road-building on the landscape pattern of the Bighorn National Forest, Wyoming. Landscape patterns were quantified for each of 12 watersheds on a series of four maps that differed only in the degree of clear-cutting and road density. Researchers analyzed several landscape pattern metrics for the landscape as a whole and for the lodgepole pine and spruce/fir cover classes across the four maps to determine the relative effects of clear-cutting and road building on the pattern of each watershed. At both the landscape and cover class scales, clear-cutting and road building resulted in increased fragmentation as represented by a distinct suite of landscape structural changes. Roads appeared to be a more significant agent of change than clear-cuts, and roads that were more evenly distributed across a watershed had a greater effect on landscape pattern than did those that were densely clustered.

Keywords: Forest fragmentation, landscape pattern, clear-cutting, logging roads, watershed analysis, Bighorn National Forest, disturbance, logdepole pine

Caveats: A common problem in GIS-intensive analyses is integrating data collected from several different sources. Data was filtered to remove single and small groups of pixels that complicated and slowed down model processing. This processing step probably removed some small patches that may have been important landscape components.

Scale: Sub-regional (watershed level analysis; aggregation analysis of multiple watersheds)

Location: Jurisdiction: Wyoming (Bighorn National Forest)
Ecoregion: Middle Rockies

Landscape Type/Pattern:
Land Use: Forest, public land, protected area
Landscape Pattern: Fragmentation

Part of the Environment: Ecosystem intactness, biodiversity indices

97. Citation: Jalkotzy, M.G., P.I. Ross, and M.D. Nasserden. 1997. The Effects of Linear Developments on Wildlife: A Review of Selected Scientific Literature. Prep. for Canadian Association of Petroleum Producers. Arc Wildlife Services Ltd., Calgary. 115pp.

Link: http://www.ceaa.gc.ca/050/documents/p59540/83236E.pdf

Synopsis: A review of the scientific literature describing the effects of linear developments on wildlife, especially large mammals, was provided. Of particular interest were the types of roads and linear developments created by the oil and pipeline industries in western Canada. The effects of linear developments (roads, powerline/pipeline rights-of-way, deforested strips) on wildlife were examined in the context of regional and landscape ecology. The review describes the different classes of linear disturbances, the various response categories for animal species and the impacts on species for the different classes. The review also provides potential mitigations and recommendations for landscape scale planning of linear disturbances, such as planning development corridors at the regional or landscape scale, access management, thoughtful planning and co-ordination of land-use, and staggering the use of landscapes across the region.

Keywords: bibliography, carnivores, corridor, linear development, disturbance, ecology, human impact, land use, landscape, mammals, research, roads, wildlife

Caveats: The resulting bibliography must still be considered a selection of the literature available on the subject. This is a very dynamic field with new findings published every month in major scientific journals.

Scale: Regional

Location:
Jurisdiction: western Canada
Ecoregion: Boreal Cordillera, Western Cordillera, Marine West Coast Forest, Cold Deserts, Taiga Cordillera, Taiga Plain, Temperate Prairies, West-Central Semi-arid Prairies (EPA level 2 Ecoregions).

Landscape Type/Pattern:
Land Use: protected area, forest, agriculture, urban and rural settlement, forestry
Landscape pattern: edge, fragmentation, connectivity, linear disturbance

Part of the Environment: Birds, terrestrial mammals, species at risk, biodiversity indices

98. **Citation**: Taylor, Brad N. "Short-horned Lizard." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 124-130. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004c.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: The short-horned lizard is Alberta's only lizard. It is indigenous to semi-arid, short grass portions of the northern Great Plains and usually found in rather rough terrain. This report evaluated habitat suitability requirements for the short-horned lizard according to the following parameters:

- Topographical Features: Most of the daily movement patterns during the summer rarely exceeded 30m, and generally occurred along the slopes of the valleys or valley bottoms. Consequently, all valleys and all prairie habitat within 100m of valleys are considered the best potential habitat.
- Native Prairie Class: Native Prairie Class (NPC) is derived from the Native Prairie Vegetation Baseline Inventory developed by Alberta Environment. Class 1 is comprised of greater than 75% native prairie components (i.e. shrubs, graminoids, riparian areas, lakes, wetlands, and trees), Class 2 is 50 - 75%, Class 3 is 25 - 50%, Class 4 is 1- 25%, and Class 5 is no native prairie components. Short-homed lizards are generally not found in areas that exhibit high levels of cultivation; consequently, as Native Prairie Class increases from class 1 (most suitable), the HSI value decreases.
- Elevation: Analysis of Short-homed lizard sites from BSOD found that they generally occur at elevations below 1100 m within the Milk River Basin of Alberta, however, a few shorthorned lizards have been observed above this point. No lizards have been recorded above 1200 m.
- Riparian Zones: Short-homed lizards generally are not found in riparian zones because thick vegetation inhibits their movement and their thermoregulatory abilities.
- Slope: Moderately shallow to moderately steep slopes (10 - 60 degrees) appear to be the selected habitat for short-homed lizards. However, this is generally at the microhabitat level.
- Aspect: The majority of short-homed lizards are found on south facing slopes, although along the Milk River, lizards have been noted on other aspects. Due to the scale and refinement of the data layer this variable was also excluded from final calculations.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Short-horned lizard

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, reptiles, species-at-risk

99. **Citation:** Cheruvelil, Kendra Spence, and Patricia A Soranno. "Relationships between lake macrophyte cover and lake and landscape features." *Aquatic Botany* 88 (2008): 219-227.

Link: http://www.sciencedirect.com/science/article/pii/S030437700700160X

Synopsis: One recent study examining Eurasian watermilfoil (Myriophyllum spicatum L., hereafter milfoil) invasions using landscape-level variables found that the amount of forest land cover in the catchment is consistently negatively related to milfoil presence (Buchan and Padilla, 2000). These results suggest that further research is needed to examine the relationships between natural and anthropogenic landscape features and macrophyte cover. The ability of lake and landscape features to predict a variety of macrophyte cover metrics using 54 north temperate lakes were examined. Univariate regression analyses demonstrated that these macrophyte cover metrics are predicted by a wide range of predictor variables, most commonly by: Secchi disk depth, maximum or mean depth, catchment morphometry, road density and the proportion of urban or agricultural land use/cover in the riparian zone or catchment ($r2 = 0.06–0.46$). Using multiple regressions, 29–55% of the variation in macrophyte cover metrics were explained. Total macrophyte cover and submersed cover were related to Secchi disk depth and mean depth, whereas the remaining metrics were best predicted by including at least one land use/cover variable (road density, proportion local catchment agriculture land use/cover, proportion cumulative catchment urban land use/cover, or proportion riparian agriculture land use/cover). The two main conclusions are: (1) that different macrophyte growth forms and species are predicted by a different suite of variables and thus should be examined separately, and (2) that anthropogenic landscape features may override patterns in natural landscape or local features and are important in predicting present-day macrophytes in lakes.

Keywords: Lake morphometry; Physio-chemistry; Land use/cover; Catchment; Hydrology; Eurasian watermilfoil

Caveats: Lakes were sampled over 2 years (variability); mechanisms for direct and indirect effects could not be determined.

Scale: Sub-regional

Location:
Jurisdiction: Michigan
Ecoregion: Southern Michigan/Northern Indiana Drift Plains
Basin: Great Lakes Basin

Landscape Type/Pattern:
Land Use: urban, agriculture, forest and wetland
Landscape pattern: fragmentation, linear disturbance, connectivity

Part of the Environment: Water quality, riparian systems, aquatic macrophytes (Eurasian watermilfoil), ecosystem health

100. Citation: Kremen, Clair, Neal M Williams, and Robbin W Throp. "Crop pollination from native bees at risk from agricultural intensification." *Proceedings of the National Academy of Sciences of the United States of America.* Washington, DC: National Academy of Sciences 99, no. 26 (2002). 16812-16816.

Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2004.00662.x/abstract

Synopsis: Few natural areas are managed or valued for the services they provide, although many are managed to produce ecosystem goods. Managing ecosystem services is critical to human survival, yet we do not know how large natural areas must be to support these services. Thirty per cent of the US food supply by volume depends on animal pollinators, of which bee species (Apoidea) are the most important. Researchers analyzed variation in crop pollination services provided by native, unmanaged, bee communities on organic and conventional farms situated along a gradient of isolation from natural habitat. Pollination services from native bees were significantly, positively related to the proportion of upland natural habitat in the vicinity of farm sites, but not to any other factor studied, including farm type, insecticide usage, field size and honeybee abundance. The scale of this relationship matched bee foraging ranges. Stability and predictability of pollination services also increased with increasing natural habitat area. This strong relationship between natural habitat area and pollination services was robust over space and time, allowing prediction of the area needed to produce a given level of pollination services by wild bees within the landscape. Crop pollination services provided by native bee communities in California strongly depended on the proportion of natural upland habitat within 1–2.5 km of the farm site, a spatial scale that accords well with maximal foraging distances for similar bee species. this predictive relationship between habitat area and pollination services could allow land-use planners to establish conservation targets in this landscape Targets are commonly applied in planning networks of protected areas to conserve biodiversity.

Keywords: Agriculture, *Apis mellifera*, Apoidea, bee community, bee foraging distance, conservation planning, landscape ecology, pollination service, scale effects

Caveats: The assessment of the importance of natural habitat based on native bee communities underestimates the utility of upland habitat for providing pollination services.

Scale: Local/Site

Location:
Jurisdiction: California
Ecoregion: California Coastal Sage, Chapparal, and Oak Woodlands

Landscape Type/Pattern:
Land Use: agriculture, natural
Landscape pattern: connectivity

Part of the Environment: Ecosystem services, biodiversity, ecosystem functionality/intactness, terrestrial micro-fauna (bees)

101. Citation: Kremen, Clair, Neal Williams, Robert L Bugg, John P Fay, and Robin W Thorp. "The area requirements for an ecosystem serivce: crop pollination by native bee communities in California." *Ecology Letters* 7 (2004): 1109-1119.

Link: http://www.pnas.org/content/99/26/16812.full.pdf+html

Synopsis: The individual species and aggregate community contributions of native bees to crop pollination are documented, on farms that varied both in their proximity to natural habitat and management type (organic versus conventional). On organic farms near natural habitat, we found that native bee communities could provide full pollination services even for a crop with heavy pollination requirements (e.g., watermelon, *Citrullus lanatus*), without the intervention of managed honey bees. Agricultural intensification diminished these pollination services by roughly 3- to 6-fold. The decline of native bee pollination services with agricultural intensification resulted in significant reductions in both diversity and total abundance of native bees. Diversity of native bee communities is important because bee populations are highly variable and fluctuate over space and time. Conservation and restoration of bee habitat are potentially viable economic alternatives for reducing dependence on managed honey bees. These issues are important for future economic and ecological research relating to ecosystem services. Because crop pollinating species are often generalists that pollinate many native plants, restoring pollination services for agriculture could also benefit wild plants and thereby promote conservation biodiversity across the agro-natural landscape.

Keywords: Ecosystem service, native bee, *Apis mellifera*, agriculture, biodiversity

Scale: Local/Site

Location:
Jurisdiction: California
Ecoregion: California Coastal Sage, Chapparal, and Oak Woodlands

Landscape Type/Pattern:
Land Use: agriculture, natural
Landscape pattern: connectivity

Part of the Environment: Ecosystem services, biodiversity indices, ecosystem health/ functionality and intactness, terrestrial micro-fauna (native bees)

102. Citation: Morandin, Lora A, and Mark L Winston. "Pollinators provide economic incentive to preserve natural land in agroecosystems." *Agriculture Ecosystems and Environment* 116 (2006): 289-292.

Link: http://www.sciencedirect.com/science/article/pii/S0167880906000910

Synopsis: Natural habitats are considered inherently indispensable to the global economy by conservationists, but few natural ecosystems afford direct and quantifiable economic benefits. Quantification of natural land value can provide compelling evidence favoring preservation over development. Wild bees are important pollinators of many crop plants, and natural patches in agroecosystems enhance pollinator services and crop yield. Bee abundance was greatest in canola fields that had more uncultivated land within 750 m of field edges and seed set was greater in fields with higher bee abundance. A cost–benefit model that estimates profit in canola agroecosystems with different proportions of uncultivated land is presented. Yield and profit could be maximized with 30% of land uncultivated within 750 m of field edges.

Keywords: Pollination; Wild bees; Canola; Sustainable agriculture; Natural land reserves; Crop yield; Ecosystem services

Scale: Local/Site

Location:
Jurisdiction: Alberta
Ecoregion: Mid-Boreal Uplands and Peace-Wabaska Lowlands

Landscape Type/Pattern:
Land Use: agriculture, natural
Landscape pattern: connectivity

Part of the Environment: Ecosystem services, biodiversity, Ecosystem health/functionality and intactness, terrestrial micro-fauna (bees)

103. Citation: Lande, R. "Demographic models of the northern spotted owl." *Oecologia* 75, no. 4 (1988): 601-607.

Link: http://www.jstor.org/stable/4218620

Synopsis: This study evaluated a model of dispersal rates and territory occupancy for northern spotted owls using data on the amount of old forest habitat remaining in the Pacific Northwest and the current occupancy of this habitat by northern spotted owls. The model aimed to predict the effect of future habitat loss and fragmentation on the population. Results indicate that northern spotted owls may become extinct if the old forest is reduced to less than a proportion of 19-23% of the total area of a regional landscape.

Keywords: Demography, territoriality, dispersal, colonization, extinction, northern spotted owl

Caveats: Ongoing studies in different parts of the subspecies range may eventually provide sufficient data to estimate geometric rates of increase and minimum habitat requirements for populations in particular regions rather than for the subspecies as a whole

Scale: Meso-regional

Location:
Jurisdiction: Western Oregon and Washington, northern California
Ecoregion: Cascades, Northern Cascades

Landscape Type/Pattern:
Land Use: logging, USFS managed forest

Landscape pattern: percent native, fragmentation

Part of the Environment: Birds, ecosystem intactness

104. Citation: Menalled, Fabian D, Paul C Marino, Stuart H Gage, and Douglas A Landis. "Does agricultural landscape structure affect parasistism and parasitoid diversity?" *Ecological Applications* 9, no. 2 (1999): 634–641.

Link:
http://www.esajournals.org/doi/abs/10.1890/10510761(1999)009%5B0634%3ADALSAP%5D2.0.CO%3B2

Synopsis: Anthropogenic landscape changes due to agriculture can influence the richness and effectiveness of natural insect enemy communities, including parasitoid communities. This study evaluates whether previous observations of a higher percentage of parasitism and parasitoid diversity in a complex agricultural landscape relate to a simple landscape and represent a general phenomenon. Rates of parasitism and parasitoid diversity of the armyworm (Pseudaletia unipuncta) were assessed in three replicate (Onondaga, Ingham, and Benton) regions in southern Michigan. Within each region, a simple landscape (primarily cropland) and a complex landscape (cropland intermixed with mid and late successional noncrop habitats) were identified through analysis of aerial photographs. In each landscape, three maize fields were selected, and second to fourth instar P. unipuncta were released into three replicate plots of maize plants. Larvae were recovered after 6 days and reared in the laboratory to record parasitoid emergence. A principal component analysis conducted on landscape variables indicated that simple and complex landscapes were true replicates. Extra-field vegetation was similar among the three simple landscapes but differed among complex sites. Parasitoid species diversity differed among regions, with six species recovered in Onondaga and two species from both Benton and Ingham. Rates of parasitism were only partially consistent with previous experimental results. In Ingham, results were similar to those found previously in this region; rates of parasitism and parasitoid diversity were higher in the complex landscape. However, in Onondaga and Benton, no differences in rates of parasitism or parasitoid diversity were found. Thus, the hypothesis that landscape complexity increases parasitoid diversity and rates of parasitism was not supported. Possible reasons for the observed differences in rates of parasitism among regions are discussed.

Keywords: agroecosystems; alternate hosts; extra-field vegetation; landscape structure; parasitism;

parasitoid diversity; Pseudaletia unipuncta; spatial replication.

Caveats: There are substantial logistical problems involved in assessing the extent to which agricultural landscape structure may alter host and parasitoid population dynamics, but future research should attempt to include a spatial approach that considers patterns and mechanisms of colonization and extinction. This study does not account for periodic oscillations in populations of alternative hosts.

Scale: Sub-regional

Location:
Jurisdiction: South Michigan
Ecoregion: S. Michigan/N. Indiana Drift Plains

Landscape Type/Pattern:
Land Use: cropland (maize), natural areas,
Landscape pattern: connectivity, fragmentation, edge

Part of the Environment: Micro-fauna (armyworm), ecosystem services, ecosystem health and functionality

105. Citation: Morandin, Lora A, Mark L Winston, Virginia A Abbott, and Michelle T Franklin. "Can pastureland increase wild bee abundance in agriculturally intense areas?" *Basic and Applied Ecology* 8 (2008): 117-124.

Link: http://www.sciencedirect.com/science/article/pii/S1439179106000569

Synopsis: Agricultural intensification and expansion are major present and future causes of global ecosystem disruption. Natural and semi-natural reserve areas in agroecosystems are thought to be important for preservation of essential ecosystem services such as pollination, but data about land use patterns and pollinator abundance are lacking. Wild bee populations in canola fields in an agriculturally intense area where virtually all land was either tilled agricultural fields or semi-natural grazed pasturelands were assessed, with the expectation that mosaics of land use types may better support ecosystem services than homogenous crop areas. Fields were chosen in two categories, five with little or no pastureland (<6%) and five with at least 15% pastureland within an 800m distance of field edges. Fields in the high pasture category had more bumble bees and other wild bees than low pasture fields and 94% of the variation in bumble bee abundance in fields was explained by variation in the amount of pastureland nearby. Lower bee abundance in fields with little pastureland around them could result in reduced pollination and seed set unless supplemented with managed pollinators such as honeybees. In areas with intense agriculture we show that mosaics of land use types can be better for wild bee populations and potentially for crop production than landscapes that are homogenous tilled crop areas. Designing agricultural areas that integrate land use and ecosystem function is a practical approach for promoting sustainable agriculture practices. Ensuring minimal disturbance by humans and human industry in the form of natural reserve areas is likely the best way to preserve natural ecosystem function, however; results show that diversity in land use also can significantly benefit ecosystem services. Understanding how ecosystems function on a landscape scale will aid in development of agroecosystems that are both profitable and sustainable.

Keywords: Pollination, agriculture, ecosystem services, canola, *Brassica*, conservation

Scale: Local/Site type specific

Location:
Jurisdiction: Alberta
Ecoregion: Northern Glaciated Plain
Basin: Oldman River

Landscape Type/Pattern:
Land Use: agriculture, natural
Landscape pattern: connectivity

Part of the Environment: Ecosystem services, biodiversity, ecosystem health/functionality and intactness, terrestrial micro-fauna (bees)

106. Citation: Meehan, Timothy D, Ben P Werling, Douglas A Landis, and Claudio Gratton. "Agricultural landscape simplification and insecticide use in the Midwestern United States." *Proceedings of the National Academy of Sciences of the United States of America.* 2011. 11500-11505.

Link: http://www.ncbi.nlm.nih.gov/pmc/articles/pmc3136260/

Synopsis: Agronomic intensification has transformed many agricultural landscapes into expansive monocultures with little natural habitat. A pervasive concern is that such landscape simplification results in an increase in insect pest pressure, and thus an increased need for insecticides. This hypothesis was tested across a range of cropping systems in the Midwestern United States, using remotely sensed land cover data, data from a national census of farm management practices, and data from a regional crop pest monitoring network. Independent of several other factors, the proportion of harvested cropland treated with insecticides increased with the proportion and patch size of cropland and decreased with the proportion of semi-natural habitat in a county. A positive relationship was found between the proportion of harvested cropland treated with insecticides and crop pest abundance. A positive relationship was also found between crop pest abundance and the proportion cropland in a county. These results provide broad correlative support for the hypothesized link between landscape simplification, pest pressure, and insecticide use. Using regression coefficients from the analysis, it is estimated that, across the seven-state region in 2007, landscape simplification was associated with insecticide application to 1.4 million hectares and an increase in direct costs totaling between $34 and $103 million. Both the direct and indirect environmental costs of landscape simplification should be considered in design of land use policy that balances multiple ecosystem goods and services.

Keywords: agriculture, bio-control, crop pests, land cover change, pesticides, ecosystem services

Caveats: It is possible that producers in simplified landscapes are not strictly basing their insecticide use decisions on the abundance of pests and optimal economics. Cultural factors that are not spatially structured cannot be captured using these methods and thus cannot be ruled out as causative mechanisms.

Scale: Regional

Location: Jurisdiction: 562 counties, mid-western United States
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: tilled agricultural
Landscape pattern: connectivity

Part of the Environment: Ecosystem services

107. Citation: Leach, Mark K, and Thomas J Givnish. "Ecological determinants of species loss in remnant prairies." *Science* 273 (1996): 1555-1558.

Link: http://www.jstor.org/stable/2891057

Synopsis: An inventory of plant species in remnant prairies of Wisconsin showed that 8-60% of the original plant species were lost over a 32-52 period. This pattern of loss is consistent with the effects of fire suppression caused by landscape fragmentation, leading the researchers to believe that fragmentation may interrupt landscape-scale processes that are key to ecosystem function.

Keywords: prairie, fragmentation, habitat loss, ecosystem processes.

Scale: Regional (Wisconsin prairie region)

Location:
Jurisdiction: Wisconsin
Ecoregion: Southeastern Wisconsin Till Plains

Landscape Type/Pattern:
Land Use: agriculture, settlement, prairie remnants
Landscape Pattern: fragmentation

Part of the Environment: Ecosystem functionality or intactness

108. Citation: Haynes, Kyle J, and James T Cronin. "Matrix composition affects the spatial ecology of a prairie planthopper." *Ecology* 84, no.11 (2003): 2856-2866.

Link: http://www.jstor.org/stable/3449957 .

Synopsis: In this study, researchers performed field experiments to investigate how the composition of the matrix surrounding affected the movement of a delphacid planthopper among patches of prairie cordgrass in North Dakota.

Keywords: Connectivity, edge effects, edge permeability, emigration, immigration, matrix, patch quality, plant hoppers, spatial distribution, tallgrass prairie. Matrix types included mudflats, native non-host grass, and introduced smooth brome grass. Plant hoppers were released onto experimental cordgrass patches. Emigration rates were 1.3 times higher for patches embedded in the non-host grasses than the mudflats. Immigration into patches isolated by 3m was 5.4 times higher in the introduced brome grass than the mudflat matrix. The lower permeability of the mudflat matrix type relative to the non-host grasses edge may explain plant hopper distribution patterns. The results of this study indicate that the continued introduction of non-native brome grass into tallgrass prairie ecosystems may enhance connectivity and increase emigration rates for plant hoppers.

Scale: Local/site

Location:
Jurisdiction: North Dakota
Ecoregion: Lake Manitoba and Lake Agassiz Plain

Landscape Type/Pattern:
Land Use: protected area
Landscape pattern: percent native

Part of the Environment: Ecosystem functionality/intactness, terrestrial microfauna

109. Citation: Gummer, David L., and Kelley J. Kissner. "Olive-backed Pocket Mouse." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 71-75. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: The olive-backed pocket mouse is a tiny, nocturnal mouse that is widely distributed in the arid grasslands of the Great Plains. In Alberta, the General Status of Alberta Wild Species 2000 designates the olive-backed pocket mouse as a "Sensitive" species due to a relatively low number of documented occurrences in the province and its reliance on grassland habitat. This report evaluated habitat suitability requirements for the olive-backed pocket mouse according to parameters of soil texture, percent bare ground per hectare, percent graminoid cover per hectare, and percent shrub cover per hectare. Olive-backed pocket mice prefer loose, sandy soil that facilitates easy burrowing. Due to their unique hopping movement, bare open ground allows the mice to move quietly through their habitat, reducing their risk of predation. Olive-backed pocket mice eat mainly native plant seeds, which are abundant in grassland habitat. Therefore, HSI values increase as graminoid habitat increases. Sites with low densities of shrubs are preferred by olive-bakced pocket mice because they provide cover from large and aerial predators, such as owls. A threshold of below 40% shrub coverage was selected as being representative of ideal habitat conditions for the olive-backed pocket mouse.

Olive-backed pocket mice occur only in grassland habitat. Rivers may act as barriers to their movement. Pocket mice are also not associated with riparian areas due to tile higher shrub component and less workable soils characteristic of these areas.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Olive-backed pocket mouse

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains
Basin: Milk River

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, terrestrial mammals

110. Citation: Issacs, R, J Tuell, A Fiedler, M Gardiner, and D Landis. "Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants." *Frontiers in Ecology and the Environment* 7, no. 4 (2009): 196-203.

Link: http://www.esajournals.org/doi/pdf/10.1890/080035

Synopsis: Beneficial arthropods, including native bees, predators, and parasitoids, provide valuable ecosystem services worth $8 billion to US agriculture each year. These arthropod-mediated ecosystem services (AMES) include crop pollination and pest control, which help to maintain agricultural productivity and reduce the need for pesticide inputs. Maximizing survival and reproduction of beneficial arthropods requires provision of pollen and nectar resources that are often scarce in modern agricultural landscapes. Increasingly, native plants are being evaluated for this purpose. Native plants can outperform recommended non-natives and also provide local adaptation, habitat permanency, and support of native biodiversity. The success of insect conservation programs using flowering plants to increase AMES on farmland will depend on landscape context, with the greatest success in landscapes of moderate complexity. Reintegration of native plants into agricultural landscapes has the potential to support multiple conservation goals, and will require the collaboration of researchers, conservation educators, and native plant experts. If biological pest control and pollination services can be increased through conservation programs, benefits will include increased farmer profit and reduced dependence on chemical pesticides. From this, region-specific lists of plants can be developed that support biological control agents and pollinating bees through the growing season. Basing arthropod conservation plantings on optimized combinations of native plant species is expected to improve the likelihood that such programs achieve their long-term goals of supporting beneficial insects and also increasing the services they provide. Further research will be needed to determine the optimal size and distribution of these plantings and the landscape context in which such conservation investments will pay off, in terms of crop yield and quality.

Keywords: arthropods, ecosystem services, agricultural landscapes, native plants, biodiversity, conservation plantings

Caveats: Only in landscapes of intermediate complexity does the addition of flowering plants provide resources that can be exploited by organisms to increase their populations. Highly complex landscapes may benefit little from the addition of arthropod conservation plantings, because these areas already contain a rich community of beneficial insects.

Scale: Regional

Location:
Jurisdiction: Michigan
Ecoregion: Michigan/N. Indiana Drift Plains

Landscape Type/Pattern:
Land Use: agriculture (till cropping - dryland/irrigated, rangeland – native/seeded)
Landscape pattern: connectivity

Part of the Environment: Micro-fauna (arthropods), biodiversity indices, Ecosystem services (arthropod-mediated)

111. Citation: Bladon, KD et al. "Wildfire Impacts on nitrogen concentration and production from headwater streams in southern Alberta's Rocky Mountains." *Canadian Journal of Forest Research* 38, no. 9 (2008): 2359-2371.

Link: http://www.nrcresearchpress.com.ezproxy.lib.ucalgary.ca/doi/pdf/10.1139/X08-071

Synopsis: The objective of this study was to examine initial effects of the 2003 Lost Creek wildfire (southwestern Rocky Mountains of Alberta) on concentrations and production (yield and total export) of several nitrogen (N) forms, and to explore initial recovery of these effects within the first 3 years after the fire. Burned and unburned reference watersheds were examined by the authors. During the first postfire year, nitrate (NO3–), dissolved organic nitrogen (DON), and total nitrogen (TN) concentrations in severely burned watershed streams were 6.5, 4.1, and 5.3 times greater, respectively, than those in reference streams. Weaker effects were evident for concentrations of ammonium (NH4+; 1.5 times) and total particulate nitrogen (TPN; 3.0 times). A rapid decline in mean watershed concentrations and production of NO3–, DON, total dissolved nitrogen (TDN), and TN was observed from burned watersheds over the three seasons after the fire. However, elevated NO3–, TDN, and TN concentrations and production were still evident during the snowmelt freshet and following precipitation events after 3 years. Effects of the burn were strongly influenced by the regional flow regime, with the most elevated N concentrations and production occurring during higher discharge periods (snowmelt freshet and storm flows).

Keywords: forest fire, water quality, natural disturbance

Scale: Local watersheds were studied, but conclusions generally extrapolated to subregional or even regional scale

Location:
Jurisdiction: Alberta, Canada
Ecoregion: Canadian Rockies
Basin: Oldman River Watershed
Subbasin: Lost Creek

Landscape Type/Pattern:
Land Use: forested
Landscape pattern: forest fire patches, salvage logging

Part of the Environment: water quality, ecosystem services (water supply provisioning)

112. **Citation**: Downey, Brad A. "Prairie Falcon." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 42-46. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division. 2004a.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: Prairie falcons prefer the dry environment of southern Alberta and can be found along the river valleys and tributaries, and in coulees containing steep cliffs and rock outcroppings. Nest sites are frequently associated with flowing rivers or large water bodies where prairie falcons could use the nearby uplands to hunt. Other key habitat characteristics are native prairies and pastures adjacent to river valleys containing ground squirrel colonies. Large-scale conversion of native pasture to cropland can be detrimental to the falcons by limiting the abundance of prey near the nest. Conversely, areas containing small amounts of cropland dispersed within large areas of grassland might be beneficial to prairie falcons in drought years by providing them with the only breeding ground squirrels in the area. Ideal foraging habitat must contain at least 20 % herbaceous vegetation with few shrubs or trees.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Prairie falcon

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains
Basin: Milk River

Landscape Type/Pattern:

Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, birds, species-at-risk

113. Citation: Fitzgerald, Jane A, David N Pashley, and Barbara Pardo. *Partners in Flight Bird Conservation Plan for Northern Mixed-Grass Prairie.* Technical Report, Jefferson City, Missouri: American Bird Conservancy, 1999.

Link: http://www.partnersinflight.org/bcps/plan/pl_37_10.pdf

Synopsis: This report identifies habitat requirements and conservation guidelines for prairie grassland birds. The authors highlight general habitat requirements for grassland birds, such as large areas of native grassland cover and regular fire regimes essential to healthy grassland systems. The report then specifies requirements for priority species by habitat type (grasslands and wetlands). For example, female greater prairie chickens require a 1500m undisturbed radius of native prairie surrounding lek sites for nesting and foraging, and short-eared owls and northern harriers require habitat patches of 100 ha or more. In addition, the report provides specific area requirements for several grassland bird species as guidelines for conservation planning. These include: <30 ha for sedge wrens, >150 ha for sprague's pipit, 10-30 ha for dickcissel, >50 ha for Baird's sparrow, 30-100 ha for grasshopper sparrow, <30 ha for LeConte's sparrow, and <30 ha for Bobolinks.

Keywords: Habitat requirements, area sensitivity, land cover, patch area, burn-sensitivity, grasslands, wetlands, grassland birds, prairie-pothole region.

Scale: Meso-regional

Location:
Jurisdiction: North Dakota, South Dakota, Montana, Saskatchewan, Alberta
Ecoregion: Northwestern Glaciated Plain, Northwestern Great Plains

Landscape Type/Pattern:
Land Use: Grazing, agriculture
Landscape pattern: fragmentation, percent native

Part of the Environment: Birds

114. Citation: Kissner, Kelley J. "Prairie Rattlesnake." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 112-123. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: The habitat associations of prairie rattlesnakes appear to differ depending on whether snakes are hibernating, foraging, or reproducing. Consequently, the HSI model for prairie rattlesnakes must incorporate the habitat requirements for all of these activities:

- Winter Hibernation Habitat: Most rattlesnake hibernacula occur within 4 km of a major river, drainage, or coulee. Low to moderate slopes appear to be common features of rattlesnake hibernacula. Slopes that are very steep tend not be used. The presence of slumping appears to be a common feature associated with rattlesnake hibernacula. In addition hibernacula are typically located on south, east, and southeast facing slopes.
- Summer Habitat (Habitat used for Foraging and Thermal Relief): The available data on home range sizes of rattlesnakes in Alberta suggests that snakes migrate as far as 25 km from their hibernacula. Den sites are typically located along major river valleys, drainages, or coulees. Consequently, the likelihood of snakes using habitat beyond 25 km from these features is less

likely. Roads may provide somewhat suitable basking habitat for snakes; however, the high incidence of mortality of snakes on roads makes a density of greater than 1.6 km per 1/4 section unsuitable for snakes. Road type should affect the number of snakes killed on roads due to differences in traffic intensity on these roads. Highways and paved roads were therefore given low HSI values. Rattlesnakes primarily use native habitat because these areas typically have higher densities of prey species, such as rodents and grassland birds. Rattlesnakes may use cultivated fields while moving across the landscape, or if small mammal abundance is high in these areas. HSI values were 1 for Class 1 sites, decreasing in value as Class increased. Areas of high human density greater than 10 per 1/4 section are unsuitable for snakes. Shrubs and trees generally provide good foraging habitat, suitable conditions for thermal relief, and cover from predators. Therefore, some cover is preferable to none. HSI values are maximal between 5-30 % cover.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Prairie Rattle Snake

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains
Basin: Milk River

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent cover, connectivity, linear disturbance

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, reptiles, species-at-risk

115. Citation: Naugle, David E, Rex R Johnson, Michael E Estey, and Kenneth F Higgens. "A landscape approach to conserving wetland bird habitat in the prairie pothole region of eastern South Dakota." *Wetlands* 21, no. 1 (2001): 1-17.

Link: http://dx.doi.org/10.1672/0277-5212(2001)021[0001:ALATCW]2.0.CO;2

Synopsis: This paper investigated the role of local and landscape factors affecting habitat suitability by integrating remotely sensed wetland and land-cover data with wetland bird habitat models in eastern South Dakota. Study results indicate that habitat suitability for some species is related to local vegetation conditions within a wetland, while suitability for others is related to landscape structure at larger scales. Small wetlands are critical components of the surrounding landscape that influence habitat suitability of larger wetlands. Models that classified the suitability of larger remaining wetlands after smaller wetlands (<0.5ha) were removed indicate that the species most vulnerable to small wetland loss are vagile species that exploit resources over broad spatial scales. In summary, the paper recommends that small wetlands be acquired not only to consolidate suitable habitat within protected core areas, but also to ensure that core areas coalesce to preserve connectivity among regional wetland landscapes.

Keywords: Habitat fragmentation, Prairie Pothole Region, small wetlands, South Dakota, waterfowl, wetland birds, wetland protection

Scale: sub-regional

Location:
Jurisdiction: Eastern South Dakota
Ecoregion: Aspen parkland/northern glaciated plain

Landscape Type/Pattern:

Land Use: agriculture
Landscape pattern: fragmentation, connectivity, percent native

Part of the Environment: Birds

116. Citation: Fuhlendorf, Samuel D, Alan J Woodward, David M Leslie, and John S Shackford. "Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations in the US souther Great Plains." *Landscape Ecology* 17 (2002): 617-628.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1023/A%3A1021592817039

Synopsis: This study examines how landscape structure and land use change affect long-term population trends of lesser-prairie chickens in the Southern Great Plains across multiple spatial scales. Using GIS to quantify landscape composition, pattern, and change at multiple scales in fragmented agricultural landscapes surrounding 10 prairie-chicken leks, the study found that changes in landscape structure over the past several decades affected population dynamics more strongly than current landscape structure. These findings indicate a response-lag in population trends as a result of changes in habitat structure, highlighting the importance of considering the perspective of metapopulations and temporal scales in future conservation efforts. In addition, the study found that any single spatial scale evaluated would not have drawn a complete picture of how landscape structure and change affect prairie chicken populations. At the smallest spatial scales, models predicted that edge density and patch size were the most important factors whereas at larger scales of analysis, the amount of cropland, increase in tree cover, and general landscape changes were considered the most important.

Keywords: agriculture, conservation ecology, fragmentation, grasslands, hierarchy, landscape change, landscape dynamics, structure, lesser prairie-chicken, rangeland, Great Plains USA, scale, species conservation

Scale: study carried out at the local scale but results are applicable to the broader mesoregional southern Great Plains eco-region

Location:
Jurisdiction: Western Oklahoma and Northern Texas
Ecoregion: Southern Great Plains

Landscape Type/Pattern:
Land Use: rangeland, agriculture
Landscape Pattern: percent native, fragmentation

Part of the Environment: Birds (lesser prairie chickens - Tympanuchus pallidicinctus), ecosystem functionality or intactness

117. Citation: Holmes, Tamara L, Richard L Knight, Libby Stegall, and Gerald R Craig. "Response of wintering grassland raptors to human disturbance." *Wildlife Society Bulletin* 21, no. 4 (1993): 461-463.

Link: http://www.jstor.org/stable/3783420 .

Synopsis: This study recorded flushing responses (whether or not an animal fled in response to disturbance) and flush distances of 6 species of diurnal raptors exposed to walking and vehicle disturbances during winter in northern Colorado, with the goal of calculating minimum distances for species-specific buffer zones. In general, walking disturbances resulted in more flushing than vehicle disturbances for all species except the prairie falcon. For walking disturbances, a linear relationship existed between flight distance and body mass, with lighter species flushing at shorter distances; however, this trend did not hold for vehicle disturbance. Study results indicate that buffer zones that would prevent flushing by approximately 90% of the wintering individuals of a species are: 75 m for American kestrel, 125 m for merlin, 160 m for prairie falcon, 210 m for rough-legged hawk, 140 m for ferruginous hawk, and 300 m for golden eagle.

Keywords: Flushing response, buffer zone, raptors, northern Colorado

Caveats: Because raptor response to disturbance varies among species and between populations, management plans should be tailored to each species, habitat, and season.

Scale: Sub-regional

Location:
Jurisdiction: Colorado
Ecoregion: High plains

Landscape Type/Pattern:
Land Use: agriculture, settlement, managed grassland
Landscape pattern: edge, linear disturbance

Part of the Environment: Birds

118. Citation: Mayer, PM, SK Reynolds, MD MCutchen, and TJ Canfield. "Meta-analysis of nitrogen removal in riparian buffers." *Journal of Environmental Quality* 36, no. 4 (2007): 1172-1180.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17596626

Synopsis: This review paper analyzed the scientific literature containing data on riparian buffers and nitrogen concentrations in streams and groundwater to identify trends between nitrogen removal effectiveness and buffer width, hydrological flow path, and vegetative cover. Nitrogen removal effectiveness varied widely. Wide buffers (>50 m) more consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0-25 m). Buffers of various vegetation types were equally effective at removing nitrogen but buffers composed of herbaceous and forest/herbaceous vegetation were more effective when wider. Subsurface removal of nitrogen was efficient, but did not appear to be related to buffer width, while surface removal of nitrogen was partly related to buffer width. The mass of nitrate nitrogen removed per unit length of buffer did not differ by buffer width, flow path, or buffer vegetation type. The meta-analysis suggests that buffer width is an important consideration in managing nitrogen in watersheds.

Keywords: nitrates, rivers, water pollution, water quality

Caveats: The inconsistent effects of buffer width and vegetation on nitrogen removal suggest that soil type, subsurface hydrology (e.g., soil saturation, groundwater flow paths), and subsurface biogeochemistry (organic carbon supply, nitrate inputs) also are important factors governing nitrogen removal in buffers

Scale: Multiple

Location:
Jurisdiction: Multiple
Ecoregion: Multiple

Landscape Type/Pattern:
Land Use: Multiple (primarily agricultural)
Landscape pattern: riparian buffers

Part of the Environment: Water quality, riparian systems

119. Citation: Anderson, Sean C, Robert G Farmer, Francesco, Houde, Aimee Lee S Ferretti, and Jeffery A Hutchings. "Correlates of Vertebrate Extinction Risk in Canada." *Bioscience*, 61, no. 7 (2011): 538-549.

Link: http://www.bioone.org/doi/full/10.1525/bio.2011.61.7.8

Synopsis: This article examined 14 possible extinction-risk correlates for mammals, fishes, and birds throughout Canada. Researchers constructed predictive models of risk status that accounted for the influence of life history (e.g., age at maturity, clutch or brood size, body size), distribution (e.g., latitude, aquatic depth), and anthropogenic disturbance (e.g., road density, fishing). Among mammals, risk is positively and strongly correlated with road density and age at maturity for land animals and weakly with body size for sea dwellers. For birds, road density is the dominant correlate of risk.

Keywords: life history, mammals, fishes, birds, human impact, COSEWIC

Caveats: Correlates of risk identified in this study are based on past rather than future conditions. This means that changes to extinction risks posed by climate change is not accounted for in the analyses.

Scale: Meso-regional/national (all of Canada)

Location:
Jurisdiction: Canada (all provinces)
Ecoregion: all ecoregions in Canada

Landscape Type/Pattern:
Land Use: road density
Landscape pattern: linear disturbance

Part of the Environment: Biodiversity indices

120. Citation: Forman, Richard T, et al. Road Ecology: Science and Solutions. Washington, DC: Island Press, 2003.

Link: http://arc-solutions.org/wp-content/uploads/2012/03/Forman-et-al.-2003-Road-Ecology-Sci-and-solutions.pdf

Synopsis: This book addresses issues of landscape fragmentation and ecology emanating from the construction and use of roads. The text highlights ecosystem implications of this type of linear disturbance in relation to the following topics:

- Roads, vehicles, and transportation planning
- Vegetation and roadsides
- Wildlife populations and collision mortality
- Water, sediment, and chemical flows
- Aquatic ecosystems
- Wind, noise, and atmospheric effects
- Road networks and landscape fragmentation

Keywords: road ecology, linear disturbance, fragmentation

Scale: multiple

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: multiple
Landscape pattern: linear disturbance, fragmentation, edge

Part of the Environment: Ecosystem function/intactness, biodiversity indices, water quality, air quality

121. Citation: Gelbard, Jonathan L, and Jayne Belnap. "Roads as conduits for exotic plant invasions in a semi-arid landscape." *Conservation Biology* 17, no.2 (2003): 420-432.

Link: http://www.jstor.org/stable/3095361

Synopsis: This study examined the effect of road improvement and environmental variables on exotic and native plant diversity in roadside verges and adjacent semi-arid grassland, shrubland, and woodland communities of southern Utah. Researchers measured the cover of exotic and native species in roadside verges and both the richness and cover of exotic and native species in adjacent interior communities (50 meters beyond the edge of the road) along 42 roads stratified by level of road improvement (paved, improved surface, graded, and four-wheel drive track). Exotic species richness and cover were more than 50% greater, and the richness of native species 30% lower, at patch interiors adjacent to paved roads than those adjacent to four-wheel drive tracks. The results indicate that the width of roadside verges is strongly positively correlated with exotic species richness and cover. Road improvements influenced both exotic and native species richness in interior communities 50 m beyond the edge of the road, suggests that road improvement affects the distribution of both exotic and native species in lands beyond the influence of roadside disturbance. However, at larger spatial scales, relationships between native and exotic species richness may correspond more with environmental variation.

Keywords: exotic species, native species, invasive species, plant diversity, road effects, semi-arid grassland

Caveats: It is likely that certain factors that were not measured, such as variation in the dominant vegetation, soil depth and moisture, nutrient levels, disturbance regimes, and topography, may have contributed significantly to the relationship between road improvement, roadside verge width, and exotic plant invasions.

Scale: sub-regional (Canyon Lands National Park)

Location:
Jurisdiction: Utah
Ecoregion: Colorado Plateau

Landscape Type/Pattern:
Land Use: protected grassland, recreation, grazing on adjacent public lands
Landscape pattern: linear disturbance, fragmentation

Part of the Environment: Ecosystem intactness and functionality, biodiversity indices

122. Citation: Stein, ED, JS Brown, TS Hogue, MP Burke, A Kinoshita. "Stormwater contaminant loading following southern California wildfires". Environmental Toxicology and Chemistry 3, no. 11(2012):2625-2638.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1002/etc.1994/pdf

Synopsis: The goal of this study was to examine contaminant loadings associated with stormwater runoff from recently burned areas in urban fringe areas of southern California, to derive regional patterns of runoff and contaminant loadings in this context. Postfire stormwater runoff was sampled from five wildfires that each burned between 115 and 658 km2 of natural open space between 2003 and 2009. The area is characterized by classic Mediterranean climate conditions of relatively mild to cool wet winter and warm to hot dry summers. Between two and five storm events were sampled per site over the first one to two years following the fires for basic constituents, metals, nutrients, total suspended solids, and polycyclic aromatic hydrocarbons (PAHs). Results were compared to data from 16 unburned natural areas and six developed sites. Mean copper, lead, and zinc flux (kg/km2) were between 112- and 736-fold higher from burned catchments and total phosphorus was up to 921-fold higher compared to unburned natural areas. Polycyclic aromatic hydrocarbon flux was four times greater from burned areas than from adjacent urban areas. Ash fallout on nearby unburned watersheds also resulted in a threefold increase in metals and PAHs. Attenuation of elevated concentration and flux values appears to be driven mainly by rainfall magnitude. Contaminant loading from burned landscapes can contribute substantially to the total annual load to downstream areas in the first several years following fires.

Keywords: fire effects, metals, polyaromatic hydrocarbons, nutrients, stormwater runoff

Caveats: Effects may be more important in streams already affected by other stressors. More focused monitoring of both the chemical and biological effects of postfire runoff will help managers better target their actions to address potential deleterious effects associated with contaminants in postfire runoff.

Scale: Regional (Southern California)

Location:
Jurisdiction: California, southern
Ecoregion: Southern and Baja California Pine-Oak Mountains, California Coastal Sage, Chapparal and Oak Woodlands
Basin: South Coast Hydrologic Region
Subbasins: City Creek, Dry Canyon, Piru Creek, Santiago Creek, Arroyo Seco, Big Tujunga wash, Sespe Creek, Bear Creek, Chesebro Creek, Coldbrook Creek, Cattle Creek, Silverado Creek, Bell Creek, Tenaja Creek, Cristianitos Creek, Fry Creek, Mill Creek, Ballona Creek

Landscape Type/Pattern:
Land Use: Forest, urban fringe
Landscape pattern: fire patches

Part of the Environment: Water Quality, air quality (ash fallout into watershed), ecosystem services (water supply provisioning)

123. Citation: Crooks, Kevin R, and Michael E Soule. "Mesopredator release and avifaunal extinctions in a fragmented system." *Nature* 400 (1999): 563-566.

Link: http://www.nature.com.ezproxy.lib.ucalgary.ca/nature/journal/v400/n6744/pdf/400563a0.pdf

Synopsis: This study examines the influence of landscape fragmentation on trophic cascades in southern California. Results indicate that, as habitat fragmentation negatively affects the persistence of coyote populations, the abundance of smaller meso-predators increase, resulting in higher mortality rates in scrub-breeding birds. Fragment size was a strong indicator of coyote abundance, and coyote abundance was a strong indicator of bird diversity, as coyotes kept down the number of meso-predators that prey on birds. The positive effect of fragment area and the negative effect of fragment age were the strongest determinants of bird diversity in this system.

Keywords: predator/prey relations, trophic cascades, fragmentation, meso-predator, scrub-breeding bird diversity

Scale: Regional (southern California)

Location:
Jurisdiction: California
Ecoregion: Mojave basin and range; California coastal sage, chapparal, and oak woodlands

Landscape Type/Pattern:
Land Use: Urban settlement
Landscape pattern: fragmentation

Part of the Environment: Terrestrial mammals, birds, biodiversity indices

124. Citation: Brandle, J.R., Hodges, L. and Zhou, X.H. 2004. Windbreaks in North American Agricultural Systems. Agronomy & Horticulture - Faculty Publications. Paper 389.

Link: http://digitalcommons.unl.edu/agronomyfacpub/389

Synopsis: Windbreaks are a major component of successful agricultural landscapes. At the farm scale, they help control erosion and blowing snow, improve animal health and survival under winter conditions, reduce energy consumption of the farmstead, and enhance habitat diversity. At a landscape scale, they provide habitat for various types of wildlife and have the potential to contribute significant benefits to the carbon balance equation, thereby easing the economic burdens associated with climate change. The effectiveness of a windbreak is determined partially by its external structure including its height, length, orientation, continuity, width, and cross-sectional shape and partially by its internal structure including the amount and distribution of solid and open portions, vegetative surface area, and shape of individual plant elements.

Windbreak height is the most important external structural element that determines the extent of wind protection. Measurements of air pressure upwind and downwind of a windbreak show that the pressure increases as the wind approaches the windbreak, drops as wind passes through the barrier then gradually returns to the original condition at or beyond 10 times the height of the windbreak (Figure 1).

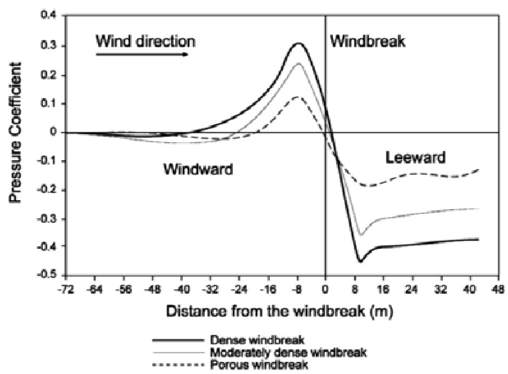


Figure 1. Changes in the pressure coefficient at ground level windward and leeward of three windbreaks with different levels of optical density. Distances from the leeward edge of the windbreak are given as positive distances and as negative distances in the windward direction.

Optical density is a measure of internal structure that is defined as the amount of solid material appearing in a two-dimensional photograph. The data for wind speed reduction by windbreaks for various optical densities presented in the paper suggests that windbreaks with higher optical densities produce higher wind speed reductions (Table 1).

Table 1. Wind speed reductions in shelter at various distances windward and leeward of shelterbelts with different optical densities in Midwestern United States[a].

Type of windbreak	Optical density	Percent of open wind speed at various distances								
		Windward			Leeward					
		−25 H	−3 H	−1 H	5 H	10 H	15 H	20 H	25 H	30 H
Single row deciduous	25–30	100	97	85	50	65	80	85	95	100
Single row conifer	40–60	100	96	84	30	50	60	75	85	95
Multi-row conifer	60–80	100	91	75	25	35	65	85	90	95
Solid wall	100	100	95	70	25	70	90	95	100	100

[a]Reductions are expressed as percent of open wind speed where open wind speed is assumed to be less than 10 meters per second and distance from the windbreak is expressed in terms of windbreak height (H).

Keywords: crop production, microclimate, shelterbelt benefits, shelterbelt structure, wind protection

Scale: Meso-regional

Location:
Jurisdiction: North America
Ecoregion:

Landscape Type/Pattern:
Land Use: agriculture
Landscape pattern: composition and configuration

Part of the Environment: Air quality; water quality; ecosystem health, functionality or intactness

125. Citation: Leuty, Todd. "Using Shelterbelts to Reduce Odors Associated with Livestock Production Barns." *Ontario Ministry of Agriculture and Food.* January 19, 2004. http://www.omafra.gov.on.ca/english/crops/facts/info_odours.htm (accessed March 18, 2013).

Link: http://www.omafra.gov.on.ca/english/crops/facts/info_odours.htm

Synopsis: Preliminary research and observations made by farmers suggest that shelterbelts placed around livestock production facilities may effectively reduce movement of odors emitted by manure to neighbouring properties. Essentially, trees can be 'put to work' to reduce the movement of livestock production odors off-site.

An odor-emitting source can include a livestock production barn, manure storage or a farm field where manure is being spread. Shelterbelts have the ability to reduce odor concentrations significantly at or very near the source, which greatly improves the effectiveness of separation distances. There are five ways that treed windbreaks and shelterbelts can reduce the effects of livestock odor and improve visual perception of production buildings:

- Dilution and dispersion of gas concentrations of odor by a mixing effect created by shelterbelts
- Deposition of odorous dusts and other aerosols (like snow fencing) to the windward and leeward sides of windbreaks
- Collection and storage (sinks) within tree wood of the chemical constituents of odor pollution
- Physical interception of odor particles (dust and aerosols)
- Aesthetic appearance
- Trees create a visual barrier to livestock barns
- Trees can make cropped fields and pastures more pleasing to look at
- Trees represent an 'environmental statement' to neighbors that the producer is making every effort to resolve odor problems in as many ways as possible

Keywords: shelterbelts, air quality, windbreaks, livestock odour

Scale: Applicable to site scale with implications at the sub-regional scale

Location: Jurisdiction: North America
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: agriculture, till cropping and grazing
Landscape pattern: linear disturbances, edge, fragmentation

Part of the Environment: Air quality, ecosystem services (regulating air quality).

126. Citation: Tibke, G., 1988. Basic principles of wind erosion control. Agric. Ecosystems Environ., 22/23: 103-122.

Synopsis: Wind erosion control is typically needed in areas with low and variable precipitation and frequent droughts, and where high winds, high temperature and consequent high evaporation are common conditions, such as in southern Alberta. Potential average annual erosion rates from wind erosion are predicted using the wind erosion equation E= f(**I**, K, C, L, V) where **I** is the soil erodibility index, K is the soil-ridge-roughness factor, C is the climactic factor, L is the unsheltered, weighted travel distance of the wind across a field and V is the equivalent vegetated cover. Wind erosion can be controlled with one or more of the following five basic principles of wind erosion control:

- Reduce field widths along the prevailing wind direction by strip cropping or establishing wind barriers and thereby reducing wind velocity and avalanching
- Establish and maintain vegetation or vegetative residues to protect the soil
- Produce, or bring to the soil surface, stable aggregates or clods large enough to resist the wind force;

- Roughen the land surface (as with furrows) to reduce the wind velocity and trap drifting soils
- Level or bench land to reduce effective field widths and erosions rates on slopes and hilltops where converging streamlines of windflow cause increased velocity and wind force.

Windbreaks and wind barriers contribute to wind erosion control by reducing windspeed on their leeward side and by decreasing field length in the erosive wind direction. If trees are used as a windbreak, single row plantings are common and are as effective and use less land than multiple row plantings. Erosion protection is thought to extend to 10 times the height of the tree species used as a windbreak. Perennial grass barriers are also effective for controlling wind erosion, trapping snow and reducing evaporation on dryland cropping areas. Data presented in the paper suggests a maximum distance between perennial grass barriers of 9m if barriers are oriented perpendicular to the erosive wind force. Strip cropping is another effective method to control wind erosion. It is accomplished by dividing a field into narrow strip where strips of erosion resistant crops or standing stubble are alternated with other crops or unprotected fallow fields. Width of strips depends on soil texture and varies from 6m for sand to 131m for silty clay loam. Other windbreaks and windbarriers include artificial barriers such as snow fencing, board walls, earthen banks, and rock walls are used for wind erosion control but on a limited basis due to high cost for materials and labour.

Keywords: wind erosion, soil erosion control, windbreaks, agriculture

Scale: Meso-regional

Location:
Jurisdiction: North America
Ecoregion:

Landscape Type/Pattern:
Land Use: agriculture
Landscape pattern: composition and configuration

Part of the Environment: Air quality; water quality; ecosystem health, functionality or intactness

127. Citation: Ticknor, K.A., 1988. Design and use of field windbreaks in wind erosion control systems. Agric. Ecosystems Environ., 22/23: 123-132.

Synopsis: Wind erosion is considered a problem when the erosion level exceeds the tolerable limit for the soil or when the erosion level is great enough to damage the crops being grown. Wind erosion control must be tailored to each farming situation and may be achieved through a combination of practices that ultimately create isolated fields, the key to wind erosion control systems. Wind erosion control measures can be grouped into four components: (1) tree and shrub windbreaks; (2) annual and perennial vegetative barriers; (3) strip cropping and trap strips; and (4) crop residues and cover crops. Wind control system design involves 4 basic principles: (1) erosion rates are predicted using the wind erosion equation; (2) an isolated field condition must be established; (3) windbreaks and other wind barriers are oriented as perpendicular as possible to the prevailing wind direction; (4) the area completely protected by windbreaks is assumed to be a distance 10 times the height of the barrier downwind from the barrier along the prevailing wind direction.

Keywords: field windbreaks, soil erosion control, wind erosion, agriculture

Scale: Meso-regional

Location:
Jurisdiction: North America
Ecoregion:

Landscape Type/Pattern:
Land Use: agriculture
Landscape pattern: composition and configuration

Part of the Environment: Air quality; water quality; ecosystem health, functionality or intactness

128. Citation: Tyndall, John, and Joe Colletti. "Mitigating swine odor with strategically designed shelterbelt systems: a review." *Agroforestry Systems* 69 (2007): 45-65.

Link: http://www.nrem.iastate.edu/research/veb/pub.swinesb.pdf

Synopsis: Recent reports clearly indicate that odor emitted from concentrated livestock production facilities in the Midwest of the US is a significant social problem that negatively impacts rural and state economies, human health, and the quality of rural life. A potential incremental approach to dealing with livestock odor is the use of shelterbelts arranged in strategic designs near and within livestock facilities. This review outlines the various ways that shelterbelts can be effective technology which biophysically mitigates odor thereby reducing social conflict from odor nuisance. The biophysical potential of shelterbelts to mitigate livestock odor arises from the tree/shrub impacts on the central characteristics and physical behavior of livestock odor. As the majority of odors generated in animal facilities that are detectable at appreciable distances travel as particulates, there is compelling evidence that shelterbelts can ameliorate livestock odor by impeding the movement of these particulates.

Because the odor source is near the ground and the tendency of livestock odor is to travel along the ground, shelterbelts of modest heights (i.e. 20–30 ft) may be ideal for odor interception, disruption, and dilution. Shelterbelts can be adapted to fit almost any production situation.

Depending on shelterbelt health, these trees can provide long term, year round odor interception, with increasing effectiveness over time. Additionally, more is becoming known about how landscape aesthetics affect how people might perceive livestock odor, suggesting that landscape elements such as shelterbelts can lead to aesthetic improvements and perhaps more positive opinions of livestock odor and the farm systems that create them. The review suggests that shelterbelts can make an incrementally beneficial contribution to improving the sustainability of agricultural industries.

Keywords: Air quality, Agricultural pollution, Odor mitigation, Swine, Vegetative buffers

Scale: Applicable to site scale with implications at the sub-regional scale

Location: Jurisdiction: North America
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: agriculture, till cropping and grazing
Landscape pattern: linear disturbances, edge, fragmentation

Part of the Environment: Air quality, ecosystem services (regulating air quality).

129. Citation: Clevenger, Anthony P, Bryn Chruszcz, and Kari E Gunson. "Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations." *Biological Conservation* 109, no. 1 (2003): 15-26.

Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/S0006-3207(02)00127-1

Synopsis: This study examined the spatial patterns and factors influencing small terrestrial vertebrate road-kill aggregations in the Bow River Valley of Alberta, Canada. Mammal and bird road-kill indices were consistently higher on low volume parkway roads than on the high-speed, high volume Trans-Canada highway (TCH). Birds were more vulnerable to collisions than mammals on the TCH. Low volume parkway road-kills were less likely to occur on raised sections of road, and tended to occur close to vegetative cover far from wildlife passages and culverts. Highway sections with forested medians were less significant barriers to forest birds than open grassy medians. Since forest dwelling birds are reluctant to cross large un-forested gaps, the increased road-kill rate on divided sections of road may be explained by a greater propensity for birds to cross the narrower gaps. In general, these findings indicate how two distinct road types can have different effects on the patterns of vertebrate mortality.

Keywords: Banff National Park, mortality, road ecology, road-kills, spatial pattern

Scale: Sub-regional

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies

Landscape Type/Pattern:
Land Use: transportation (roads), grazing, managed forest, protected area
Landscape pattern: linear disturbance

Part of the Environment: Birds, terrestrial mammals

130. Citation: Peterson, B. "Control of Nitrogen Export from Watersheds by Headwater Streams". Science 292 (2001): 86-90.

Link: http://www.sciencemag.org.ezproxy.lib.ucalgary.ca/content/292/5514/86

Synopsis: This study summarized results of a comparative 15N-tracer study from a wide variety of sites throughout the United States, to derive general principles related to headwater streams and nitrogen dynamics. Standardized protocols were applied in 12 headwater streams representing a wide diversity of biomes throughout the United States. These sites were part of the Lotic Intersite Nitrogen eXperiment (LINX). The most rapid uptake and transformation of inorganic nitrogen occurred in the smallest streams. Ammonium entering these streams was removed within a few tens to hundreds of meters, primarily through assimilation by microorganisms, sorption to sediments, and nitrification. Nitrate was also removed from stream water but traveled a distance 5 to 10 times as long, on average, as ammonium. Nitrate was removed by biological assimilation and denitrification processes. During seasons of high biological activity, the reaches of headwater streams retain and transform important amounts of inorganic N, frequently more than 50% of the inputs from their watersheds.

<u>O2 Interpretation of study context</u>: Conclusions indicate that small streams are the most important at regulating water chemistry in large drainages, because their large surface-to-volume ratios favour rapid nitrogen uptake and processing. Yet small streams are often the most vulnerable to diversion, channelization, and elimination in urban and agricultural environments. Therefore, restoration and preservation of small stream ecosystems should be a central focus of management strategies to ensure maximum N processing in watersheds, which in turn will improve the quality of water delivered to downstream aquatic systems.

Keywords: headwater streams, nitrogen export, water quality, nitrification

Caveats: Most of the variation in nitrogen uptake length among streams was due to differences in physical characteristics such as depth and current velocity, which correlate with discharge. Most streams observed tended to have low inorganic N levels (<10 μg/L), although streams with higher nitrate concentrations also tended to have high nitrification rates As N inputs to streams increase, the capacity of streams to effectively retain and transform nitrogen inputs will be overwhelmed and inorganic N will be transported much farther. In addition, experiments were done during periods of relatively high biotic activity, so excesses of inorganic N removal over regeneration are expected; over annual cycles stream channels do not normally accumulate nutrient or organic matter stocks so most stored N will be exported as regenerated inorganic, gaseous, or organic N over a period ranging from weeks to several years.

Scale: Meso-regional (finding is meant to apply North America-wide)

Location:
Jurisdiction: United States (observed sites were in Alaska, Oregon, Arizona, New Mexico, Minnesota, Michigan, Kansas, Ohio, Tennessee, North Carolina, New Hampshire, and Puerto Rico)

Ecoregion: multiple

Landscape Type/Pattern:
Land Use: Varied (but assumed mostly non-intensive and natural due to headwater status of streams)
Landscape pattern: Dendritic headwater streams, percent native

Part of the Environment: Water quality, ecosystem services (nutrient cycling), riparian systems

131. Citation: Downey, Brad A., Brandy L. Downey, Richard W Quinlan, Oriano Castelli, Vernon J. Remesz, and Paul F. Jones. MULTISAR: The Milk River Basin Project; Habitat Suitability Models for Selected Wildlife Management Species No. 86. Alberta Species At Risk Report, Alberta Sustainable Resource Development, 2004.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: This document details the Milk River Basin project, designed to produce innovative approaches to multi-species management in Southern Alberta. The Milk River basin contains a variety of 'sensitive', 'at risk', and 'may be at risk' species. The process of prioritizing the landscape for conservation and stewardship was driven by species inventories to identify known locations, and Habitat Suitability Index (HSI) models to delimit suitable key habitat for the 17 selected species. The construction of the models was limited to the available variables and resolution of the databases. For MULTISAR: the Milk River Basin Project area this was the quarter section, the resolution of the Native Prairie Vegetation Inventory. Because of the resolution of available databases, the models produced for this project are coarse in nature. Model parameters were chosen as a result of literature review and expert opinion; field validation of model outputs was recommended by the authors.

Table 1.1 Model variables available for selection during the development of the 17 habitat suitability index models for the Milk River Basin project area

Variable	Units	Source*	Resolution
Structural			
Native Prairie Cover	Categorical	NPVI	Quarter section
Grass Cover	Percentage	NPVI	Quarter section
Shrub Cover	Percentage	NPVI	Quarter section
Tree Cover	Percentage	NPVI	Quarter section
Riparian	Percentage	NPVI	Quarter section
Lake	Percentage	NPVI	Quarter section
Soil Texture	Categorical	AGRASID	25 meter
First and Second Order Soil Classification	Categorical	AGRASID	25 meter
Badlands (shallow to gravel)	Categorical	AGRASID	25 meter
Valleys	Categorical	AGRASID	25 meter
Elevation	Meter	DEM	25 meter
Slope	Degrees	DEM	25 meter
Aspect	Categorical	DEM	25 meter
Spatial			
Distance to Access (roads)	Meter	PBF	5 – 20m
Distance to Hydro (rivers, water bodies)	Meter	PBF	5 – 20m

*NPVI - Native Prairie Vegetation Inventory
AGRASID - Agricultural Region of Alberta Soil Inventory Database
DEM - Digital Elevation Model
PBF - Provincial Base Features

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains
Basin: Milk River

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native

Part of the Environment: Ecosystem health, functionality/intactness, biodiversity indices, species-at-risk

132. Citation: Koper, Nicola, and Fiona KA Schmiegelow. "A multi-scale analysis of avian response to habitat amount and fragmentation in the Canadian dry mixed-grass prairie." *Landscape Ecology* 21 (2006): 1045-1059.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s10980-007-9083-9

Synopsis: Researchers measured the effects of grassland amount and fragmentation on upland and wetland songbird and duck densities and nest success across 16 landscapes in southern Alberta. By comparing these landscape-level effects with local-scale responses, including distance to various edges and vegetation characteristics, the study demonstrated that few species were in fact influenced by grassland amount or fragmentation. In contrast, distance to edge and local vegetation characteristics had significant effects on densities and nest success of many species. Landscape level effects were much less apparent when local characteristics were included in the models. Therefore, researchers concluded that local habitat management is more important for ensuring adequate reproduction of these species.

Keywords: Akaike's information criterion, habitat loss and fragmentation, mixed-effects models, mixed-grass prairie, model selection, nest success, prairie birds, spatial scale

Caveats: The power to detect landscape effects was relatively low, due to small sample sizes and pooling nests across species.

Scale: Regional (southern Alberta)

Location:
Jurisdiction: Alberta
Ecoregion: Northwestern glaciated plain, aspen parkland/northern glaciated plain

Landscape Type/Pattern:
Land Use: grazing, managed prairie and wetlands
Landscape pattern: fragmentation

Part of the Environment: Birds

133. Citation: Buffam, I, H Laudon, J Seibert, CM Morth, and K and Bishop. "Spatial heterogeneity of the spring flood acid pulse in a boreal stream network." *Science of the Total Environment* 407, no. 1 (2008): 708-722.

Link: www.ncbi.nlm.nih.gov/pubmed/18940271

Synopsis: This paper describes the spatial distribution of pH measurements from 60 sites distributed throughout the Kychlan River catchment, a 67km^2 boreal watershed in northern Sweden. Water samples were collected during a period of winter baseflow and during a spring flood episode. Chemical analyses included pH, Dissolved Organic Carbon (DOC), major cations (K, Mg, Na, Ca) and total filterable aluminum. Spring flood pH was shown to be highest in larger, lower altitude catchments underlain by fine sorted sediments, and lowest in small, higher altitude catchments underlain by a mixture of peat wetlands and forested till. There was also a trend with distance downstream of higher pH, acid neutralizing capacity and based cation concentrations together with lower DOC. The study concluded that due to a combination of spatial heterogeneity in landscape characteristics (presence of wetlands and lakes, underlying geology, etc.) and scale-related processes, boreal catchments, such as the Kychlan River, can be expected to experience high spatial variability in chemistry at any point in time and in the change experienced during high discharge events.

Keywords: ANC, boreal catchments, DOC, pH, snowmelt, spatial heterogeneity, wetlands

Caveats: According to the authors, it is difficult to disentangle landscape effects on stream chemistry since many landscape parameter effects co-vary. They did, however, show that chemistry patterns showed associations with landscape characteristics, but considerable variability remained. They suggest that modelling of dynamic stream chemistry from map parameters will continue to present a challenge.

Scale: local (catchment of a watershed)

Location:
Jurisdiction: Sweden
Ecoregion: n/a
Basin: Krychlan River

Landscape Type/Pattern:
Land Use: protected area
Landscape pattern: percent native

Part of the Environment: Water quality

134. Citation: Downey, Brad A. "American Badger." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 64-70. Edmonton, AB.: Alberta Sustainable Resource Management, Fish and Wildlife Division., 2004b.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: This report evaluates habitat requirements of the American badger according to parameters of soil texture, graminoid cover, slope, and proximity to roads. Badgers tend to prefer sandy loam and silty loam, medium and moderately coarse textured soils. In terms of graminoid coverage, badgers generally prefer open grassland habitat, but can also be found in agriculturally dominated landscapes containing isolated pockets of Richardson 's ground squirrel colonies. Graminoid coverage of 23% was chosen as the minimum requirement for suitable badger habitat. As slope increases, habitat suitability decreases to a point at which the likelihood of badgers existing there (i.e. cliffs and badlands) is extremely low to nil. After examining the coarse data used for mapping, a slope of ~ 15 degrees was determined to be the most representative of suitable American badger habitat in the Milk River Basin. In general, habitat further away from main roads which contain ground squirrels and open grassland are the most beneficial for badgers. The degree to roads affected badger populations depended upon the road type.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, American Badger

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains
Basin: Milk River

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity, linear disturbance

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, terrestrial mammals, species-at-risk

135. Citation: Bowers, Michael A, and Stephen F Matter. "Landscape ecology of mammals: relationships between density and patch size." *Journal of Mammology* 78, no. 4 (1997): 999-1013.

Link: http://www.jstor.org/stable/1383044 .

Synopsis: This study tested the null hypothesis that densities of mammalian populations are constant over patches of varied size. In other words, performance as estimated by density does not covary with patch area. Researchers used a composite database from published studies and found that densities of 20 out of 32 species did not vary with patch area. Five species showed increasing density-area relationships and seven species showed decreasing density-area relationships. Landscapes comprised of smaller, less isolated patched tended to have negative density-area relationships and landscapes with large, more isolated patched tended to have positive density-area relationships. These results indicate that there are no density-area relationships that operate over all systems of patches. Rather, patterns appear to be scale dependent: frequent movement of individuals in the habitat (patch) selection process over smaller-scaled landscapes produced negative density-area relationships. Movement of individuals among more isolated patches appeared to be related to larger and longer-scale population processes involving colonization and extinction and positive density-area relationships.

Keywords: landscape ecology, patches

Caveats: To aid in making comparisons among studies, we only consider extreme examples of patchiness (i.e., where inhabitable patches are embedded in a largely uninhabitable habitat).

Scale: literature review; world-wide

Location:
Jurisdiction: World-wide
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: multiple
Landscape pattern: percent cover, fragmentation

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices.

136. Citation: Flather, Curtis H, and Michael Bevers. "Patchy reaction-diffusion and population abundance: the relative importance of habitat amount and arrangement." *American Naturalist* 159, no. 1 (2002): 40-52.

Link: http://www.jstor.org/stable/10.1086/324120 .

Synopsis: This study aimed to independently examine the effects of varying amounts and configurations of habitat at a landscape scale, with particular attention to critical persistence thresholds. A discrete reaction-diffusion model was used to estimate long-term equilibrium population persistence of a hypothetical species in a patchy landscape. When examined over a broad range of habitat amount and arrangements, population size was largely determined by the proportion of habitat (amount) in a landscape. However, when habitat coverage dropped below 30-50%, population response deviated, coinciding with a persistence threshold. Species persistence declined rapidly at this threshold range (50% for low degrees of aggregation, 40% for high and moderate degrees of aggregation). At this point, habitat arrangement explained a greater amount of variation in population size than did habitat amount.

Keywords: Persistence threshold, spatially explicit population model, fragmentation, landscape ecology, structured landscapes, dispersal

Scale: n/a; model based

Location:
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: n/a
Landscape pattern: percent native, fragmentation

Part of the Environment: biodiversity indices, ecosystem functionality/intactness

137. Citation: Bruun, H, H. "Patterns of species richness in dry grassland patches in an agricultural landscape." *Ecography 23*, (2000): 641-650.

Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0587.2000.tb00307.x/abstract

Synopsis: Eighty-five patches of semi-natural grassland of varying size scattered in an agricultural landscape were investigated for their flora of vascular plants. Relationships between species richness and patch area, spatial isolation and local habitat conditions including heterogeneity were examined. Differences between single species and among groups of species defined by life-history traits were also investigated.

Area was shown to be an important determinant of species richness irrespective of habitat heterogeneity. Isolation in space and habitat heterogeneity also play significant roles. These results are consistent with results from a multitude of studies on fragments of ancient deciduous woodland in northern Europe, They are, however, contradictory to results from previous studies in grasslands within the same region. Seed mass and dispersal syndrome were poor predictors of the degree to which the species were affected by isolation of grassland patches. Seed mass deviation from community median could explain a small percentage of the variation in regional abundance. Logistic regression on species occurrences showed that few species are associated with large patches, and less than half seem to avoid isolated patches.

Keywords: flora, semi-natural grassland, agricultural landscape, landscape patterns, patch dynamics, habitat heterogeneity

Scale: Sub-regional – dry semi-natural grassland (alpine slopes)

Location:
Jurisdiction: Sjslland, Denmark
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: agricultural, grazing
Landscape pattern: edge, fragmentation, connectivity

Part of the Environment: Biodiversity indices, ecosystem intactness

138. Citation: Roth, NE, JD Allan, and DL Erickson. "Landscape influences on stream biotic integrity assessed at multiple spatial scales." *Landscape Ecology* 11, no. 3 (1996): 141-156.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/BF02447513

Synopsis: This study aimed to determine whether land use/cover was an effective predictor of stream integrity, and if so, at what spatial scale. Researchers evaluated stream condition using an Index of Biotic Integrity (IBI) and a habitat index (HI), and compared them to landscape and riparian conditions at different spatial scales. Stream biotic integrity and habitat quality were negatively correlated with the extent of agriculture and positively correlated with extent of wetlands and forest. Correlations were strongest at the catchment scale and tended to become weak and non-significant at local scales. Local riparian vegetation was a weak secondary predictor of stream integrity. In this Michigan watershed, upstream regional land use was the primary determinant of stream conditions, able to overwhelm the ability of local site vegetation to support high-quality habitat and biotic communities.

Keywords: stream biotic integrity, land use, agriculture, land cover, index of biotic integrity, habitat index

Scale: sub-regional (watershed and catchment scale)

Location:
Jurisdiction: Michigan
Ecoregion: Eastern Cornbelt Plains

Landscape Type/Pattern:
Land Use: agriculture, settlement
Landscape pattern: fragmentation, percent native

Part of the Environment: Riparian systems, biodiversity indices, ecosystem function/intactness

139. Citation: Castelle, A., A. Johnson, C. Conolly. "Wetland and stream buffer size requirements-a review". *Journal of Environmental Quality* 23 (1994): 878-882.

Link:
http://www.state.nj.us/drbc/library/documents/Flood_Website/FRES/WendelgassBuffer_publications.pdf

Synopsis: This paper provides a literature review and synthesis of the scientific functions of wetland and stream buffers at a range of widths. The literature search reconfirmed the need for buffers as an important landscape pattern, and emphasized the need to consider specific buffer functions such as water temperature modification, sediment removal, nutrient removal, species diversity, and noise mitigation. A range of buffer widths from 3m to 200m were found to be effective. However, they conclude that buffers less than 5-10m provide little protection of aquatic resources under most conditions. Overall, buffers necessary to protect wetlands and streams should be a minimum of 15 to 30 m in width. Generally, minimum buffer widths toward the lower end of this range may help maintain natural physical and chemical characteristics of resources. Higher buffer widths may be required to maintain biological components of many wetlands and streams.

Fixed width and variable width buffers and related benefits and disadvantages were also discussed. Fixed width buffers are most often based on a single parameter, such as functional value. Fixed width buffers are more easily enforced, do not require regulatory personnel with specialized knowledge of ecological principles, allow for greater regulatory predictability, and require smaller expenditures of both time and money to administer. However, fixed width buffers do not consider site-specific conditions, and therefore may not adequately buffer aquatic resources. Variable width buffers are based on a combination of criteria based on site-specific conditions. They may be adjusted accordingly to protect valuable resources. However, variable width buffers also require greater expenditure of resources and more training for agency staff, while offering less predictability for land use planning.

Keywords: Stream buffers, buffer widths, riparian systems, aquatic health

Caveats: Site-specific conditions may indicate the need for substantially larger buffers or for somewhat smaller buffers than the guidelines provided.

Scale: Site (Streamside Buffers)

Location:
Jurisdiction: Multiple
Ecoregion: Multiple

Landscape Type/Pattern:

Land Use: Multiple
Landscape pattern: Riparian buffers and connectivity

Part of the Environment: Riparian systems

140. Citation: Schlosser, IJ, and JR Karr. "Water quality in agricultural watersheds: impact of riparian vegetation during base flow." *Water Resources Bulletin* 17, no. 2 (1981): 233-240.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1111/j.1752-1688.1981.tb03927.x/abstract;jsessionid=5EBBA5BB1F3D6C080E087CB48C14CE30.d04t04

Synopsis: The influence of riparian vegetation on suspended solids and nutrients was measured by monitoring 6 agricultural watersheds differing in type of riparian vegetation and magnitude of point source inputs. In areas with no riparian vegetation, both in-stream algal production and seasonal low flows appeared to be major determinants of suspended solids, turbidity, and phosphorus concentrations. Peak levels of all parameters were reached during summer when flows were reduced and benthic algal production was high. In-stream organic production was less important in regulating water quality in areas with riparian vegetation and permanent flows. When riparian vegetation is maintained in areas of intensive agriculture, suspended solids levels are generally lower due to reduced in-stream organic production. Sediment deposition in near stream areas and stream bank scour are also reduced when riparian vegetation is present. Efforts to improve water quality in agricultural watersheds during base flow should emphasize riparian vegetation maintenance, as well as stable flow conditions.

Keywords: Agricultural watershed, water quality, riparian vegetation, seasonality, base flow, suspended solids, nutrients

Caveats: Intermittent flow conditions in summer increased the importance of in-stream organic production as a control on water quality, even when riparian vegetation was present. In addition, phosphorus and turbidity increase in association with leaf fall in autumn.

Scale: Local watersheds (e.g., ~20-85 km2)

Location:
Jurisdiction: Illinois (Champaign, Vermilion, Coles, and Cumberland Counties)
Ecoregion: Central Corn Belt Plains
Basin: Mississippi River
Subbasin: Wabash River, Embarras River

Landscape Type/Pattern:
Land Use: Agriculture-row crops (dominates)
Landscape pattern: riparian vegetated buffers surrounded by cropland

Part of the Environment: Water quality, riparian systems

141. Citation: Heslinga, J. L. Patterns and predictors of plant diversity and compositional change in a restored Michigan tallgrass prairie. Master of Science Thesis, Natural Resources and Environment (Terrestrial Ecosystems) University of Michigan, December, 2008.

Link: http://deepblue.lib.umich.edu/handle/2027.42/61355

Synopsis: To preserve or expand remaining prairie ecosystems, it is critically important for ecologists, land managers, and restoration practitioners to have a firm knowledge of prairie ecology and to understand how management practices affect prairie ecosystems. Tallgrass prairies are one of the most threatened ecosystem types in Michigan and throughout North America. Dow Field is a small remnant prairie in the University of Michigan's Nichols Arboretum in Ann Arbor, Michigan, that is being actively restored after many years of fire suppression. Starting in 1991, the prairie was divided into 10 management zones that were burned on 1 or 3 year intervals in April or November, and vegetation in 60 2m2 sample plots was monitored annually until 2007. In this study, trends in the plant community over time were examined, including diversity, species abundance, and community compositional change. The environmental and management factors that most influenced diversity and compositional change were explored, and successional trajectory in the context of restoration goals was evaluated.

Over time, native species richness increased slightly, but dropped dramatically after several years of burning. Andropogon gerardii (big bluestem) was the most dominant species in the prairie and reduced diversity through competitive exclusion, but there were no clear patterns in how the different fire regimes affected diversity or the abundance of A. gerardii. Instead, soil depth and soil clay were found to be the most reliable predictors of diversity, likely because increased soil moisture led to higher A. gerardii productivity and competitive ability. Year-to-year change in community composition was found to be affected by time since fire and fluctuations in growing season temperature and rainfall. Examining successional trajectory showed that the restoration has been most successful at reducing exotic species and increasing species heterogeneity, but has largely failed to increase native species richness to the level of remnant prairies, likely because of high A. gerardii abundance and low availability of native propagules.

Keywords: tallgrass prairie, diversity, community ecology, environmental management, restoration

Caveats: Only one site was studied. There was no replication in burn treatments and treatment cases did not start on equal footing. In addition, the fire regime was changed mid-study, thereby limiting the types of statistical analysis that could be considered.

Scale: Site - University of Michigan experimental remnant prairie

Location:
Jurisdiction: Michigan
Ecoregion: S. Michigan/N. Indiana Drift Plains
Basin: Huron River valley

Landscape Type/Pattern:
Land Use: agriculture
Landscape pattern: fragmentation, ecosystem health and functionality, ecosystem services, biodiversity

Part of the Environment: Biodiversity indices, ecosystem health and intactness

142. Citation: Downey, Brad A. "Swift Fox." In MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86, by Brad A. Downey, Brandy L. Downey, Rachael W. Quinlain, Oriano Castelli, Vernon J. Remesz and Paul F. Jones, 82-89. Edmonton, AB: Alberta Sustainable Resource Management, Fish and Wildlife Division. 2004d.

Link: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SAR86-MULTISAR-MilkRiverProject-HabitatSuitabilityModels-Mar-2004.pdf

Synopsis: This report evaluated habitat suitability requirements for swift foxes. Swift foxes prefer short or mixed grass unfragmented prairies that are predominately flat with sparse vegetation that allows them easy mobility and high visibility when it comes to eluding and detecting predators. Forest, coulees, steep slopes, broad agricultural areas, and dense shrubs are usually avoided because they often function as barriers between populations. The swift fox is typically found in open flat prairies. Numerous shrubs would limit visibility as well as provide nesting habitat or cover for species that would predate on swift foxes. However a few scattered shrubs would provide habitat and cover for prey such as birds, microtines, or lagomorphs, which are important in the winter. As such a threshold of <5% shrubs was chosen for full habitat value. Flat ground, <15 degrees, would be considered suitable swift fox habitat. Slope variables were selected based on the coarse nature of the data layer available for mapping. A slope of 30 degrees highlighted by the data layer represents ~75 degree slopes on the ground. Swift foxes are predominately found on open native prairie and tend to avoid cultivation. Quarter sections containing 75-100% grassland were deemed most suitable, while the sections containing less than 75 % were given lower values relating to the decrease in percent grassland. Out of 252 sightings within BSOD along the Alberta/Saskatchewan border 227 (90%) were in 75-100% graminoid coverage. Low HSI values are assigned to coarse textured soils (sand), which are prone to collapsing and fine textured soils (clay), which are prone to flooding.

Keywords: HSI models, biodiversity, habitat quality, agriculture, native prairie, terrain, Swift Fox

Caveats: This study generated landscape level models with coarse variables, and the thresholds and values used may not be directly applicable to other areas or for site-specific analysis.

Scale: Sub-regional (Milk River Basin)

Location:
Jurisdiction: Alberta, Saskatchewan
Ecoregion: Northwestern Glaciated Plains

Landscape Type/Pattern:
Land Use: Native Prairie
Landscape Pattern: Percent native, connectivity

Part of the Environment: Ecosystem functionality/intactness, biodiversity indices, terrestrial mammals, species-at-risk

143. Citation: Jules, Erik S. "Habitat fragmentation and demographic change for a common platn: trillium in old growth forests." *Ecology*79, no. 5 (1998): 1645-1656.

Link: http://www.jstor.org/stable/176784 .

Synopsis: This study examines the influence of forest fragmentation on an understory herb, Trillium ovatum, in a fragmented forest landscape of the Siskiyou Mountains of Oregon. The process of clearcutting and subsequent conifer planting results in the mortality of almost all trillium in a given area. In general, the remaining plants do not recruit new individuals, even in sites clearcut 30 years ago. Therefore, trillium is restricted to smaller amounts of remnant, uncut forest. Trillium populations in forest remnants that were within 65 meters of forest clearcut edges generally do not succeed in recruiting young plants after adjacent clearcutting, whereas forest interior populations contained higher recruitment levels. Edge populations decline in size while interior populations do not decline. In summary, this study demonstrates that habitat fragmentation results in demographic changes in plant populations associated with increased extinction risk.

Keywords: Clearcutting, edge effects, extinction, habitat fragmentation, island biogeography, plant demography, plant diversity, Siskiyou Mountains, Trillium ovatum

Scale: Regional

Location:
Jurisdiction: Oregon
Ecoregion: Klamath Mountains

Landscape Type/Pattern:
Land Use: managed forest, logging
Landscape pattern: fragmentation, edge

Part of the Environment: Biodiversity indices, ecosystem functionality and intactness

144. Citation: Tews, J, et al. "Animal species diversity driven by habitat heterogeneity: the importance of keystone structures ." *Journal of Biogeography* 31 (2004): 79-92.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1046/j.0305-0270.2003.00994.x/pdf

Synopsis: This literature survey synthesises findings from several studies that correlated habitat heterogeneity with species diversity. The review brings to light evidence that the ecological effects of habitat heterogeneity vary considerably between species groups depending on whether landscape structural attributes are perceived as heterogeneity or fragmentation by a given species. Not all species in an ecosystem are equally affected by spatial structures. The effect of habitat heterogeneity for one species group may differ in relation to spatial scale. In several studies, different species groups are tied strongly to “keystone structures”, which greatly influence several species groups across spatial scales.

Keywords: Habitat heterogeneity hypothesis, structural diversity, structural heterogeneity, foliage height diversity, species richness, biodiversity, spatial scale, habitat fragmentation

Caveats: Published literature is strongly biased towards studies of vertebrate species, even though vertebrates make up only 3% of all animal species. This trend speaks to the need for more diversified studies of invertebrates in the context of heterogeneity in order to understand how habitat heterogeneity affects a more universal range of species diversity.

Scale: Meso-regional (world-wide overview)

Location:
Jurisdiction: World-wide
Ecoregion: world-wide

Landscape Type/Pattern:
Land Use: many
Landscape Pattern: fragmentation, connectivity, heterogeneity

Part of the Environment: Biodiversity indices

145. Citation: Telang, SA, GW Hodgson, and BL Baker. "Effects of forest clearcutting on abundances of oxygen and organic compounds in a mountain stream of the Marmot Creek Basin." *Canadian Journal of Forest Research* 11 (1981): 545-553.

Link: http://www.nrcresearchpress.com/doi/abs/10.1139/x81-075#.UTkefVetrf0

Synopsis: In this study, stream water concentrations of oxygen, refractory compounds (e.g., tannins and lignins, humic and fulvic acids) and labile organic compounds (e.g., phenols, carbohydrates) were measured in Cabin Creek after clear-cutting. Cabin Creek is a small tributary to Marmot Creek which is located in the Kananaskis range of the eastern Rocky Mountains in Alberta. Clear-cutting in Cabin Creek was conducted at 6 sites, each about 10ha in size. It was found that concentrations of tannins and lignins increased by a factor of about 4 after clear-cutting and persisted at the higher concentration for several years. Humic substances also increased but the effect only lasted about 2 years. No effect was observed on concentrations of oxygen or labile organic compounds.

Keywords: forest clear-cutting, stream water quality, eastern Rocky Mountains

Caveats: Direct data for refractory and labile compounds in Cabin Creek were not available prior to clear-cutting so a neighbouring stream in the Marmot Creek drainage basin was used as an analogue. In the analogue sub-basin, 67% of the total vegetation is nonforest and alpine vegetation and the other 33% is coniferous vegetation. In the Cabin Creek sub-basin, 26% of the vegetation is nonforest and alpine vegetation and the other 74% is coniferous forest.

Scale: Local/site

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies
Basin: Saskatchewan
Sub basin: South Saskatchewan

Landscape Type/Pattern:
Land Use: forest
Landscape pattern: fragmentation

Part of the Environment: Water quality

146. Citation: Johnston, Carol A, Naomi E Detenbeck, and Gerald J Niemi. "The cumulative effect of wetlands on stream water quality and quantity. A landscape approach." *Biogeochemistry* 10 (1990): 105-141.

Link: http://download.springer.com/static/pdf/146/art%253A10.1007%252FBF00002226.pdf?auth66=1363130744_ab324a559badfe7c474f94effe9489d5&ext=.pdf

Synopsis: This study investigated the relationship between watershed mosaics and the water quality and flow output from those watersheds. Wetland extent was related to decreased concentrations of chloride, lead, and specific conductance. Proximity of wetlands to the sampling station was related to decreased annual concentrations of inorganic suspended solids, fecal coliform, nitrates, specific conductivity, and dissolved phosphorus. Finally, the position of a wetland in a watershed (downstream wetlands have greater influence on water quality) appears to have a substantial influence on the amount of sediment and nutrients affecting water quality.

Keywords: cumulative, flow, GIS, landscape, lead, nitrogen, phosphorus, suspended solids, watershed, wetlands

Caveats: Further research is needed to determine distance relationships between wetlands and downstream water quality.

Scale: Meso-regional

Location:
Jurisdiction: Minnesota
Ecoregion: North-central hardwood forests

Landscape Type/Pattern:
Land Use: Agriculture
Landscape pattern: fragmentation, percent native

Part of the Environment: water quality, riparian systems

147. Citation: Mitsch, WJ, and JG Gosselink. "The value of wetlands: importance of scale and landscape setting." *Ecological Economics* 35, no. 1 (2000): 25-33.

Link: http://www.cop.noaa.gov/pubs/das/das19.pdf

Synopsis: This report identifies and evaluates approaches to solve the problem of nutrient enrichment from land runoff causing a large zone of hypoxia in the Gulf of Mexico. Methods applied included a broad literature review on the effects of land use, land cover, and best management practices on nutrient loading and nitrogen specifically. This literature review was placed in the context of the Mississippi River basin, and key recommendations to address the problem were presented, including:

- Restoring 10 million hectares of riparian zones and wetlands, representing 3.4% of the Mississippi River basin, would reduce nitrogen in the Mississippi River Basin and its tributaries by an average of 40%
- If wetlands alone were used, percentages of nitrogen removal would be higher than if riparian areas alone were used, as wetlands are generally more efficient per unit area in nutrient removal
- Wetlands and riparian zones should be strategically placed in watersheds to optimize nitrogen removal, as, for example, in tile-drained farmlands prone to high concentrations of nitrate

Additional recommendations not specifically related to landscape patterns but more related to land management practices included:

- On farm practices such as a 20% reduction of nitrogen fertilizer applications through appropriate crediting of legumes and manure, optimum timing of fertilizer application, use of alternative crops such as perennials, wider spacing of subsurface drains, and better management of livestock manure whether stored or applied to the land could lead to a 15-20% reduction of nitrogen loading to the Gulf of Mexico

- Although point sources of nitrate appear to be of little consequence (<5% overall), controlling these through tertiary treatment should be a formal policy for new wastewater treatment plants in the basin

Nitrate reduction should be an important consideration in the design and operation of diversions of the Mississippi River for flood events in the Mississippi Delta in Louisiana, as inshore forested wetlands, marshes, and water bodies can be used for nitrate reduction in diverted waters. There is a strong need for any nitrogen mitigation effort to be coupled to a comprehensive program of monitoring, research, and modeling to evaluate which practices are effective and why, to allow for “adaptive management” of the hypoxia problem

In addition to mitigating nitrogen pollution in the Gulf of Mexico, additional benefits were discussed such as local water quality improvement, ecological values including biodiversity associated with wetland and river ecology, terrestrial wildlife enhancement, and flood control were discussed.

The above recommendations as well as the approach taken in this study may be very relevant in many other contexts where reducing nutrient loadings is a key objective. The approach is not just limited to nitrogen but may also be applied to phosphorus, suspended solids, or other contaminants of concern.

Keywords: nutrient loading, nitrogen, eutrophication, water quality, best practices, restoration

Caveats:

- Detailed design considerations and limitations for riparian areas, wetlands, and controlled drainage are provided within the report
- Caution is advised due to the application of data derived from small scale studies to entire watersheds-however larger scale studies are almost impossible to conduct in a controlled environment due to a number of economic and institutional reasons so
- Loss rates reported should be compared with caution, as, for example, on-site source reduction practices do not translate to an equivalent reduction in load to the Gulf of Mexico
- There is considerable delay and buffering within a watershed between, for example, the time fertilizer is applied and the time that nitrogen appears in the Gulf
- There is the question of whether other chemicals such as phosphorus or silicate are also co-limiting factors for algal growth along with nitrogen
- Catastrophic flooding could overwhelm any engineered solution to nitrate pollution
- Additional research needs are outlined to improve the knowledge base over time

Scale: Meso-Regional

Location:
Jurisdiction: Missouri, Illinois, Wisconsin, Minnesota, Iowa, Kansas, Nebraska, South Dakota, North Dakota, Wyoming, Montana
Ecoregion: Multiple
Basin: Mississippi River

Landscape Type/Pattern:
Land Use: agriculture, rural and urban settlement, managed forest and prairie, protected area, roads, oil and gas development, recreation
Landscape pattern: percent native, fragmentation, connectivity, linear disturbance, edge

Part of the Environment: Water quality

148. Citation: Feller, Michael C. "Forest harvesting and streamwater inorganic chemistry in western North America: a review." *Journal of the American Water Resources Association*, 2005: 785-811.

Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2005.tb03771.x/abstract

Synopsis: This paper presented a review of available literature from western North America that 1) integrate the influence of major factors on the chemical constituents of stream water; and 2) explain forest harvesting impacts on stream water chemistry. According to the article, important factors that control stream water chemistry include geological weathering, atmospheric precipitation and climate, precipitation acidity, terrestrial biologic process, physical/chemical reactions in the soil, and physical, chemical and biological processes within streams. The relative importance of each of these different factors on the concentration of different chemical constituents is shown in Table 2. The influence of forest age on nutrient concentrations in stream water is shown in Figure 1.

TABLE 2. The Relative Influence of Different Factors on the Concentration of Different Inorganic Chemicals Dissolved in Stream Water.

	Chemical Constituent														
Factor	Al^{3+}	C (CO_3^{2-}, HCO_3^-)	Ca^{2+}	Cl^-	Fe^{2+}	H^+	K^+	Mg^{2+}	Mn^{2+}	N (NO_3^-, NH_4^+)	Na^+	P (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	Si (Si-O forms)	SO_4^{2-}	Trace Metals (As, Cd, Cu, Ni, Pb, Se, Zn)
1. Geological weathering	i	*	*	x	*	m	*	*	*	m	*	i	*	m	m
2. Atmospheric precipitation/climate															
(a) Precipitation chemistry	*	i	i	m	i	*	i	i	i	*	i	m	i	*	i
(b) Hydrologic influences	*	*	i	*	*	i	m	i	*	i	*	m	i	*	*
(c) Temperature	*	*	*	x	*	m	*	*	*	*	*	i	*	m	m
3. Terrestrial biological processes															
(a) Chemical uptake	x	x	i	m	m	m	i	i	i	*	i	*	x	i	x
(b) Chemical transformations	x	m	x	x	x	i	x	x	x	*	x	x	x	i	i
(c) Production of soluble chemicals	x	m	m	x	m	m	m	m	m	i	m	i	x	m	x
4. Physical-chemical reactions in the soil	*	m	*	x	*	*	*	*	*	i	i	*	i	i	*
5. Processes within aquatic ecosystems															
(a) ion exchange reactions	i	x	i	x	i	i	i	i	i	m	i	i	x	m	*
(b) chemical redox reactions	m	x	x	x	i	x	x	x	i	i	x	x	x	m	m
(c) evaporation-crystallization	x	i	m	m	x	x	x	x	x	x	m	x	x	m	x
(d) pH-induced transformations	*	i	x	x	i	i	x	x	m	m	x	i	x	x	m
(e) uptake by primary producers	x	m	m	x	x	x	m	m	x	*	x	*	x	m	i
(f) microbial transformations	x	x	x	x	x	x	x	x	x	*	x	x	x	m	m

Notes: * is the primary and dominant factor; i is an important, but not a dominant factor; m is a factor with some, but relatively minor, influence; and x is a factor with little to no influence.

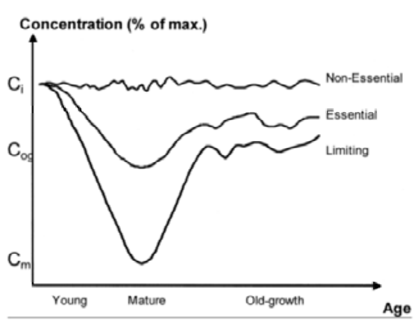


Figure 1. Nutrient Concentrations in Stream Water, Expressed as Percentage of the Maximum, as a Function of the Age of Vegetation in the Surrounding Watershed (adapted from Vitousek and Reiners, 1976).

The response of stream water chemistry to forest harvesting was explained through the major factors affecting stream water chemistry listed above. In general, forest harvesting can have the following effects:

- Increased geological weathering rates due to exposing land surfaces to greater temperature extremes and greater amounts of often more acidic water
- Decreased acidity of water passing through the soil as well as the acidity of stream water
- Initial increase in streamflow, depending on the extent of forest removal
- Increased summer soil surface temperatures and stream water temperatures
- Reduced nutrient uptake and, if plant uptake was a dominant process influencing stream water concentrations, then concentrations would respond according to Figure 1 above may increase nitrification
- Decreased organic matter and litter originating soluble chemical inputs into streams due to an initial decrease in litter producing riparian vegetation
- Increased anion exchange capacity of a soil as pH decreases
- Influence on most processes within aquatic ecosystems

According to the article, responses of stream water chemistry to forest harvesting are highly variable, and depending on site-specific characteristics, has the potential to increase, decrease or have no effect on the concentration in stream water for nearly every chemical considered as shown in Table 3 below.

TABLE 3. Initial Trends in Concentrations of Different Inorganic Chemicals Dissolved in Stream Water Resulting From the Impacts of Forest Harvesting on the Different Factors Controlling Stream Water Chemistry.

Factor	Al^{3+}	C (CO_3^{2-}, HCO_3^-)	Ca^{2+}	Cl^-	Fe^{2+}	H^+	K^+	Mg^{2+}	Mn^{2+}	N (NO_3^-, NH_4^+)	Na^+	P (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$)	Si (Si-O forms)	SO_4^{2-}	Trace Metals
1. Geological weathering	↑	↑	↑	–	↑	↓	↑	↑	↑	↑–	↑	↑	↑	↑	↑
2. Atmospheric precipitation/climate															
(a) Precipitation chemistry	↑–	↓–	↑–	–	↑–	↑–	↑–	↑–	↑–	↑–	↑–	↑–	↑–	↑–	↑–
(b) Hydrologic influences	↑↓	↑↓	↑↓	–	↑↓	↑↓	↑↓	↑↓	↑↓	–	↑↓	↑↓	↑↓	↑↓	↑↓
(c) Temperature	↑	↑	↑	–↑	↑	↑↓	↑	↑	↑	↑	↑	↑	↑	↑	↑–
3. Terrestrial biological processes															
(a) Chemical uptake	–	–	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	–	↑	–
(b) Chemical transformations	–	↑↓	–	–	–	↑↓	–	–	–	↑↓	–	–	–	↑↓	–
(c) Production of soluble chemicals	–	↑–	↑–	↑	↑–	↑–	↑–	↑–	↑–	↑–	↑–	↑–	–	↑–	↑–
4. Physical/chemical reactions in the soil	–	↓	–	↓–	–	↓–	–	–	–	↓–	–	↓–	–	↓–	–
5. Processes within aquatic ecosystems															
(a) ion exchange reactions	↑↓	–	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	–	↑↓	↑↓
(b) chemical redox reactions	↑↓	–	–	–	↑↓	–	–	–	↑↓	↑↓	–	–	–	↑↓	↑↓
(c) evaporation-crystallization															
(d) pH-induced transformations	↑–														
(e) uptake by primary producers	↓–	–	↓–	–	↓–	–	↓–	↓–	↓–	↓–	↓–	↓–	↓–	↓–	↓–
(f) microbial transformations	–	–	–	–	–	–	–	–	–	↑↓	–	–	–	↑↓	–

Notes: ↑ Effects lead to an increase in concentration; ↓ effects lead to a decrease in concentration; and – effects have little to no impact on concentration.

Important landscape pattern indicators related to forest harvesting discussed in the article included the following:

- Extent of the watershed harvested, as in general, the greater the percentage of trees cut in a watershed, the greater will be impacts on stream water chemistry

- Presence of uncut buffer strips between streams and harvested areas, with the efficiency of filtering by buffer strips increasing with buffer strip width
- Additional, more site-specific variables affecting the impacts of forest harvesting on downstream stream water chemistry included:
- Nature of site preparation following forest harvesting
- Rate of revegetation following forest harvesting
- Pre-harvesting chemical content of the soil (soil fertility)
- Buffering capacity of the soil

Keywords: aquatic ecology, biogeochemistry, forest harvesting, nutrients, stream water chemistry, water quality

Scale: Meso-regional

Location:
Jurisdiction: Western North America, plus some examples from eastern North America
Ecoregion: multiple

Landscape Type/Pattern:
Land Use: forest
Landscape pattern: percent forest cover, fragmentation

Part of the Environment: Water quality

149. Citation: Tobin, A, AA Khan, L Moores, and J Taylor. "Forestry Water Quality Index: a planning tool for the assessment and communication of the impacts of forestry activities on water quality." *The Forestry Chronicle* 83, no. 2 (2007): 207-214.

Link: www.env.gov.nl.ca/env/waterres/quality/.../207_2005_105_tobin.pdf

Synopsis: This paper describes the development and use of the Forest Water Quality Index (FWQI), an index to capture, to evaluate and communicate the impact of forestry activities on water quality. The FWQI was developed based on the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), and includes the use of historical pre-and post-forestry water quality data from similar watersheds. The data is used to predict the water quality in the watershed being evaluated for forestry by assuming that the predicted changes in water quality due to future forestry in the watershed of interest will be similar to changes experienced in a similar watershed that has already experienced forestry activities. Impacts in similar watersheds are analyzed to develop multipliers for factors of interest and then applied to the watershed being evaluated for forestry.

Keywords: Forest Water Quality Index, FWQI, sustainable forest management, water quality, Newfoundland and Labrador

Caveats: Predictions of water quality after forestry activities are dependent on accurate selection of a corresponding watershed. Each watershed of interest should have a set of multipliers developed to predict water quality.

Scale: Meso-regional

Location:
Jurisdiction: Newfoundland and Labrador
Ecoregion: Newfoundland Island

Landscape Type/Pattern:
Land Use: Forestry
Landscape pattern: fragmentation

Part of the Environment: Water quality

150. Citation: Weller, Donald E, Thomas E Jordan, and David L Cornell. "Heuristic models for material discharge from landscapes with riparian buffers." *Ecological Applications* 8, no. 4 (1998): 1156-1169.

Link: http://www.jstor.org/stable/2640969 .

Synopsis: This study analyzed the ecological effects of spatial patterning and heterogeneity in regards to water quality in riparian systems. Researchers developed and analyzed models predicting landscape discharge based on material release by an uphill source area, the spatial distribution of riparian buffers along a stream, and retention within the buffer. Variation in buffer width and continuity were considered in order to quantify the relative contributions of source elimination and buffer retention to total discharge reduction. Results indicate that width variability reduces total buffer retention. Variable-width buffers are less efficient than uniform-width buffers because transport through areas of below-average buffer width, especially through gap areas, overwhelms the system's capacity for discharge reduction. Results were statistically simplified in order to suite larger scale landscapes, rendering the following general conclusions: for un-retentive buffers, average width is the best predictor of landscape discharge, while the frequency of gaps was best for narrow, retentive buffers.

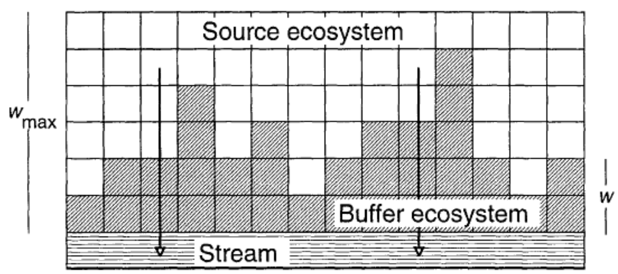


Figure 1. Conceptual model of a landscape with a riparian buffer. The landscape is divided into a grid, and cells along the stream are occupied by the buffer ecosystem. Water and materials flow downhill from the source ecosystem, through the buffer, and to the stream

Keywords: grid cell; landscape ecology; landscape index; model; nonpoint source pollution; nutrient discharge; raster; riparian buffer; riparian management; scaling; sediment discharge; water quality

Caveats: Tests with landscape and water quality data are needed to determine whether results for different predictors are robust in real landscapes where some model assumptions may not apply.

Scale: applicable to sub-regional and regional scales

Location: model based
Jurisdiction: n/a
Ecoregion: n/a

Landscape Type/Pattern:
Land Use: hypothetically, agriculture and grazing
Landscape pattern: fragmentation, connectivity, edge

Part of the Environment: Riparian systems, water quality, ecosystem services (regulating water quality).

151. Citation: United States Trust for Public Lands and American Water Works Association, 2004.Protecting the Source: Land Conservation and the Future of America's Drinking Water. US Trust for Public Land and American Water Works Association.

Link: http://www.tpl.org/publications/books-reports/report-protecting-the-source.html

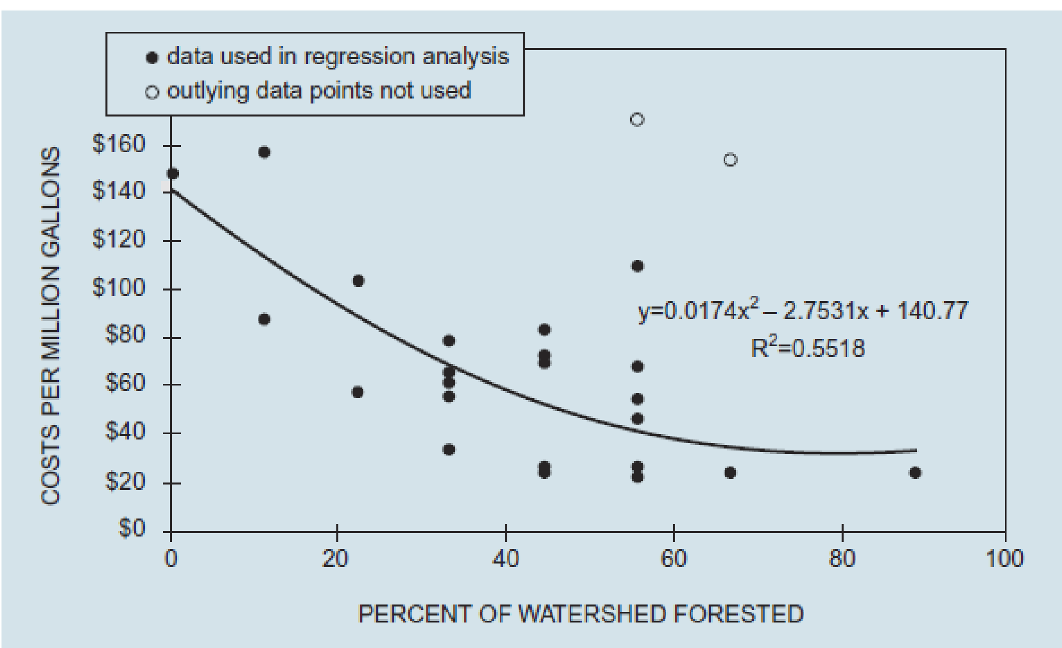
Synopsis: This is a very useful document that synthesizes scientific, planning, and policy-related aspects on the importance of land conservation in areas producing water for potable uses, including watersheds and aquifers. The document includes the following components:

- Importance of a multiple-barrier approach to drinking water protection and the role of land conservation in source protection
- A step by step approach for understanding a watershed and providing a foundation for an effective source protection plan
- Suggested methods to prioritize lands for protection based on landscape patterns, including generalized GIS overlay procedures and examples for a Surface Water Conservation Priority Index, and a Groundwater Conservation Priority Index
- A discussion of Pollution Mitigation Potential provided by different ecosystem types, including small streams, riparian zones, forests, wetlands, and floodplains
- Comprehensive decision support for planning, land conservation, regulatory and design tools, incorporation of best management practices, implementation, financing, and management
- Case Studies of innovative source water protection plans that have been implemented throughout the United States

One particularly useful component of the study was the discussion of a regression analysis of 27 water suppliers, which found that the more forest cover in a watershed, the lower the treatment costs. According to the study:

- Approximately 50-55% of variation in water treatment costs can be explained by the percent of forest cover in the source area
- For every 10% increase in forest cover in the source area, treatment and chemical costs decreased by about 20%, up to about 60% forest cover

The study did not gather enough data on suppliers with >65% forest cover to draw any conclusions; however, it is suspected that treatment costs level off when forest cover is somewhere between 70-100%



Keywords: source protection, watershed, prioritization

Caveats: The data in the figure regarding percent of watershed forested is based on average production of surveyed suppliers. There is remaining high variation in treatment costs that cannot be explained by % forest cover. Other factors that likely can explain this variation include varying treatment practices, the size of the facility, the location and intensity of development and row crops in the watershed, and agricultural, urban, and forestry management practices. Land use activities including increased development, poor forestry practices, mining or intensive farming within the watershed can affect key water quality variables of concern, including turbidity and the presence of microorganisms.

The impact of development and loss of forestland on water quality happens over time and is usually greatest during periods of heavy rainfall. At first, heavy pollutant loads are isolated events during storms. Gradually, larger and more complex pollutant loads appear with greater frequency and severity until an acute event or revised water quality regulations cause suppliers to alter treatment strategies or upgrade facilities.

Scale: National

Location:
Jurisdiction: United States
Ecoregion: Multiple

Landscape Type/Pattern:
Land Use: Multiple
Landscape pattern: Multiple, including fragmentation, connectivity, linear disturbance, edge, and percent native/converted

Part of the Environment: Water quantity, water quality, groundwater quantity, groundwater quality, riparian systems, ecosystem services (water supply provisioning)

152. Citation: Freeman, J., R. Madsen, K.Hart et al. 2008. Statistical Analysis of Drinking Water Treatment Plant Costs, Source Water Quality, and Land Cover Characteristics. United States Trust for Public Land.

Link: http://cloud.tpl.org/pubs/landwater_9_2008_whitepaper.pdf

Synopsis: Revisiting an earlier study conducted by The Trust for Public Land in 2004, this research brings new data and methodologies to offer insight on the impact of the decline of forest cover on drinking water treatment costs. It also examines the increase of agriculture or urban land cover in a drinking water source drainage area on both water quality and drinking water treatment costs. The relationship of a 100 foot and 300-foot buffer of the water bodies in the source watershed were also tested separately.

Overall, this study found statistically significant relationships among source water quality, percent land cover, and drinking water treatment cost. Increased percent agriculture and urban cover were significantly related to decreased water quality, while decreased forest land cover was significantly related to decreased water quality. Further, low water quality was related to higher treatment cost. High percent land cover by non-forest vegetation was significantly related to low treatment cost, while high percent land cover by urban area was related to high treatment cost.

Keywords: water quality, drinking water, water treatment, forest cover, land use cover, watershed

Caveats: The data exhibited very high variability, indicating possibly unaccounted constraining factors – such as the differences in water treatment plant practices/processes and hydrological, geological, and regional differences. There are numerous possible reasons for the high variability shown in the data, which may provide further consideration and guidance to those who wish to endeavor further study in this field as discussed in the paper. In particular, the land cover statistics used did not capture the effects of location of specific land cover types and relative loading rates in each watershed, which may greatly affect the water quality. For example, the statistic may be that 60% of the watershed is forested, 30% is agriculture, and 10% is urban. In one watershed, the headwaters are forested, there are fields and pastures in the middle, and there is a city in the lower reaches of the watershed near the drinking water intake. However, the exact same set of statistics could be associated with a different signature in another watershed such that all the riparian buffers are forested, and the agricultural land and urban land is dispersed in clusters. Although two watersheds may have the same percentage of land cover types, the latter has significantly better water quality. The statistical method in this study did not account for the spatial pattern of land cover that impacts the water quality.

Scale: Data taken from individual sites (treatment plants), but results are meant to inform planning at a regional scale.

Location:
Jurisdiction: New England/Mid-Atlantic states
Ecoregion: Northern Appalachian and Atlantic Maritime Highlands, Eastern Great Lakes and Hudson Lowlands, Northeastern Coastal Zone, Maine and New Brunswick Plains and Uplands, Northern Appalachian Plateau and Uplands

Landscape Type/Pattern:
Land Use: urban and suburban settlement
Landscape pattern: percent forested, percent land use (agriculture and impervious).

Part of the Environment: Water quality, ecosystem services (water quality provisioning).

153. Citation: Dodds, WK, and RM Oakes. "Headwater Influences on Downstream Water Quality." *Environmental Management* 41 (2008): 367-377.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1007/s00267-007-9033-y

Synopsis: The authors investigated the influence of riparian and entire watershed land use as a function of stream size on surface water chemistry, and assessed regional variation in these relationships. Sixty-eight small watersheds (mean watershed area 280 km2) were identified in four level III USEPA ecoregions across eastern Kansas. Riparian land cover and watershed land use were quantified for the entire watershed using Geographic Information Systems. Riparian land cover was assessed at four spatial scales: (A) land cover in the whole watershed, (B) land cover adjacent to first-order streams of watersheds, and (C) land cover 2 km upstream of the water chemistry sampling point, and (D) land cover 4 km upstream of the sampling point. Water chemistry data were collected and analyzed by the Kansas Department of Health and Environment as part of their stream chemistry monitoring network. Total nitrogen, nitrate, ammonium, total phosphorus, total suspended solids, atrazine, faecal coliform bacteria, and dissolved oxygen data were used to assess the impact of riparian land cover on water chemistry. Samples are collected every 2 months.

Multiple regression analyses using riparian land cover classifications as independent variables explained among-site variation in water chemistry parameters, particularly total nitrogen (41%), nitrate (61%), and total phosphorus (63%) concentrations. Whole watershed land use explained slightly less variance, but riparian and whole watershed land use were so tightly correlated that it was difficult to separate their effects. Water chemistry parameters sampled in downstream reaches were most closely correlated with riparian land cover adjacent to the smallest (first-order) streams of watersheds or land use in the entire watershed, with riparian zones immediately upstream of sampling sites offering less explanatory power as stream size increased. Interestingly, headwater effects were evident even at times when these small streams were unlikely to be flowing. Relationships were similar among ecoregions, indicating that land use characteristics were most responsible for water quality variation among watersheds. These findings suggest that nonpoint pollution control strategies should consider the influence of small upland streams and protection of downstream riparian zones alone is insufficient to protect water quality.

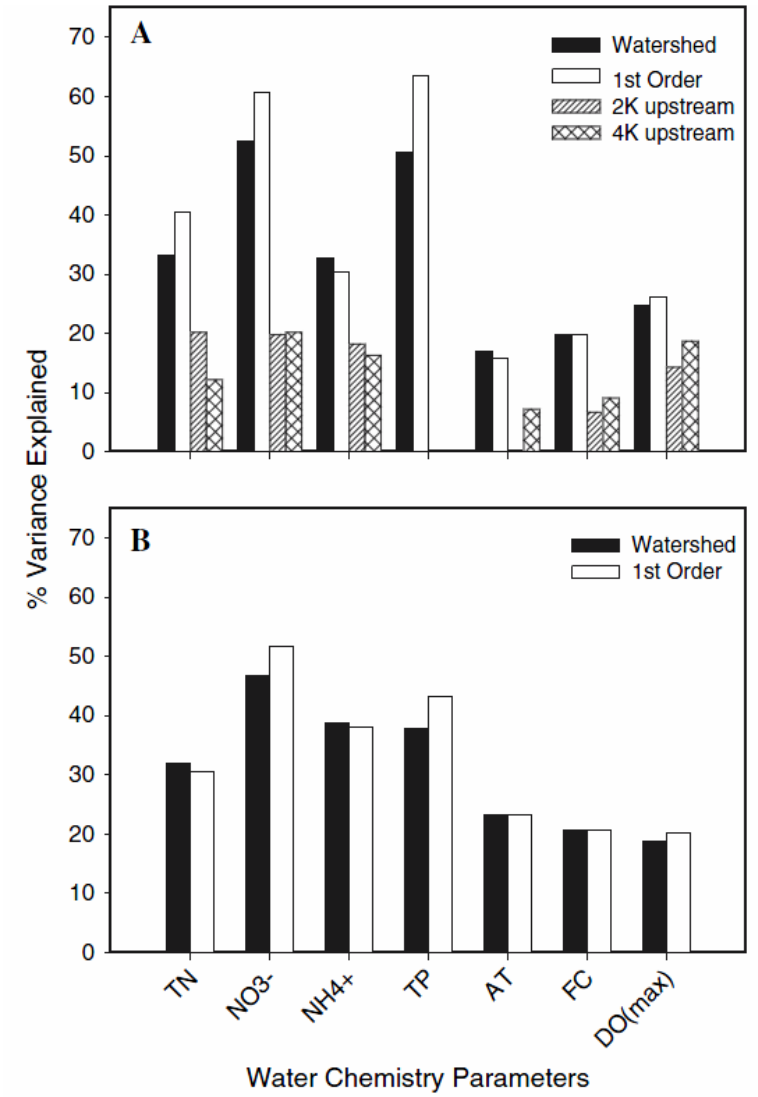


Fig. 3 Variance in water chemistry variables (R^2 values) accounted for by (**A**) land cover in the riparian ecotone (33 m) at multiple scales and (**B**) catchment land cover at two scales, using multiple linear regression analyses. TN analyses based on 57 watersheds; all other analyses based on 68 watersheds. Bars for R^2 values were not plotted when there was not a significant relationship ($p > 0.05$)

Keywords: water quality, Geographic Information Systems, headwater streams, nonpoint source pollution, riparian zones, watershed management

Caveats: Although whole watershed land use explained slightly less variance, riparian and whole watershed land use were so tightly correlated it was difficult to separate their effects. Results suggest a statistically significant effect of riparian cover of first order streams on water quality because partial correlations among riparian land cover classifications were significant predictors in regression models when controlling for predictor catchment land cover classifications. We take the conservative approach in our interpretation, but it is possible that riparian cover has much stronger effects than whole-watershed land cover and that most of the correlation is driven by riparian effects.

Several other studies have addressed the relative importance of riparian versus whole catchment land use in regulating water quality and reports in the literature have been mixed.

Scale: Regional

Location:
Jurisdiction: Kansas
Ecoregions: Central Great Plains, Flint Hills, Central Irregular Plains, Western Corn Belt Plains

Landscape Type/Pattern:
Land Use: Cropland agriculture, prairie, oak hickory forests
Landscape pattern: Variable

Part of the Environment: Water quality, ecosystem intactness

154. Citation Arnold, Chester L, and James C Gibbons. "Impervious surface coverage: the emergence of a key environmental indicator." *Journal of the American Planning Association*, 62, no.2 (1996): 243-258.

Link: http://dx.doi.org/10.1080/01944369608975688

Synopsis: This paper reviewed the application of impervious land cover as an environmental indicator for water resource protection and proposed a framework to enable regional and municipal governments to use the indicator during the planning process. A review of scientific literature established that impervious surface coverage is directly related to water quality impacts, such that water quality decreases as imperviousness increases. The review identified generally accepted threshold values of imperviousness on overall stream health, as follows: protected (less than 10%), impacted (10% - 30%), and degraded (more than 30%). To achieve water quality objectives, the study suggests using imperviousness as a general indicator of potential development impacts on water resources when making land use decisions. The indicator can be used to identify development patterns that will protect water quality, ranging from impervious surface analyses at the watershed level to direct regional growth planning to site planning decisions designed to mimic natural hydrologic functions at the stream level. The indicator can also be used to develop regulations to further achieve environmental planning objectives. The paper also briefly reviewed case studies to illustrate the application of the indicator, but did not examine in detail its relative success or failure. The paper concludes by suggesting that the use of the indicator can functionally integrate concerns about water quality into a host of planning decisions ranging from transportation and land use to design and economic development.

Governance regime: Regional or municipal governments

Keywords: environmental indicator, community planning, land use regulation, water resource protection, urbanization

Caveats: The thresholds identified in this study are based on a generalized relationship between water quality and impervious coverage derived from the authors' review of scientific literature of stream health evaluation. No primary research on the ecological impacts of imperviousness, or on the relative success or failure of adopting the indicator, was directly undertaken for this paper.

Scale: Regional; local/site

Location:
Jurisdiction: United States (municipal and regional governments)
Ecoregion: watersheds

Landscape Type/Pattern:
Land Use: Settlement (urban/suburban)
Landscape pattern: percent of landscape covered

Part of the Environment: Water quality

155. Citation: Lorenz, K.N., Depoe, S.L., and Phelan, C.A. 2008. Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project. Volume 3: AESA Water Quality Monitoring Project. Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada. 487 pp.

Link:
http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr12914/$FILE/vol3_aesa_waterqualitymonitoringproject_rtw.pdf

Synopsis:
This report summarizes studies on the impacts of agricultural land use on water quality within Alberta. The report compiles and evaluates a range of water quality and quantity data collected from 1995 to 2006 on the impacts of agriculture on water quality, in 23 small, representative agricultural watersheds across Alberta. The study clearly found that the impacts of agricultural activities on water quality depend strongly on the amount and distribution of land under cultivation, as well as other measures of agricultural intensity such as fertilizer expenses, chemical expenses and animal unit densities. Generally, streams draining watersheds with more agriculture had higher concentrations of nutrients, bacteria, and pesticides. Other factors, such as farming practices, soil type, topography, weather and climate patterns also influenced water quality. Additional more detailed findings of the study included:

- Nutrients
- – Small to moderately sized agricultural watersheds (3200-95000 ha effective drainage area) have elevated levels of P and N, and concentrations increase as agricultural intensity increases
- – Compliance with provincial and national surface water quality guidelines for nutrients decreased with increasing agricultural intensity (e.g., in high intensity watersheds, only 9% of total nitrogen samples and 7% of total phosphorus samples met guideline values)
- – Mean Total Phosphorus (flow weighted means) was 0.15 mg/L for watersheds with low agricultural intensity, and 0.53 mg/L for high intensity watersheds
- – Mean Total Nitrogen (flow weighted means) was 1.09 mg/L for low intensity watersheds, and 3.12 mg/L for high intensity watersheds
- Bacteria
- – Peaks in faecal bacteria occasionally occur in agricultural streams and may indicate a risk to human or animal health
- – The highest risk of faecal contamination occurred in watersheds in the Grasslands Natural Region in Southern Alberta
- – Faecal bacteria annually were typically <100 CFU/100 mL, although extreme peaks (>1000 CFU/100 mL) occurred, most often in summer months in association with peaks in discharge or suspended sediment. However, based on the data the agricultural intensity metric was not a good predictor of streams with the highest risk of faecal contamination
- Pesticides
- – Low level concentrations of a variety of pesticides were commonly found in surface waters of agricultural watersheds
- – Pesticide detection frequency, total pesticide concentrations, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high
- – Eight pesticide compounds were detected solely in watersheds under irrigated agriculture
- – Guidelines for the protection of aquatic life for pesticides were exceeded in some samples (most frequently for MCPA and dicamba)
- – Correlations between dissolved nutrient fractions and the overall agricultural intensity metric supported the use of the metric as an indicator of agricultural influence on nutrient concentrations

- Correlations between total pesticide detection frequency and the overall agricultural intensity metric supported the use of the metric to predict pesticide contamination in small agricultural watersheds

Keywords: agriculture, water quality, nutrients, bacteria, pesticides, agricultural intensity

Caveats: Export coefficients were influenced by climatic and geographic characteristics including interannual and seasonal variations in stream flow, which differed among ecoregions**.** Seasonal and interannual variability was observed in most watersheds for the majority of parameters

Scale: Sub-regional- small agricultural watersheds (32 km2 to 1370 km2)

Location:
Jurisdiction: Alberta
Ecoregion: Grassland, Parkland, Boreal
Basins: Peace River, Athabasca River, North Saskatchewan River, Red Deer River, Battle River, Bow River, South Saskatchewan River, Oldman River
Subbasins: Hines Creek, Paddle River, Prairie Blood Coulee, Rose Creek, Willow Creek, Blindman River, Grande Prairie Creek, Kleskun Drain, Meadow Creek, Tomahawk Creek, Trout Creek, Buffalo Creek, Haynes Creek, Ray Creek, Renwick Creek, Strawberry Creek, Stretton Creek, Threehills Creek, Wabash Creek, Battersea Drain, Crowfoot Creek, Drain S6, New West Coulee

Landscape Type/Pattern:
Land Use: Agriculture
Landscape pattern: Amount of Agriculture

Part of the Environment: Water quality, water quantity

156. Citation: AENV. Indicators for Assessing Environmental Performance of Watersheds in Southern Alberta. Assessment report, Edmonton, Alberta: Alberta Environment, 2008a.

Link: http://environment.gov.ab.ca/info/library/7945.pdf

Synopsis: This report identifies and describes generic condition and pressure indicators for land, water quantity, water quality, and aquatic and riparian systems, as well as their relationships to environmental outcomes. The document presents this information as a series of categorized indicators of environmental quality. These broadly include: land quality condition indicators, land use pressure indicators, water quantity pressure indicators, water quality pressure indicators, and indicators of aquatic and riparian ecosystem health. Many of these indicators relate directly to the linkage between landscape pattern (such as the amount of land in a watershed covered by natural cover types) and water quality. Land use is given special consideration as an indicator or environmental quality. All information relating to patterns of human activity are reported separately for areas of watersheds within 500m of water bodies. The information compiled in this report is intended to assist land use managers in setting targets for planning and conservation in Alberta's watersheds.

Keywords: Indicators, environmental outcomes, water quality, water quantity, land use, watershed, riparian and aquatic systems, Alberta.

Scale: Meso-regional

Location:
Jurisdiction: Alberta
Ecoregion: Clear Hills and Western Alberta Uplands, Mid-Boreal Uplands and Peace Wabaska Lowlands; Aspen Parkland/Northern Glaciated Plains, Northwestern Glaciated Plains, Canadian Rockies, Hay and Slave River Lowlands

Landscape Type/Pattern:
Land Use: agriculture, grazing, rural and urban settlement, roads, oil and gas development, recreation
Landscape pattern: percent native, linear disturbance, fragmentation, connectivity

Part of the Environment: Water quantity, water quality, riparian systems, biodiversity indices, ecosystem health and functionality/intactness

157. Citation: Alberta Environment and Sustainable Resource Development (AESRD). Guide to Reporting on Common Indicators Used in State of the Watershed Reports. Watershed Report, Edmonton: Government of Alberta, 2012.

Link: http://environment.gov.ab.ca/info/library/8713.pdf

Synopsis: This document serves as a guide to consistent reporting for Alberta's State of the Watershed Reports. It outlines a framework for reporting watershed conditions by providing specific criteria and direction to guide the universal shape, accessibility, and applicability of the State of the Watershed reports for watershed groups throughout the province of Alberta. The suggested framework includes major indicators of watershed health applicable to the following areas: surface water quality, surface water quantity, groundwater quantity, landscape, and the biological community. The section on landscape provides particularly relevant information on the influence of land cover and land use pattern on watershed health, and provides a series of helpful road density thresholds for wildlife to be incorporated into land use planning and management targets.

Among these thresholds are a series of road density thresholds for:

Grizzly bears: grizzly bears- 0.4 km/km2

Elk: 0.62 km/km2

Black bears: 1.25 km/km2

Bull trout: 0.0-0.1 km/km2 = low risk; 0.1-0.2 km/km2 = moderate risk; 0.2-0.6 km/km2 = high risk; 0.6-1.0 km/km2 = very high risk; >1.0 km/km2 = extirpation.

In addition, the report identifies general road density threshold indicators for watershed health: <2km/km2 = good; 2-3km/km2= fair; >3km/km2 = poor*.

Keywords: Watersheds, Alberta, environmental indicators, water quality, water quantity, groundwater, riparian systems, land cover, State of the Watershed reporting

Caveats: The indicators identified in this report are not a prescriptive suite of essential indicators, but a subset of more conventional indicators from which to build a comprehensive assessment of overall watershed health. Developing a broadly acceptable suite of indicators will require further refinement. This guide, in its current format, is designed to encourage consistency rather than standardization.

* These general thresholds for watershed health have been documented in several recent state of the watershed reports produced by watershed groups in Alberta. However, they may not be appropriate in all watershed or sub-watersheds. Groups undertaking these assessments should seriously consider watershed specific characteristics and objectives, and seek expert advice to assist with selecting measures and thresholds.

Scale: Meso-regional

Location:
Jurisdiction: Alberta
Ecoregion: 5.4.2-Clear Hills and Western Alberta Uplands, 5.4.1-Mid-Boreal Uplands and Peace Wabaska Lowlands; 9.2.1-Aspen Parkland/Northern Glaciated Plains, 9.3.1-Northwestern Glaciated Plains, 6.2.4-Canadian Rockies, 3.3.2-Hay and Slave River Lowlands

Landscape Type/Pattern:
Land Use: agriculture, grazing, rural and urban settlement, roads, oil and gas development, recreation
Landscape pattern: percent native, linear disturbance, fragmentation, connectivity, edge

Part of the Environment: Water quantity, water quality, riparian systems, biodiversity indices, ecosystem health and functionality/intactness

158. Citation: Andrews, Daniel. Water Quality Study of Waiparous Creek, Fallentimber Creek, and Ghost River. Technical Report, Calgary, Alberta: Alberta Environment, 2006.
Link: http://environment.gov.ab.ca/info/library/7763.pdf

Synopsis: This report provides a baseline prior to implementation of an Access Management Plan in response to concerns that increased usage of the Ghost-Waiparous basin for random camping and off-highway vehicles have impacted water quality. Sediment loading coefficients in the lower regions of the Waiparous and Ghost rivers were much greater than would be expected in rivers draining a similar forested environment in the upper foothills of southern Alberta and were even greater than loading coefficients in streams draining agricultural lands at lower elevations where sediment erosion is a common problem.

Keywords: Sediment loading, erosion, water quality, forest cover, agriculture

Caveats: A weight of evidence was used to link recreational activities with the large increase in sediment load between the upstream and downstream monitoring stations.

Scale: Sub-regional

Location:
Jurisdiction: Southern Alberta
Ecoregion: Northwest Glaciated Plains
Basin: South Saskatchewan
Subbasin: Ghost-Waiparous basin

Landscape Type/Pattern:
Land Use: random camping, off-highway vehicle (OHV) use
Landscape pattern: Fragmentation, linear disturbance

Part of the Environment: Ecosystem functionality/intactness, water quality

159. Citation: Fowler, W.B.; Anderson, T.D.; Helvey, J.D. 1988. Changes in water quality and climate after forest harvest in central Washington State. Res. Pap. PNW-RP-388. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Link: www.fs.fed.us/pnw/pubs/pnw_rp388.pdf

Synopsis: This study assessed chemical concentrations, climatic change, and turbidity and sediment production after forest harvesting in 5 treatment watersheds in central Washington State. A control watershed was also assessed. Harvesting methods included longspan skyline and helicopter logging. Water sampling was conducted during April to October for 3 pre-treatment and 3 post-treatment years. Chemical concentrations of nitrate, calcium, magnesium, sodium, potassium and organic nitrogen were measured for the 6 watersheds. Regression analysis showed no significance difference between pre-harvest and post-harvest concentrations except for calcium which was 5 times higher and sodium which was 20 times higher in the harvested watersheds. Concentrations declined over the 3 year post-harvest span. Turbidity and suspended sediment were measured adjacent to a road construction site. They increased with road construction but declined rapidly to nearly background levels after 2 years. Air temperature increased after harvesting in all of the smaller watersheds but stream temperature was not affected. It was found that clearcutting only portions of watersheds reduces harvest impact on all nutrient outputs. The harvesting methods used were determined to be effective in protecting the water resources from unacceptable damage.

Keywords: Water quality, sediment production, temperature, logging effects, Washington.

Scale: Local/site

Location:
Jurisdiction: Washington State
Ecoregion: Columbia Plateau
Basin: Columbia River

Landscape Type/Pattern:
Land Use: Forestry
Landscape pattern: fragmentation

Part of the Environment: water quality

160. Citation: O2 Planning + Design Inc. Background Technical Report on Riparian Areas, Wetlands, and Land Use. Technical Report, Red Deer River Watershed Alliance, 2013.

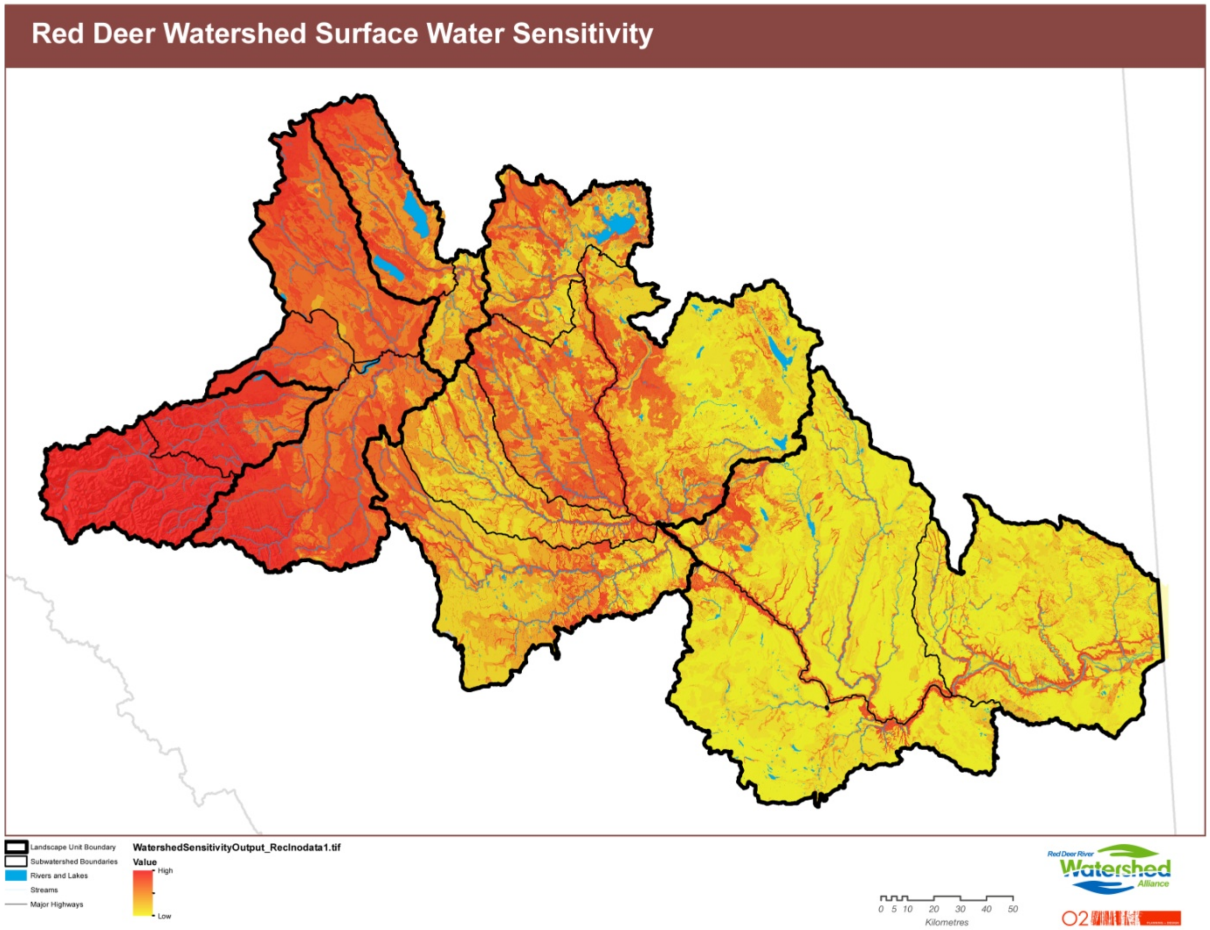
Link: http://www.rdrwa.ca/node/5

Synopsis: Focused on developing draft outcomes, indicators, and targets for the Red Deer River Basin in three topic areas: (i) wetlands, (ii) riparian areas, and (iii) land use. For each topic, goal and outcome statements were developed, followed by recommendations on key environmental, social, and programmatic indicators and associated targets. Targets established were based on a detailed literature review, combined with Geographic Information Systems (GIS) queries of existing conditions. Separate targets were recommended for different landscape units in the watershed to reflect differences in dominant land use issues and natural patterns. Examples of indicators and associated targets in the report related specifically to landscape patterns and environmental quality included:

- Wetland cover: >7.5% in the watershed
- Peatland cover :> 6.0% in the Upper Headwaters
- 82% of all riparian areas (variable width) in the watershed should have perennial vegetation cover
- 97% of all riparian areas (variable width) in the Upper Headwaters should have perennial vegetation cover
- Riparian areas assessed that are considered to be “Healthy”: >30%
- Riparian areas along the Little Red Deer River main stem considered to be “Healthy”: >60%
- Number of farms using grassed buffers as a Best Management Practice (Stats Canada): >50%
- Total Natural Land Cover in the watershed: >44%
- Total Natural Land Cover in the Upper Headwaters: >87%
- Impervious Areas in the Waskasoo subwatershed: <10%
- Linear Density of roads/railways in the watershed: <0.40 km/km2
- Linear Density of roads/railways in the Upper Headwaters: 0.25 km/ km2

A range of social and programmatic indicators were also established to support plan development and implementation and achievement of the recommended watershed-based environmental quality targets.

Another key component of this study was a GIS overlay exercise conducted to map the sensitivity of the watershed to non-point source contamination. Slope, annual water yield, erosion risk potential, non-contributing areas, riparian area location and condition, and floodplain were all combined together. The map indicates which parts of the watershed have the highest risk of exporting non-point source contaminants (e.g., sediments, excessive nutrients, etc.) downstream if current or future resource extraction activities occur. This exercise represents a key concept regarding landscape patterns and watershed environmental quality: where land use activities coincide with areas of higher sensitivity, environmental quality is likely to be affected. Conversely, if land use activities are oriented in patterns that avoid more sensitive areas, environmental quality is likely to be maintained or improved.



Keywords: Watershed management, wetlands, water quality, riparian areas, land use, ecosystem services

Scale: Sub-regional (Red Deer Watershed Basin)

Location:
Jurisdiction: Alberta
Ecoregion: Northwest glaciated plains, northern glaciated plains
Basin: Red Deer River

Landscape Type/Pattern:
Land Use: agriculture, settlement, forest, and prairie
Landscape Pattern: fragmentation, linear disturbance, connectivity

Part of the Environment: Water quality, riparian systems, wetlands, ecosystem services

161. Citation: Stewart, Jana S, Lizhu Wang, John Lyons, Judy A Horwatich, and Roger Bannerman. "Influences of watershed, riparian corridor, and reach scale characteristics on aquatic biota in agricultural watersheds." *Journal of American Water Resources Association* 37, no. 6 (2001): 1475-1487.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1111/j.1752-1688.2001.tb03655.x/pdf

Synopsis: This study aimed to identify the importance of continuity and width of in riparian corridor in influencing the health of fish populations and water quality. Multivariate analyses and correlations revealed strong relations between watershed health and riparian-corridor land cover. Correlations between land cover, habitat, and stream-quality indicators revealed significant relations at the watershed, riparian corridor, and reach scales. Higher percentages of forest cover within the watershed and within a 30m buffer (riparian corridor scale) were related to healthy fish communities and water quality, while near stream grasslands and urban land cover in the watershed contributed negatively to the health of fish communities and water quality. Fish density increased with increase in the average length of riparian vegetation without gaps (>30m). Streams with higher percentages of forested land and non-forested wetlands in the watershed and forested land within a 10 m buffer has less organic and sediment pollution. Biotic integrity declined as riparian vegetation became more fragmented.

Keywords: riparian; aquatic biota; agriculture; watershed; land cover; biotic integrity

Caveats: The results from near stream grasslands were somewhat confounding because it was often difficult to determine if land adjacent to the stream was natural vegetation or used as pasture.

Scale: sub-regional (individual watersheds)

Location:
Jurisdiction: Wisconsin
Ecoregion: Southeastern Wisconsin Till Plains

Landscape Type/Pattern:
Land Use: Agriculture
Landscape pattern: edge, fragmentation, connectivity of riparian corridors, percent native land cover

Part of the Environment: Water quality, riparian systems, biodiversity indices

162. Citation: Booth, Derek B, and Rhett C Jackson. "Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation." *Journal of the American Water Resources Association* , 33, no. 5 (1997): 1077-1090.

Link: http://onlinelibrary.wiley.com.ezproxy.lib.ucalgary.ca/doi/10.1111/j.1752-1688.1997.tb04126.x/pdf

Synopsis: The study examined the limits of regulatory thresholds and on-site retention mitigation for managing the impacts of urbanization on aquatic system degradation. Watershed research showed that approximately 10% effective impervious area (EIA) typically yields demonstrable loss of ecosystem function. 10% EIA is the typical regulatory threshold for the application of mitigation to land development activities. The study evaluated the effectiveness of on-site detention facilities, the most common mitigation measure, by assessing performance of retention/detention (R/D) ponds. The results showed that mitigation is effective when design policy is sufficiently robust and design analysis accurately predicts true performance of the facility. However, the research found that about 10% of development within a watershed falls below the regulatory threshold and is therefore not subject to drainage regulations. At issue is that the cumulative impacts of this 10% unregulated development can significantly degrade aquatic systems. The study concluded that a better process-based understanding of urbanization impacts on aquatic systems is required to develop flexible development process controls that can be applied to all developments. Without regulations that can address cumulative impacts, the only truly effective policy option is to impose strict development limits within watersheds.

Keywords: water quality, water quantity, urbanization, watershed, mitigation, regulatory thresholds

Caveats: The study cautions against the use of discrete “thresholds” to predict specific physical and biological effects, but does suggest that thresholds are appropriate indicators for when the perception and tolerance of watershed impacts triggers a regulatory response.

Scale: sub regional

Location:
Jurisdiction: Western Washington
Ecoregion: Coastal Range

Landscape Type/Pattern:
Land Use: Settlement (urban/suburban)
Landscape pattern: percent of landscape covered

Part of the Environment: Water quality, water quantity, riparian systems, ecosystem services

163. Citation: Adams, PW, and M Taratoot. *Municipal Water Supplies from Forest Watersheds in Oregon: Fact Book and Catalog.* Technical, Portland, Oregon: Oregon State University, 2001.

Link: http://water.oregonstate.edu/roundtables/download/Adams&Taratoot.pdf

Synopsis: This paper reviews how forests and their management affect the quality and quantity of downstream municipal water supplies in the state of Oregon. Key noteworthy facts compiled included:

- Water quality from forested lands in Oregon is generally very high
- Forests typically result in significant water loss through canopy interception and evapotranspiration
- High sediment levels can occur in streams in undisturbed forest watersheds in Oregon, especially during large storms that can cause natural erosion on hillslopes or in stream channels
- Typically, timber harvest increases local streamflow, while afforestation decreases local streamflow
- A measurable increase in annual streamflows from forest watersheds in Oregon is unlikely unless a large portion (>25%) of a watershed's area is clearcut over a short period of several months.
- Streamwater temperatures will often increase where timber harvest or other practices remove vegetation; recovery of cool temperatures can occur when revegetation restores shade
- Timber harvest and related practices (e.g., slash burning) can increase stream sedimentation if soil is exposed near streams; maintaining streamside vegetation or reducing soil disturbance can reduce this effect
- Natural erosion can be an important sediment source and difficult to distinguish from management sources
- Rapid revegetation and favourable soil properties and climate patterns in western Oregon appear to greatly limit nutrient losses to streams following timber harvest
- Manufactured chemicals (e.g., pesticides) are most likely to enter streams during direct application to stream channels, and measures to control such entry can reduce or eliminate stream contamination
- Landslides can occur in both logged areas and undisturbed mature forests in unstable terrain; although landslide rates can increase shortly after timber harvest
- Forest roads can increase landslides and other erosion in steep terrain, but this can be greatly reduced with improved road location, design, and maintenance
- Streamside alder stands can reduce the quality of domestic water supplies when extended low flows combine with heavy leaf fall; effective chlorination of such water can require more chlorine and produce undesirable chemical by-products

Keywords: Water supplies, forest management, water quality

Caveats: In some cases, historical research on the effects of forest practices does not reflect available technology or management methods not commonly in use or required by law

Scale: Sub-regional

Location:
Jurisdiction: Oregon
Ecoregion: Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Klamath Mountains, Coast Range, Willamette Valley, Columbia Plateau, Northern Basin and Range

Landscape Type/Pattern:
Land Use: Managed forest, logging
Landscape pattern: Percent clearcut, edge (riparian buffers)

Part of the Environment: Water quantity, water quality, riparian systems, ecosystem services (water supply provisioning)

164. Citation: Naugle, David E, Kenneth F Higgins, Sarah M Nusser, and Carter W Johnson. "Scale dependent habitat use in three species of prairie wetland birds." *Landscape Ecology*14 (1999): 267-276.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1023/a:1008088429081

Synopsis: This study investigated the influence of landscape heterogeneity and scale on nesting and foraging patterns amongst prairie wetland birds in South Dakota. Yellow-headed blackbirds commonly nested in small wetlands, whereas pied-billed grebes were a more area-sensitive species that used larger wetlands regardless of landscape pattern. Area requirements for black terns, a vagile species that typically forages up to 4 km away from the nest wetland, fluctuated in response to landscape structure. Black tern area requirements were small (6.5 ha) in heterogeneous landscapes compared to those in homogeneous landscapes (15.4–32.6 ha). Low wetland density landscapes composed of small wetlands, where few nesting wetlands occurred and potential food sources were spread over large distances, were not widely used by black terns. In summary, this study presents empirical evidence that characteristics of entire landscapes, rather than individual patches, must be quantified to assess habitat suitability for wide-ranging species that use resources over larger areas.

Keywords: landscape structure, matrix, patches, prairie wetland birds, scale, South Dakota

Scale: Sub-regional

Location:
Jurisdiction: South Dakota
Ecoregion: Northwestern Great Plains

Landscape Type/Pattern:
Land Use: grazing, agriculture
Landscape pattern: edge, percent native

Part of the Environment: Birds, biodiversity indices

165. Citation: Houlahan, Jeff E, and Scott C Findlay. "Estimating the 'critical' distance at which adjacent land use degrades wetland water and sediment quality." *Landscape Ecology* 19 (2004): 677-90.

Link: http://sd-cite.iisd.org/cgi-bin/koha/opac-ISBDdetail.pl?biblionumber=27503

Synopsis: Conversion of forested lands to agriculture or urban/residential areas has been associated with declines in stream and lake water quality. Less attention has been paid to the effects of adjacent land-uses on wetland sediment and water quality and, perhaps more importantly, the spatial scales at which these effects occur. The variation in water and sediment nutrient levels in 73 southeastern Ontario, Canada, wetlands was examined. The relationship between water and sediment nutrient concentrations and various measures of adjacent land-use such as forest cover and road density, measured over increasing distances from the wetland edge were modelled. Results suggest that the effects of adjacent land-use on wetland sediment and water quality can extend over comparatively large distances. As such, effective wetland conservation will not be achieved merely through the creation of narrow buffer zones between wetlands and more intensive land-uses. Rather, sustaining high wetland water quality will require maintaining a heterogeneous regional landscape containing relatively large areas of natural forest and wetlands.

Keywords: Buffer zones, Landscape, Phosphorous, Nitrogen, Scale, Sediments, Wetland management, Ontario, Canada

Caveats: It is difficult to test the hypothesis that the negative relationship between forest cover and wetland nutrient levels is due to intensive agriculture occurring in areas of greater soil fertility because there was no historical wetland water and sediment nutrient data. There is still a great deal of unexplained variation in wetland nutrient levels that may be explained by factors such as topography and soil type.

Scale: Sub-regional (73 wetlands southeastern Ontario)

Location:
Jurisdiction: Ontario
Ecoregion: Algonquin/Southern Laurentians

Landscape Type/Pattern:
Land Use: forest, agriculture, settlement (urban)
Landscape pattern: connectivity

Part of the Environment: Water quality, riparian systems, ecosystem health/functionality

166. Citation: Mitsch, WJ, and JG Gosselink. "The value of wetlands: importance of scale and landscape setting." *Ecological Economics* 35, no. 1 (2000): 25-33.

Link: http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/S0921-8009(00)00165-8

Synopsis: In this study on the value of wetlands in human dominated landscapes, wetlands were found to work best, in terms of providing ecosystem services, as spatially distributed systems. Wetland value was also found to be highly depended on its hydrogeomorphic position in the landscape relative to other landscape features and human settlements. For example, if a wetland is situated along a river, it will have a greater functional role in stream water quality. Likewise, wetlands function differently when situated at the headwaters of a stream as opposed to when situated further downstream. The fauna supported by a wetland depends highly on the size of the wetland and the home range size of the animal in relation to the wetland. In general, this study indicates that 3-7% of temperate zone watersheds should be comprised of wetland cover to provide adequate flood control and maintain water quality.

Keywords: Wetland value, marginal value, watershed management, landscape ecology, wetland economics.

Scale: Meso-regional

Location:
Jurisdiction: Studies from Midwestern states and Scandinavia
Ecoregion: Western Cornbelt Plains, Central Irregular Plains

Landscape Type/Pattern:
Land Use: agriculture, forest, settlement
Landscape pattern: percent wetland cover

Part of the Environment: Water quality, riparian systems, biodiversity indices, ecosystem services, ecosystem functionality/intactness

167. Citation: Yang, W., X. Wang, S. Gabor, L. Boychuk, P.Badiou. 2008. Water Quantity and Quality Benefits from Wetland Conservation and Restoration in the Broughton's Creek Watershed. Research

Report Submitted to Ducks Unlimited Canada.
Link: http://www.ducks.ca/assets/2012/06/broughtons.pdf?9d7bd4

Synopsis: This study examined the impacts of wetland loss between 1968 and 2005 in the Broughton's Creek watershed, Manitoba. A land cover change analysis showed that over 21% of the total area of wetlands had been lost primarily due to agricultural drainage. This changed wetland cover in the watershed from 12% in 1968 to approximately 9.5% in 2005. A model using the Soil and Water Assessment Tool (SWAT) was then applied and calibrated to assess the impacts of wetland drainage on peak flood discharge and water quality. Restoration scenarios were examined and modelled.

Key findings were that the 21% wetland loss since 1968 has resulted in the following impacts:

- Peak flows (annual average) increased by 37%
- Overall water flows increased by 62%
- Phosphorus loads in the watershed increased by 32%
- Nitrogen loads in the watershed increased by 57%
- Sediment loads in the watershed increased by 85%
- Release of approximately 34,000 tonnes of carbon, equivalent to annual emissions of 23,200 cars
- Estimated 28% decrease in waterfowl production

Keywords: wetlands, water quantity, water quality, flooding, restoration, waterfowl, carbon

Scale: Local Watershed

Location:
Jurisdiction: Manitoba
Ecoregion: Aspen Parkland / Northern Glaciated Plains
Basin: Saskatchewan-Nelson River, Red River
Subbasin: Broughton's Creek

Landscape Type/Pattern:
Land Use: Agriculture, Wetlands
Landscape pattern: % wetlands in a "pockmarked" prairie pothole wetlands landscape

Part of the Environment: Water Quantity, water quality, wetlands, carbon storage, birds

168. Citation: Barko, Valerie A, George A Feldhamer, Matthew C Nicholson, and Kevin D Davie. "Urban habitat: a determinant of whitefooted mouse (peromyscus leucopus) abundance in southern Illinois." *Southeastern Naturalist*, 2, no. 3 (2003): 369-376.

Link: http://dx.doi.org/10.1656/1528-7092(2003)002[0369:UHADOW]2.0.CO;2

Synopsis: This study aimed to assess the degree to which white-footed mouse abundance was related to habitat features within and surrounding bottomland forest patches. Habitat features included patch size, patch shape, and land use within a 300 meter buffer surrounding each patch. Sample sites where less than 10 individuals were captured were surrounded by a large percentage of upland deciduous forest and a low percentage of urban land use. By contrast, sample sites where 30 or more individuals were captured were surrounded by a large percentage of urban land use and only a small percentage of upland deciduous forest. Researchers concluded that unsuitable habitat may surround and create islands of high species density from which successful dispersion becomes difficult. Therefore, habitat surrounding a patch, rather than the quality of the patch itself, may be a more important determining factor of species abundance.

Keywords: Habitat features, patch size, patch shape, urban land use, white-footed mouse, dispersion rates, species abundance

Scale: local/site

Location:
Jurisdiction: Illinois
Ecoregion: Interior river valleys and hills

Landscape Type/Pattern:
Land Use: agriculture, settlement
Landscape pattern: fragmentation, edge, percent native

Part of the Environment: ecosystem intactness, biodiversity indices

169. Citation: Bow Corridor Ecosystems Advisory Group. Guidelines for human use within wildlife corridors and habitat patches within the Bow Valley. Guidelines, Bow Corridor Ecosystem Advisory Group, 1999.

Link: http://www.biosphereinstitute.org/wp/wp-content/uploads/BCEAG-Human-Use.pdf

Synopsis: This report sets out guidelines intended to provide BCEAG member jurisdictions with a coordinated approach to recommendations regarding the management of human use activities within wildlife corridors and habitat patches in the Bow Valley of Alberta. These guidelines provide an advisory framework for decision making related to wildlife management as well as recommendations for mitigating the negative effects of human activity on wildlife in the region. The report examines the level of human use that is currently occurring on the land with primary emphasis on those lands that have been identified as wildlife corridor or habitat patches, and makes recommendations for seasonal or permanent closures and stipulations on future expansions for each trail within the area.

Keywords: wildlife management, human activity, wildlife corridor, habitat patch

Scale: Regional

Location:
Jurisdiction: Alberta
Ecoregion: Canadian Rockies
Basin: Bow River

Landscape Type/Pattern:
Land Use: Roads, settlement, recreation
Landscape pattern: linear disturbance, fragmentation, percent native

Part of the Environment: Terrestrial mammals, biodiversity indices, ecosystem functionality and intactness

170. Citation: Dyer, Simon J, Jack P O'Neill, Shawn M Wasel, and Stan Boutin. "Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeast Alberta." Canadian Journal of Zoology 80 (2002): 839-845.

Link: http://search.proquest.com.ezproxy.lib.ucalgary.ca/docview/220500818?accountid=9838

Synopsis: The study examined rates of road and seismic line crossing behaviour for threatened woodland caribou in northeastern Alberta. The study sought to determine if these linear features act as barriers to movement for caribou and to develop a more sophisticated approach to animal movement models that better quantifies parameters for animal movement decisions. The study found that woodland caribou crossed roads less than expected for all time periods except calving. The study further found that woodland caribou use areas close to roads less frequently than expected. Seismic lines did not present barriers to caribou movement.

The study results indicate that roads are semipermeable barriers to caribou movement with the greatest barrier effects occurring during late winter. Barrier effects may result in habitat loss through fragmentation and avoidance. In northeastern Alberta, woodland caribou tend to be restricted to local populations within peatland complexes. Barrier effects associated with roads could be more severe at the edges of these peatland complexes where barriers could arrest dispersal. These effects should therefore be considered in developing strategies to maintain woodland caribou in Alberta.

Keywords: Linear disturbance, woodland caribou, simulated behaviour, barrier effects, roads, habitat loss, road ecology

Caveats: Detailed information about traffic volumes was not obtained for all roads in the study area at all times.

Scale: Regional

Location:
Jurisdiction: Alberta
Ecoregion: Mid-Boreal Uplands and Peace-Wabaska Lowlands

Landscape Type/Pattern:
Land Use: forest (boreal-mixed wood)
Landscape pattern: Linear disturbance, connectivity

Part of the Environment: Terrestrial mammals, species-at-risk (threatened)

171. Citation: Kinley, Trevor A, and Clayton D Apps. "Mortality patterns in a subpopulation of endangered mountain caribou." *Wildlife Society Bulletin* 29, 1 (2001): 158-164.

Link: http://www.jstor.org/stable/3783993 .

Synopsis: The study conducted population surveys and mortality monitoring for mountain caribou in the southern Purcell Mountains of British Columbia. The study examined the effects of habitat fragmentation on caribou mortality and rates of mortality for females and males. The research found that the mountain caribou population was decreasing rapidly due to low calf recruitment and high adult mortality and that a continuation of this trend would likely lead to extirpation. Adult mortality appeared to be largely the result of predation, with cougars accounting for half of the known-cause mortalities. Road development, cutblocks, and habitat fragmentation associated with forest harvesting are extensive in the southern caribou activity zone, where caribou mortality is higher than in the north.

The results suggest that the much higher rate of mortality observed in the more developed portion of the study area supports a link between predation and forestry development. Specifically, these disturbances may have changed the distribution of other ungulates showing affinity to edges and the resulting change in prey distribution may have caused cougars and other predators to expand into landscapes they might not normally. These results are consistent with the general expectation that habitat fragmentation is expected to alter community structure and exacerbate predation for many species. To prevent extirpation, the study recommends augmenting the caribou subpopulation, conducting research into the relationships between predation and patterns of forest harvesting and further examining reasons for low calf recruitment. Further, the study recommends limiting predation by reducing numbers of cougars and alternate prey.

Keywords: forest harvesting, habitat fragmentation, woodland caribou, mortality, predation, mountain caribou, cougars

Scale: Regional

Location:
Jurisdiction: British Columbia
Ecoregion: Columbia Mountains / Northern Rockies

Landscape Type/Pattern:

Land Use: forest
Landscape pattern: fragmentation

Part of the Environment: Terrestrial mammals, endangered species

172. Citation: Coppedge, Bryan R, David M Engle, Ronald E Masters, and Mark S Gregory. "Avian Response to Landscape Change in Fragmented Southern Great Plains Grasslands." *Ecological Applications* 11, no. 1 (2001): 47-59.

Link: http://link.springer.com.ezproxy.lib.ucalgary.ca/article/10.1023/a:1014495526696

Synopsis: This study documented land cover and landscape pattern changes in the Central Great Plains region relative to the expansion of juniper and Conservation Reserve Program (CRP) activity. Researchers examined how local landscape dominance by either anthropogenic or woody vegetation patches affected landscape pattern indices. Changes in landscape pattern generally reflected the influx of juniper into many areas. Landscapes dominated by woody vegetation had significantly more patches, smaller patches and patch core areas, more total edge, and higher patch diversity than landscapes dominated by anthropogenic cover types. Results indicate that expanding juniper is exacerbating the fragmentation process initiated by previous human activity, and represents a serious threat to the continued integrity and conservation of remaining southern Great Plains grasslands.

Keywords: Conservation Reserve Program (CRP), encroachment, fragmentation, grassland conversion, juniper, landscape pattern, Oklahoma, Great Plains

Scale: sub-regional (CRP research area in Northwestern Oklahoma)

Location:
Jurisdiction: Oklahoma
Ecoregion: Central Great Plains

Landscape Type/Pattern:
Land Use: Agriculture, grazing, protected land
Landscape pattern: percent native, fragmentation

Part of the Environment: Ecosystem health/functionality and intactness.

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