ABMI 10-YEAR SCIENCE AND PROGRAM REVIEW

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Contents

Please note: Throughout this document, we present key findings while referencing supplementary 'Technical Reports' that contain even more detail, should the reader wish to dig deeper. These supplementary documents are available separately.

Many of the documents provided in the supplementary package are, in effect, living documents. While they are accurate to the best of the respective authors' knowledge, they remain works in progress. The supplementary documents have not been reviewed or edited for public release, and any views or opinions expressed therein are those of the respective authors. They do not necessarily reflect the views, values, or policies of the ABMI.

1 Executive summary

The ABMI was formed as a collaboration between industry, academia, and government to collect credible, scientifically rigorous biodiversity data and inform land-use decisions in Alberta. Reflecting on the first ten years of operations in its current form, we discuss details of the ABMI's monitoring program at length over the pages and chapters that follow.

To facilitate sustainable natural resource and land use management, it is necessary to understand the effects of human development on biodiversity and native ecosystems. Some ecological effects result from the cumulative changes brought about by many disturbances throughout the landscape. Conversely, other environmental changes may be localized and tightly coupled to a specific stressor. The ABMI was designed to address both ends of this spectrum, by monitoring and reporting on cumulative effects on biodiversity throughout Alberta and by identifying how species abundance varies in relation to the intensity of specific human development stressors. To achieve this, the ABMI collects information on species, habitat structure, and landscape data at both systematic and complementary targeted sites. ABMI data are analyzed to create products that government, industry and environmental stakeholders can use during planning and management.

The ABMI has been in operation in its current form for a decade. In this review, we evaluate the degree to which the ABMI has achieved its goal "to monitor and report on status and trend of biodiversity throughout Alberta". First, we summarize the products created by the ABMI to describe status and trend in species, land cover, and human footprint elements; second, we describe the accuracy/precision obtained in these products; third, we evaluate the degree to which multiple types of ABMI information corroborate each other; and finally, we compare the effectiveness of ABMI status and trend monitoring to monitoring conducted by comparable programs around the world.

Understanding the historic and present state of biodiversity in Alberta and, by extension, the changing relationships between anthropogenic land uses and ecological systems, requires a multi-year monitoring, data collection, and reporting framework. The ABMI implements various monitoring systems to achieve this. It collects data on human-created land disturbances with such products as the Human Footprint Inventory (HFI) and 3 × 7-km HF datasets. These HF products describe historic and current land use and the spatial distribution of human footprint throughout Alberta. The HFI dataset, the product of a partnership between the ABMI and AEP, is divided into 21 sublayers according to land use type, contains six major reporting categories, and is updated biennially, which enables data-users to interpret changes in land transformation across the entire province. The 3 × 7-km sample-based dataset has been updated annually from 1999 to 2015 (except 2000, 2002, and 2003). It lets data users understand land use in the time before the HFI dataset was created. Both datasets are key components of land use monitoring and management activities.

The ABMI collects data on 7 taxonomic groups (birds, mammals, vascular plants, bryophytes, lichens, mites, and aquatic invertebrates) and builds statistical models that relate the occurrence and relative abundance of species to predictor variables of native land cover, human footprints, and climate. The results from this work inform land-use decision-makers about the high-resolution distribution of species, their associations with different ecosystem land covers (ecosites, vegetation types, forest-age classes), and the effects of human development on these species. The coefficients from the predictive models can be used in spatially explicit scenario analyses to predict the expected effects of different management options on species' relative abundances.

We use the models to predict species abundance for individual pixels spanning all of Alberta based on the land covers and human footprints present in each pixel. The difference between predictions under current landscape conditions and predictions under 'reference' landscapes where all human footprints have been removed ('backfilled'), is the predicted cumulative effect of all human developments on the species. To obtain a measure of condition across species (biodiversity intactness) we standardize the differences between current and reference conditions to a common scale (0–100) and average the standardized scores across species. Both increases for species and decreases for other species contribute to changes from reference, and thus changes to biodiversity intactness. We further attribute these species changes to different industrial sectors by grouping footprint types into the appropriate sectors and integrating the effects for all footprint types in that sector.

Some species, especially rare species, do not always show strong associations with the predictor variables we have used in our generic models. However, ABMI data can be used to develop more complex species-specific models for rare species using additional predictor variables. This would support better management and more efficient conservation of rare species and natural resources in Alberta.

The ABMI is an integrated monitoring program that tracks trend in species, land covers and human footprints across Alberta. Our extensive set of verified 3 × 7-km GIS plots from 1999 to 2015, and complete mapping of human footprint throughout the province since 2010, allow us to track changes since 2000 in land use (human footprint), and the resulting loss of native vegetation, with high precision. Tracking trend for species is still in its early stages. We present initial trend estimates based on revisited sites for the breadth of taxa the ABMI surveys. However, with less than 30% field sites revisited so far, and the revisits only 5–8 years apart, there is low power to describe trend for species that are changing slowly over time. Simulations based on the initial information have shown that field monitoring will produce precise trend estimates for many species after 20 years at the large regional scale, with trends for many more species achieving high precision after 30 years. In addition, initial results from the field revisits are being evaluated, and where appropriate improved sampling is being developed, so that trends will be identified with high precision in the long term.

The ABMI continuously evaluates its program to seek efficiencies. In the present report, we explore two possible ways to make the ABMI's program more efficient: 1) reducing effort in helicopter-access sites (and increasing effort correspondingly in cheaper ground-access sites); and 2) re-evaluating which taxonomic groups to monitor.

Helicopters double the costs of field work, but when non-field costs are factored in (i.e., such as managing the field program, processing the specimens and information, and presenting the results), helicopter sites cost 1.32 times as much as ground access sites. Reducing sampling effort in helicopter sites and increasing it in ground-access sites would alter the representation of natural regions and some habitat and human footprint types, but would not significantly affect our modelling abilities for many species. Other factors are listed that will be more important than helicopters when making decisions about allocating effort.

When making decisions about which taxa to include in monitoring, their degree of similarity in response to human development is an important consideration. There is extensive overlap among taxa in how species vary among vegetation, ecosite, and human footprint types, but there are also unique features for each group. Vascular plants, the most species-rich group, often encompass the distributions of species in other taxa. However, sampling costs, reliability of field methods, and importance to policy, management, and public funding sources are other key criteria for selecting species to survey. There is also potential to restrict surveys of some taxa to regions or habitats where they are most informative, or to use an “ABAB” revisit design, where two taxa are alternated between rounds of revisits to facilitate including more taxa without increasing overall monitoring costs. These sorts of questions will continue to inform the ABMI’s ongoing effort to deliver comprehensive biodiversity data from a monitoring program that is both robust and efficient.

Throughout this review, we also highlight significant advances from the ABMI. These include contributions to Alberta and to (monitoring) science, as well as to Alberta’s legacy of knowledge, data, and expertise.

2 Introduction to the ABMI and the 10-year review

Jim Schieck and Kurt Illerbrun

2.1 Looking back after 10 years

The ABMI was formed as a collaboration between industry, academia, and government to collect credible, scientifically rigorous biodiversity data and inform land-use decisions in Alberta. Prior to the ABMI's inception, Alberta had no organized, provincial-scale biodiversity monitoring program in place, and what data were available varied widely in scope, methodology, and rigor. As an arms-length not-for-profit scientific organization, the ABMI developed its monitoring protocols over several years in consultation with academic researchers, and government and industry stakeholders. This resulted in an ambitious program to monitor Alberta's biodiversity from border to border, providing detailed data on species status and trend, and extensive geospatial data on human footprint and native land-cover. At the core of the ABMI's monitoring is the idea that *you manage what you measure*. This philosophy explains key aspects of ABMI operations—for example, why we pursue a systematic province-wide cumulative effects monitoring program, rather than a simpler but less versatile alternative. Details of the ABMI's monitoring program are discussed at length over the pages and chapters that follow.

The ABMI monitors thousands of species across a 660,000 km^2 region. This geographic and taxonomic scope of monitoring is unique compared to programs in other jurisdictions. This uniqueness posed a significant challenge during early development, as there were few benchmark programs against which to weigh design decisions. The ABMI's initial form was based on scientific consensus, but scientific consensus inevitably evolves. In keeping with best scientific practices, the ABMI's monitoring protocols have also evolved, and some have been replaced or removed altogether. With that in mind, the ABMI 10-year Science Review is an opportunity to evaluate the ABMI's operations and, where needed, seek efficiencies. This, too, is discussed at length in the present report.

In the past ten years, most ABMI operations have focused on monitoring and reporting on the status and trend of Alberta's species, habitats, and human footprint across the province. The key output of this activity is the largest publicly available collection of environmental monitoring data in Alberta. We currently provide—free of charge—province-wide information on human footprint and land cover, and a range of data products, such as species abundance, on hundreds of Alberta's plants and animals. ABMI data have been used to inform management decisions around Alberta, from the local to the provincial scale. It is easy to forget that such information was essentially unavailable before the ABMI came about: in filling this information gap, the ABMI (including its products, partnerships, and organizational expertise) represents a significant advance for Alberta, and is unique in Canada.

Before delving into the specifics of the 10-year Review, we briefly summarize advances from the ABMI to science, management practice, and to the people of Alberta—tangible, long-lasting benefits of a program that continues to evolve (**Text box 1**).

Text box 1 Key ABMI advances from its first 10 years of operation

Value to Alberta	The ABMI has produced a wealth of data and derived data products on species, vegetation, and land-use in Alberta. These data are freely available through the ABMI's website (abmi.ca), and form an essential resource for land managers, policy makers, researchers, and the public. *Key examples*: • ABMI data are integral to developing Biodiversity Management Frameworks (BMFs) for Alberta, as part of the Government of Alberta's (GoA) Land-use Frameworks (LuF). • The ABMI and Alberta Environment and Parks (AEP) founded and lead the Alberta Human Footprint Monitoring Program (AHFMP) initiative.
Value to Science	The ABMI's monitoring program uses a systematic approach that integrates cumulative effects monitoring with targeted monitoring and shows that the two monitoring styles, often considered mutually exclusive, can in fact be complementary. Through its scope and rigor, it serves as a benchmark for managers and other monitoring programs nationally and abroad. *Key examples*: • The ABMI has made important advances in sampling methods, including emerging digital technologies, and in the use of predictive models in monitoring science. • Since 2012, the ABMI has directly contributed to the production of more than 85 peer-reviewed papers, more than 50 technical reports, and more than 55 conference presentations.
Legacy	The ABMI is globally unique. Few programs of its scale exist, whether measured spatially or taxonomically; still fewer have existed for as long, or provide comprehensive data on as many species. The ABMI serves as a model program and global leader in its field. Through its monitoring efforts, and through its commitment to ensuring that all ABMI data are freely available, the ABMI represents a true "Heritage Fund" of biodiversity data in Alberta. Standardized and repeatable, these data are an invaluable baseline for future generations. *Key examples*: • The ABMI expends substantial effort updating and sharing its data and reports, while the ABMI's physical collections at the Royal Alberta Museum represent invaluable genetic, ecological, and taxonomic resources. These resources provide huge potential for future research, and are an important legacy. • The ABMI invests in the people of Alberta, developing and supporting taxonomic expertise, encouraging publication of novel research, seeking collaborations, and engaging the public.

The ABMI was built from the ground up for Alberta, and perhaps reflects the Albertan aversion to half-measures: it is a large, ambitious, sometimes unruly program, and its development is the result of the shared efforts of Albertans from industry, government, and academia who saw a need and acted.

As a direct result of the ABMI's work:

- Albertans have access to the information necessary for a better biogeographical understanding of their province;
- Our understanding of biodiversity in under-sampled ecosystems such as grasslands has improved dramatically, increasing knowledge of the province's biodiversity hotspots and revealing how much of Alberta's natural heritage is, and isn't, protected under current land designations;
- Our understanding of many species' distributions has improved, with important implications for conservation priorities.

As the 10-year Science Review will reveal, the ABMI must continue to evolve and improve. But even as we acknowledge that need and seek efficiencies, it's undeniable that over its years of operation to date, the ABMI has already made significant contributions to Alberta.

2.2 Background to the 10-year Review

To facilitate sustainable environmental management, it is necessary to understand the effects of human developments on native ecosystems (Hegmann et al. 1999, Alberta Environmental Protection and Enhancement Act 2010). Many human activities change the vegetation, topography, hydrology, and soils in an area, and concomitantly affect the species that live there. Major human disturbances in Alberta's landscapes include oil and gas exploration and extraction, agriculture, forestry, urban development, and transportation (Schieck et al. 2014). Some of these disturbances (e.g., seismic lines, forest harvest) are designed as temporary removals of native vegetation, with the expectation that it will re-grow and native biotic communities will re-emerge within a few decades (Zedler and Callaway 1999, Schieck and Song 2006). Other disturbances (e.g., mines, industrial facilities, well-pads) result in changes to vegetation, soils, and hydrology that are expected to remain on the landscape for decades, although they are still projected to be reclaimed and eventually recover to near-natural ecosystems after resource extraction has been completed (Alberta Environment and Parks 2015). Roads, agriculture and urban footprints are essentially permanent changes to the landscapes. These human disturbances are all increasing over time (Schieck et al. 2014).

The Alberta Biodiversity Monitoring Institute (ABMI) was designed to help managers understand both the local impact of human activity on natural systems, and the cumulative effects of these at regional and provincial scales. The program originated in 1997 when a group of Alberta researchers and foresters posed the question: *We understand the local impact of industrial activity on natural systems, but how do we draw connections between local impacts* *and changes observed at a regional scale?* This question catalyzed the development of a prototype for the ABMI that was completed by 2002. Four years (2003–2006) of piloting, including rigorous field testing, established many of the protocols, analyses and reporting methods that define ABMI operations today.

In 2007, the ABMI was formally incorporated as an arm's length, not-for-profit scientific organization, and launched its business of providing scientifically credible products and services on Alberta's biodiversity and human footprint to provincial government, industry, and environmental decision-makers. In 2017, the ABMI entered its 10th year of formal operations. Over those 10 years, a large amount of biodiversity, land cover, and human footprint information has been collected and is being used widely by stakeholders. To formally evaluate the degree to which the ABMI is delivering on its goals and objectives, we are conducting a 10-year review.

The review has two main components: a science review, and a review of the effectiveness with which existing products and services meet stakeholder needs (**Figure 2-1**). The Science Review is described in detail in this document. The Stakeholder Needs Assessment, not described in detail here, focuses on: i) evaluating the degree to which ABMI data and products meet stakeholder needs, and ii) obtaining stakeholder feedback for future product development.

Figure 2-1 Components and governance structure of the ABMI 10-year review.

2.3 Scope of the Science Review

The ABMI is designed to monitor and report on the status and trend of Alberta's biodiversity. This includes assessing cumulative effects and describing how species respond to broad classes of human disturbance. The ABMI's goals and objectives are summarized in **Text box 2**.

Text box 2 ABMI goals and objectives.

ABMI Goal: Monitor and report on the status and trend of biodiversity throughout Alberta.
ABMI Objectives:

1. Describe status (distribution, abundance, and land cover associations) and trend (change over time) of species throughout Alberta.
    a) Model how species abundance varies among land cover and human footprint categories.
    b) Predict species change between reference (no human footprint) and current conditions, plus in simulated future conditions.
    c) Describe trend in species abundance and distribution since the start of ABMI data collection.
2. Describe the status and trend of native land cover throughout Alberta.
    a) Map native land cover throughout Alberta.
    b) Describe change in native land cover over time, including between reference and current conditions.
3. Describe the status and trend of human footprint throughout Alberta.
    a) Map human footprint throughout Alberta.
    b) Describe human footprint change over time.

As part of the science review we evaluated the degree to which the ABMI's goals and objectives have been achieved. The evaluation:

- summarizes products created by the ABMI to describe status and trend in species, land cover, and human footprint elements;
- describes accuracy and precision obtained in these ABMI products;
- evaluates the degree to which multiple types of ABMI data corroborate each other; and
- compares the effectiveness of ABMI status and trend monitoring to monitoring conducted by comparable jurisdictions around the world.

Hundreds of species and landscape elements have been surveyed by the ABMI. Detailed results for individual species and landscape elements are described on ABMI webpages (e.g., the ABMI's Data & Analytics Portal at **abmi.ca/data**) and in ABMI reports, and have been shared with stakeholders on numerous occasions. In the interests of concision, we have summarized the results and analyses of our 10-year review in this document, and refer the reader to assorted technical reports describing more detailed information if a deeper exploration of the methods and results is desired. Where necessary, new technical reports have been created to describe details for the review evaluation.

In this document, an overview of data collection methods is described in **Chapter 3**, along with their strengths and limitations. Methods used to model how species abundance varies among land cover and human disturbance types are described in **Chapter 4**, along with a review of the precision with which these models can be used to predict reference (i.e., historical), current, and simulated future conditions. Methods used to track trend in species and landscape elements are described in **Chapter 5**, along with an assessment of the precision with which trend can be determined.

Throughout its first decade of operations, the ABMI has received periodic feedback from stakeholders and researchers on potential ways to reduce costs while still meeting core goals and objectives. Two main questions emerged from this feedback: i) What is the unique value of each taxon monitored by the ABMI? and ii) What are the financial costs and information benefits of surveying difficult-to-access sites? These two questions are reviewed in **Chapter 6**.

Beyond its core mandate, information collected by the ABMI has been used in many other ways that were not originally envisioned. This includes helping managers evaluate how species use the environment, developing new methods to process and analyze biodiversity information so it can be used more easily, and developing new processes to engage stakeholders about biodiversity and new ways to share information on the status and trend of Alberta's biodiversity. We highlight advances brought about by the ABMI's work throughout this document.

2.4 Context for biodiversity monitoring in Alberta

Alberta covers 661,848 km^2, approximately 1200 km north to south and 400 km east to west. The province's native ecosystems are complex and varied—mountains occur in the west, grading into foothills and then prairies in the southeast, with boreal forest and Canadian Shield in the north and northeast respectively (**Figure 2-2**). All regions show topographic variation, creating upland areas with embedded wetlands, streams, rivers, and lakes.

Alberta's bedrock is mostly the surface of Upper Cretaceous or Paleogene formations, though geomorphic features created by Quaternary glaciation and river erosion are embedded throughout (MacCormack et al. 2017). Bedrock is at the surface in some areas (mainly in the Rocky Mountain and Canadian Shield natural regions) and covered by sediment up to 450 m deep where plains and paleovalleys were infilled during Quaternary and Cenozoic glaciation (Fenton et al. 2017). Fluvial deposits and glaciogenic materials cover much of Alberta.

The Grassland Natural Region is the warmest and driest in Alberta, with native vegetation dominated by semi-arid grasslands in the southeast, merging to tall grasslands in the north and west where precipitation is higher (Alberta Parks 2015). The Parkland climate varies from warmer and dryer adjacent to the Grasslands, to cooler and moister in the north and west. Native vegetation in the Parkland is dominated by a patchwork of aspen, willow and native grass. Aspen and white spruce trees grow in river valleys throughout both the Parkland and Grassland (**Figure 2-3**), with stands of cottonwood present in the southern river valleys. The Foothills have a cool, moist climate supporting deciduous and mixedwood forests at lower elevations, with spruce and pine dominating higher up. The Rocky Mountains have cool, moist summers and cold, snowy winters. Bare areas are common at high elevation with shrubs and herbs growing in protected places. Pine, spruce, fir, and a variety of other trees, shrubs, herbs, and grass grow at lower elevations. The Boreal Forest has moderate precipitation with short, warm summers and long, cold winters. Upland areas are dominated by a mix of deciduous, mixedwood, and coniferous trees, with extensive bogs, fens, and swamps in the lowlands. The

Canadian Shield has a climate like that of the northern Boreal, with vegetation dominated by pine and birch intermixed with rocky and wetland areas.

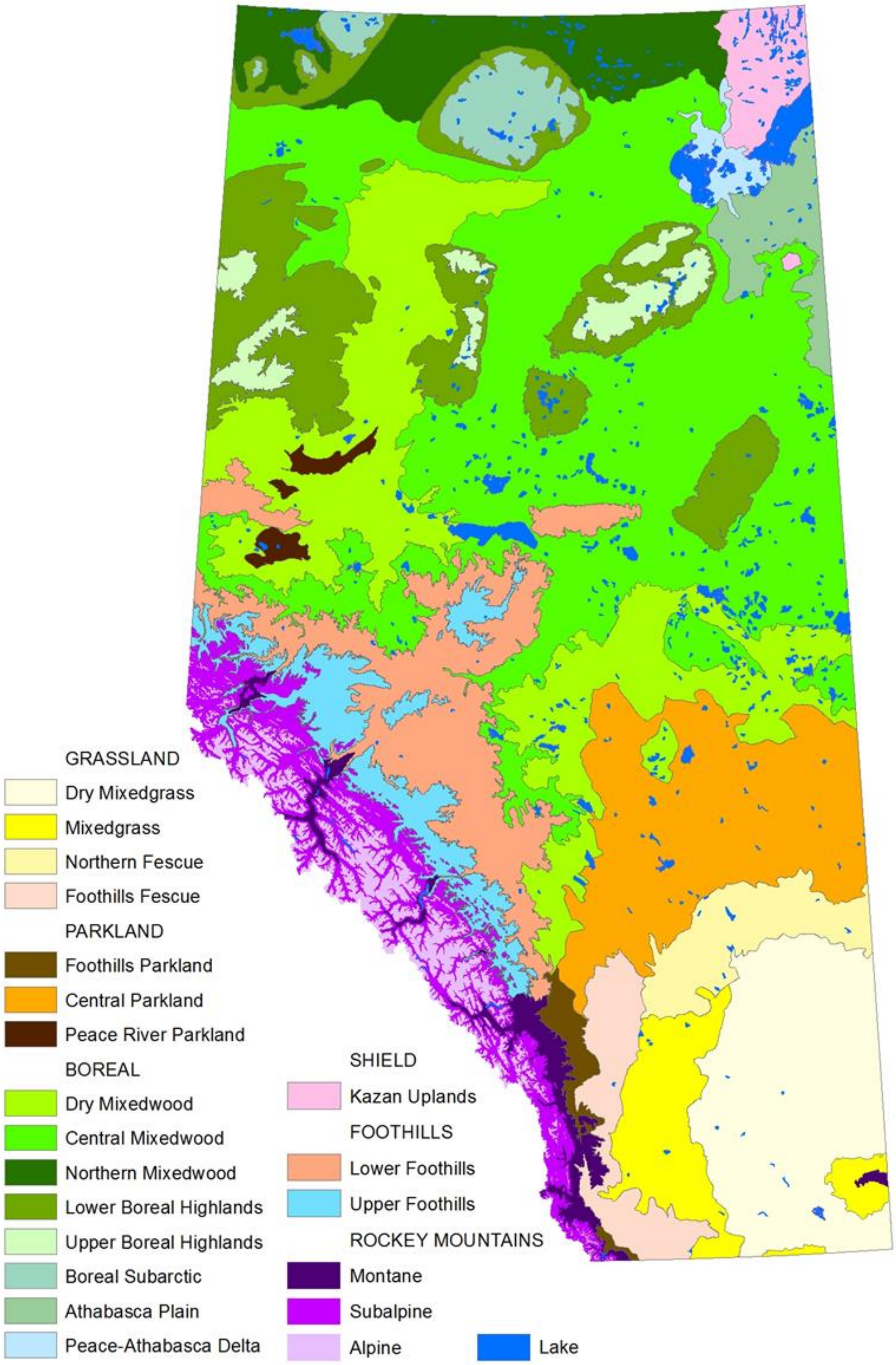

Figure 2-2 Alberta's natural sub-regions (Alberta Environment and Parks 2017).

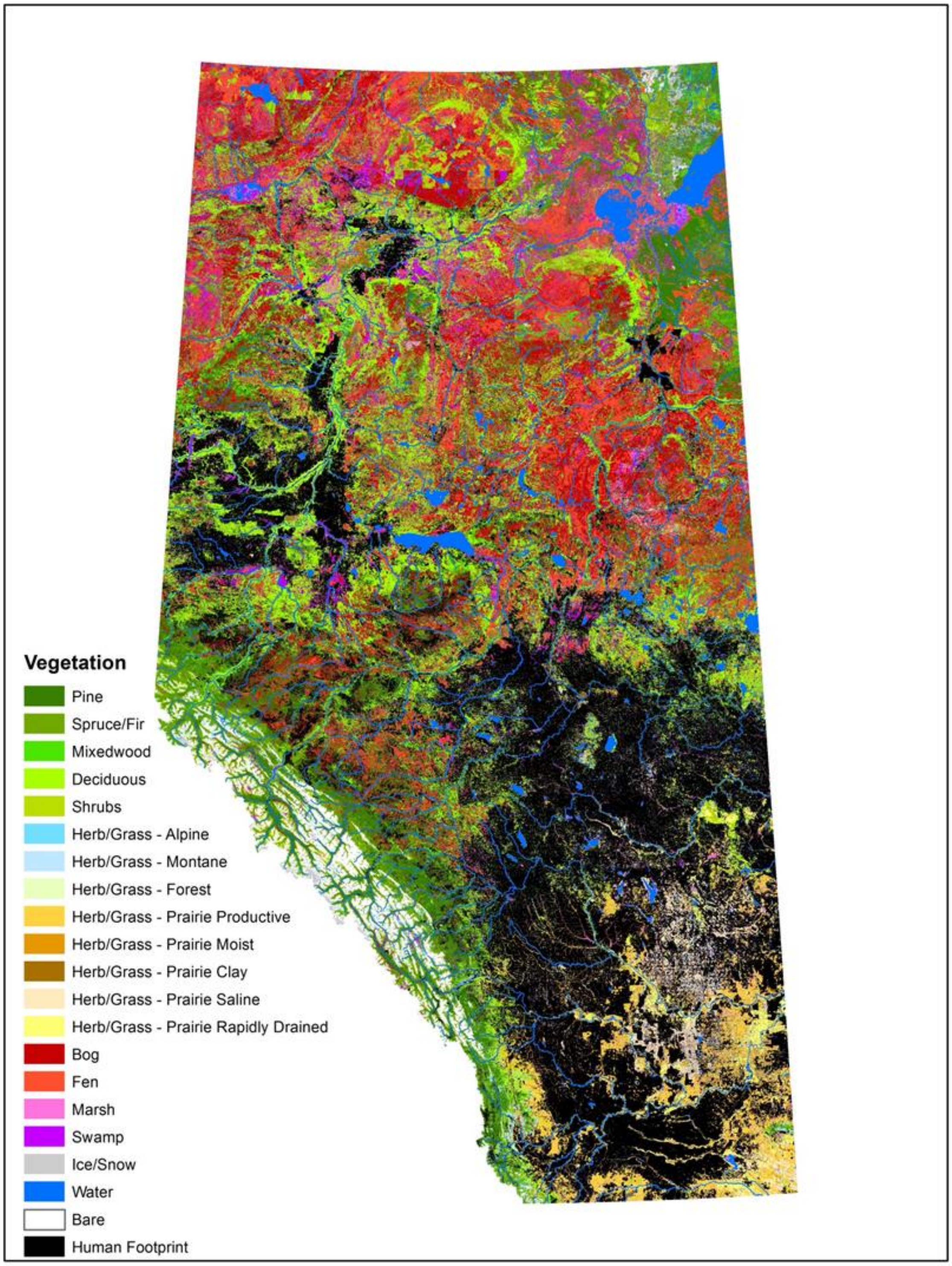

Figure 2-3 Map of land cover types throughout Alberta based on an amalgamation of existing information from various sources (Alberta Biodiversity Monitoring Institute 2016).

Human development is most extensive in the Grassland, Parkland, and Dry Mixedwood regions (**Table 2-1**, **Figure 2-4**). Agriculture and urban developments have altered approximately 40–70% of the native vegetation in these regions. Forestry is the dominant type of human development in the Boreal and Foothills regions, affecting approximately 5% of the area. Energy development occurs throughout all regions of Alberta, and although they occupy only a small percentage of the area, seismic lines and pipelines bisect native vegetation in many places, creating extensive anthropogenic habitat edge (Alberta Biodiversity Monitoring Institute 2017a). Despite the dominance of particular disturbance types in each region, many disturbance types are present in all regions and frequently overlap (**Figure 2-5**).

Table 2-1 Percentage of each natural sub-region that is disturbed by various types of human footprint (Alberta Biodiversity Monitoring Institute 2017b).

	Cultivation	Forestry	Urban/ Industrial	Mines	Soft Linear	Hard Linear	Human Water	Total Footprint	Total Area of Region (km^2)
Grassland									
Dry Mixedgrass	46.6	0.0	1.6	0.2	3.4	0.5	1.0	53.3	46,937
Mixedgrass	60.8	0.0	1.5	0.1	2.4	0.8	1.0	66.6	20,072
Northern Fescue	60.8	0.0	0.8	0.1	2.5	0.6	0.3	65.1	14,933
Foothills Fescue	57.0	0.0	4.2	0.3	2.7	1.5	0.9	66.6	13,623
Parkland									
Central Parkland	72.6	0.0	2.6	0.2	2.7	1.3	0.2	79.8	53,706
Foothills Parkland	35.2	0.2	7.7	0.3	4.1	2.0	0.6	50.1	3,922
Peace River Parkland	69.6	0.1	3.6	0.1	2.4	1.4	0.6	77.8	3,120
Boreal									
Dry Mixedwood	43.6	2.0	1.5	0.2	2.3	0.7	0.2	50.7	85,321
Central Mixedwood	3.5	4.8	0.8	0.3	2.0	0.2	0.1	11.8	167,856
Northern Mixedwood	0.0	0.3	0.1	0.0	0.9	0.0	0.0	1.3	29,513
Lower Boreal Highlands	0.5	4.7	0.3	0.0	2.2	0.1	0.1	7.8	55,615
Boreal Subarctic	0.0	0.1	0.0	0.0	0.5	0.0	0.0	0.6	11,823
Athabasca Plain	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.6	13,525
Peace-Athabasca Delta	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	5,535
Upper Boreal Highlands	0.0	1.0	0.1	0.0	1.3	0.0	0.0	2.5	11,858
Canadian Shield									
Kazan Uplands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	9,719
Foothills									
Lower Foothills	4.8	18.3	1.0	0.1	3.8	0.4	0.2	28.6	44,899
Upper Foothills	0.0	22.6	0.5	0.3	2.8	0.3	0.1	26.6	21,537
Rocky Mountain									
Montane	5.5	5.3	1.4	0.2	2.5	0.7	0.8	16.3	8,768
Subalpine	0.0	4.2	0.1	0.3	0.6	0.1	0.2	5.4	25,218
Alpine	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	15,085

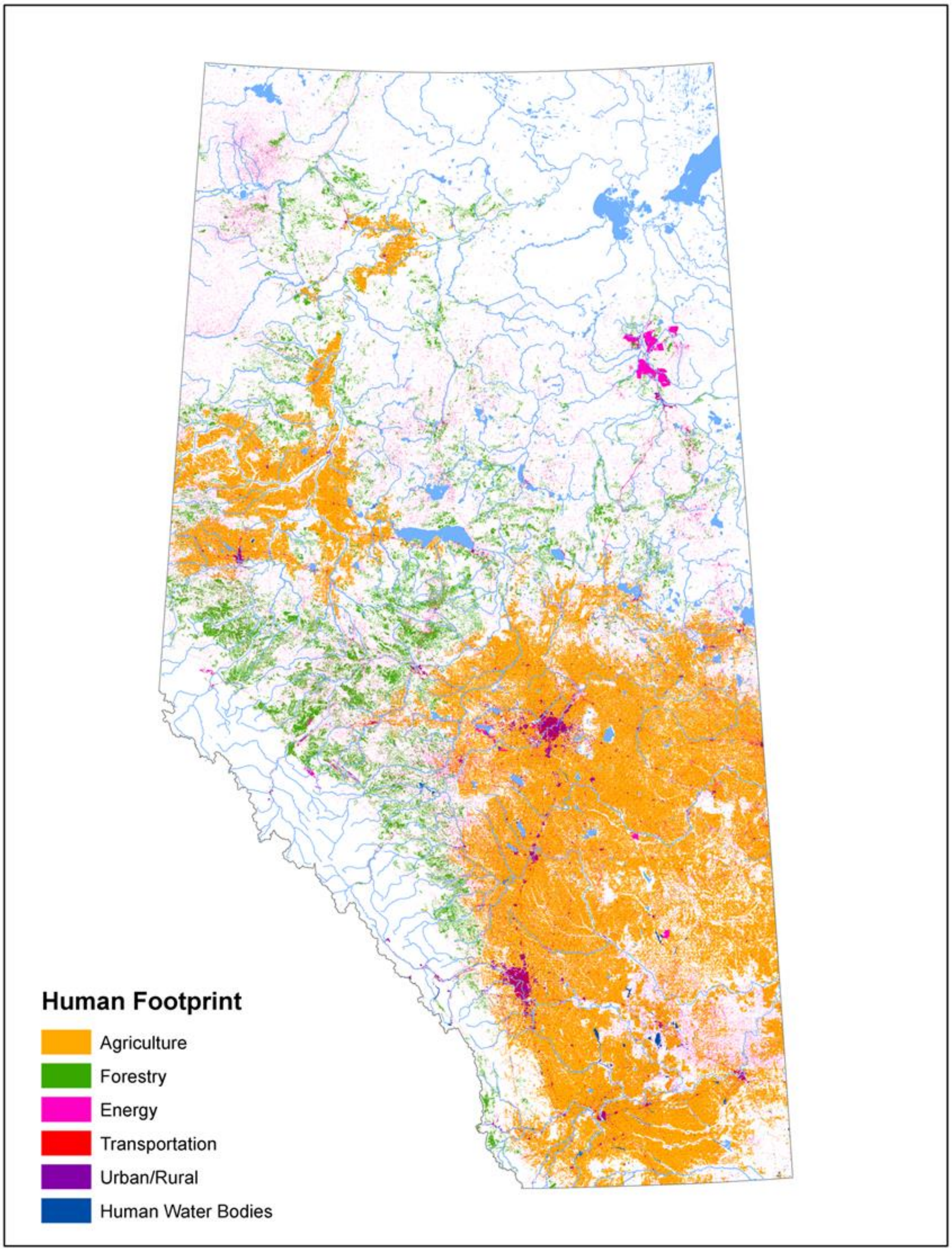

Figure 2-4 Map of human footprint throughout Alberta. Underlying data used to create this aggregate image were obtained through the Alberta Human Footprint Monitoring Program, a collaboration between the ABMI and Alberta Environment and Parks (AEP) (Alberta Biodiversity Monitoring Institute 2017b).

Figure 2-5 Example from the foothills of Alberta highlighting the variety of human disturbances that occur and overlap within a landscape.

2.5 ABMI monitoring design

Alberta's complex native ecosystems, and their embedded mixes of human disturbances, make it difficult to evaluate how each type of human development affects biodiversity at local and regional scales. Synergistic effects of the different developments negate the possibility of simply "adding up" individual effects; interactions differ among landscapes due to the differing amounts and compositions of native vegetation, differing species communities, and species meta-population dynamics being affected by the ecosystems and biotic communities that are present (Saunders et al. 1991, Ramalho et al. 2014). In addition, due to differences among landscapes in the amount and arrangement of native vegetation and human disturbances, synergistic effects are expected to vary among landscapes (Wintel et al. 2010). There are never enough resources to study all effects of human development on the environment, at all spatial and temporal scales. As such, the ABMI implemented a monitoring design that integrated cumulative effects monitoring (based on systematic sampling) with stressor-response research (based on targeted monitoring) to understand how species and biodiversity are affected by specific stressors and how the cumulative effects of stressors affect biodiversity in the region. This integrated approach is a cost-effective solution to environmental monitoring (Haughland et al. 2010).

2.5.1 Cumulative effects monitoring

Assessing the cumulative effects of human developments on native ecosystems is complex (Elvin and Fraser 2012), especially given the secondary interactions that occur in these systems (Burton et al. 2014). For effective cumulative effects assessment, it is necessary to implement rigorous sampling throughout the region and through time—before, during, and after development. The next step is to determine the ecological conditions of species and habitats, plus their change over time, and confirm whether the appropriate trajectory has been established for the future management outcomes desired. The choice of sampling locations must be unbiased so that the information collected can be applied to the complete region. In addition, given daily, seasonal, and inter-annual variation, information collected must be able to separate cumulative effects due to human development from changes due to natural variability. If cumulative effects monitoring is well designed, undesirable changes will be highlighted before they become acute and management actions can be implemented early (Burton et al. 2014). Cumulative effects monitoring facilitates discovering “unknown unknowns” within complex ecosystems that have many interacting processes (Magunsson et al. 2008, Wintel et al. 2010).

To monitor cumulative effects, the ABMI samples landscapes, vegetation, and species across Alberta using a systematic study design consisting of 1,656 sites arranged on a 20-km grid that spans the province (more information below). By monitoring wall-to-wall changes in native vegetation and human footprint, the ABMI tracks coarse-filter measures of biodiversity change. By implementing a field sampling program at sites spaced systematically throughout Alberta, the ABMI can track changes in medium-filter measures of biodiversity (e.g., habitat elements and water physiochemistry), and fine-filter measures of species distribution and abundance across Alberta. The ABMI monitors a wide diversity of species and habitat structures so that most changes to the environment will be detected.

2.5.2 Targeted monitoring

Identifying change to the environment isn’t enough: when change occurs, managers want to understand the causes. To achieve this, it is necessary to sample a gradient from low (ideally no) through high development, and model biotic change along it (Gotelli and Ellison 2004, Nichols and Williams 2006). This targeted sampling is critical so that the complete range of conditions can be included during model development. In addition, since ecological effects occur at a variety of spatial scales, modelling must incorporate information from local areas through to whole landscapes (Wintel et al. 2010, Toews et al. 2017). Although the resulting models are often used to make predictions about other landscapes, these predictions are only as good as the information used to build the models, and only apply to landscapes with similar compositions to where the modelling data were collected. Cumulative effects monitoring is required to confirm the predictions, and in places where the models are found to be inaccurate, additional research/sampling is needed to improve modelling over time (Burton et al. 2014).

The ABMI collects information at a variety of targeted sites to model how species are affected by particular anthropogenic stressors. Approximately 200 of these targeted sites were chosen to complement the ABMI's systematic sites. An additional approximately 4,000 targeted locations were surveyed as part of ABMI collaborative projects; only mammals, birds, plants, or a combination of these were surveyed in these collaborations. Together the systematic and targeted locations provide the information needed to model how species respond to human development stressors (locations that were surveyed during cumulative effects monitoring are used to describe part of the stressor gradient, with the rest being filled by targeted surveys). Data collection methods are identical at the systematic and targeted sites to facilitate integration.

2.6 Overview of ABMI data collection and analyses

The ABMI includes sampling of land cover (through remote sensing) and species/habitats (through on-the-ground field sampling) to evaluate both status and trend in biodiversity. Field sampling provides direct information on the presence and abundance of species and habitat structures and, through repeated measures, how these are changing over time. Remotely sensed information provides descriptions of the amounts and distributions of native land cover and human footprints, and how these are changing over time.

2.6.1 Native land cover and human footprint

The ABMI monitors land cover and human footprint at two resolutions. First, province wide "wall-to-wall" maps combine available GIS layers from a variety of sources to provide a coarse- to medium-filter overview. Second, The ABMI's sample-based dataset, based on 1,656 sample sites, each 3 km × 7 km in size, spaced on a 20-km grid across Alberta, and cumulatively representing around 5% of the province's land surface, extends the survey of human disturbance back to the year 2000. This information is created at a higher resolution than the wall-to-wall information. Here and throughout this report, we will regularly refer to these as "wall-to-wall" and "3 × 7" datasets.

2.6.1.1 Native land cover

Native land cover is defined as vegetation or other land cover types that have not been visibly affected by human footprint (**Chapter 3**). Native land cover information is collected and used by the ABMI as a coarse-filter measure of how ecosystems are changing over time. This information is also used as covariates for species modelling. To create a seamless "wall-to-wall" map of vegetation, wetlands, and other native land cover throughout Alberta (**Figure 2-3**), the ABMI combined existing GIS layers from a variety of existing sources of native land cover. The vegetation map describes vegetation age and type that currently occur throughout Alberta; these will change temporally due to natural disturbance / recovery and climate change. A second layer describing pre-disturbance, or reference, native land cover was then created by "backfilling" current human footprint polygons with the land cover that would be expected based on soil type and surrounding vegetation (**Figure 2-6**; **Chapter 3**). Resolution and accuracy of the integrated native land cover layer, and the reference (backfilled) layer, vary spatially due to differences in quality in the source information.

As another way of tracking changes in native land cover over time, the ABMI also maps detailed land cover on its systematic grid of 1,656 plots, with each plot scheduled to be remapped every 10 years.

2.6.1.2 Human footprint

The ABMI collects information on human disturbance (footprint) to describe the major stressors on Alberta's ecosystems. Human footprint is defined as any visible alteration of native land cover, and includes all areas that have lost their native vegetation for extended periods of time. Over the last two years, a collaboration between Alberta Environment and Parks (AEP) and the ABMI has led to the creation of a human footprint inventory for Alberta. (**Figure 2-4**; **Chapter 3**). Existing GIS layers of human disturbance were updated and corrected as required by the partnership, plus many new layers were created for disturbances that were not otherwise mapped. To track changes in human footprint over time, human footprint information throughout Alberta is updated every two years.

In addition, to extend human disturbance information back to the year 2000, and to have higher-resolution information, human footprint data is mapped yearly for the systematic grid of 1,656 3 × 7 plots.

2.6.2 Species

The ABMI conducts field sampling at both systematic (i.e., part of the 1,656-site grid across Alberta) and targeted (i.e., in addition to the systematic grid) sites. Each of the 1,656 systematic grid sites is located with a random off-set of up to 5 km from the "true" 20-km grid. Systematic sites are surveyed using a rotating panel design; 20% of the sites are surveyed each year, with each site revisited every 5 years. The ABMI is still in the process of ramping-up to this study design (**Figure 2-7**; and see Limitations below).

By employing a systematic design, ABMI sites provide a random sample for any management region of interest. A repeated-measures design is used so that changes over time to species and habitat elements can be most easily determined (Quinn and Keough 2004). With more than 1600 sites, the ABMI design is effective at assessing trend at regional scales—the scale at which management of native species populations is required. It is possible to track change in smaller regions, but statistical power becomes limiting in small areas (e.g., a region of 40,000 km^2 only has 100 sites). A higher density of sites (i.e., less space between sites) would be required to determine species trend in small areas.

At each of the 1,656 systematic sites, the ABMI uses a "paired" terrestrial + wetland sampling scheme (**Chapter 3**). Information on mammals, birds, vascular plants, bryophytes, lichens, mites, vegetation structure, vegetation cover, and soil characteristics is collected according to rigorous protocols at each site. Additionally, information on wetland vascular plants, aquatic invertebrates, and water characteristics is collected at the open-water wetland closest to each systematic site. The ABMI deliberately monitors a wide and taxonomically diverse range of species, as species differ in their use of the environment (i.e., have different levels of mobility, occur at different trophic levels, or have different life histories, etc.) and thus are expected to respond differently to habitat change. Data collection methods for each taxon are integrated as much as possible to increase efficiency. ABMI field sampling methods are effective for detecting change for many common species (**Chapter 5**). To the degree possible, ABMI methods are designed to also detect rare/sensitive species, but many of these are best monitored using species-specific methods. Overall, the ABMI's methods are designed as a robust compromise between detail, taxonomic representation, and efficiency.

To facilitate modelling of species variation among natural land cover and human footprint types, the ABMI's systematic grid of sites is supplemented by targeted sites located in uncommon habitats (**Chapter 4**). Approximately 10% of the targeted sites (**Figure 2-8**) are designed specifically to complement ABMI systematic sites, and the complete suite of ABMI information is collected. The remaining targeted sites are surveyed as part of collaborations between the ABMI and other organizations. The study design for these collaborations is determined based on their particular research questions, with only a subset of ABMI protocols implemented. Information from the collaborators is used in ABMI species modelling. Species models are created to describe how species relative abundance varies among native land cover and human footprint types, and in relation to climatic variation across Alberta. The models can also be used to predict species relative abundance in simulated landscapes. However, since the models were developed using data collected across large regions, predictions of abundance at smaller spatial scales have substantial uncertainty; this uncertainty tends to "average out" at larger scales.

2.6.3 Data collection limitations

The ABMI program has been successful in many respects, including some not initially foreseen. Nevertheless, incomplete funding for the ABMI has slowed two aspects of data collection. First, the ABMI is not yet at full operational capacity, and thus does not yet resurvey all sites every 5^{th} year as initially planned. Though slower than anticipated, field data collection continues to ramp up, with increasing numbers of site revisits taking place each year.

Relatedly, field sampling to date has been concentrated in the eastern 60% of Alberta, with a lesser amount performed in northwestern Alberta, and only a few sites sampled in the Rocky Mountains (**Figure 2-7**). The ABMI's focus on the eastern regions was necessary to ensure a sufficient sample size to determine status and trend of biodiversity for that region. Thus, in this review we are effectively evaluating the degree to which the ABMI is achieving its goals and objectives for the eastern regions of Alberta. We continue to explore ways to increase funding so that field sampling can be ramped up throughout the remainder of the province.

The second main limitation to ABMI data collection involves land cover. Due to resource limitations, most native land cover information used by the ABMI was obtained from GIS layers created by other organizations. The land cover types that are mapped, and the resolution of that mapping, varied somewhat among sources (**Chapter 3**). That resulted in inconsistent and occasionally lower quality information on native land cover being used. A new data partnership involving the ABMI and others—a unique program for Alberta—is being developed to collect consistent high-quality native land cover information throughout Alberta (see section **3.3.2**).

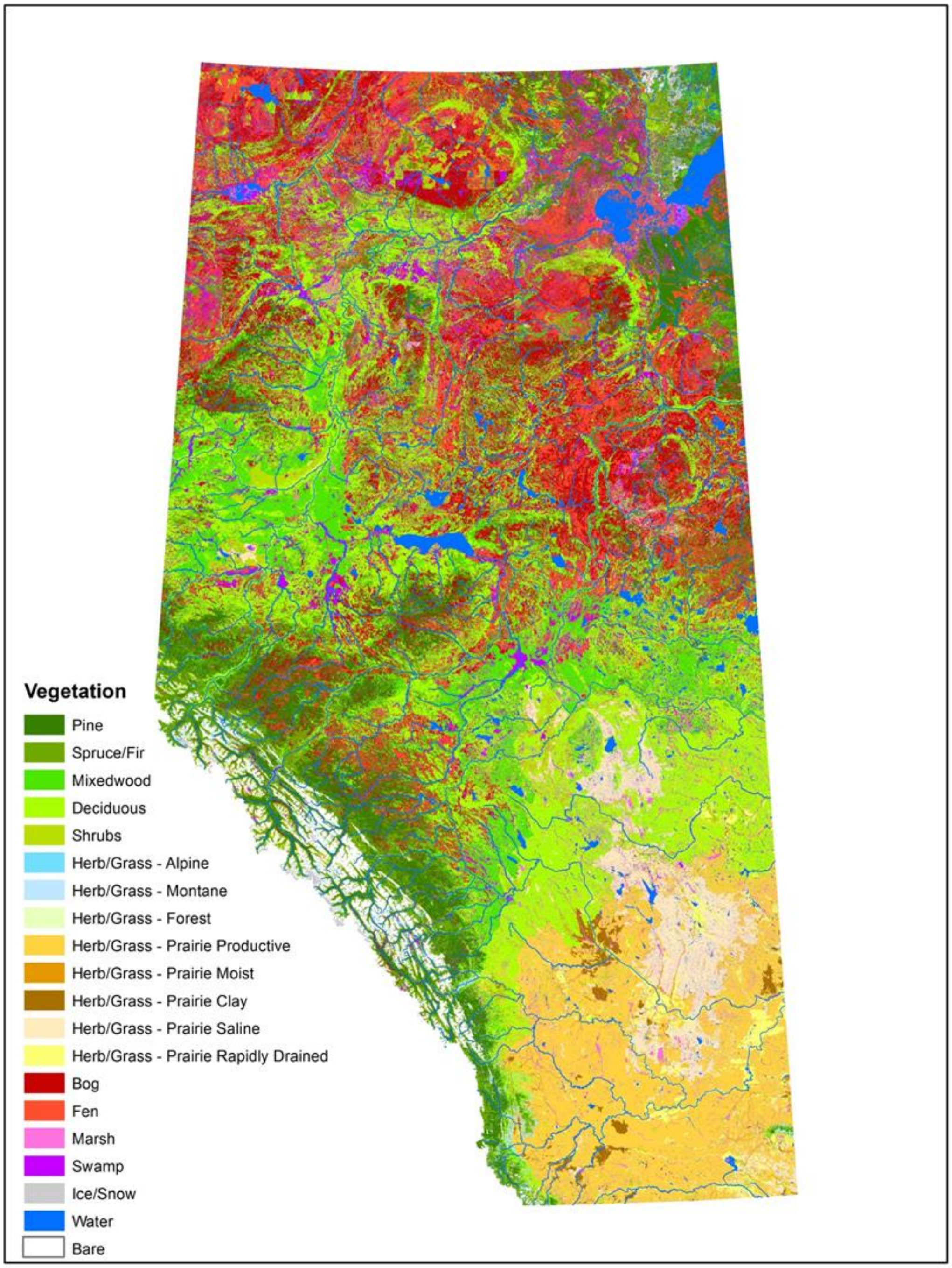

Figure 2-6 Backfilled land cover throughout Alberta. This information was created by amalgamating existing vegetation information created by other organizations, and then "backfilling" human footprints based on the adjacent vegetation and the underlying soils (Alberta Biodiversity Monitoring Institute 2016).

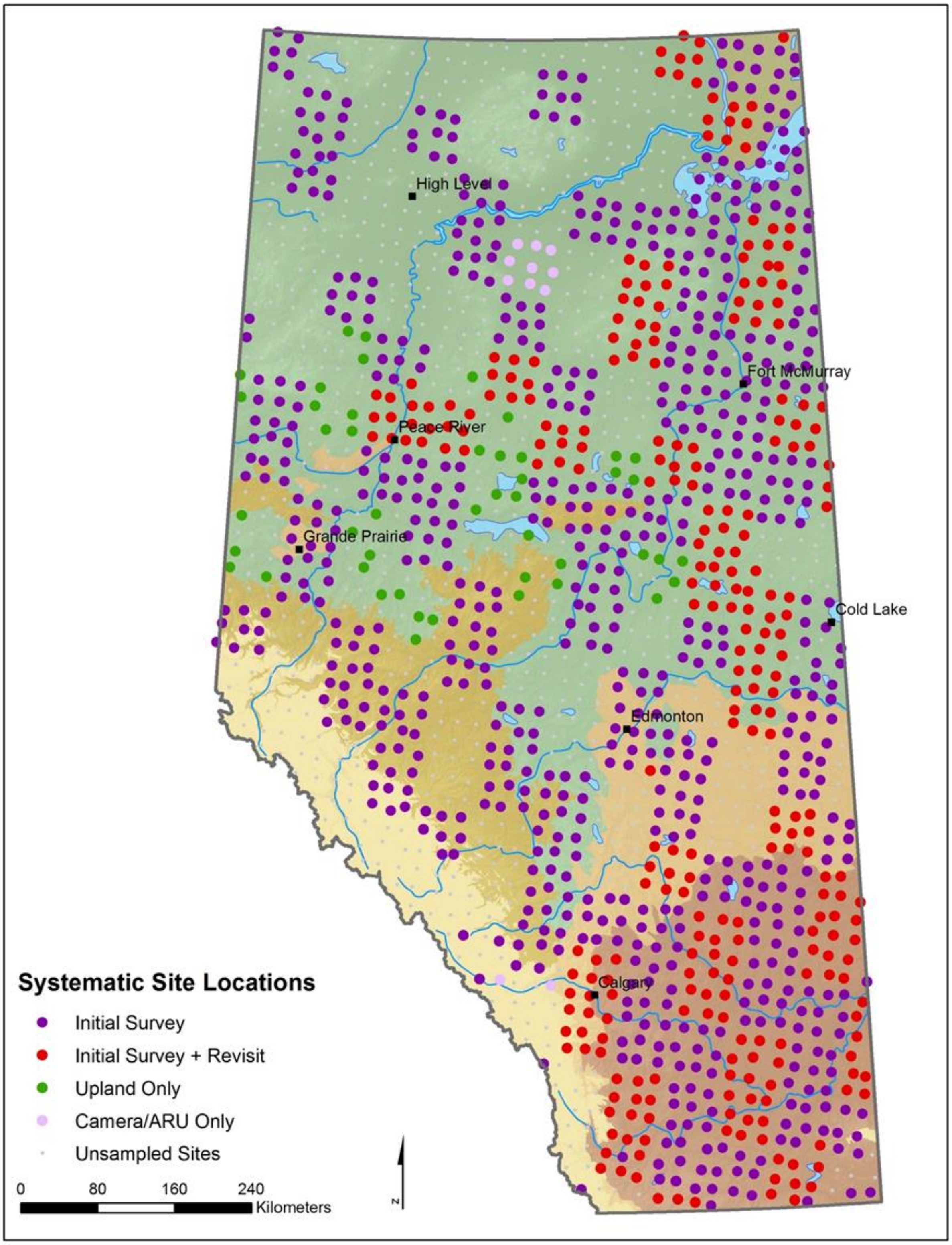

Figure 2-7 Location of ABMI systematic sites that have been surveyed during an initial visit, and those that have been surveyed twice.

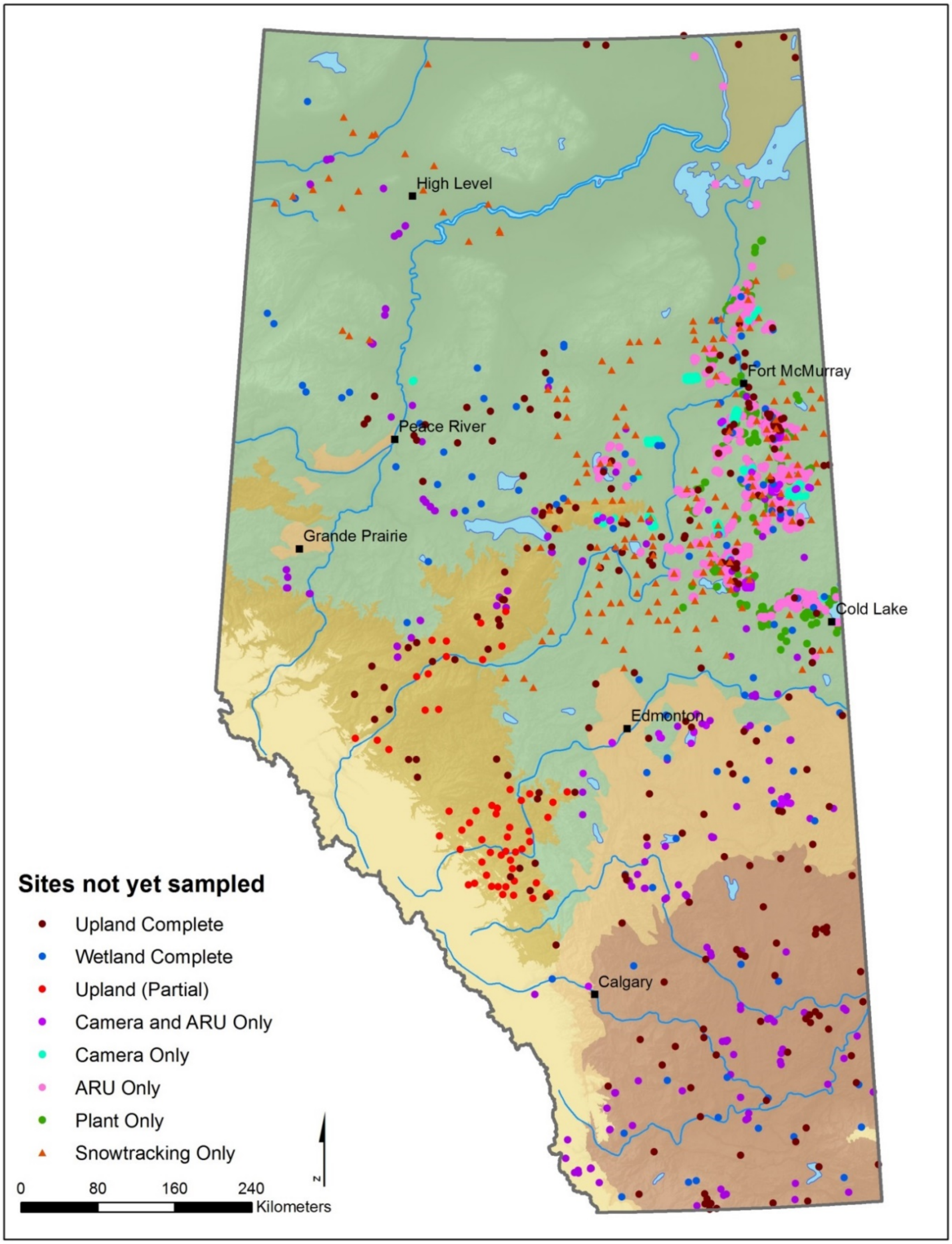

Figure 2-8 Location of targeted sites sampled by ABMI to complement the systematic sampling. At some of the targeted sites the complete suite of taxa were sampled, whereas at others only a subset were sampled. ARU = autonomous recording units.

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3 Data collection

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3.1 Species and site characteristics

3.1.1 Introduction

The ABMI surveys 1656 locations spaced systematically on a 20-kilometre grid across the entire province (**Figure 3-1**)—a number and arrangement of sites chosen explicitly to ensure statistical power sufficient to detect cumulative effects and biodiversity change at regional scales. Each location includes both terrestrial and wetland survey sites. Using a series of scientifically-reviewed protocols tailored to specific taxonomic groups, trained field technicians collect data on terrestrial and aquatic species (more than 3000 species monitored to date; e.g., mammals, birds, vascular plants, bryophytes, lichens, mites, aquatic invertebrates) and habitat characteristics (e.g., physical condition, tree composition, low vegetation, etc.) at each site. The ABMI's monitoring program was designed to sample each site once every five years. The same monitoring protocols are also used at additional "targeted" off-grid sites that complement the systematic sites. At time of writing, the ABMI has already sampled 1005 systematic and 281 targeted terrestrial sites. In addition, the ABMI has sampled 934 systematic and 81 targeted wetland sites, which are chosen as the nearest open-water wetland to each grid site. Finally, as part of collaborative projects, approximately 4,000 additional sites have been surveyed for mammals, birds, plants, or a combination of these. ABMI systematic sites, ABMI off-grid sites, and collaborative off-grid sites were used to model species-habitat associations and assess the effects of human footprint on species abundance. Information collected at ABMI sites, and partner sites when permission is granted, is made publicly available on the ABMI's website at **abmi.ca/data**. To ensure that ABMI sites are not deliberately altered, that sensitive species are not disturbed, and that land-holders' rights are maintained, the locations of the systematic sites are offset in a random direction and distance from the 20-kilometer grid and the exact locations are kept confidential (Sólymos et al. 2013).

The ABMI has developed detailed standard operating procedures (SOPs) for each type of data collection to ensure field technicians collect consistent, high-quality data. This chapter provides an overview of: i) how and what biodiversity and physical site characteristics are collected; ii) limitations and gaps to ABMI data collection protocols and how we are addressing these issues; iii) how the ABMI evaluates our field training, laboratory, and data verification methods; and iv) a comparison of ABMI data collection protocols to those of other monitoring groups.

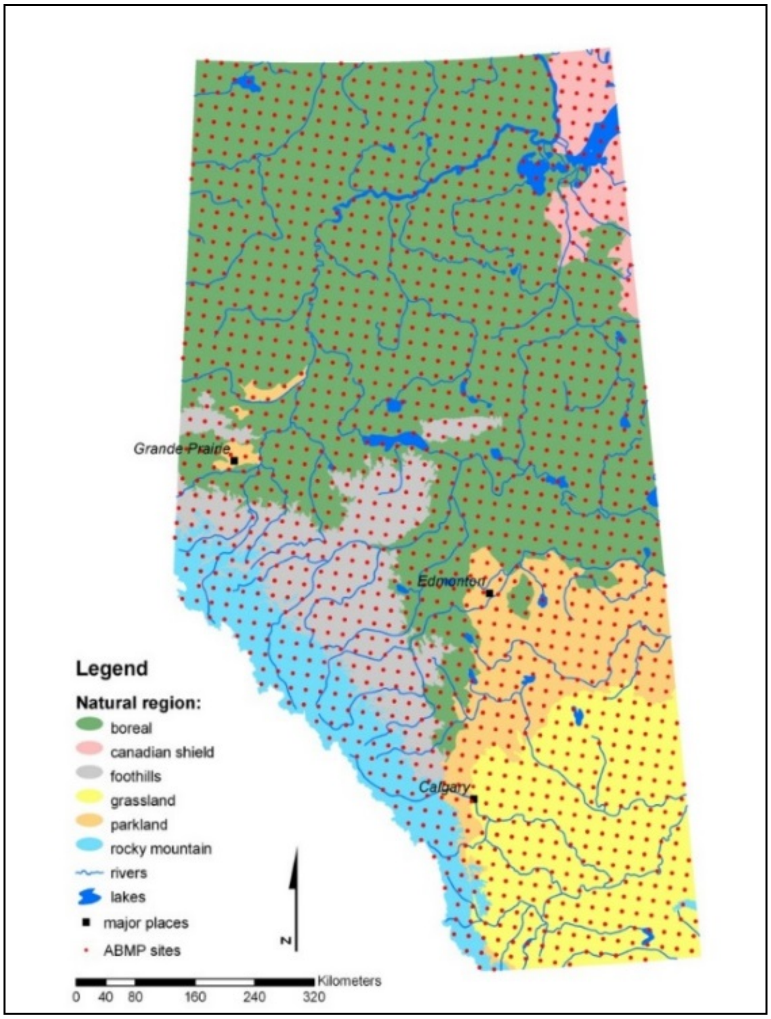

Figure 3-1: Location of 1656 terrestrial and wetland sites spaced throughout Alberta using the 20-km National Forest Inventory (NFI) grid.

3.1.2 Data collection

In this section, we review the field and laboratory protocols associated with the collection of biodiversity and site characteristic data. A detailed explanation of ABMI data collection protocols can be found in the **Species and Site Characteristics Data Collection** technical report (2017a).

3.1.2.1 Basic survey practices

Each ABMI survey site consists of a 100 m × 100 m square based around a central point (**Figure 3-2**). At each field site, information on general (e.g., latitude, longitude, natural and human disturbance, etc.) and detailed (e.g., standing dead vegetation, soil characteristics, etc.) habitat characteristics, and the occurrence of seven taxonomic groups (vascular plants, bryophytes, lichens, birds, mammals, mites, aquatic inverts) is collected (see overview of ABMI Data Collection in the **ABMI Terrestrial Field Protocols** technical report). Site centre is located as precisely as possible using hand-held GPS units, with a 1.5-m steel bar driven into the ground so that it protrudes 1 m (see *Establishing Plots, Transects and Stations* in the **Terrestrial Field Protocols** document). This marker is left in place when possible to facilitate future revisits; however, permission to do so cannot always be obtained, in which case the site's location is based only on GPS coordinates.

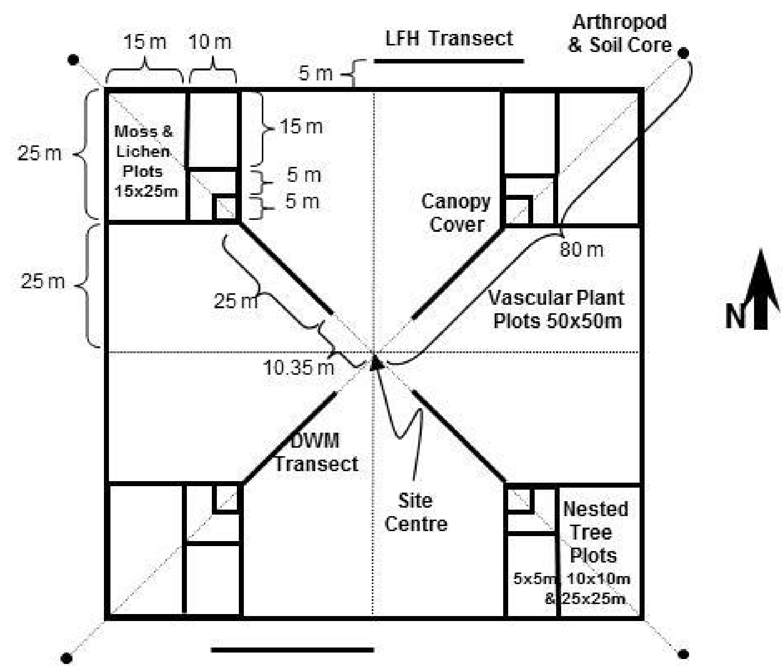

Figure 3-2 A typical 100 m × 100 m ABMI terrestrial sampling plot.

3.1.2.2 Biodiversity sampling

3.1.2.2.1 Mammals

Between 2001 and 2014, mammals were surveyed during winter by counting tracks along a 10-km snow transect. In 2015, the ABMI began using remote cameras (ABMI 2014a), allowing us to gather additional data regardless of weather conditions. Cameras are triggered based on heat (infrared signature) and movement of mammals in front of the camera and are deployed between October and March, remaining in place until July. The camera method increases our ability to detect mammals outside the winter months. A camera is installed at each corner of a 600 m × 600 m square centered on each ABMI site (Figure 3.3; ABMI Monitoring Centre 2015). To increase the detection of mammals, a scent is used at the northeast and northwest cameras. Cameras are retrieved in July, and pictures subsequently interpreted by experts with the aid of computer programs.

3.1.2.2.2 Birds

For the ABMI's bird analyses, ABMI data are combined with data from the Boreal Avian Modelling Project (BAM). Within Alberta, the BAM database is a compilation of data from the Breeding Bird Survey (BBS), Breeding Bird Atlases, Environment and Climate Change Canada (ECCC), the University of Alberta Bioacoustics Unit, other monitoring projects, and short-term research projects (see **Technical Report 5.5**). In particular, the ABMI, BAM, and ECCC have enjoyed a long and mutually beneficial relationship during which both data and ideas have been shared, occasionally complicating deterministic, single attribution. BAM has developed techniques to allow survey data collected under different protocols to be included in one analysis (Solymos et al. 2013, Barker et al. 2015).

Unless otherwise noted, bird analyses in this report use a composite BAM + ABMI dataset, harmonized using BAM's techniques. This composite database represents the majority of all avian point count data in the province. The ABMI has currently contributed 10,771 of 83,029 surveys to the composite BAM + ABMI dataset (13%). ABMI data improves this collective dataset in various ways. First, ABMI sites cover many areas that otherwise have little or no sampling due to the southern bias present in the BBS and many research projects due to road coverage. Second, ABMI sites are randomly located at the local scale, increasing the number of samples that are collected far from roads. Third, the ABMI makes regular revisits to sites. Together with contributions from ECCC and the Bioacoustic unit, this increases the number of sites with revisits. Fourth, like other recent contributions to the BAM database, ABMI surveys use audio recordings. Once standardized computer interpretation is possible, this will eliminate the large effect of different observers. In addition, old recordings will be available for re-analysis with new technologies.

Prior to 2015 (2016 in the Grassland and Parkland natural regions), the ABMI monitored birds by capturing sound recordings for 10-minute periods at nine point-counts in each site between late May and late June (ABMI 2014b). Bird vocalizations are now recorded using autonomous recording units (ARUs). ARUs are deployed between October and March (at the same time as cameras), retrieved in July, and record vocalizations during eight specified periods throughout each day between March 1 and June 30 (ABMI 2014a, ABMI – Monitoring Centre 2015). An ARU is installed at each corner of a 600 m × 600 m square centered on the ABMI site (**Figure 3-3**; ABMI Monitoring Centre 2015). Vocalizations on the recordings are interpreted by experts with the aid of computer programs.

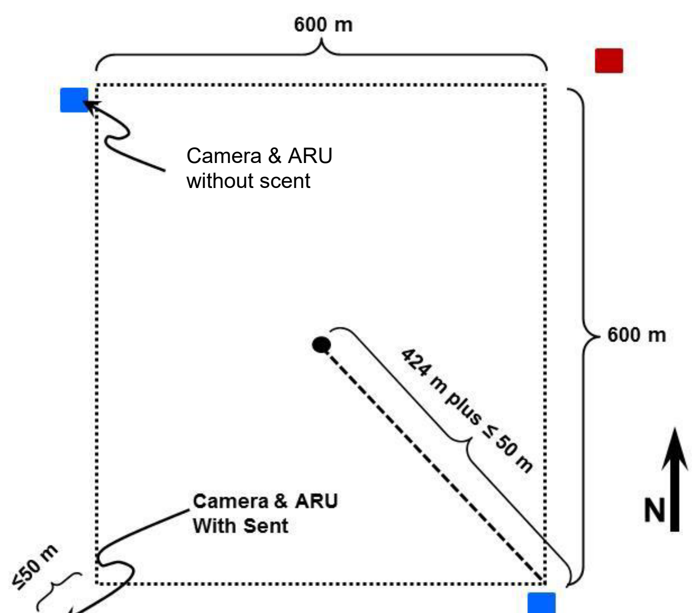

Figure 15

3.1.2.2.3 Vascular plants

A single technician searches four 50 m × 50 m quadrants (20 minutes each for a total of 80 minutes) within the central 1 ha at each site. To make the best use of limited search time, unknown specimens are collected for identification after the search period. Specimens that cannot be easily identified by the field technician are sent to the Royal Alberta Museum (RAM) for identification by taxonomic experts. In addition, if a specimen is categorized as S1 or S2 (i.e., rare) by the Alberta Conservation Information Management System (ACIMS), it is collected and sent to the RAM for confirmation by experts (ABMI 2010). Finally, percent cover is estimated in four 5 m × 5 m plots for low vegetation, shrubs and small trees, and physical features.

Camera & ARU
with scent

Figure 3-3 A 600 m x 600 m square for ARU-based monitoring.

3.1.2.2.4 Wetland vascular plants

The nearest open water wetland to each ABMI survey site is used for wetland surveys (**Figure 3-4**). At these wetland sites, vascular plants are sampled at fourteen 2 m × 10 m plots. In each plot, field technicians record the occurrence and relative abundance of vascular plant species. Wetlands are sampled between June 15th and July 31st each year, when aboveground standing crop is at its peak and most vascular plants have matured and can be easily identified. Vascular plants are identified in the field, with specimens that can't be identified, or are designated rare by ACIMS, collected and forwarded to experts at the RAM.

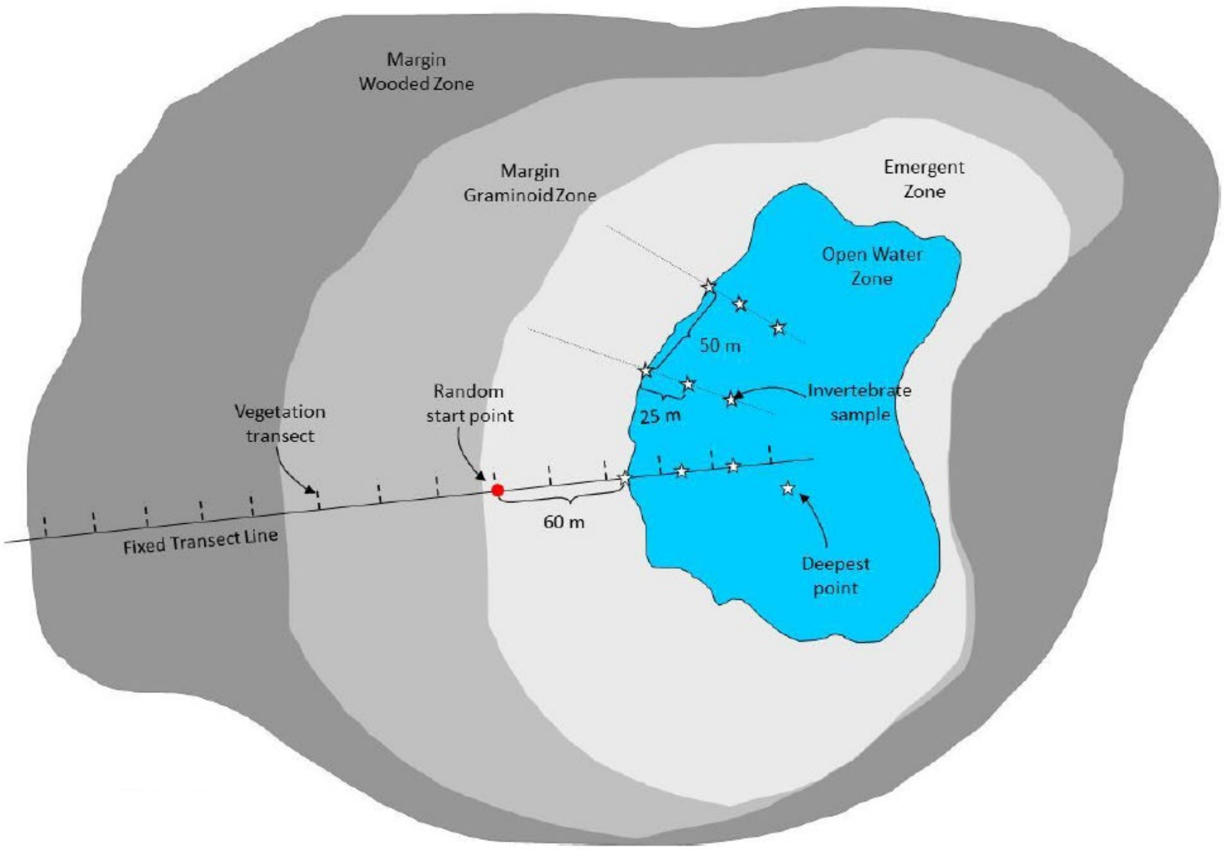

Figure 3-4 An example of an ABMI wetland survey site.

3.1.2.2.5 Bryophytes and lichens

Bryophytes and lichens are collected in four 25 m × 15 m plots during a 35-minute search period (140-minutes per site). During this process, five "strata" are searched for bryophytes and lichens. These include: i) logs and stumps; ii) trees, shrubs, and other vertical structures; iii) wetlands and peatlands; iv) rocks and cliffs; and v) upland soils. Within each plot, 25 minutes are spent searching the most diverse strata and 10 minutes spent searching the less diverse strata (ABMI 2014a). When collecting specimens, a small sample (5–10 cm^2) is taken so that the vegetation community remains intact. Collected specimens are forwarded to the RAM to be identified by taxonomic experts (ABMI 2009; ABMI 2011).

3.1.2.2.6 Mites

At the corner of each ABMI field site, four soil core samples are collected and preserved (ABMI 2014a). Soil samples are collected outside the 1-ha area to maintain the integrity of the forest floor within the 1-ha plot. Organic and mineral soil from each core are separated and sent to the RAM where mites are sorted, identified and slide mounted, and verified by the lead taxonomist (ABMI 2013a).

3.1.2.2.7 Wetland Aquatic invertebrates

Aquatic invertebrates are collected at wetland sites in the open-water zone and emergent/open-water interface (**Figure 3-5**). Ten invertebrate sweeps are collected using a D-ring net. Nine of these sweeps are performed systematically along transect lines, with an additional single sweep taking place at the deepest point in the wetland. Collected specimens are combined into a composite sample and sent to the Royal Alberta Museum (RAM) for processing by taxonomic specialists (ABMI 2015).

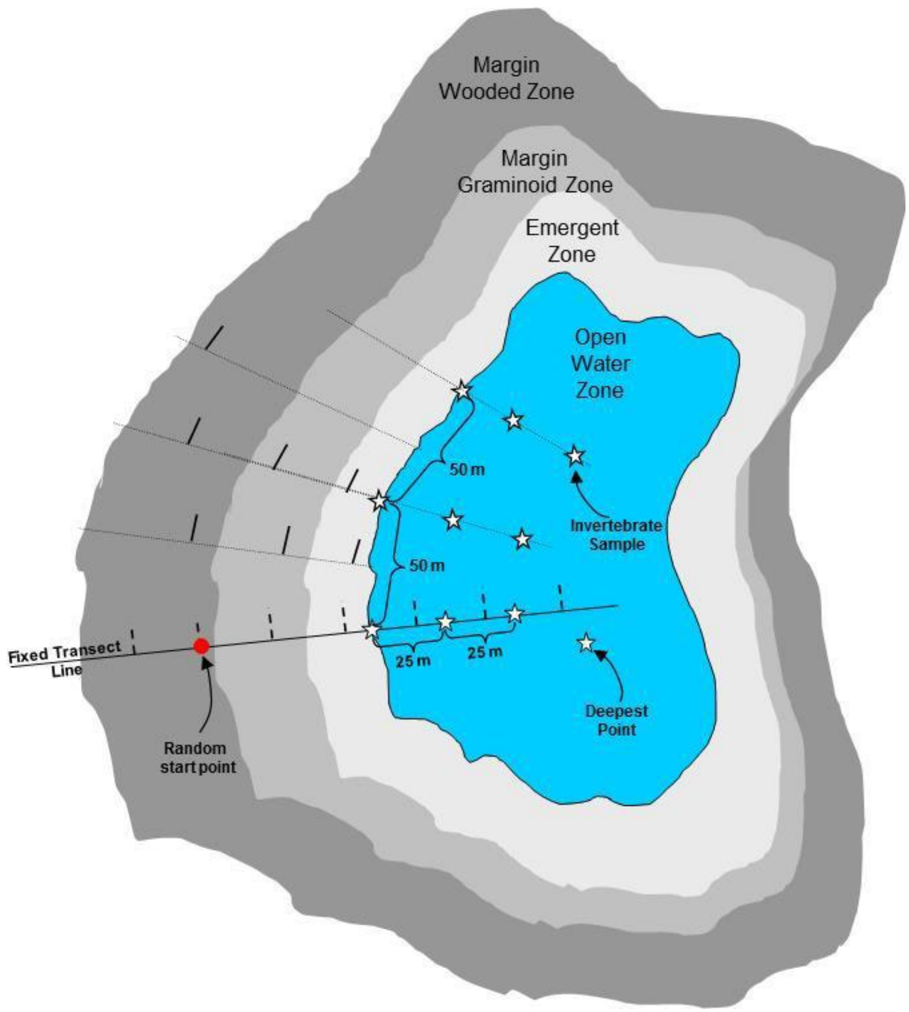

Figure 3-5 An example of the ABMI invertebrate sampling protocols.

3.1.2.3 Physical site characteristics

3.1.2.3.1 Site characteristics

Systematic site characteristics are described at nine locations for each site where photographs, physical conditions, tree composition, low vegetation, ecological site type, natural disturbance (e.g., fire, wind, erosion) and human disturbance (forest harvest, pipelines, cultivated fields) are recorded (ABMI 2014a). In addition, field technicians identify general site characteristics in four 5 m × 5 m tree plots prior to performing vascular plant surveys (ABMI 2014a).

3.1.2.3.2 Soils

Surface substrate is measured on two 30-m transects located to the north and south of each site (ABMI 2014a). Along each transect, information on the slope position, slope direction, depth of organic litter, fibric and humic layers (LFH), and human and natural disturbances is recorded. Four soil core samples are collected on the outside corners of the site and the ecosite type is recorded (these same soil samples are also used for the mite sample). Organic soil, mineral soil, and soil mites are collected and stored separately to be analyzed by trained technicians.

3.1.2.3.3 Trees, snags, and downed woody material (DWM)

Tree, snag, and DWM data are collected in three nested plots sized, respectively, 5 m × 5 m, 10 m × 10 m, and 25 m × 25 m at the four corners of each ABMI 1-ha site (ABMI 2014a). For each tree, snag, and stump sampled, the species identity, diameter-at-breast-height (DBH), and canopy crown class is record. A subset of tree heights is measured, with the surrounding trees estimated based on the measured trees; snag and stump heights are measured, and the state of decay recorded for all snags. The number of pieces and stage of decay of DWM are recorded along sub-ordinal transects. Tree cores are sampled and canopy cover and base height are measured for trees with DBH > 7 cm at each site.

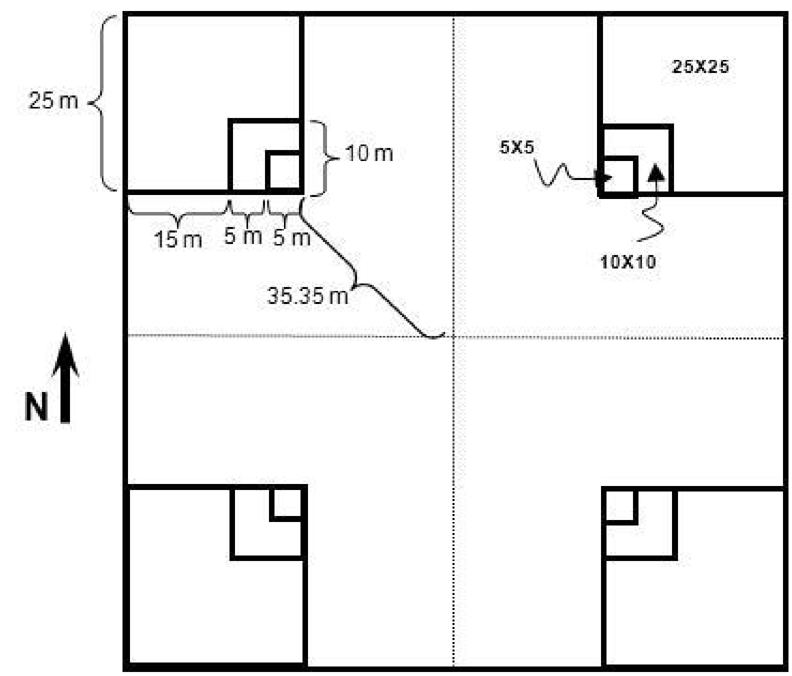

Figure 3-6 An example of ABMI protocols for sampling trees, snags, and downed woody material.

3.1.2.3.4 Vegetation disturbance intensity

Human disturbance intensity is inferred based on the degree to which vegetation characteristics differ from that expected under natural conditions. Surveys are conducted by experts between late June and late September using sampling methods adapted from the **Range health**

assessment for grassland, forest, and tame pasture and **Riparian health assessment for lakes, sloughs, and wetlands** manuals (Adams et al. 2009; Ambrose et al. 2009).

3.1.2.3.5 Wetland site characteristics

Wetland site characteristics are described using site photos, bathymetric maps, wetland zones, human and natural disturbances, and maps of shoreline characteristics (ABMI 2016a; ABMI 2017a). Water samples and physiochemistry (e.g., temperature, pH, dissolved oxygen) readings are also collected at three locations in each wetland site at locations determined by bathymetric maps.

3.1.3 Evaluation

The ABMI is proud to have developed industry-leading quality-assurance and quality-control (QAQC) measures and performed field studies to ensure accurate field data collection. QAQC documentation is reviewed annually and updated to ensure they accurately reflect actions prior to, during, and after field data collection. The ABMI's quality-assurance can be broken down into four broad categories: i) field and laboratory training; ii) equipment calibration; iii) data verification and validation procedures; and iv) field studies and next steps.

3.1.3.1 Field and laboratory training

To ensure high quality data collection, field technicians hired by the ABMI are required to have prior professional field experience and academic knowledge in environmental data collection. After hiring, field technicians undergo rigorous training. Training modules for each type of data collection use a combination of classroom and field exercises. Vascular plant searches are performed by a field technician who can identify at least 80% of species expected at the site. This person must have at least one year of experience surveying vascular plants and have spent a minimum of two days "brushing up" on identification skills. Training is supplemented through detailed data collection manuals including maps, guidebooks, cheat-sheets, and other materials (ABMI 2016c). Field technicians also practice skills such as ocular estimation of percent ground cover to ensure consistent data are collected among technicians. Before technicians begin field data collection, they are tested on a mock field day and given feedback on which skills need further training. A second quality check of technicians is performed early in the field season to ensure protocols are being followed and species identifications are accurate. Field coordinators implement additional random quality checks throughout the season to provide feedback to technicians (ABMI-MC-SOP-003 2013). See the **Quality Control** (2017) technical report for more details.

For each taxon (except for vascular plants), laboratory technicians are trained to identify specimens to the desired taxonomic level with > 95% accuracy. For vascular plants, the taxonomic specialist identifies specimens that cannot be identified in the field, which are then verified by an external expert (ABMI 2016c). For all taxa, internal audits are performed on a regular basis to ensure the minimum standard of accuracy for identifications.

3.1.3.2 Electronic equipment calibration

The ABMI uses the Quanta Hydrolab to measure water characteristics in wetlands. To ensure proper functionality, field coordinators calibrate and test each unit pre-season, within-season, and post-season. Units are also tested in the field by technicians. Tests compare the units against reference standards and to each other to ensure accuracy and consistency. Expected readings and ranges are provided for wetland sites based on historical data; readings that fall outside the expected range are confirmed by alternative techniques (e.g., pH strips).

The ABMI deploys cameras to monitor mammals, and ARUs to monitor birds. Protocols ensure the units are deployed properly at field sites, data collection is standardized, firmware is updated, and damage is recorded and repaired after collection. Pilot studies are used to establish baselines for new units and test how detection varies between new and old units.

The ABMI uses Panasonic tablets so field data can be entered electronically during data collection. For each field protocol, there is an associated data sheet preprogrammed into the tablet to input data efficiently and consistently. Field coordinators ensure each field tablet is loaded with the appropriate field protocol data sheets. Before field use, new models are tested on a small scale to ensure hardware and software perform as planned.

3.1.3.3 Data verification and validation

Data collected by field technicians, species identifications by taxonomic experts, and data collected from ARUs and cameras are checked and verified before being made available to the public or used for downstream analyses. Field data are reviewed by field coordinators at the end of each shift and a checklist for each site is completed. This review provides feedback to field technicians and corrects any inconsistencies/incompleteness of the data before the data are compiled for post-season verification (ABMI-MC-SOP-002 2013). At the end of the field season, all data are reviewed and verified by the field coordinators (ABMI-MC-SOP-001 2013). In addition to these reviews, the ABMI has developed procedures to correct errors in the data, provide appropriate metadata, ensure sensitive data are not publicly released, and maintain regular back-up schedules to ensure high quality data are used in downstream analyses. See the **Quality Control** (2017) technical report for more details about data quality control and assessments, storage, and dissemination of data.

3.1.3.4 Field studies and next steps

To ensure accurate data is collected at sites, the ABMI has performed, and continues to develop, supplementary field studies as part of our ongoing field protocol testing. For example, a recent field study assessed the repeatability of vascular plant surveys by comparing species detection rates of both technicians and experts under different sampling scenarios. Additional studies currently in development are focused on the repeatability of bird detections when using a subsample of available ARU data at each site. This research helps identify how field, training, and analysis protocols can improve data quality. Continued development and implementation of these studies will be essential in allowing the ABMI to collect accurate field data.

3.1.4 Limitations

3.1.4.1 Limitations of monitoring site characteristics

No monitoring program can account for every potential source of error. There are challenges when resampling sites, especially at locations where the ABMI is not allowed to place permanent markers. Even with highly sensitive GPS technology, accurately identifying plot locations has error. This can lead to slight differences between the area sampled initially and during the revisit. Furthermore, for sites on private land, owners may not allow resampling, forcing a new site to be chosen. Changes in site location between visits reduce the ABMI's ability to estimate trend.

Wetland information has additional limitations. The ABMI is only able to sample water chemistry once per season, but water chemistry may change over the growing season. Thus, single sampling events may not fully represent the characteristics of the wetland.

3.1.4.2 Limitations to Field data collection

3.1.4.2.1 Birds

Prior to the deployment of ARUs, the ABMI's bird monitoring protocol had several limitations. Point counts conducted at a grid of systematic sites during the early mornings between late May and late June may be insufficient for monitoring waterfowl, shorebirds, rails, owls, and raptors (ABMI 2016b). In addition, the systematic sampling design did not effectively capture species that live in rare patchy habitats (ABMI 2016b). With the implementation of ARUs, sampling is greatly improved for nocturnal bird species, species that vocalize mainly during the early spring, and species with irregular or infrequent vocalization periods. As an added benefit, ARUs also detect vocalizing amphibians.

3.1.4.2.2 Mammals

Facing similar challenges to birds, data collection through snow tracking only provided data on species active during the winter and identifiable from snow tracks. As a result, bears were not sampled, and white-tailed/mule deer, marten/fisher, hares/rabbits, and weasels/ermine had to be grouped due to the similarity in their tracks. With the implementation of cameras, mammals are now detected across multiple seasons and most images can be identified to species.

3.1.4.2.3 Vascular plants, lichens, and bryophytes

Limitations are similar for these three taxa. The survey window during July is not optimized for all species, potentially complicating identification for species that develop characteristic features during other periods. In addition, it is difficult for field technicians with less than a decade of experience to accurately survey taxonomically complex groups like bryophytes and lichens (ABMI 2016b). These taxa are sampled during a fixed search period and many species, especially rare species, may not be not detected. In turn, incomplete sampling, due to the fixed sampling period, decreases repeatability and reduces power to detect trend.

Cover for vascular plant surveys is difficult to estimate accurately and consistently (Kennedy and Addison 1987). Inaccurate determination of plot locations (i.e., in those cases when site centre cannot be marked) decreases repeatability even further. To overcome these issues, a "gold standard" test plot has been proposed. The gold standard plot would contain a complete inventory of species present in addition to precise plot coordinates. That plot would then be used to test field technicians throughout the season and document biases among technicians.

3.1.4.2.4 Aquatic invertebrates

The ABMI is assessing if current monitoring protocols are adequate to assess the occurrence and abundance of aquatic invertebrates. Modified wetland sampling protocols are being evaluated. These include the value of increased site revisit frequency (multiple visits per year) plus sampling fish, dominant vegetation, and substrate characteristics.

3.1.4.3 Limitations to species identification

Even taxonomic experts and trained technicians can make species identification errors (Culverhouse et al. 2003). The ABMI reduces these errors through training, verification, and by flagging taxonomically difficult species for future improvements. In addition, difficult-to-identify species are classified to genus, although this results in species-habitat models being generalized to the genus.

3.1.5 Comparison to external monitoring programs

Large programs, such as the ABMI's, that monitor a variety of taxa across a large area are unique among biodiversity monitoring programs (see the **Biodiversity Programs Review**). Most other programs are focused on fewer taxa in a smaller geographic region (ABMI 2017b). In addition, the systematic grid approach used by the ABMI to determine plot locations is often not implemented by other biodiversity monitoring programs. The ABMI's systematic approach allows sites to be consistently resampled and data on all taxa to be collected in direct proportion to species' actual occurrence across the landscape. Programs that compile data from a variety of sources, sampling times, and methods have added complications (ABMI 2017b).

Some biodiversity programs that monitor on a scale similar to the ABMI's use citizen scientists to collect data (ABMI 2017b). Using citizens is popular in part because it is more cost-effective to sample a large area with volunteers instead of paid employees. However, it is unreasonable to expect citizens to do systematic data collection, particularly in remote areas and for rare or hard-to-identify species. The ABMI is evaluating whether citizen science data can be used to supplement core data collection, especially for cameras and ARUs. More information on how the ABMI compares to other biodiversity programs can be found in the review of biodiversity monitoring programs technical report (ABMI 2017b).

3.1.6 References

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3.2 Native Land Cover

3.2.1 Introduction

Documenting and mapping Alberta's land cover is critical to understanding how human activity is affecting ecosystems, and to supporting sustainable, evidence-based land-use decisions (e.g., Alberta's Land Use Framework[1]). To that end, the ABMI has the broad goal of describing the distribution, abundance, and trend of native land cover. Accomplishing this goal entails having high quality vegetation information for developing species-habitat models, detecting trends in biodiversity, and monitoring changes in the extent and distribution of native vegetation across the province (Nielsen et al. 2007, Alberta Biodiversity Monitoring Institute 2015a).

The ABMI has created map products that describe native land cover including: (i) the Alberta Wall-to-Wall Vegetation layers (Alberta Biodiversity Monitoring Institute 2017a) and (ii) the 3 × 7 photo plot layer (Castilla et al. 2016a, 2016b). Each product is described in the following sections with respect to how it was created, its intended purpose, and its strengths and limitations (see *Section 1.1.1* in the **Native Land Cover Technical Report**).

3.2.2 Wall-to-Wall Vegetation layers

The Wall-to-Wall Vegetation layers (Alberta Biodiversity Monitoring Institute 2017a) provide information on current vegetation, soil, and human footprint conditions for the entire province of Alberta (i.e., *wall-to-wall* coverage), at a maximum scale of 1:5000. In addition, the expected native vegetation conditions that existed prior to human disturbance (i.e., *reference* conditions) were created by replacing current (circa 2014) human footprint with the predicted vegetation types for that location in the absence of human footprint (in other words, the human footprint was 'backfilled' to native vegetation) (Alberta Biodiversity Monitoring Institute 2017a).

The layers (current and reference) are fundamental to the ABMI's assessment of biodiversity status and intactness. Besides describing the distribution and extent of native habitat, they are used extensively to develop species-habitat associations and to determine the effects of anthropogenic changes on individual species. The layers are regularly refined, and their accuracy, utility, and depth of information increase with each version release. Currently, Wall-to-Wall Vegetation layers are available for the years 2007, 2010, 2012, and 2014, each with a version history and recurrent updates.

3.2.2.1 Data sources

The Wall-to-Wall Vegetation layers are an amalgamation of vegetation and physical information available from multiple sources, listed below in the order of precedence used when multiple sources are available for the same area (**Figure 3-7**).

[1] https://landuse.alberta.ca/Pages/default.aspx [Accessed 20 June 2017]

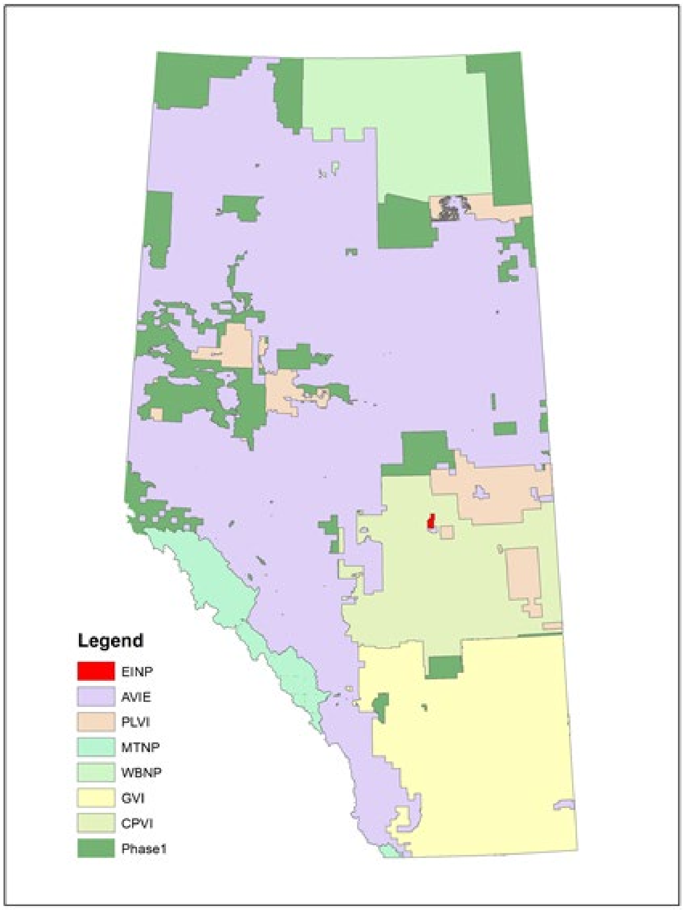

Figure 3-7: Extent of the major source layers used to create the ABMI Wall-to-Wall Vegetation Layers (Version 6). Source layers are described briefly in Section 3.2.2.1 and in greater detail in Alberta Biodiversity Monitoring Institute 2017a and b)

- **Mountain National Park** (MTNP): Ecological Land Classification data for Banff, Jasper, and Waterton Lakes National Parks
- **Wood Buffalo National Park** (WBNP): Vegetation classification derived primarily from Landsat 7 remote sensing data.
- **Alberta Vegetation Inventory (Extended)** (AVIE): A photo-based polygon layer produced by the Government of Alberta[2].
- **Elk Island National Park** (EINP): A vegetation thematic map that follows the AVI format.

- **Grassland Vegetation Inventory** (GVI): A polygon layer based on stereo photography that provides an inventory for portions of Alberta's White Area. It is produced by the Government of Alberta.
- **Primary Land and Vegetation Inventory** (PLVI): A coarse-scale vegetation inventory that provides basic ecological site phases for large areas of Alberta (Alberta Government 2016).
- **Central Parkland Vegetation Inventory** (CPVI): A polygon layer based on aerial photos and Landsat Thematic Mapper 7 imagery produced by the Government of Alberta that provides vegetation information for the Central Parkland Natural Subregion.
- **Phase 1 (Broad Scale) Forest Inventory:** This layer, based on aerial photo interpretation, was created by the Government of Alberta to provide information on the province's forest resources located on public lands (with some exceptions).

Rule sets were developed to harmonize the polygon attributes from each source and facilitate their combination into a single layer. The procedures and rule sets are fully described in Alberta Biodiversity Monitoring Institute 2017a.

3.2.2.2 Layer contents

The information available for each polygon includes:

1. Vegetation type, including wetland types,
2. Moisture regime,
3. Year of polygon origin (e.g., forest stand age),
4. Supplementary wetland information,
5. Supplementary soil information (for the Grassland and Parkland Natural Regions, and the Dry Mixedwood Natural Subregion),
6. Larch (*Larix* sp.) information for forested areas, and
7. Type of human footprint.

In addition, to support ABMI analyses the following supplemental information was added for each polygon: Natural Region and Natural Subregion, Hydrologic unit code (HUC), Landuse framework region, and Green/White Area.

These layers are an amalgamation of the best available spatial data. This amalgamation facilitates the creation of a province-wide layer describing the distribution and abundance of native vegetation. Combined with the 2014 human footprint layer, the Wall-to-Wall Vegetation layer lets managers track changes occurring to Alberta's native vegetation and make evidence-based land-use planning decisions. Within the ABMI, these layers are a critical resource and are heavily used for assessing the status of biodiversity and for modelling species–habitat associations.

The source layers used to create the current and reference vegetation vary with respect to their content, original purpose, spatial extent, resolution, and accuracy. Therefore, while the layer achieves its goal of describing native vegetation across Alberta, the strengths and limitations of the layer vary both spatially and thematically (**Section 3.2.3**). The ABMI has devoted substantial effort to increasing this accuracy and mitigating limitations with each version release by using the latest version of each component layer, adding new source layers (and new polygon attribute data) when available, and refining the rule sets used to merge layers, harmonize attributes, and backfill native vegetation.

3.2.2.3 Evaluation and cross-referencing

3.2.2.3.1 Ground-truthing

In accordance with Alberta Vegetation Inventory Interpretation Standards, vegetation is ground-truthed before mapping to provide detailed information for interpreters, such as age and heights. However, this is better viewed as interpretation aid than as a vehicle for quality control.

The spatial layers describing native land cover represent the best available information, but have not been formally ground-truthed after development to assess their accuracy. Ground-truthing would allow for the accuracy of these datasets to be evaluated and provide information to improve subsequent versions. However, a ground-truthing program would come at considerable financial costs. As an alternative, we made comparisons among the various datasets.

3.2.2.3.2 Comparing Wall-to-Wall Vegetation and field data

The ABMI collects land cover information at each of its survey sites, which presents an opportunity to compare ABMI field-based land cover data with the Wall-to-Wall product. The locations of ABMI site centers (1-ha squares) were intersected with the current and reference vegetation layers (Version 6). Sites that fell completely within (> 99%) a single polygon were selected and compared to the field data collected at that site. Neither data type was considered to represent the 'true' vegetation type. Rather, the comparison was intended to assess the degree of similarity between the two datasets.

For each site, we used variables that had been determined through field surveys to indicate habitat elements; for example, for treed sites, we considered variables such as basal area (BA), proportion of BA canopy closure, and shrub cover. We used canopy closure and shrub cover to check non-treed sites. Some sites received multiple visits. The reported sample size weights each record for revisited sites as 1 divided by the number of revisits. When there is a fractional sample size, the vegetation and human footprint information for the site changed between visits.

3.2.2.4 Results and discussion

Results are shown for treed and non-treed sites and include land cover types representing native vegetation. Comparisons were limited to categories containing at least 20 sites; comparisons for categories with < 20 sites are provided in Alberta Biodiversity Monitoring Institute 2017b.

Deciduous stands

Of 33 polygons labeled 'deciduous', 23.5 were accurate, 8.5 were inaccurately labeled as mixedwood, and one was too young to determine (currently conifer/mixedwood). The polygons incorrectly identified as mixedwood comprised 20–80% deciduous and the rest upland conifer. These were all mid-seral to older stands, and should be classified as deciduous. The progression of BA with stand age class was reasonable.

Treed bogs

Of 20 polygons labeled as treed bogs, the field data indicated that 18 were labeled accurately, one was a pine stand, and one was a deciduous stand. The relationship between age and basal area was reasonable given the variability in tree density in this lowland type.

Grass and herbaceous

Of 89 polygons labeled 'grass and herbaceous', 74 were accurate according to the field data, 10–15 sites had as much shrub cover as "Shrub" sites, and three were deciduous stands (with high levels of canopy cover, and thus not open grass/herb sites). The sites with more shrub cover than expected for a grass/herb site included sites with more, similar and lower levels of grass cover compared to shrub cover.

Limitations of our approach

Our comparison approach has some limitations vs. ground-truthing. First, the information within each dataset was not collected specifically to test against other independently collected information. Thus, the evaluation required a 'cross-walk' between layers for polygon attribute data. Second, in some circumstances, data were taken from the same base layers (such as AVI) to either (a) directly provide data (i.e., in the creation of the wall-to-wall products) or (b) aid photo-interpreters and digitizers (i.e., in the development and interpretation of the 3 × 7 sample-based layers). Thus, the data were not totally independent. Third, the layers were created with different spatial resolutions to meet different needs. Overall, the Wall-to-Wall Vegetation layer comprises coarser data from multiple sources spanning the entire province; by contrast, photo plots entail higher levels of detail for smaller areas.

The field data collection protocols were not designed to formally ground truth the Wall-to-Wall Vegetation layer (or other layers). In addition, most sites were excluded because they spanned multiple land cover types and it was not possible to compare many land cover types. A dedicated ground-truthing program with appropriate sample sizes in all land cover types would be a more robust method of comparison and evaluation.

3.2.2.5 Next steps

The Wall-to-Wall layer could be improved in the following ways:

- The current suite of vegetation types is diverse but could be expanded to include additional sub-categories. This expansion would facilitate more specific species-habitat models and allow for improved tracking of smaller-scale, or rare/uncommon, ecosystems. However, the sub-categories would not be consistent among source vegetation layers and thus would be inconsistently mapped throughout the province.

- Replacing human footprint (e.g., crops) with native vegetation in agricultural regions (primarily in the White Zone) is based on rule sets created for the entire Natural Sub-region, and thus the backfilling is done at a coarse scale which might not accurately reflect local conditions. The information on soil types is broadly accurate but is not sufficiently refined to allow for robust prediction of vegetation types at a given location.

These limitations will be addressed as new—or better—data become available through ABMI initiatives or third-party sources.

3.2.3 3 x 7 photo plot layer

The 3 × 7 photo plot layer is a high-resolution inventory of vegetation and human footprint within 3 × 7-km plots located at each of ABMI's 1656 systematic sites (Castilla et al. 2016a, 2016b; **Figure 3-8**). When completed, the total area inventoried within these 3 × 7-km plots will represent approximately 5% of Alberta's land base.

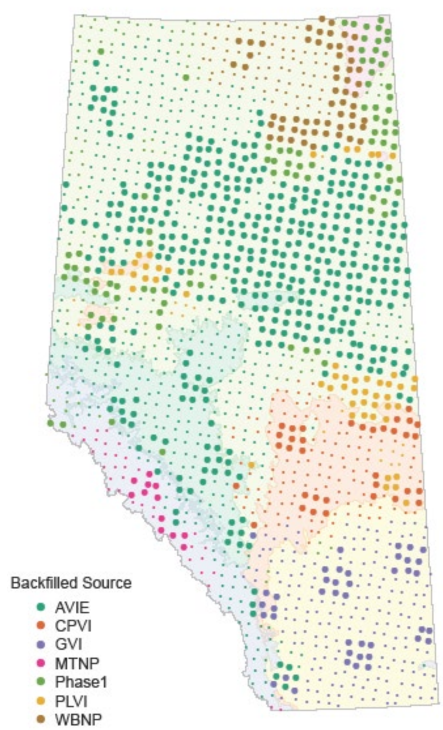

Figure 3-8: Location of completed 3 × 7 photo plots (large circles) in Alberta. Small circles represent ABMI core sites that do not currently have digitized photo plot data. All circles are colour-coded by the underlying data source for the Wall-to-Wall Vegetation (including reference, or 'backfilled' vegetation) layer. Natural regions are also displayed.

The plots are interpreted using soft-copy interpretation of aerial photographs, aided by other existing information, such as the AVI (forested areas), GVI (grasslands), AGRASID (soils), and base layers for roads, pipelines, etc., when available (Castilla et al. 2016b). The mapping protocol (Castilla et al. 2016b) builds on AVI standards. However, AVI products are not copied to the photo plot layer because (1) the AVI is limited to the Green Area of Alberta, whereas the GVI is used in the White Area (which has its own standards and methodology) and (2) AVI data vary in up-to-dateness and level of detail within the Green Area. Thus, we used a single protocol to consistently map the entire province.

The ABMI's 3 × 7 layer expands upon the AVI and GVI layers in several key areas, including:

- distinguishing among land cover (i.e., a biophysical description like 'herbaceous'), land use (e.g., agricultural land), and infrastructure (e.g., pipelines or houses);
- using the most current GIS capabilities to avoid problems associated with size limitations for polygons (simultaneous use of polygon, line, and multipoint features allows the appropriate representation of a wide variety of features); and
- mapping some features such as wetlands and human footprint attributes in finer detail.

The data within the layer are audited to ensure high quality and accuracy; the auditing process is described in **Section 3.2.3.1.1**.

3.2.3.1 Strengths and limitations

The 3 × 7 photo plot layer is the ABMI's most detailed and accurate dataset for native vegetation and human footprint. Considerable effort has been invested to map a wide range of characteristics at high spatial resolution and accuracy (both spatially and thematically).

The primary limitation of this layer is its spatial extent and distribution. The layer represents a sample and will only cover 5% of Alberta when completed. At time of writing, 713 of the 1656 photo plots have been completed, with most located in northeastern Alberta. The labour-intensive photo-interpretation process is the primary factor limiting completion. Expanded coverage of Alberta could be accomplished with additional resources.

3.2.3.1.1 Auditing

The ABMI conducts a 2-part audit process on the 3 × 7 photo plot layer to ensure quality data and to allow for reliable monitoring of Alberta's land cover that exceeds established standards. The first part of the audit process involves semi-automated software tools to assess each photo plot (Castilla et al. 2016c) to ensure compliance with interpretation protocols, metadata completeness, and that topology standards are met. The second phase of the audit process involves review by independent auditors to assess spatial (e.g., polygon borders) and thematic (e.g., vegetation descriptions) accuracy. Any issues identified by the auditing process are reviewed and corrected prior to release.

3.2.3.2 Comparing Wall-to-Wall Vegetation and 3 × 7 photo plots

We assessed the degree of correspondence between the Wall-to-Wall Vegetation and 3 × 7 photo plot layers. A grid of points, spaced at 100 m, was generated for each 3 × 7 plot. This process provided up to 2100 points per photo plot for analysis. For each point, the corresponding polygon data were extracted from the photo plot and Wall-to-Wall Vegetation layers. Comparisons were stratified by type of source information and by natural region.

Comparisons were made at two spatial scales: (1) point-level and (2) full 3 × 7 area.

Point-level

Vegetation types for each dataset were compared for individual points. For each underlying data source (i.e., AVIE, etc.), we created a confusion matrix to determine the degree of similarity between the layers.

Most of the 3 × 7 photo plots currently available for analysis are located in north-eastern Alberta (**Figure 3-8**). With respect to the Alberta Wall-to-Wall Vegetation Layer, this resulted in most sites deriving their vegetation type information from the AVIE layer (presented here). Confusion matrices for all seven data sources are provided in a companion report (Alberta Biodiversity Monitoring Institute 2017b).

In general, the forested vegetation types within the AVIE source layer were more consistent with the photo plot layer than were non-forested types. Coniferous (72.1%) and deciduous (82.4%) vegetation types were highly consistent between data sources, although the mixedwood type agreed in only 29.2% of comparisons. For mismatches, mixedwood stands in the Wall-to-Wall layer were often classified as other forested types such as coniferous and deciduous in the photo plots. Of the three treed wetland types, treed fens were more consistent (56.8%) with the photo plots than were treed bogs (12.2%) or treed swamps (9.9%). Treed bogs were generally classified as other treed wetland types.

Full 3 × 7 area

In general, the proportions of bare, coniferous, deciduous, and water cover types were similar between the Wall-to-Wall Vegetation and photo plot layers (Alberta Biodiversity Monitoring Institute 2017b). This suggests that the two layers corresponded well in estimating the amount of these land cover types (without factoring in the location, size, or shape of individual polygons). Similarly, the proportions represented within each Natural Region, and within each data source, when the 3 × 7 areas were pooled accordingly matched well for those land cover types. The remaining cover types—representing mostly wetland (both treed and non-treed wetlands)—differed in their proportions suggesting a low degree of similarity between the two layers. Dissimilarities were present across all Natural Regions an data sources.

3.2.4 Other land cover layers

The ABMI has developed, and continues to improve, a series of land cover layers that will improve the accuracy, and depth of knowledge, regarding native vegetation in Alberta. A brief description of these layers follows:

Landsat-based Wall-to-Wall

The Landsat-based 'wall-to-wall' layers (circa 2000 and 2010) provide Alberta-wide, polygon-based representations of provincial land cover (Castilla et al. 2014). Both layers use 30-m Landsat satellite images and were enhanced using GIS datasets provided by the Government of Alberta. The layers contain approximately 1 million polygons each, and comprise 11 land cover classes, including water, shrubland, grassland, agriculture, exposed land, developed land and several forest types. Although the layer provides provincial-scale coverage, the level of detail is insufficient for many management uses.

Current surface water

The 2016 Lower Athabasca Region Current Surface Water Extent (Alberta Biodiversity Monitoring Institute 2017c) is a layer developed from Sentinel-1 and -2 imagery from 2016 (Copernicus Sentinel data 2016). For each 10 m × 10 m pixel, the area of each surface water polygon is provided, accurate to 0.01ha.

Hydro temporal variability

The hydro temporal variability (HTV) dataset (Alberta Biodiversity Monitoring Institute 2017d) identifies the location of surface water during ice-free months (April–October) over 2014–2016 in Alberta. It is a 'proof-of-concept' raster product based on Sentinel-1 C-band Synthetic Aperture Radar (10-m pixels) that describes how the water levels of open water in lakes and wetlands change during the summer.

Native vegetation edge

The 2015 Edge Buffer Layer describes the distance of native vegetation from human footprint (Alberta Biodiversity Monitoring Institute 2015b). The distance from human footprint is calculated both when seismic lines are included as human footprint and when they are not.

Native vegetation mesh size

This layer provides estimates of *effective mesh size*—a measure of habitat fragmentation that incorporates the size of native vegetation patches and proximity to human footprint. The 2012 Wall-to-Wall Human Footprint Inventory (Section 3.3) was the primary data source used to derive this product (Alberta Biodiversity Monitoring Institute 2015c).

3.2.5 Comparison to external monitoring programs

Similar to other monitoring programs (see also the **Biodiversity Programs Review** document), the ABMI has focused on using existing sources of data to compile an inventory of native vegetation that spans the entire province. This inventory is updated whenever new data and new technologies become available. To deliver timely and relevant remote sensing and geospatial products, the development of new analytical methods and visualization approaches are priorities of the ABMI. To complement the ABMI's internal expertise, collaborations with external experts ensure ABMI products are based on up-to-date data and methodologies.

3.2.6 Section conclusion

The ABMI creates multiple mapping products to describe the distribution, abundance, and trend of native land cover in Alberta. The information is fundamental to the ABMI's biodiversity intactness modelling and to understanding species-habitat associations. The primary products used by the ABMI are (1) the Alberta Wall-to-Wall Vegetation Layer including "backfilled" vegetation (2) the 3 × 7 photo plot layer. The Wall-to-Wall Vegetation Layer provides information on the current vegetation, soil, and human footprint conditions for the entire province of Alberta, including—via "backfilling"—the expected vegetation that existed prior to human disturbance. This layer forms the basis for the ABMI's province-wide assessment of biodiversity status and trend. The 3 × 7 photo plot layer is a high-resolution inventory of vegetation and human-use characteristics within 3 × 7-km plots located at each of the ABMI's 1,656 systematic sites. This layer is the ABMI's most detailed and accurate dataset for native vegetation and human footprint. Comparing the Wall-to-Wall Vegetation Layer and the 3 × 7 layer revealed that forest, water, and bare cover types were mapped more consistently than were other cover types. Additional vegetation datasets include a province-wide land cover inventory based on remote sensing imagery, surface water extent and variability, and native vegetation edge and mesh metrics that describe how native vegetation is affected by human footprint. All layers are regularly refined and updated as new data become available and new methodologies are developed.

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3.3 Human footprint

3.3.1 Introduction

Human land-use, including human footprint (HF) as the ABMI defines it, plus other land-use activities, is a key driver of biodiversity change (Watson et al., 2016). Consistent and scientifically credible monitoring of the state and trends of Alberta's HF is crucial in understanding the past, current, and future relationships between anthropogenic land use, habitat, and species abundance across the province.

The ABMI has been collecting data on land-use activities and mapping HF across the entire province for the past ten years. The ABMI defines HF as the temporary or permanent change of native ecosystems to support industrial, residential, and recreational land uses, where natural land cover is lost for extended periods of time or is reset to earlier successional conditions (Schieck et al., 2014). In this section, we describe: a) collection/compilation of ABMI HF data; b) strengths and limitations of ABMI HF data; c) consistency of data among sources, and (d) future directions.

ABMI HF datasets comprise comprehensive, unique-in-Canada information on human-made disturbances across Alberta, and continue to improve with each version. Alberta is approximately 66,000,000 hectares in area; consequently, the most recent HF dataset has approximately 5.3 million features. A dataset of such scope and detail represents a major undertaking in both creation and maintenance.

3.3.2 Data collection and updates

The ABMI tracks changes in HF across Alberta using publicly available datasets as its starting point (ABMI 2017). The category-dependent source data come with varying spatial and thematic accuracies, and thus the delineation processes associated with each vary for different HF categories. Some features are compiled from existing information, while others are created from scratch using digitization (**Table 3-1**). Regardless of the approach, we use high resolution remotely sensed imagery, e.g., the 1.5-m Colourmerge product from Satellite Pour l'Observation de la Terre (SPOT6), as a backdrop to visually interpret and manually digitize anthropogenic disturbances on the land surface. We also use orthorectified mosaic images created from aerial photographs (ABMI 2017) as a visual validation reference when needed. The ABMI's imagery resolution and HF interpretation practices continue to improve with each generation of HF dataset produced.

HF interpretation and delineation updates are implemented by a team of GIS and geospatial technicians who are trained in heads-up (i.e., manual) digitization. Training first consists of familiarity with ArcGIS software, followed by continuous peer calibration to maintain a stringent collective standard and to limit individual subjective differences in interpretation and digitization. Once the HF dataset digitization is complete, it goes through several rounds of internal (ABMI Geospatial and Science Centre staff) and external (typically government; e.g., Alberta Environment and Parks staff members) auditing and quality control (QC) processes. The auditing and QC processes assess accuracy for HF detection, feature type classification, and precision of delineation. During production, HF datasets are continuously backed up and stored on internal servers. All auxiliary imagery (e.g., SPOT6 data) are also stored on dedicated servers. All HF products and related updated versions are uploaded onto the ABMI's website and made publicly accessible from an FTP server.

The ABMI produces HF information at provincial and sample-based spatial scales. The provincial scale or Wall-to-Wall Human Footprint Inventory (HFI) (**Figure 3-9**) is updated by panning at a scale of 1:30,000 for detection, and a scale of 1:3,000–1:5,000 for interpretation and digitization. The wall-to-wall inventories are created on a two-year update cycle and are available for the years 2007, 2010, 2012, and 2014, with the 2016 HFI currently in production.

At the sample-based scale, the ABMI produces several datasets. The most widely used is the 3 × 7-km HF time-series dataset, available yearly for 1999–2016 except for 2000, 2002, and 2003. In this dataset, each HF feature detected in satellite imagery is mapped for a grid of 1,656 3 × 7-km permanent sample sites (**Figure 3-10**) evenly spaced 20 km apart across Alberta, and covering approximately 5% of the province. Other sample-based HF datasets include a delineation of HF features within the ABMI's terrestrial and wetland field sites. These datasets are created to establish and assess relationships between species abundance and human land-use patterns. Regardless of the mapping scale, the ABMI divides HF features into 115 feature types classified into 21 sublayers, then rolled up into six categories of generalized footprint for analysis and reporting: energy, forestry, agriculture, residential and industrial, human-created waterbodies, and transportation.

Standardization is essential for monitoring changes and trends in Alberta's landscape disturbances. Going forward, the ABMI will continue to produce each new update—for both the HFI and the 3 × 7 sample-based dataset—using the best available data. We have also committed to maintaining (i.e., retroactively updating) every fifth iteration of the HFI, and every tenth iteration of the 3 × 7 sample-based dataset starting with the year 2000 (i.e., 2000, 2010, 2020, etc.) in perpetuity to allow decadal change analysis. Currently, the 2010 and 2014 HFI datasets have the highest and most up to date quality and enhancement upgrades, while all existing 3 × 7 datasets are in the process of being updated.

For planning and management initiatives to address gaps in data, and to access the required data for particular areas and/or periods of interest, the ABMI and AEP co-founded and continue to lead the Alberta Human Footprint Monitoring Program (AHFMP) initiative. The AHFMP creates comprehensive human footprint information for Alberta at the scale identified by stakeholders as necessary to support their needs (AHFMP, 2017), and coordinates the collection and distribution of data from other sources. Coordination and management of data collection facilitates implementation of standard data protocols, avoids gaps in information, and provides free access to all data. The main focus of the AHFMP has been to enhance existing human footprint data to provide more source and attribution information (e.g., when did the disturbance occur and what is its reclamation status?).

Table 3-1 Delineation and update summary for human footprint sub-layers mapped by the ABMI.

Sublayer	Process
Borrow pits, Sumps, Dugouts, and Lagoons Mine Sites Industrial Sites Reservoirs Landfill Canals Other Vegetated Facilities and Recreation Wind Generation Facilities Confined Feeding Operations (CFOs) and High-density Livestock Disturbed Vegetation	Visually and manually interpreted, digitized using historic datasets as a base, and updated.
Transmission Lines Roads Rail Lines	Based on open-source Base Features and then Avisually and manually updated.
Vegetated Surfaces	Buffered from Base Features and updated manually where needed.
Urban and Rural Residential	Visually and manually interpreted buffers created around points historically. Using historic datasets as a base, new features are visually interpreted and manually digitized without buffers.
Cutblocks	Created from both proprietary and open-source data, as well as open-source land survey references. Various types of imagery used to interpret details of vegetation growth. New features visually interpreted and manually digitized
Cultivation	Created from both proprietary and open-source data. New features visually interpreted and manually digitized.
Pipelines Seismic Lines	Created from proprietary-sourced data. New features visually interpreted and manually digitized.
Well Sites Active Well Sites Abandoned	Created from proprietary-sourced data. New features visually interpreted and manually digitized and sent back to be reviewed.

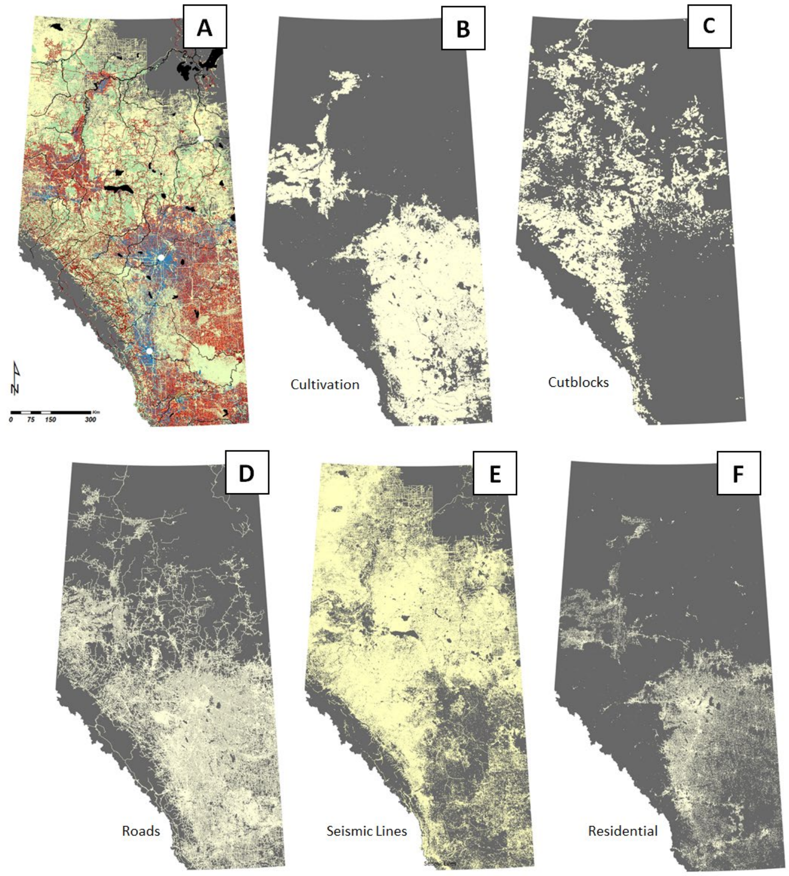

Figure 3-9 Example of final wall-to-wall Human Footprint Inventory (A) that includes all HF features mapped by the AHFMP, and individual sublayers: Cultivation (B); Harvested Areas (C); Roads (D); Seismic lines (E); and Residential (F).

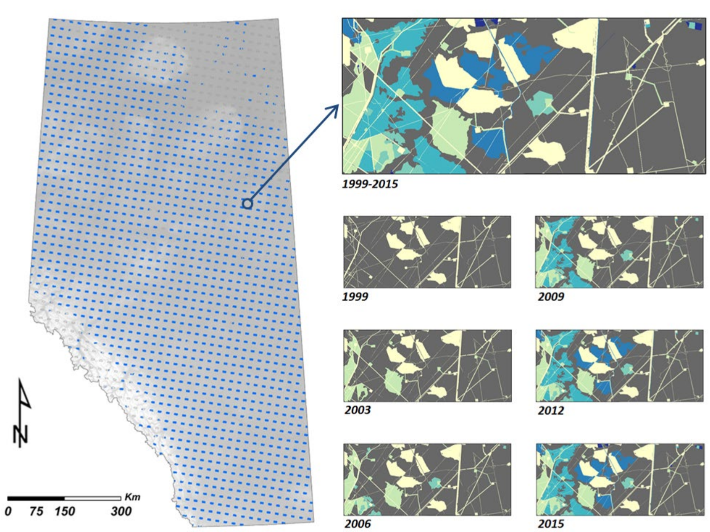

Figure 3-10 Sample-based Human Footprint information delineated for the 1,656 systematic 3 × 7-km plots and example of HF change over time in one of the sample plots.

3.3.2.1 Strengths and limitations in the data collection

The HF data provided by the ABMI provide unique value to stakeholders. Compared to other datasets created for similar purposes, the ABMI's data have broader scope and coverage, and collectively represent an extensive, detailed look at the spatial distribution of surface disturbance throughout Alberta. HF product updates are completed by a team of experts who are trained in HF interpretation and digitization. Once the HF dataset digitization is complete, it goes through several rounds of internal and external QC processes.

3.3.2.1.1 Strengths in the data collection

- The HF products are created with a heads-up digitization method that entails tracing HF features from satellite imagery. Manual digitization is a laborious process and data heavy, but it provides consistent and detailed HF products at a large spatial scale. A high level of detail is obtained by manually digitizing and interpreting.
- The breadth of mapped HF features and spatial extent of HF data support broad operational and integrated applications for end-users.
- Interpretation and delineation is consistent among GIS technicians, achieved by everyone using the same scale of 1:30,000 for HF detection and a scale of 1:3,000–1:5,000 for interpretation and digitization in the 3 × 7-km HF datasets.
- The fine detail of the delineation and classification system, scale of interpretation, and manual comprehensive QC/auditing processes results in HF products that fulfill many stakeholder data needs.
- Standardised and regularly updated HF interpretation documentation, such as the Standard Operating Procedures manual and metadata documentation, produce higher quality successional datasets.

3.3.2.1.2 Limitations in the data collection

- The HF digitization and delineation scales create a lot of information and might complicate some fine-scale analyses (e.g., using the exact width of individual seismic lines).
- Accuracy of the digitization and interpretation is affected by the spatial and thematic accuracy of source datasets, as well as by image spatial resolution. Pre-2013 HF products were created using panchromatic (black and white) imagery with a spatial resolution of 2.5–5 m, whereas from 2013 onward HF products were created using coloured imagery with a spatial resolution of 1.5 m, allowing higher accuracy.
- Human disturbance information and attributes that cannot be detected from satellite imagery (e.g., type of native land cover prior to human disturbance, age of HF features created before the satellite imagery era, grazing by livestock, buried and belowground operations, flooding and shrinking of reservoirs, indirect physical disturbance such as pollution events, application of pesticides and herbicides, recreation activities,

hunting/trapping/fishing activities) limit the type of information that can be included in the layers and may affect management use of the products. Consequently, not all types of human footprint (i.e., those which cannot be seen or measured by means of satellite imagery or available software) are represented in the HFI dataset.

- Generalization of delineated features can be a limitation when using the data for finer scale modelling and analysis; e.g., HF features are generalized where narrow linear and single occurrence features are buffered in order to cover a certain area; e.g., a pipeline extending for hundreds of kilometers is drawn using a centerline, after which the centreline is buffered on both sides using one value to represent the width of the pipeline. The width may vary throughout the length of the pipeline in the real world, but is digitized using buffering methods (ABMI 2017).
- Update cycles of the ABMI HF data (e.g., two years for provincial HF and annual updates for the 3 × 7km HF dataset) do not allow for near-real time tracking and monitoring of HF in Alberta.

3.3.3 Evaluation

3.3.3.1 Summary of data accuracy/precision

The HF data is not completely error free; each sublayer's foundational data were taken and updated from various sources with different spatial and thematic accuracy. However, internal and external auditing suggests a high—and, in newer releases, increasing—level of accuracy. For example, the Cutblocks HF sublayer was internally audited to assess the precision of the interpreters' delineation, and accuracy of identification, with results presented in **Table 3-2**. The HF datasets have not been systematically ground-truthed for the entire extent of the province, as systematic ground-truthing is not financially feasible. However, the ABMI is implementing a rigorous validation process through auditing and verification (ABMI, 2017). Once the HF dataset passes internal auditing it then goes through external auditing by Alberta Human Footprint Monitoring Program (AHFMP) members. For example, the 2014 HFI sublayers were audited by AEP and Alberta Agriculture and Forestry (AAF) staff members, and by other organizations, e.g., the Southern Alberta Institute of Technology (SAIT).

Table 3-2 Internal audit of the HFI Cutblocks sublayer, including percentages of correct delineation, interpretation, and feature type identification

	Delineation Acceptable (Y/N)	Human footprint (Y/N)	Feature type correct (Y/N)
2012 or earlier	62%	96%	88%
2013-2014	80%	96%	95%

3.3.3.2 Cross-validation of data accuracy and precision

We cross-validated the Wall-to-Wall HFI, pre-AHFMP W2W versions, and 3 × 7-km HF datasets using the 3 × 7-km vegetation photoplot data (ABMI, 2016[1]; hereafter *photoplots*) to evaluate the accuracy and precision of interpretation, delineation, and attribution.

To ensure comparability of HF and vegetation photoplot products, all cross-validation data had matching temporal (imagery vintage) resolutions. Therefore, only photoplots mapped for 2008 (3 × 7-km HF data), 2010 (3 × 7-km HF and AB-wide 2010 HFI data), 2011 (3 x 7-km HF data), and 2012 (HF 3 × 7-km HF and AB-wide 2012 HFI data) were used for cross-validation. Comparisons were made at two spatial scales: area-based and individual points. Photoplots and HF products use different human footprint feature classification; thus, the comparison began by reclassifying all anthropogenic features mapped in photoplots into HF feature classes used in the HFI, older W2W, and 3 × 7-km HF datasets. Then, the total area of sublayers in the Wall-to-Wall HFI, older W2W, and 3 × 7-km HF datasets was compared to the total area of each corresponding feature in the photoplots dataset. Secondly, 131,903 systematically generated points were created 100 m apart to facilitate spatial comparison. These points were overlaid on each of the three datasets. Features containing a point in the HFI, older W2W, and 3 × 7-km HF datasets were then compared by their feature names with the photoplot dataset containing the same point. Values and percentages of area and correct/corresponding feature classification were then calculated (see Figure 7 and Tables 8–11 in HF Technical Review).

3.3.3.3 Analyses and results

Area

Difference in total footprint area between photoplots and the 3 × 7-km (sample-based) HF and HFI, and older W2W products ranged between 1.35% and 15.29% (**Table 3-3**). The greatest discrepancies were in the Cultivation and Cutblocks sublayers, with the 3 × 7-km HF and HFI products having a larger area compared to the same feature type in the photoplots. This may be due to the extent of digitization and the resolution of the imagery from which the datasets are identified (i.e., satellite-based vs. air photo-based). Area compared differs between years because the number of sites surveyed and digitized per year varied.

Table 3-3 Percent differences in total footprint area between HFI and photoplot data; Wall to Wall HF (2012) and photoplot data; and HF 3 × 7-km and photoplot data.

	Photoplot (m^2)	HF 3 x 7-km (m^2)	Percent diff. (%)	HFI (m^2)	Older W2W (m^2)	Percent diff. (%)
2008	905,564,677	1,017,233,819	12.33			
2010	276,182,214	293,610,474	6.31	272,448,416		1.35
2011	120,415,635	135,156,852	12.24			
2012	166,457,943	191,908,847	15.29		155,804,686	6.40

Points

There was 82.4–94.4% correspondence in the sublayer classification between the photoplots and the 3 × 7 HF and HFI (**Table 3-4**) datasets. The differences were mainly due to the 3 × 7 HF and HFI products classifying all temporary forestry roads as part of cutblock polygons, whereas in the photoplots both features were digitized separately due to higher (range 1:500–1:1,500) interpretation resolution. Also, some smaller and/or temporary roads in the 3 × 7 HF and HFI datasets could have been classified as seismic lines, e.g., due to lower detection and interpretation resolution, and generalization of linear features less than 6 m wide.

Table 3-4 Percent correct for HF (3 × 7 HF, HFI, and Older W2W) sublayer classes verified using photoplots.

Year	Dataset	Total #	Correct #	Correct %
2008	3 x 7 HF	86,192	81,368	94.40
2010	3 x 7 HF	22,431	20,900	93.17
	HFI	24,144	22,595	93.58
2011	3 x 7 HF	7,518	6,640	88.32
2012	3 x 7 HF	13,416	11,049	82.36
	Older W2W	14,049	11,730	83.49

3.3.3.4 Future directions

Mapping and quantification of Alberta's human-made land surface disturbances is mainly conducted by the ABMI, Alberta Environment and Parks (AEP), Alberta Agriculture and Forestry (AAF), Alberta Energy, Forest Management Agreement (FMA) holders, the oil and gas industry, and academia. However, organizations that map human disturbances often focus on small parts of the province (e.g., Agriculture by the AAF in the Grassland Vegetation Inventory [GVI]), or only on individual footprint types (e.g., Cutblocks [Harvested Areas] by the AAF and FMA), which restricts certain data types to subregions of the province. Re-mapping frequencies (e.g., the AHFMP's two-year cycle for HF) also restrict successional production of future datasets (e.g., 2016, 2018, etc.). For planning and management initiatives to address inconsistent gaps in data or to access the required data for particular areas and/or periods of interest, the ABMI and AEP founded and continue to lead the Alberta Human Footprint Monitoring Program (AHFMP) initiative. The AHFMP creates comprehensive human footprint information for Alberta at the scale identified by stakeholders as necessary to support their needs (AHFMP, 2017) and coordinates the collection and distribution of the source data from other valued sources. This facilitates the implementation of standard data protocols, avoids gaps in information, and provides free access to all data. The long-term goal of the AHFMP is to enhance regulatory datasets to directly support all related human footprint inquiries in Alberta.

3.3.4 Chapter summary

To understand the historic and present state of biodiversity in Alberta and, by extension, the changing relationships between anthropogenic land uses and ecological systems, a long-standing, multi-year monitoring, data collection, and reporting framework is necessary. The ABMI implements various monitoring systems within its mandate; among these, it collects data on human-created land disturbances with such products as the Human Footprint Inventory (HFI) and 3 × 7-km HF datasets. These HF products help to determine historic and present land use, and natural resource sustainability. These two types of datasets, delineated using ArcGIS computer software, represent the spatial distribution of human footprint in Alberta. The HFI dataset is a complete wall-to-wall summary of temporary and permanent anthropogenic land disturbances and associated structures. It is divided into 21 sublayers according to land use type, contains six major reporting categories, and is updated biennially, which enables data-users to interpret changes in land transformation across the entire province. The 3 × 7 dataset is a smaller, sample-based dataset that represents all of the ABMI's 1,656 3 × 7-km plots and has been updated nearly every year from 1999 to 2016. It lets data users understand land use trends over time in specific areas. Both datasets are key components of land use monitoring and management activities.

The ABMI and AEP founded and continue to lead the Alberta Human Footprint Monitoring Program (AHFMP) initiative. The AHFMP creates comprehensive human footprint information for Alberta updated every two years and coordinates the collection and distribution of data from other sources. Coordination and management of data collection facilitates implementation of standard data protocols, avoids gaps in information, and provides free access to all data.

3.3.5 Comparing ABMI data collection to that of other monitoring programs

Although the ABMI has not conducted a comprehensive review of methods and technologies used by other monitoring programs that collect information on anthropogenic disturbance, there are several organizations that provide publicly accessible data on HF at a global scale (see **Biodiversity Programs Review** document). For example, Global Forest Watch maps industrial, mineral, and forestry disturbances (GFW 2016; Pasher et. al., 2013); the Center for International Earth Science Information Network provides information on settlements, nuclear power plants, hazardous waste sites, roads, reservoirs, and dams (CIESIN2007); GlobCover maps agricultural areas (Bontemps et al. 2011); and the National Imagery and Mapping Agency maps railways and waterways (NIMA1997). Generally, HF features at the global level are mapped using lower resolution, a larger minimum polygon size, and at a coarser scale than that used by the ABMI.

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4 Predicting species status and relationships

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4.1 Executive summary

The ABMI collects data on 7 taxonomic groups (birds, mammals, vascular plants, bryophytes, lichens, mites and aquatic invertebrates) and builds statistical models to identify how the occurrence and relative abundance of species varies in relation to predictor variables comprising native land cover and human footprints. The results from this work inform land-use decision-makers about the high-resolution spatial distribution of species and their associations with different land covers (ecosites, vegetation types, forest-age classes) and the effects of human development on these species. We determine spatial predictions of cumulative effects on species by comparing predictions under current landscape conditions to predictions in *reference* landscapes where all human footprints have been removed (*backfilled*). We calculate species intactness by quantifying the difference between current and reference predictions considering all footprint types in the landscape. We further attribute these changes to different industrial sectors by looking at specific footprint types and assessing how they affect overall intactness. The predictive models can be used for spatially explicit scenario analyses to predict the expected effects of different management options on species' relative abundances. Some species, especially rare species, do not always show strong associations with the predictor variables we have used in our generic models because these are intended to address general broad scale management questions. ABMI data can help build species-specific models using additional predictor variables that better capture variation in the data for rare species, which will enhance the ABMI's ability to support better management and more efficient conservation of species and natural resources in Alberta.

4.2 Introduction

The main mission of the ABMI is to give information on status and trend of species and their habitats throughout Alberta and provide tools that support land management and stewardship. This includes monitoring trends in biodiversity (see **Chapter 5**) and assessing the status (current distribution and abundance) of species, and estimating the extent to which species' distributions and relative abundance have been modified by human footprint.

The foundational information used to describe the status of Alberta species is derived from data collected at the ABMI systematic and targeted monitoring sites (see **Chapter 3**). For birds, the BAM + ABMI composite dataset is available through collaborative partnerships (**Section 3.1.2.2.2**). The many sites surveyed by the ABMI make predictive modelling (Elith &

Leathwick 2009) possible and thus, with models in hand, predictions for unsampled landscapes in the province or for expected past or future landscapes can be made. Our models relate species occurrence or abundance at sampled sites to native vegetation and human footprint found there, as well as to spatial and climatic variables at those sites.

This chapter explains and summarizes the results of the modelling, and only briefly explains the underlying methods. We refer the reader to **Chapter 3** for the datasets used in the analyses and to **Technical Report 4.1** for detailed modelling methods and additional references. In this chapter we (1) show modelling results for a few example species, and (2) summarize results across species within each taxon (i.e., mammals, birds, vascular plants, bryophytes, lichens, and mites). These results include (2a) species-land cover relationships, (2b) the overall effects of human footprint on species and taxonomic groups ("intactness"), and (2c) attributing footprint effects to industrial sectors ("sector effects"). Finally, we (3) evaluate the relative performance of the models based on (3a) goodness-of-fit metrics, (3b) the degree to which predictions can be applied to new geographic regions, and (3c) the repeatability of species-land cover association coefficients. We conclude by discussing the general implications of our results and future avenues of research, and comparing our approach to those of other monitoring programs.

4.3 Single species results and examples

4.3.1 Methods

Data collected for different taxa (mammals, birds, vascular plants, bryophytes, lichens, soil mites, wetland plants, and wetland invertebrates) and habitat elements are summarized as described in **Technical Report 4.1**. Analyses and resulting data products are publicly available through the ABMI's Data & Analytics Portal (**abmi.ca/data**).

Mammal snow transect data are summarized as the occurrence of each species on each 1-km segment along 9–10-km-long transects. For birds, we use the count of each species at each of 9 or 4 points per ABMI site (see **Field Protocols** described in **Chapter 3**). For mammals and birds, we also used data collected and maintained by other organizations (see **Technical Report 4.1** and **Section 3.1.2.2.2**). Other taxa are sampled in the four quadrants of a 1-ha plot at the centre of each ABMI site, and are summarized as occurrence in 0–4 quadrants per site. Habitat elements are tallied for each site.

We model species' relative abundances using generalized linear models (GLMs) in a multi-model inference framework combined with bootstrapping to estimate uncertainty. The error distribution for the response variables is Binomial for occurrence type data (**Technical Report 4.1**). For birds, the error distribution is Poisson, with offsets to account for possible biases due to variation in survey protocol and species detectability, based on techniques developed by BAM (Solymos et al. 2013).

4.3.2 Species–land-cover associations

We relate the occurrence and relative abundance of each species to descriptors of land cover. The areas of different types of native vegetation, ecosites, and human footprint are extracted at various spatial scales for the different taxa: 250-m-wide buffers around winter snow tracks for mammals and around the open water edge for wetlands; 150-m-radius buffers around bird point locations; and 1-ha squares at site centres for all other taxa sampled in the 1-ha plots. Where possible, we use the ABMI-verified human footprint for each site (see **Chapter 3**). Human footprint types are grouped based on the similarity of their perceived ecological effects (*Table 2* in **Technical Report 4.1**).

We differentiate "alienating" human footprint, where native vegetation is removed and prevented from regenerating, from "successional" human footprint, where native vegetation has been removed but has the potential to regenerate. Alienating disturbances include cultivation (typically forage or tame pasture in the north and crops in the south), urban-rural-industrial development, and hard (unvegetated) linear features including roads and railways. Successional disturbances include forestry, and soft (vegetated) linear features including seismic lines, pipelines, power lines, and road verges. Alienating and successional footprint together make up total human footprint.

Forestry footprint is differentiated by broad stand type and modelled using the same age classes as natural forest. Human created water-bodies are treated as open water and assumed to contain no terrestrial species. Active mine sites, where we are unable to sample but which are bare and unlikely to support biodiversity, are also assumed to contain no species.

For our analyses, we used the province-wide vegetation layer created by the ABMI through the amalgamation of existing information on vegetation, ecosite types, and human footprint types throughout Alberta (see **Chapter 3**). Vegetation types include main forest stand types (white spruce, pine, deciduous, mixedwood, black spruce) by broad age classes (0–9 years, 10–19 years, then 20-year increments up to 140+ years), treed fen/larch, treed swamps and shrub as well as several categories of open vegetation (upland grass, upland shrub, non-treed fen and marsh) (*Table 2* in **Technical Report 4.1**; **Chapter 3**).

Because most ABMI sites cover several habitat types, we use a multiple regression approach to separate the effect of each type. In the north analysis region (boreal, foothills, Canadian shield, parkland), we use proportions of major land cover (vegetation and footprint) types, including separate age classes for forest stand types, as predictor variables for most taxa. For bird models, developed in partnership with BAM, land cover types are defined based on the dominant type with linear features as effect modifiers, and forest stand age is treated as a continuous variable (see **Technical Report 4.1** and Ball et al. 2016 for details). In the south analysis region (grasslands, parklands, dry mixedwood and some of the central mixedwood subregion of the boreal), we use human footprint and broad soil-based ecosite types (productive, clay, saline, and rapid draining) as predictor variables. The South models also include a term for the probability of aspen occurrence to describe the treed or non-treed nature of the locations.

Based on the models that are developed for each species, we make predictions for their relative abundance in each land cover type. These results are summarized in figures for each species and in tabular format along with 90% confidence intervals. See **abmi.ca/data** for results on 922 species with detailed models and an additional 1435 species with basic data summaries.

4.3.2.1.1 Example: Alder Flycatcher

As an example of a species with a detailed model, **Figure 4-1** shows land cover associations in northern Alberta for the Alder Flycatcher (*Empidonax alnorum*), a songbird. Alder Flycatcher is a neotropical migrant insectivore that can be found throughout the province and prefers wet thickets and early successional scrubby vegetation for nesting and foraging (Lowther 1999).

BAM and the ABMI found that the species is most abundant in young forests with a monotonic decrease in abundance with forest age in all stand types. Relative abundance was higher in lowland habitats and lowest in old upland forests, cultivated and urban-industrial areas. Forest harvest had a positive effect on relative abundance of this species, as indicated by the relative abundance estimates being much higher than for stands with natural (i.e., fire) origin.

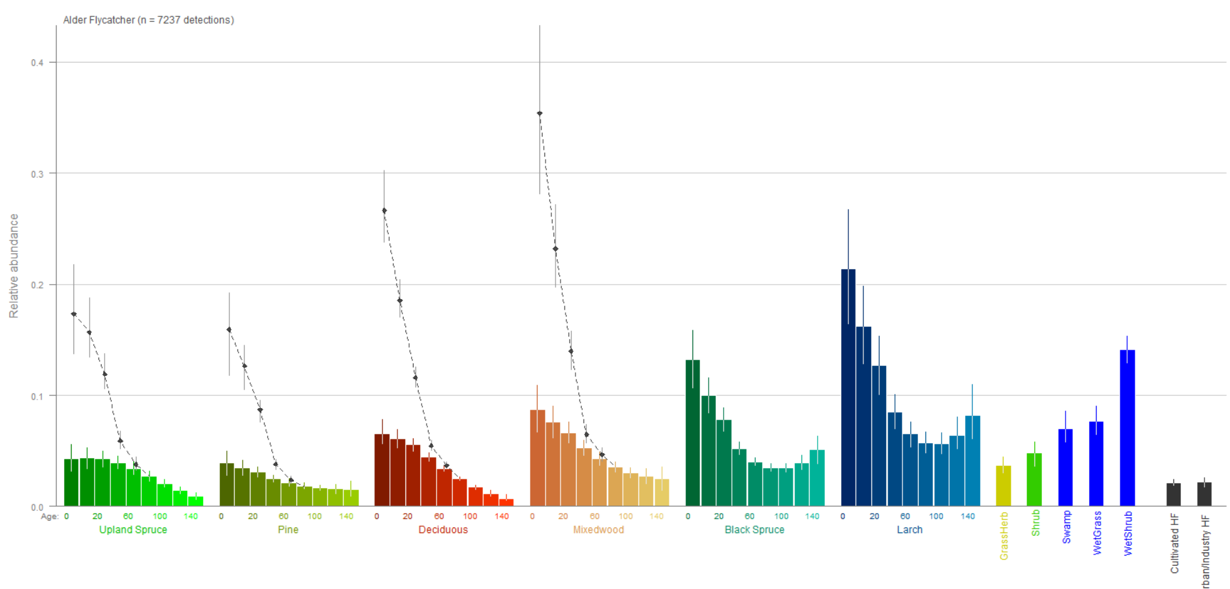

Figure 4-1 Relative abundance of Alder Flycatcher in different vegetation and footprint types in the northern analysis region. Predictions are made for age classes of forest stands (bars show 20-yr increments, except that the first two are 0–10 and 10–20 years). Error bars represent 90% confidence intervals. Footprint types are in black. Forest harvest is indicated by black dots to show how harvested trajectories differ from forest stands originating from fire.

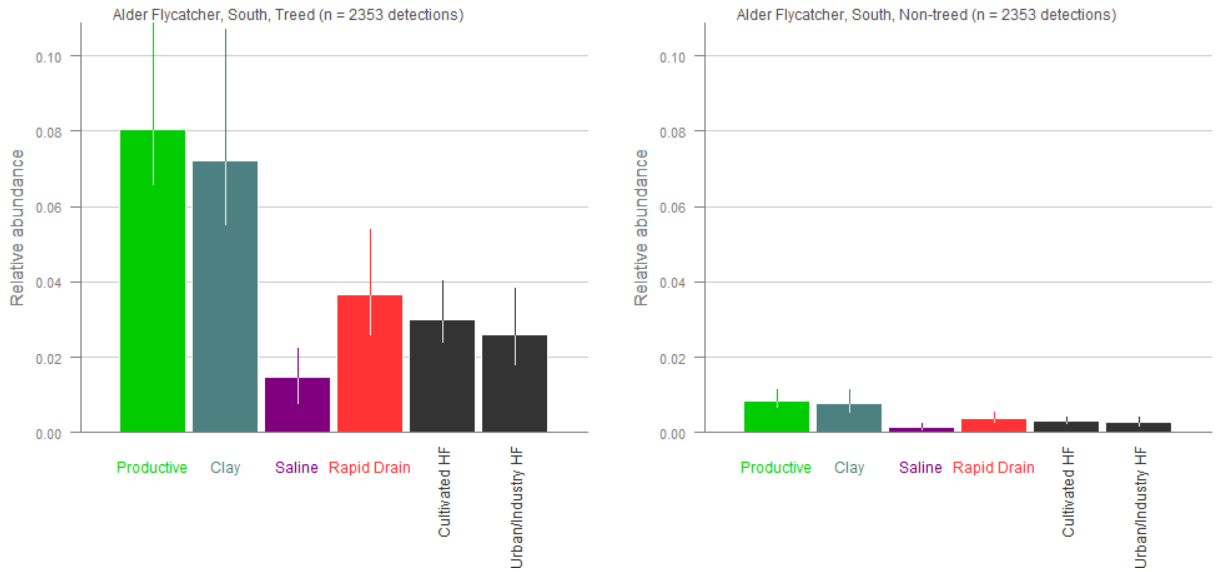

Figure 4-2 Relative abundance of Alder Flycatcher in different ecosite and footprint types in the southern analysis region. Relative abundance is estimated in treed (left) and non-treed (right) types. Error bars represent 90% confidence intervals.

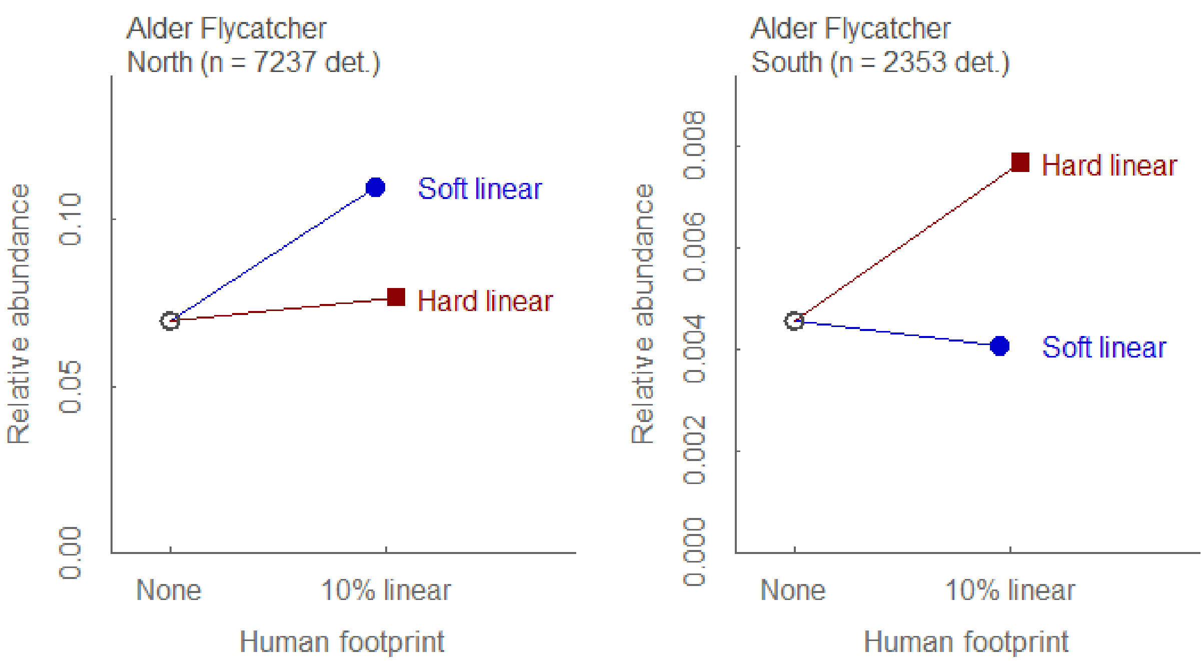

Figure 4-3 The effects of vegetated (soft) and non-vegetated (hard) linear features on relative abundance of Alder Flycatcher in the northern (left) and southern (right) analysis region. The pairs of points show the change in relative abundance expected between average habitat with no linear footprint (left point) and average habitat when 10% linear footprint is present (right point).

In the south, the abundance of our example species, Alder Flycatcher, was higher on productive and clay ecosites (**Figure 4-2**) than on saline, rapid-draining ecosites and human-disturbed areas. Its abundance was almost an order of magnitude higher in sites with tree cover than in non-treed sites.

The effects of non-vegetated (roads and rails) and vegetated (seismic lines, pipelines, power lines, and road verges) linear features are estimated within the same framework as all the other land cover types. These linear features, however, would never occupy more than 25% of the survey area, as opposed to other land cover types which sometimes cover 100% of the survey area. As a result, a hypothetical prediction for species response at 100% linear features would therefore be unrealistic. Instead, we present relative abundance in landscapes composed of 10% linear features, which falls in the middle of the range of actual values in our samples.

In our example, the Alder Flycatcher responded positively to the presence of vegetated linear features in the north that is consistent with the species' preference towards early seral shrubby vegetation. In the south, while relative abundance tended to be higher along non-vegetated than vegetated linear features, the increment was still very small (**Figure 4-3**).

4.3.2.2 Wetlands

Analysis of wetland data differs from that for terrestrial data, because the relevant human footprint is not just in the wetland itself, but also in the surrounding area. In addition, the classification and mapping of wetland types is not as fully developed as for upland land cover types. Finally, modelling in the wetland also includes other important wetland ecosystem variables, such as wetland depth or chemistry.

Species-habitat modelling for wetland species first analyzes three sets of ecosystem covariates: wetland physicochemical properties (e.g., wetland depth, pH, total nitrogen), climate and spatial variables, and broad surrounding native vegetation (north) or ecosite (south) types. The best sets of these covariates are chosen with a model selection procedure. Using those best covariates, the analysis then examines the effect of footprint in the surrounding area on the species' abundance. This results in relationships of each species to surrounding footprint types, having factored out the effects of relevant physical and climate covariates. Currently we define the surrounding area using a 250-m-wide buffer around the wetland's (water) edge. In the future, we plan to use catchment boundaries when the data become available.

Data for 1265 wetland sites and 220 species were included in the analysis. In total, 17 submersed and floating plant species were analyzed in the open-water zone, 44 in the emergent zone, and 202 in the wet-meadow and margin zones combined (some species were included in more than one zone). All species in the open-water zone were unique to that zone. Only one species of the 44 found in the emergent zone was unique to that zone, with the remaining 43 species shared with the other two zones. A total of 160 species were unique to the wet-margin zone, with 42 species shared with the other two wetland zones. Many of the species detected in the wet-margin zone were also sampled by the terrestrial vascular plants protocol.

4.3.2.2.1 Example: Duckweed

As an example for the wetland analyses, we present duckweed (*Lemna turionifera*), a common perennial species in the open-water zone occurring across the province. This is a floating species that feeds on nutrients in the water column. Duckweeds are used in bioremediation because they thrive in eutrophic conditions that often occur in shallow wetlands with higher nutrient concentrations. Our results indicate that this species prefers shallow wetlands and nutrient-rich (high total nitrogen and phosphorous) water (**Figure 4-4**).

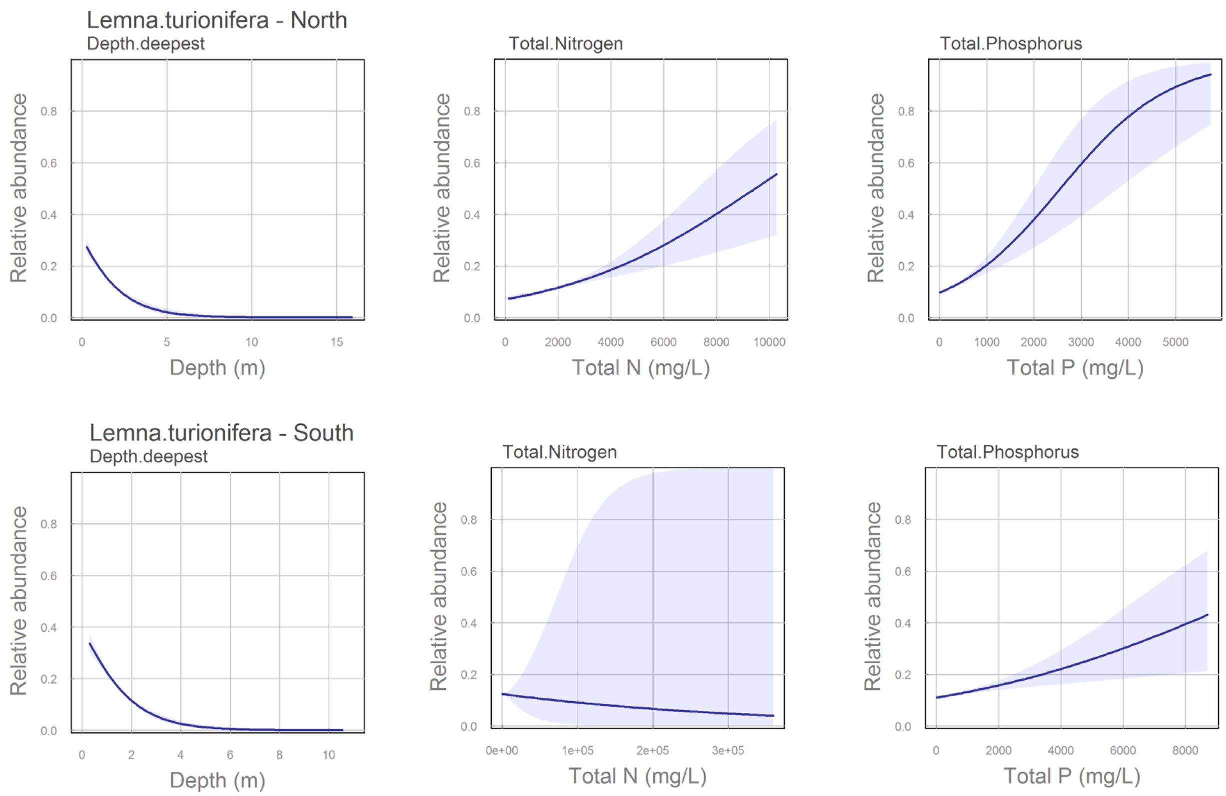

Figure 4-4 Effects of wetland depth, total nitrogen, and total phosphorous on relative abundance of duckweed (*Lemna turionifera*) in the northern (top row) and southern (bottom row) analysis regions of Alberta. Bands around the lines indicate 90% confidence intervals.

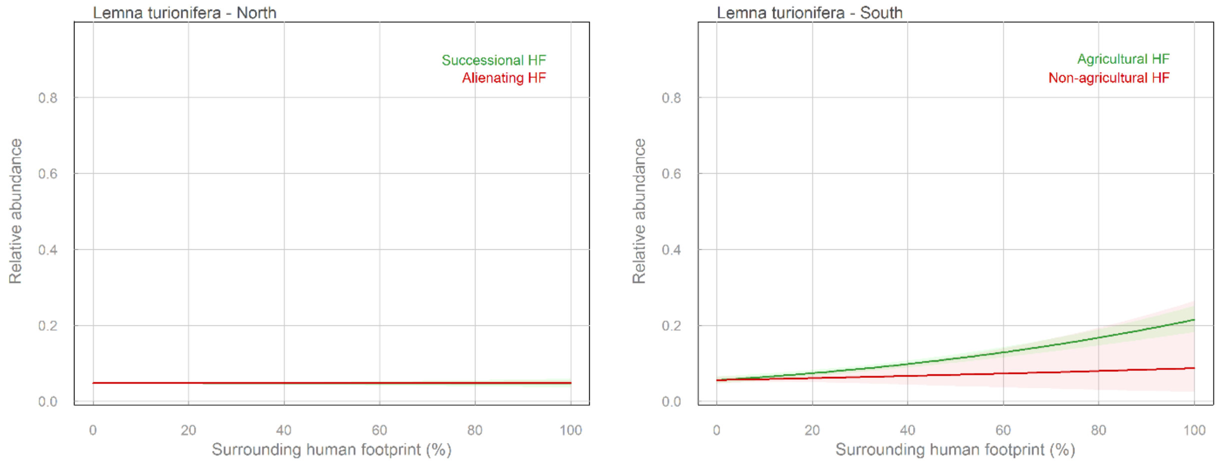

Figure 4-5 Effects of different footprint types surrounding the wetlands on duckweed (*Lemna turionifera*) in the northern (left) and southern (right) analysis regions of Alberta. Bands around the lines indicate 90% confidence intervals.

We found no relationship between this species and ecosite types around the wetland in the south but found a positive relationship with deciduous/mixedwood vegetation surrounding wetlands in the north (not shown). This may indicate its preference for nutrient-rich habitats because bogs and fens are low in nutrients and duckweed is less abundant in those landscapes. Duckweed is positively associated with agriculture (which results in wetlands having high total N and P) in the south, but showed no relationship with surrounding footprint in the north (**Figure 4-5**).

4.3.3 Predictive mapping and intactness

Predictive mapping

In our modelling, we incorporate spatial and climatic variables to capture variation in species distribution not accounted for by our land cover variables. The residual effect of climate and geographic location is estimated by first predicting the species' abundance at each site based on human footprint and ecosystem type. The size of the BAM + ABMI composite bird dataset allowed us to fit joint models to land cover and climate/spatial terms. Climatic variables are based on monthly climate normals for temperature and precipitation averaged over 1961–1990, as interpolated from climate stations (see **Technical Report 4.1** for details).

In the South analysis area, where spatially explicit historical information about the vegetation before human settlement is missing, we use the potential distribution of aspen derived from bioclimatic envelope modelling, to represent the probability of the site being covered by trees (see **Technical Report 4.1** for details).

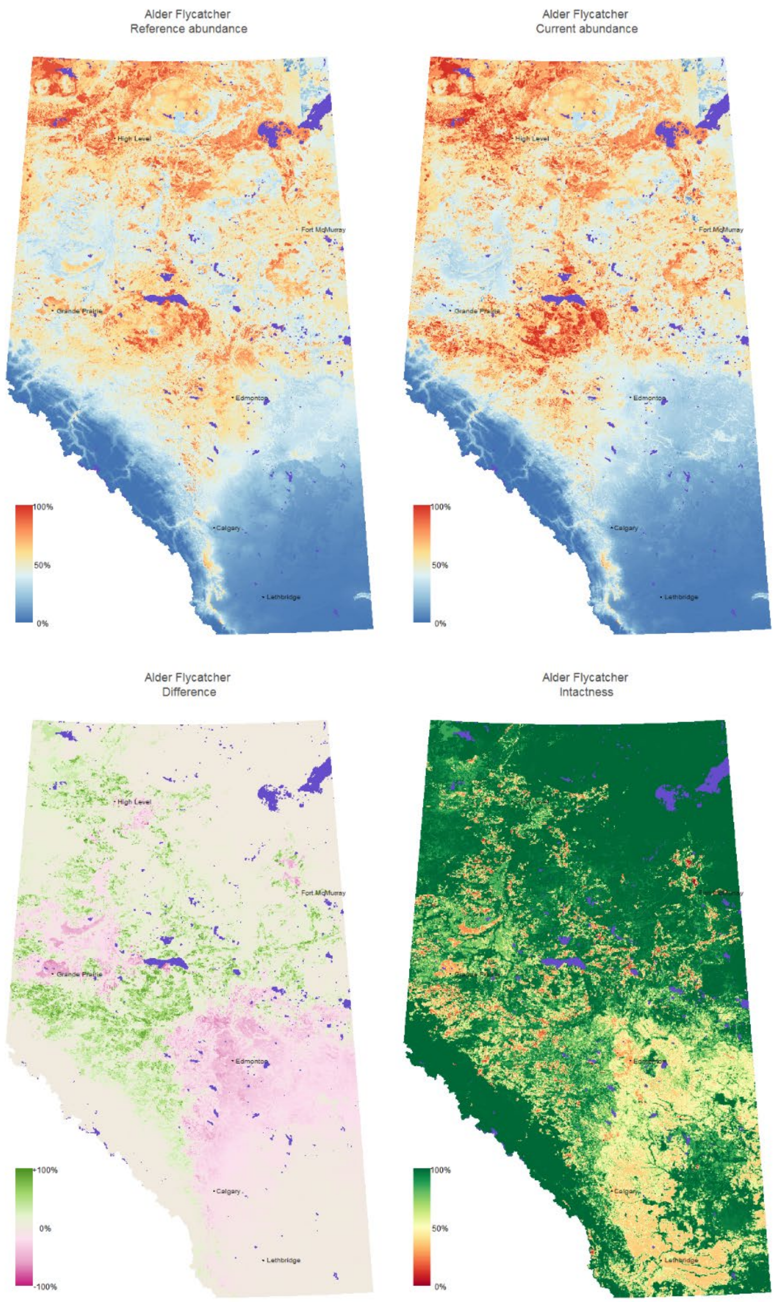

Figure 4-6 Predicted relative abundance of Alder Flycatcher under 'reference' (top left) and current (top right) landscape conditions in 1 km² pixels. Predictions of relative abundance of the species in reference conditions were made after all human footprint in the pixel had been removed and 'backfilled' based on native vegetation in the surrounding area. The bottom left map shows the difference between predicted current and reference abundances. The intensity of green and pink depict the relative magnitude of any increase or decrease for the species between reference and current conditions. The intactness map (bottom right) represents the ratio of current and reference abundances irrespective of the sign (positive or negative) of the difference (see text for more explanation).

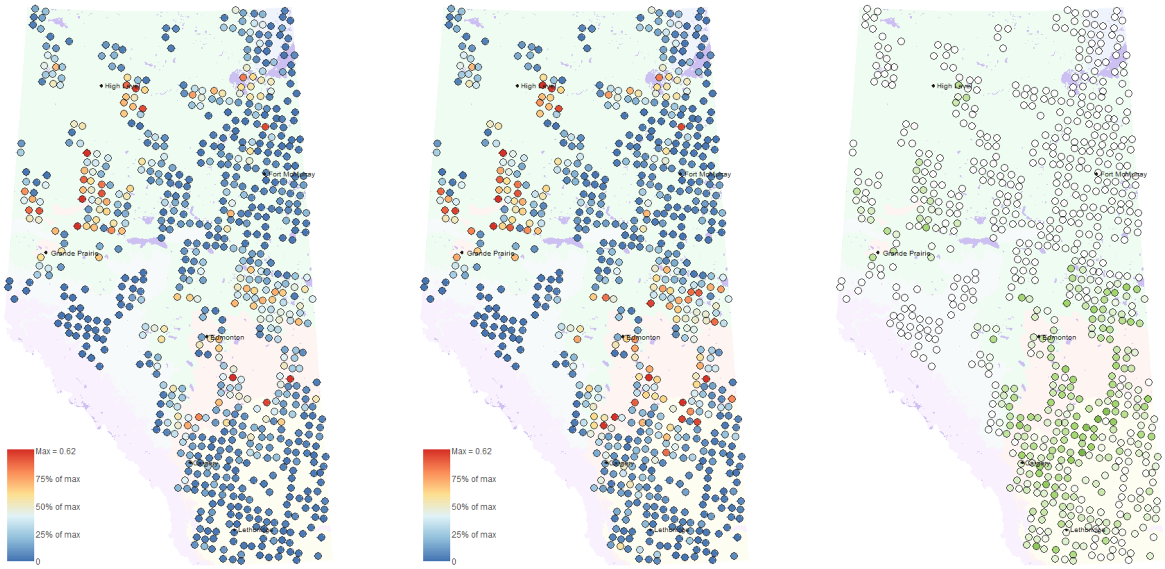

Figure 4-7 Predicted relative abundance of Duckweed (*Lemna turionifera*) in Alberta under reference (left) and current (middle) conditions, and the difference between the current and reference relative abundances (right; pink = decrease, green = increase). Dots represent sampled wetland sites.

We combine land cover and climate/spatial information to make predictive province-wide maps of 1-km^2-resolution for each species. We summarize the amount of native vegetation, as well as soil ecosite types and human footprint types, in each 1-km^2 pixel and use these in area-weighted relative abundance predictions. Climate variables and probability of aspen occurrence are also summarized at each pixel unit.

We predict *current* relative abundance for each species based on the effects of land cover (including human footprint) and climate/spatial covariates. To predict *reference* relative abundance, first information describing a reference land cover condition was created by removing human footprint from the landscape and adding back ('backfilling') the land cover type that is predicted to have been present prior to disturbance (**Chapter 3**). The *reference* relative abundance for each species is predicted based on this 'backfilled' map. We use the results from bootstrap iterations to quantify a measure of uncertainty (standard error) around the predicted current abundances (see **abmi.ca/data** for the detailed maps and downloadable results).

We also calculate the *difference* between predicted current and reference abundances to highlight where abundance is expected to have increased (current > reference) or decreased (current < reference) due to native land cover types being replaced by human footprint types.

Intactness

We convert the difference in relative abundance between predicted current and reference abundances to a scaled *intactness* index, which is a comparable measure of change among species. This index is scaled between 0 and 100, with 100 representing no difference in expected abundance between current and reference conditions, and 0 representing current species abundance as far from reference conditions as possible. Intactness thus reveals deviations in species' abundance from intact conditions. The direction of deviation is purposely not captured in the index; i.e., both downwards and upwards differences from reference conditions are viewed as deviations from intact conditions. For example, an intactness value of 50% might mean that the current species abundance is either half or twice as abundant as that predicted under reference conditions. The index is estimated as:

current / reference × 100%, when current < reference, or

reference / current × 100%, when reference < current.

Intactness is calculated for each 1-km^2 prediction pixel to produce an intactness map for each species.

4.3.3.1.1 Examples

Our example species, the Alder Flycatcher, was found to be abundant in the province, except in the Grassland and Rocky Mountain natural regions (**Figure 4-6**). The map of difference between predicted current and reference abundances shows notable increases in the Foothills and Boreal regions (potentially due to forest harvest), whereas decreases are most prominent in the Parkland region and dry mixedwood subregion, where urban and agricultural human footprint provides suboptimal habitats for the species. The intactness map shows a very similar pattern to the difference map but does not reflect the direction (positive or negative) of the difference. It also highlights that species intactness can be high even in places where relative abundance is low, so long as current and reference relative abundances are similar. For example, Alder Flycatcher has low relative abundance but high intactness in the Grassland natural region simply because its predicted abundance is low there even under reference conditions. The average province-wide intactness for Alder Flycatcher was 93.5%.

We cannot currently map wetland species' relative abundance across the province, because we do not have accurate maps of wetland types, and also because the wetland models include physical and chemical variables that must be measured in each wetland. Therefore, for wetland sites, habitat association models developed for species are used to predict species' relative abundance in wetlands under reference and current conditions at sampled site locations only. **Figure 4-7** shows the predicted relative abundance of Duckweed under reference and current landscape conditions. The predicted values at the sampled wetlands reflect the positive effects of agriculture on Duckweed abundance in the South (compare with **Figure 4-5**).

4.3.4 Attributing sector effects

Using methods developed in partnership with BAM, we calculate the effects of different industrial sectors on species by predicting the abundance of each species in the current landscape versus in a reference landscape in which the footprint associated with that particular industrial sector has been backfilled. The difference between the total predicted population in the current and backfilled (reference) landscapes is the predicted "total effect" of that sector on the species' abundance (see Sólymos et al. 2015 and Sólymos and Schieck 2016 for details).

The industrial sectors include energy, forestry, agriculture, transportation, and urban structures. The effect of an industrial sector on a species is affected by three factors: (1) how much area is occupied by the footprint of that sector; (2) how strongly—positively or negatively—the species responds to each of the sector's footprint types (the sector's *unit effect*); and (3) how much of the sector's footprint is in higher- versus lower-quality habitat for the species. For example, a species that lives in old upland forest may be more affected by the forestry sector than the energy sector, because forestry activities occur mainly in older merchantable upland stands. We get the area of footprint for a sector by summing the footprint types belonging to that sector in the target geographic region. We then divide the *total effect* of a given sector in a region by the footprint area specific to that sector to get its average "per unit area" effect on the regional species abundance. Unit area effects greater than 100% indicate disproportionate effects on species' habitat supply; i.e., a 1% increase in that footprint type leads to more than a 1% change in habitat supply for the target species. The converse is true for unit effects lower than –100%.

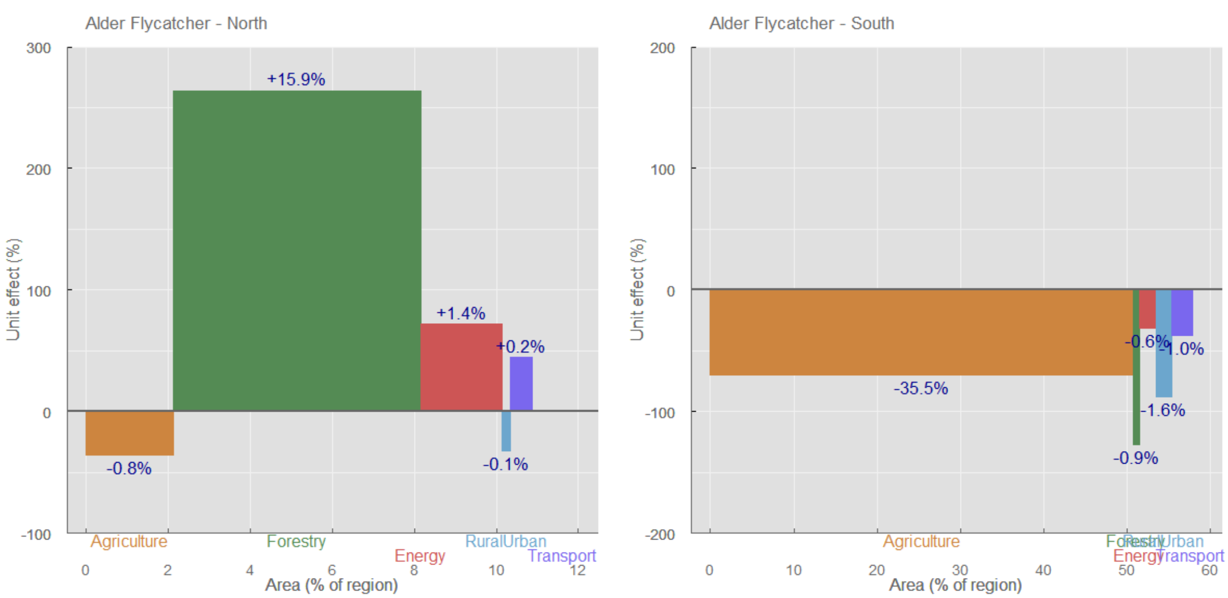

Figure 4-8 Sector effects for Alder Flycatcher in the northern (left) and southern (right) analysis areas. The y-axis shows the effect per unit area of the sector footprint on the species. The x-axis represents the extent of each industrial sector footprint in the region. The areas of each sector-specific rectangle (numbers above/below the bars) are proportional to the total sector-specific effect on abundance for the species in the region. Note that the y-axis scales are differ between the North and South figures.

4.3.4.1.1 Example

Figure 4-8 depicts sector effects for Alder Flycatcher in the northern and southern analysis regions. Compared to the total regional reference abundance, the overall current abundance in the north was predicted to be 16.6% higher than the abundance expected under reference conditions, and this was primarily due to the positive effects of forestry (+15.9% sector effect) creating more habitat for the species. Forestry footprint covers a large area of the region (~6%), and has a high (> 250%) unit effect. In addition, energy development (+1.4%) and transportation (+0.2%) contributed slightly to increased habitat for Alder Flycatcher by creating open habitats along linear features. In contrast, agriculture and urban development has a negative effect on the species, but the overall effect of these sectors is small due to the relatively low unit effect and the small area of the footprint. In southern Alberta, agriculture is the most important driver of habitat supply for the Alder Flycatcher; it was predicted to decrease habitat availability by 35.5%. The large decrease was mainly due to the large extent of agriculture (~50%) rather than its unit effect, which was only moderate (–75%).

4.4 Summaries by main taxonomic groups

To better understand the influence of land cover, including various types of human footprint, on species relative abundance across the six main taxonomic groups (mammals, birds, vascular plants, bryophytes, lichens, mites), we summarize individual species results into results for each taxonomic group.

4.4.1 Species–land-cover associations

Species relative abundance estimates are available for each major land cover type (native vegetation in the North and soil-based ecosite types in the South, and human footprint). We use ordination (canonical correspondence analysis) to summarize these estimates and identify the main environmental gradients that drive species-land cover associations.

In the North, the first ordination axis separates forested and open (including cultivated and urban-industrial disturbances) habitats for all taxa except bryophytes. For bryophytes, the first axis differentiates between the wet lowland and drier upland habitats while the second axis reflects the closed canopy–shrubby–open gradient. For the other five taxa, the second axis separates lowland habitats and upland forests and also portrays the gradient of black spruce–pine/white spruce–mixedwood–deciduous stands. Recent forest harvests are near the corresponding non-harvested forest stands but somewhat shifted, indicating that responses to major habitat types are generally more important than variation in age or origin of stands (**Figure 4-9**).

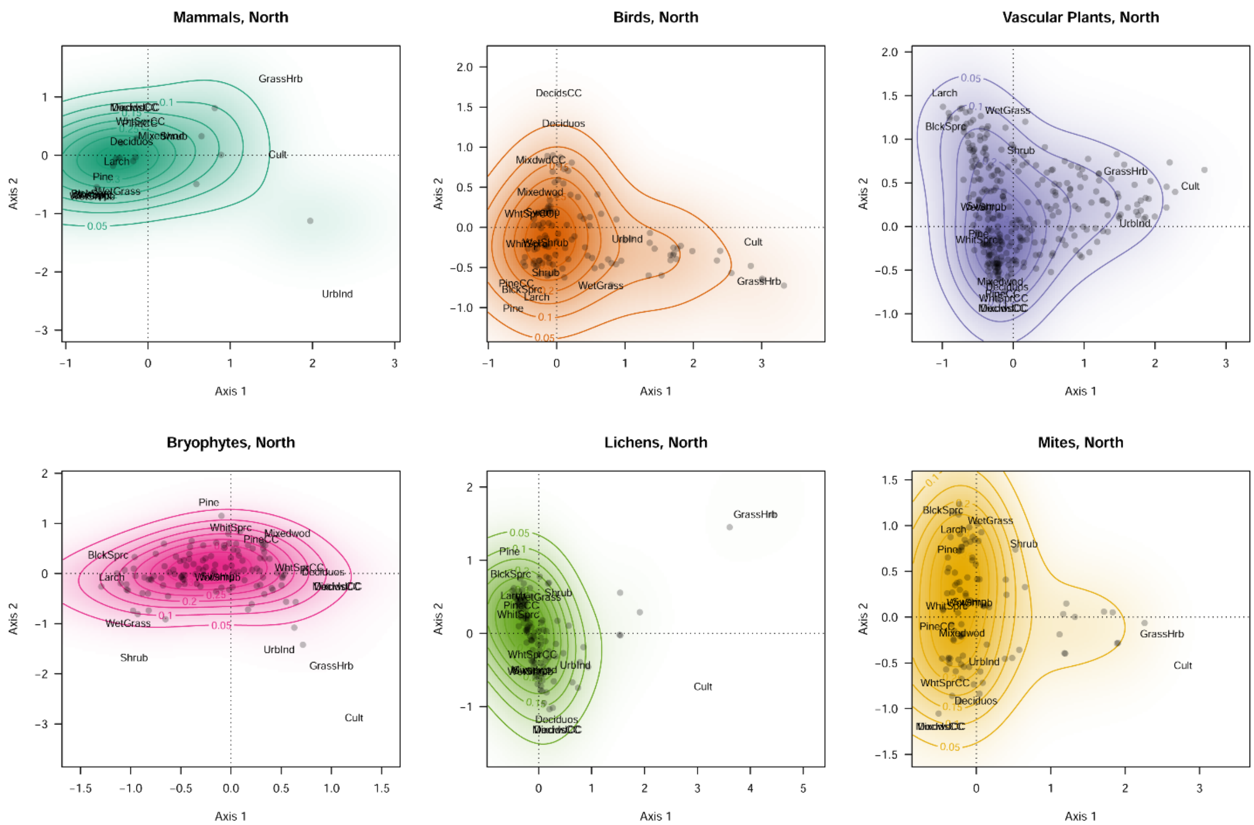

Figure 4-9 Canonical correspondence biplots for the 6 main taxa based on estimated coefficients in the northern analysis region. Each dot represents a species; land cover category names are abbreviated. Contours are based on estimated density of the ordination point patterns.

The ordination plots indicate that most species are concentrated in forested habitats, which was particularly evident for bryophytes and lichens. For mammals, birds, and vascular plants, some species spread out more to the open/disturbed side of the ordination plot, indicating that some species in these taxa prefer open habitats. Some mite species also showed a preference for more open environments (**Figure 4-9**).

In the South, species were markedly separated in their association between undisturbed ecosites and disturbed areas; most species are concentrated and occupy a small ordination space on the undisturbed side of the ordination plot. However, many species of vascular plants are associated with cultivated and urban-industrial areas, which also tended to be separate. A similar separation was also noted for lichens and mites, while it was smaller for mammals and birds, and smallest for bryophytes. (*Fig. 4* in **Technical Report 4.1**).

Besides the ordination results summarizing the estimated coefficients, we also analyzed the raw data using ordination (*Fig. 4-9.5*). We used site centres where detection/non-detection (coded as 0/1) of birds, mites, mosses, lichens, and vascular plants was available (mamma snow tracks were not used) (2158 species from 1112 sites). The ordination of the raw data of all taxa combined revealed that the first ordination axis captured a strong climatic gradient responsible for the separation of open habitats (in the right) and forests. The second ordination axis captured a disturbance gradient (bottom, cultivation being the most extreme), and to some extent an upland-lowland separation (black spruce dominated sites to the top left). Species showed highest concentration in the undisturbed forests, some species (mostly vascular plants) extended towards the grassland arm of the point pattern.

We evaluated if species with < 20 detections (thus not used in modelling) had special habitat requirements than the more common species. We found that rare species were scattered around more in the ordination, but the general distribution of rare (< 20 detections) species was similar to the rest of the species, not exhibiting different concentrations of the species along the main gradients. In canonical correspondence analysis, the points represent the estimated optima of species assuming a multivariate Gaussian response model. When a species has a single detection, the point is drawn at the projected location of that single site in the ordination (site scores not shown in the graph). As species have more detections, the point is drawn at the projected centroid that is always less extreme than any species with a single detection can be. This is the reason why the rare species contour in *Fig. 4-9.5* is more extensive than the contour for the more common species.

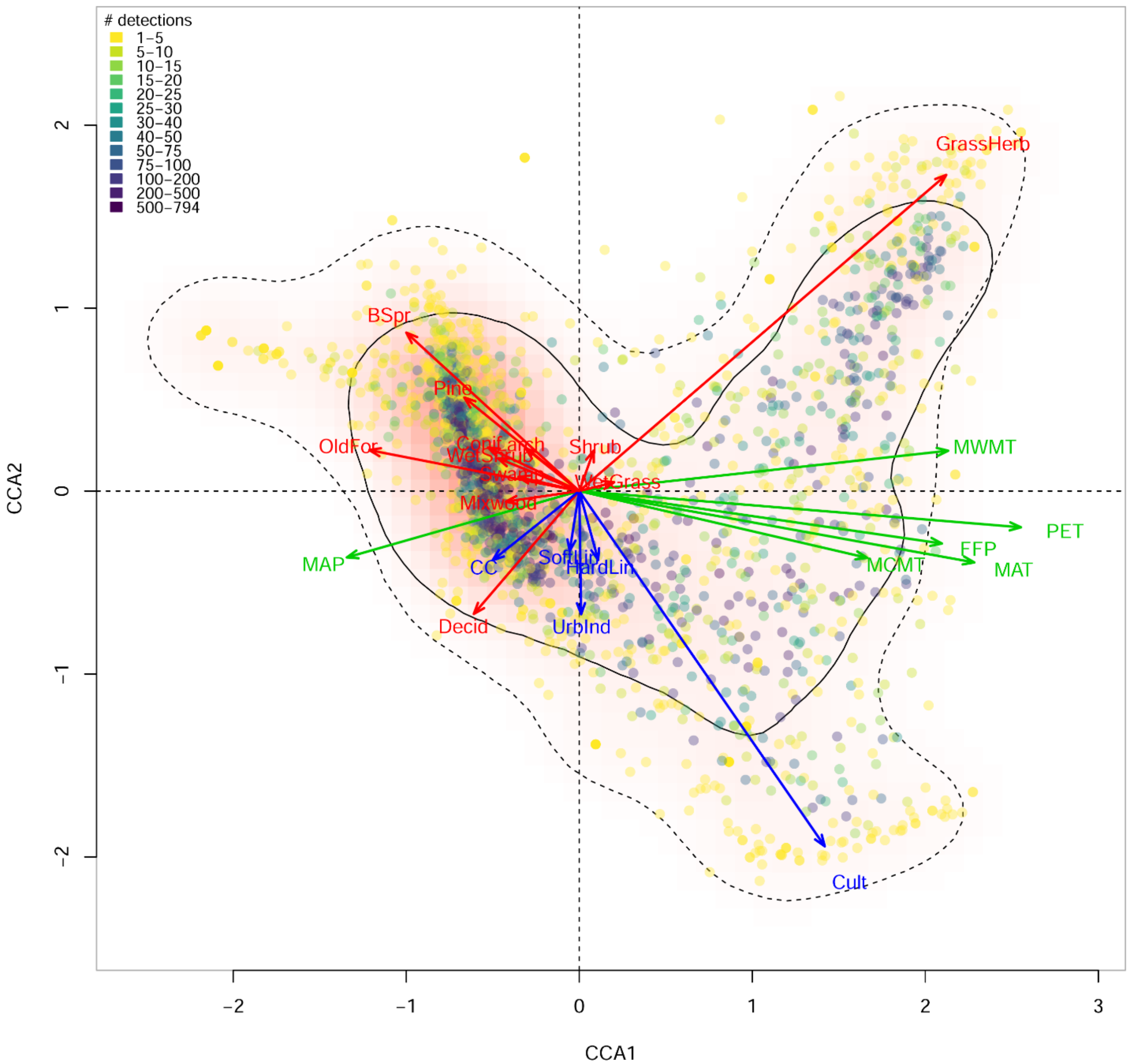

Figure 4-9.5. Canonical correspondence analysis (CCA) of the raw detection/non-detection (0/1) data of 2158 species (points, all taxa combined except mammals) from 1112 sites (centre plots from sites where all terrestrial taxa have been surveyed, mammal snow transects not included); 23 variables (arrows) were used as constraints (red: % native land cover, blue: % disturbance, green: climate). Point colours correspond to number of detections according to inset legend. Contours enclose 95% of the rare (scattered line, < 20 detections) and common (solid line, ≥ 20 detections) species.

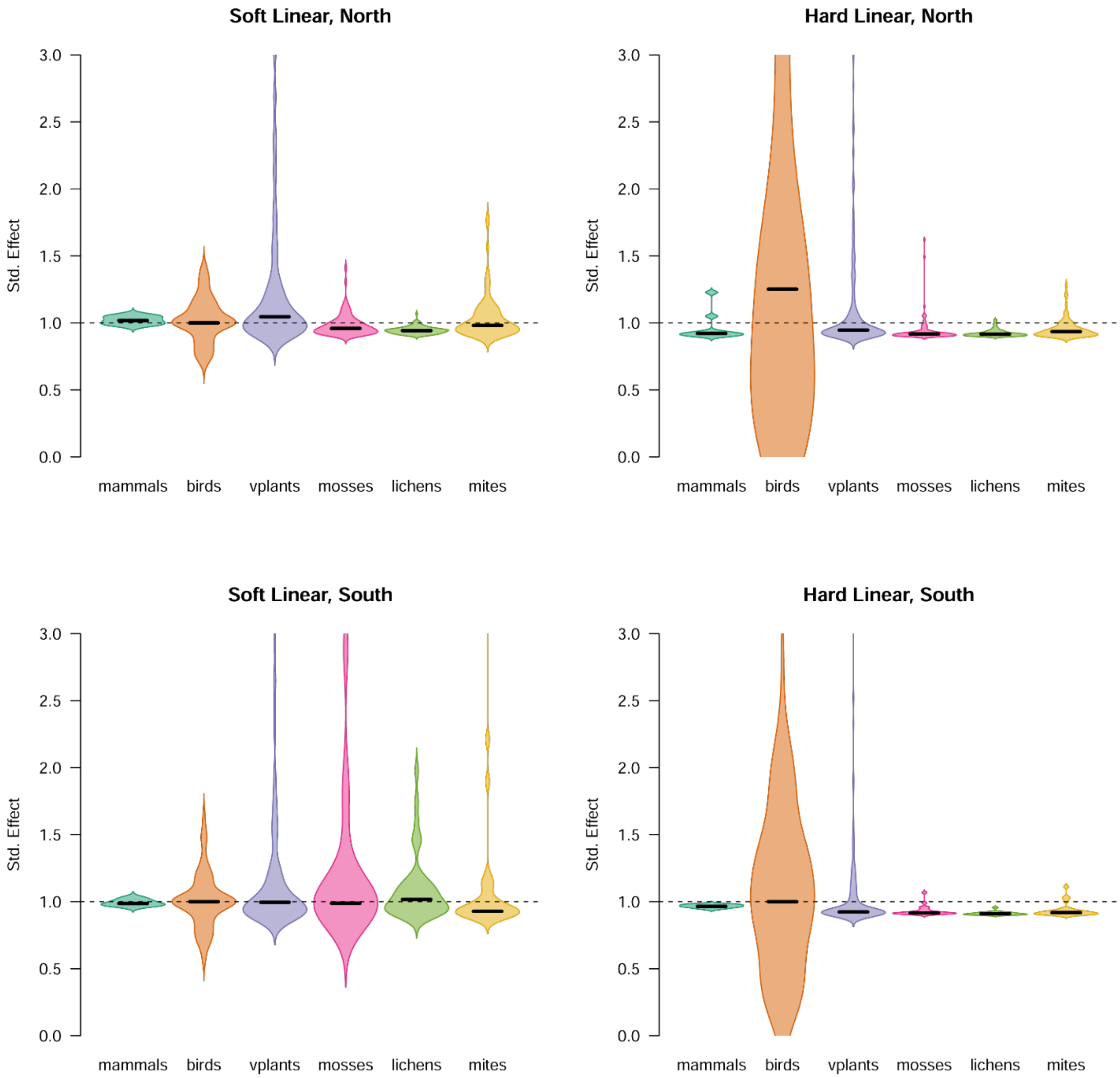

Figure 4-10 Soft and hard linear effects on species in the different taxa. Effects corresponding to 10% linear feature in the sampling area are standardized by dividing by the average expected abundance in habitats without linear features. The separate polygons for each taxon in the figure indicate the distribution of standardized effects for each, while narrow regions indicate few species, and wide regions more species. Horizontal lines indicate the median value, and the dashed line at 1 indicates no effect. Above the line means positive effects, and below negative responses to the presence of linear features in an average survey area.

For the association patterns for vegetated or non-vegetated linear features, we present separate summaries from the previous ordinations because these land cover types do not occupy large portions of our survey areas (usually < 20%). We present the ratio of expected abundances of the species with 10% linear features vs. 0% linear features. The distributions of these ratios for the six major taxa are shown in **Figure 4-10**.

Effects of vegetated linear features are similar across taxa with median values close to neutral (ratio = 1). Some vascular plant species (e.g., non-native species), and a few mite species showed large positive responses to vegetated linear features. The range of variation in bryophytes and lichens increased somewhat in the south compared to the north, with more species showing large positive responses (**Figure 4-10**).

The effects of hard linear features (mostly roads) were consistently negative for most species both in the north and south, except for birds. For the non-bird taxa, the ratios were around 0.9, indicating lower habitat availability of the non-vegetated linear features replacing the native land cover types (**Figure 4-10**).

In contrast, birds showed high variation in both the north and south compared to the other taxa. Hard linear features appear to both positively and negatively influence bird species. These singular results for birds are in part due to the different modelling approach used for birds, which treats the presence of a road as a modifier for the surrounding dominant land cover type instead of as part of the composition mix; thus, the effect depends on the presence of the road and the quality of the habitat around it. This methodological difference is necessary because the percentage of roads within the 150-m-radius buffers around bird point locations is bimodal in our sample due to the combination of off-road (0%) and roadside (~8–10%) surveys (i.e., North American Breeding Bird Surveys). As a result, the standardized effects for birds are not only capturing the numeric response of species to roads, but also a mix of numeric, behavioral responses, and detectability along them. A roadside effect of similar magnitude has been reported by Matsuoka et al. (2011) from boreal North America. In addition, experiments have demonstrated that effective detection radii for birds are substantially higher on roads than in adjacent forests (Yip et al. 2017), accounting for some of the extreme positive responses. Extreme negative responses most likely represent a combination of behavioral and numeric responses to edges created by roads, or behavioral responses to the presence of observers during surveys. It is also possible that the unbounded (0–infinity) nature of log-linear bird models compared to the bounded (0–1) predictions for other taxa is responsible for the extreme extrapolated values. The ABMI and BAM are actively exploring ways to improve this aspect of the bird models.

4.4.2 Intactness

We calculate provincial and regional intactness for each species (see Alder Flycatcher example in **Figure 4-6**) and summarize the distribution of intactness values for the six main taxonomic groups (**Figure 4-11**). We also average 1 km^2-pixel-level intactness values across species within each taxon to produce taxon-specific intactness maps (**Figure 4-12**).

Spatial patterns in intactness for the six taxa show similarities that are closely associated with the distribution of human footprint in the province (see Figure 2 3). Lower intactness was a general characteristic in the Grassland, Parkland regions and Dry Mixedwood sub-region, as well as in active mines in the Oil Sands region. Intactness is usually less extreme for mammals and birds than for other taxa (**Figure 4-12**).

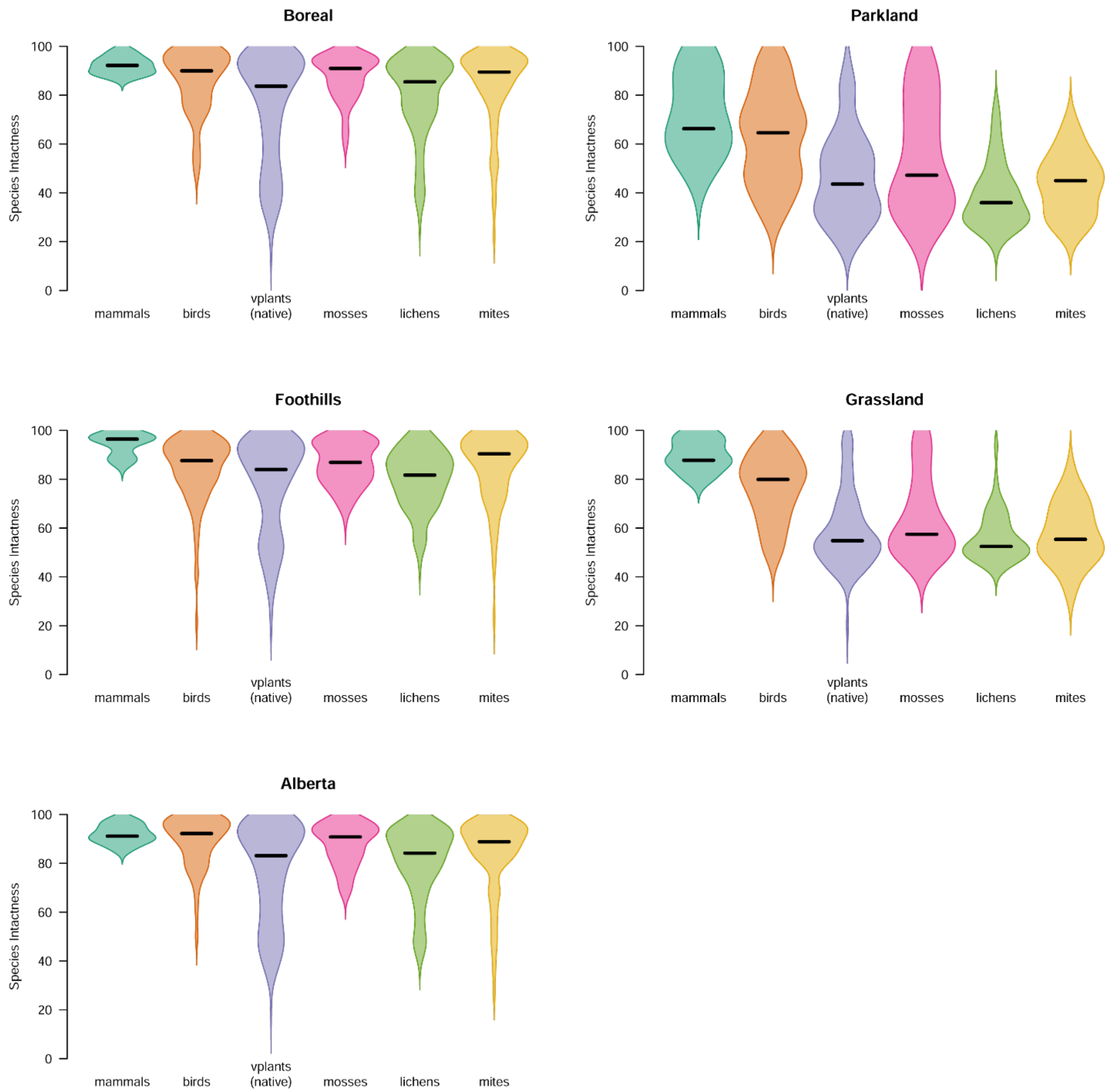

Figure 4-11 Distribution of species intactness by taxonomic group in Alberta and within natural regions. The width of each taxon-specific polygon is proportional to the number of species with different regional intactness values.

The relatively higher intactness for birds may be due to differences in the analysis of birds compared to other taxa. Bird modelling uses the single dominant habitat type approach vs. the multiple regression approach for other taxa. Sites for which footprint is treated as being the dominant habitat type also often have some native vegetation around them (Bayne et al. 2016), and these probably pull the habitat coefficient estimates for human footprint types closer to that of surrounding native types consequently, overestimating intactness. Moreover, habitat coefficients are estimated simultaneously with spatial/climate gradients for birds, whereas for the other taxa habitat coefficients are estimated first and then coefficients for space/climate are estimated as residual effects. Therefore, it is likely that any shared variation between footprint

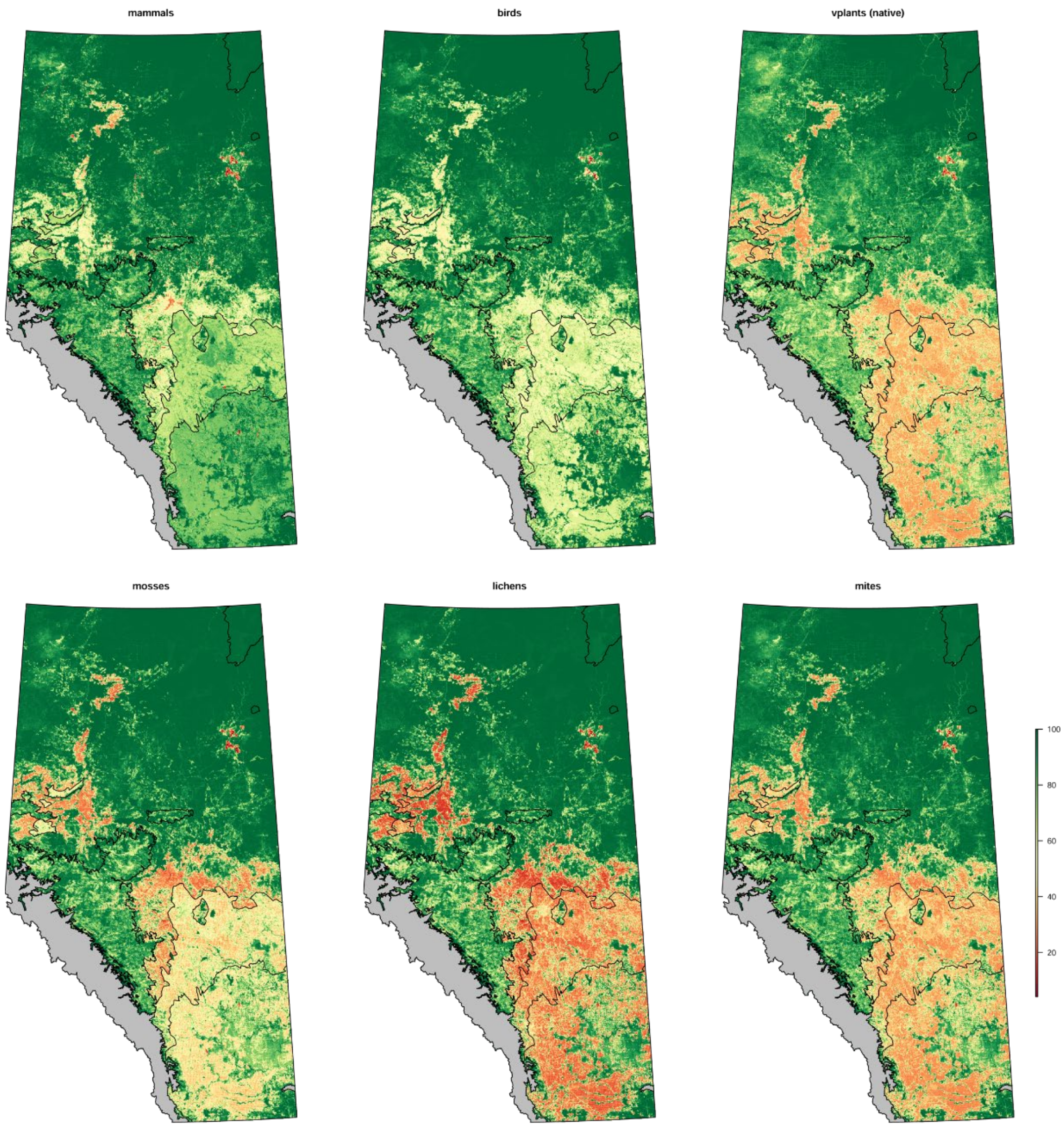

Figure 4-12 Spatial distribution of taxon intactness (0–100%) in Alberta. Black lines indicate natural regions (Rocky Mountains masked out). Maps for each taxon reflect the averaged intactness maps of species within that group. High intactness indicates less difference between current and reference abundances. Map resolution is 1 km^2.

and space/climate is assigned fully to footprint for the other taxa, but only partially to footprint for birds. However, since regional intactness differences for mammals are similar to those found for birds it simply may be that mobile taxa with large home ranges and territories perceive and respond to disturbances differently from taxa that are sessile or of limited mobility.

For all taxa, intactness was highest in the Canadian Shield due to the virtual absence of human footprint there. Intactness was somewhat lower (80–90% median) in the Foothills and Boreal natural regions only with a few species showing low (< 60%) intactness values in these areas. Species intactness was lowest in the Parkland and Grassland regions with < 60% intactness for most plant, moss, lichen and mite species; mammals and birds had median intactness values ~20% higher in these regions (**Figure 4-11** and **Figure 4-12**).

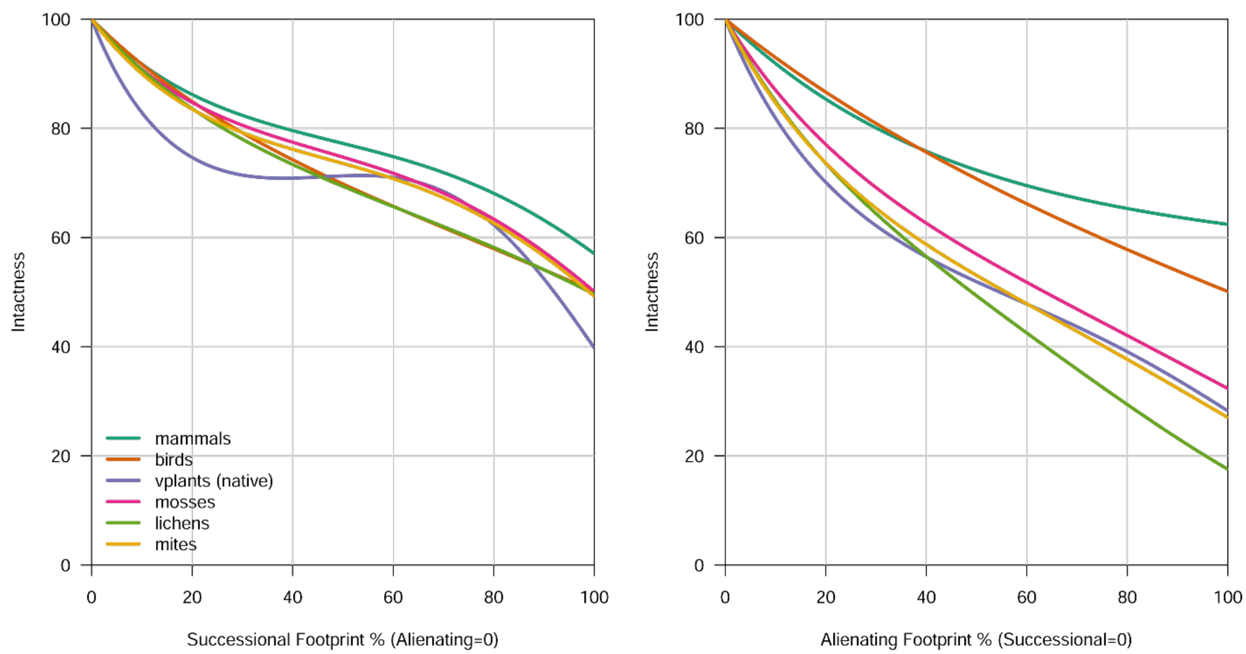

Figure 4-13 Intactness for the six taxa as a function of percent successional (left) and alienating (right) human footprint in the 1 km^2 pixel unit. Curves are based on a 3rd order polynomial model while keeping the other type of footprint at 0%.

We assessed the relative impact of successional and alienating disturbances on taxon-specific intactness (**Figure 4-13**). Successional disturbance results in a sudden drop in intactness (most noticeable in vascular plants) due mainly to the increased abundance of many human-associated species and to a lesser degree decreased abundance of a few species. This relationship becomes less steep as the amount of disturbance increases further. The final downturn of the curves is due to complete habitat loss for species requiring native habitat. A landscape composed of 50% successional disturbance and no alienating disturbance results in intactness of 70–80%, whereas 100% successional disturbance results in 40–60% intactness.

Alienating disturbance leads to a steep drop in intactness initially, that becomes somewhat less steep as more footprint is added. The drop for mammals and birds is comparable to the effect of successional disturbances; 50% alienating disturbance results in ~70% intactness, whereas 100% alienating disturbance results in ~50–60% intactness. The other taxa (vascular plants, bryophytes, lichens, mites) exhibit steeper decreases and reach ~70% intactness at 20% alienating disturbance. Intactness is ~50–60% at 50% alienating disturbance and ~20–35% at 100% alienating disturbance levels.

We did not include non-native plants in the calculation of average intactness, because doing so might result in counterintuitive and biased results. All things being equal, if rare non-native plant species are included (their predicted abundance will be close to zero in most pixels), the average intactness would be higher because the reference condition is 0 for these species. We use a different approach to calculate a species' intactness for non-native plants: non-native plant intactness = 100% – percent occurrence of the species. In addition, the average intactness of non-native plants is estimated by modelling the richness of non-native plant species in a Poisson log-linear model and presenting predicted spatial richness results. Non-native plants reach their highest richness in cultivated and urban areas, followed by shrubby habitats, open wetlands, and mixed/deciduous forests. Richness in harvested coniferous stands is also higher than in similar stands of natural (i.e., fire) origin. Non-native plants have the highest richness in heavily footprinted regions (see **abmi.ca/data** for results and map).

For wetland plants, intactness was modelled based on wetland predictor data while setting all human footprints to 0 (Nielsen et al. 2007). Average wetland plant intactness for the province is 85%. In the north, intactness was highest in the open-water zone (91.6%) followed by the emergent (87.5%) and wet-margin (87.0%) zones. In the south, intactness was higher in the open-water and emergent zones (81.3% and 84.6%, respectively) than in the wet-margin zone (78.2%).

4.4.3 Sector effects

We summarized total population effects of industrial sectors separately for the north and south analysis areas (see example in **Figure 4-8**). In the North (**Figure 4-14**), the effect of the urban/rural sector was the smallest (because there is very little of this disturbance type present) although a few plant species had large positive effects. This was followed by transportation (likewise, relatively little of this disturbance type was present), with an average effect close to 0, but with some variation (between –2% and +2% and a few positive outliers among plants). The other disturbance types were more common in the region and had larger sector effects. Energy sector development in the north on average affected mammals, birds, and vascular plants less negatively (median close to 0; both negative and positive effects among species, ranging between –3% and +5%) than the other three taxa (negative median values with very few species responding positively, ranging between 0 and –2%). The effect of agriculture was predominantly negative for all taxa with median values between –1% and –2% for the six taxa, although there were a few positive species in each taxon. The total effects of the energy and agriculture sectors have high per-unit area effects since the average sector effect was larger than expected due to area developed (2.0% and 2.1%, respectively) for these sectors in the north.

Species responses to forestry disturbance were more varied than for other sectors, with species effects ranging greatly in both positive and negative directions. Sector effects for mammals were smaller than for the other taxa. Birds showed a symmetric distribution with many species at above +5% or below –5% total population effect. Forestry effects for plants, bryophytes, and mites on average were more negative. Lichens were impacted most negatively by the forestry sector. The often-large total effect of the forestry sector is due to the large extent (6%) of this sector in the north and a moderate per unit area effect as compared to the energy and agriculture sectors.

In the south analysis area (**Figure 4-15**), total effects of energy and urban-rural sectors were mainly between +2% and –2%, with slightly negative or neutral medians for most taxa. The transportation sector had larger total effects for plants, bryophytes, lichens, and mites. Only a small percentage of the south region is disturbed by each of these sectors. Agriculture had the largest total effect on native species, with magnitudes ranging between –100% and 100%. Median values decreased from mammals and birds, through mites to plants, bryophytes, and lichens. The dominance of agriculture effects in the south is a result of that sector's large extent (50.8%) in the region, and its large per unit area effect. Note that a few plant and mite species had large positive (> 10%) effects across all sectors.

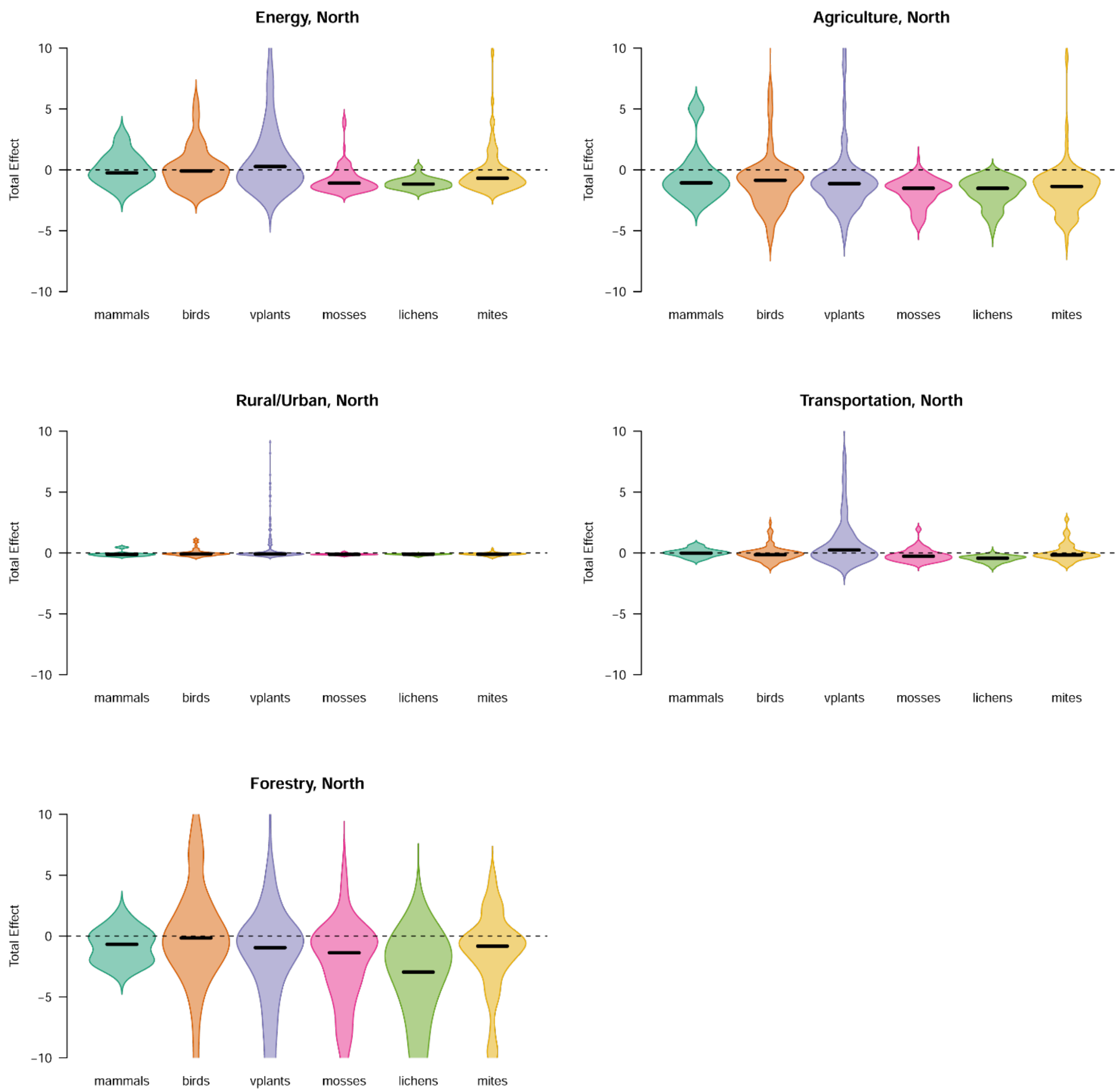

Figure 4-14 Total population effects by industrial sectors for the different taxonomic groups in the north analysis area.

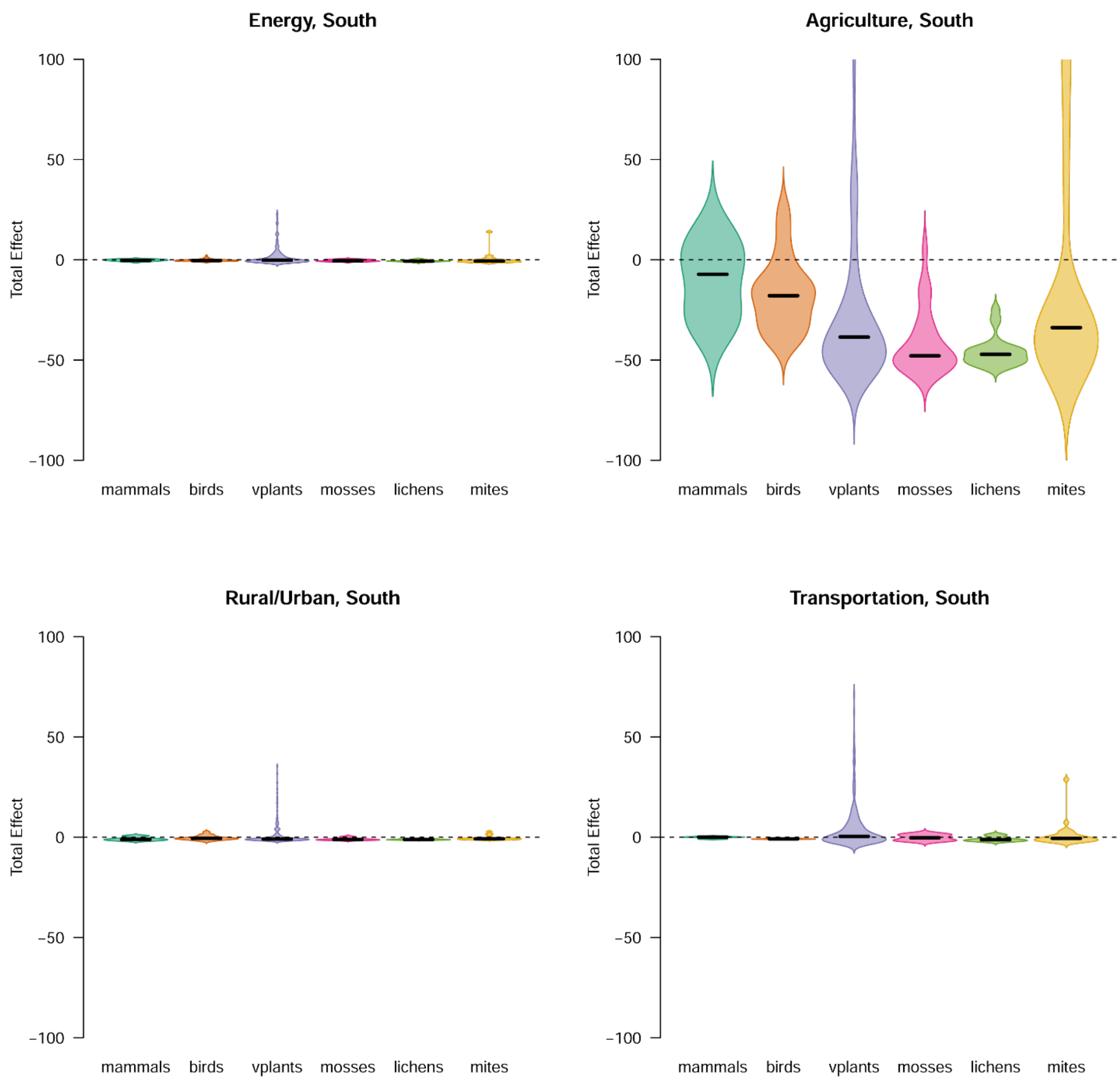

Figure 4-15 Total population effects by industrial sectors for the different taxonomic groups in the south analysis area.

4.5 Model validation

The ABMI (in partnership with BAM for bird analyses) uses statistical modelling techniques to relate species observations at sampled sites to land cover conditions (native vegetation and ecosites, human footprint) as well as to spatial and climatic variables. Results from modelling are used both to describe patterns of species distribution with respect to environmental conditions, and for making predictions for unsampled locations or different hypothetical landscape scenarios. We validate our models to understand the limitations of our data and analytical methods. Detailed results from model validation are presented in **Technical Report 4.2**; here we present a summary of the findings.

4.5.1 Goodness-of-fit

We assessed model performance using several statistical metrics to see how well we classify species based on environmental predictor information. This includes understanding how well model predictions fit the observed data (we use pseudo R^2 to quantify goodness-of-fit in general), and evaluating if we predict higher relative abundance where a species was detected vs. where it was not (we use area under the curve [AUC] to quantify classification accuracy).

Based on data from the North, model fit was good ($R^2 > 0.2$) for > 80% of lichen and bryophyte species, and between 70% and 80% for birds, vascular plants, and soil mites. The percentage of species with good classification accuracy (AUC > 0.7) was highest for lichens (99%) followed by bryophytes (98%), vascular plants (96%), mites (96%) and birds (94%) (**Figure 4-16**).

In the South, a lower proportion of species had good model fit based on pseudo R^2: 80% of lichens, 77% of bryophytes, 64% of mites, 63% of vascular plants and 56% of birds. Classification accuracy was good for 99% of lichens, 92% of bryophytes, 89% of vascular plants, 87% of mites, and 86% of bird species (**Figure 4-16**).

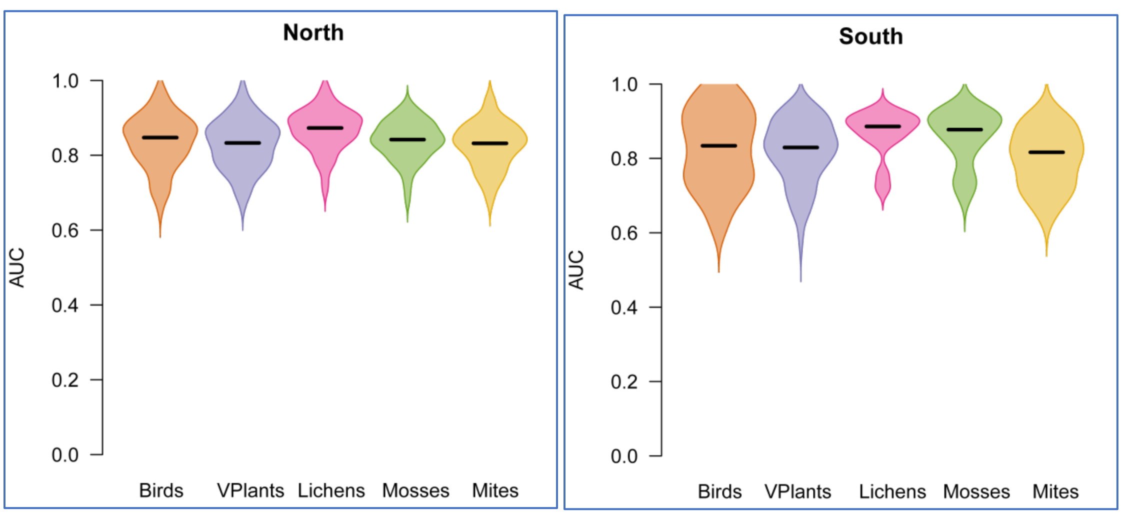

Figure 4-16 Distribution of the goodness-of-fit and area under the ROC curve (AUC) in the north (left) and south (right) for the full model by taxonomic groups.

In our modelling, we incorporate spatial and climatic variables to capture variation in species distribution not accounted for by land cover variables. As expected, these covariates generally improve model fit (see **Technical Report 4.2**). Species prevalence has no effect on goodness-of-fit, although these vary more among uncommon species than for common ones. Uncommon species with higher AUC values tended to be more range-restricted, possibly because species with a small range may be highly associated with particular land cover features. In addition, the contribution of spatial/climate information to the models may be much better for range-restricted species.

4.5.2 Geographic validation

Besides good fit between predictions and observations, we also expect that the models will have reasonable predictive ability outside the sample space (extrapolation), for example in less intensively sampled regions of the Province. To assess this aspect, we evaluated the degree to which model predictions based on a geographically-constrained subset of the data apply to new geographic regions (we calculated AUC to compare within-sample and out-of-sample classification performance of the models).

In the north, out-of-sample validation of model performance was repeated for each taxonomic group via "leave-one-cluster-out" cross-validation for eight geographical clusters (**Figure 4-17**; see **Technical Report 4.2**). Out-of-sample prediction error varied widely across regions, except for birds where model and validation performance (in terms of AUC) were very similar. The ability of the bird models to extrapolate well to unsampled regions may be related to the large sample size in the BAM + ABMI composite dataset. This could provide adequate representation of ecological conditions that are more transferable across regions. Model transferability was not strong for taxa where out-of-sample performance was much lower. Transferability is most significant for some regions (northeast, northwest, and southwest boreal) where only a small proportion (as low as 36%) of the species with good fit in the modelling have good fit in the validation. The proportion of species with good performance was higher for lichens and bryophytes than for vascular plants.

In the south, seven geographical clusters and geographic validation results indicate that extrapolation ability was highly variable among taxonomic groups. For birds, validation was generally high across regions, though somewhat lower than that obtained for the north analysis region. Overall, performance validation was lower for the Parkland-Boreal transition zone, and in the case of the Peace River Parkland tended to be consistently low for all other taxa. Models developed in the west and central geographical clusters performed well for lichens and bryophytes, and to some extent for vascular plants.

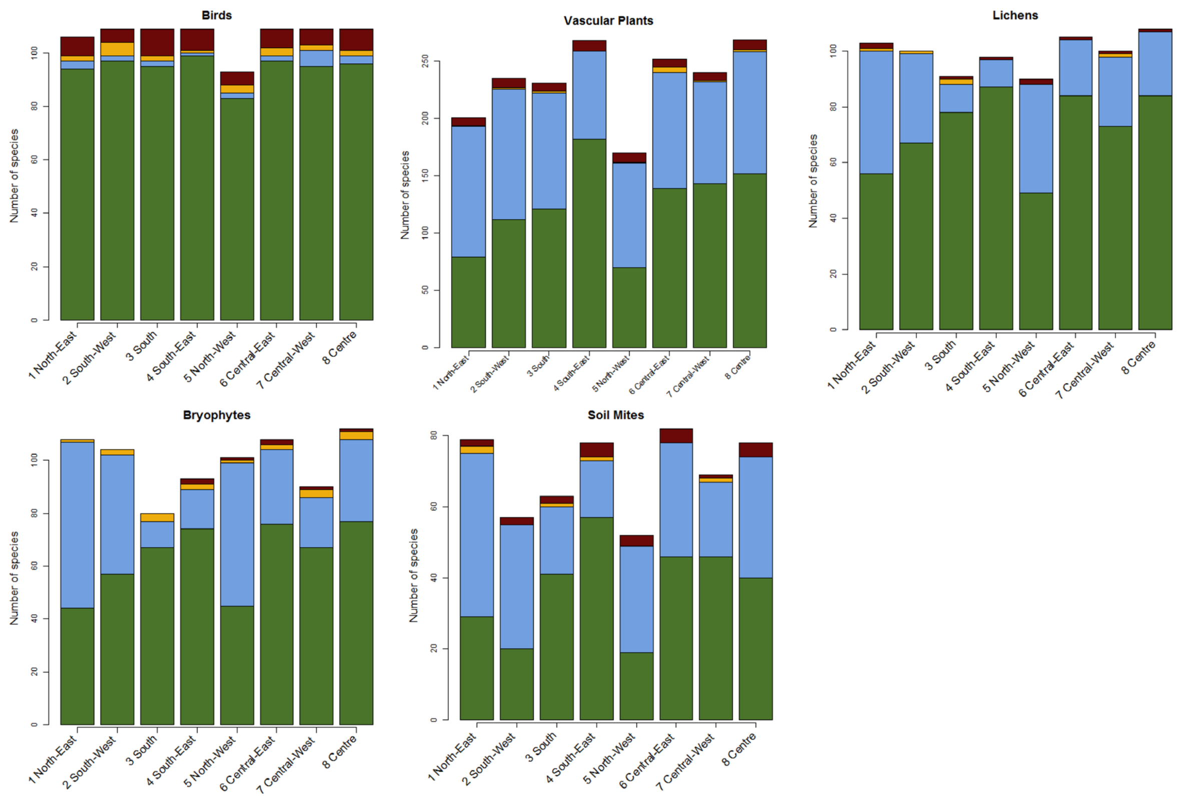

Figure 4-17 Number of species that fall into the poor (AUC < 0.7) vs. fairly good-to-excellent (AUC ≥ 0.7) categories in the modelling and validation data. Green: Fairly good-to-excellent in both modelling and validation data; Blue: Fairly good-to-excellent in modelling, but poor in validation; Brown: Poor fit in both modelling and validation; Orange: poor fit in modelling but fairly good in validation.

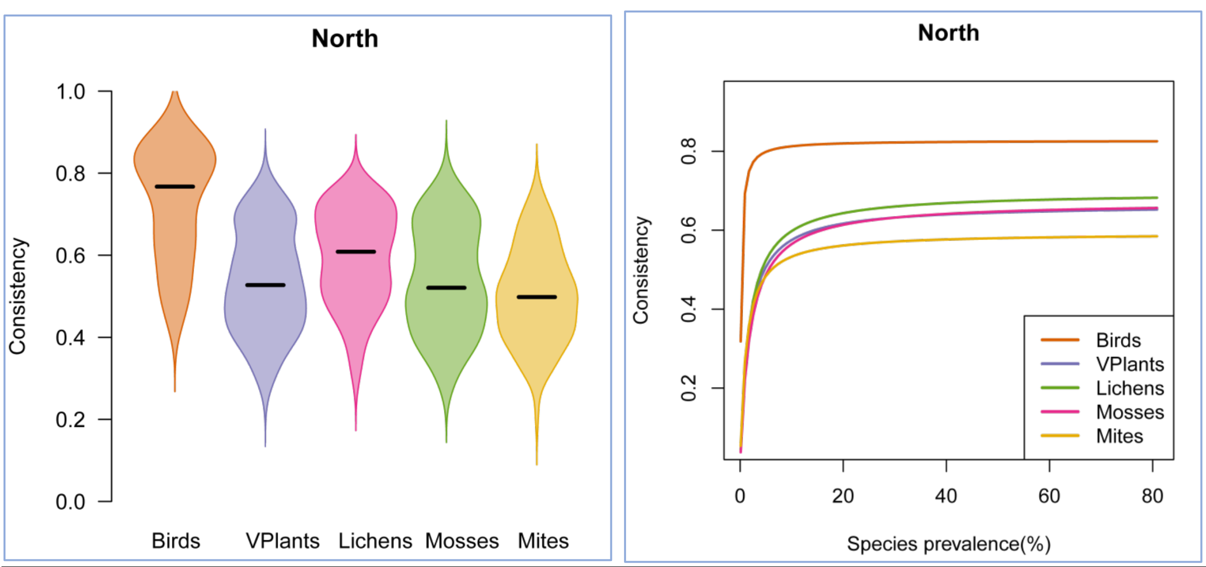

Figure 4-18 Distribution of repeatability of land cover coefficients (left) and the relationship with species prevalence (%) in the north analysis region (right) by taxonomic group.

4.5.3 Repeatability

Besides capturing relative abundance differences among different land cover types and transferability among geographic regions, we also want our models to provide low uncertainty around their coefficient estimates. This aspect is assessed through a distance-based index, which quantifies the repeatability of species–land cover coefficients based on iteratively refitting the models to resampled datasets 100 times (see **Technical Report 4.2**).

Repeatability of the coefficients is highly variable across species and taxa. Most bird species have high repeatability (i.e., narrow average confidence intervals). For species, the distance measure of repeatability increased steeply with species prevalence reaching an asymptote at approximately 200 detections. The high repeatability for birds is, thus, most likely due to large sample size and increased number of detections (**Figure 4-18**).

We also summarized the frequency at which different spatial and climate variables were selected during model selection in our bootstrap resampling framework (see **Technical Report 4.2)**. Selection frequencies for these terms varied greatly across taxa. In general, more of the spatial and climate variables (including interactions among them) are selected in the bird models than for other taxa where the number of terms is smaller and often without interactions. More complex spatial interactions allowed by large sample size might explain the better extrapolation ability of the bird models. Interestingly, the mean warm month (July) temperature was less often selected for birds than for the other analyzed taxa, indicating that summer temperature could limit sessile and resident species more (see **Technical Report 4.2**).

4.6 Discussion

In this chapter, we describe how data collected by the ABMI and other collaborators are used to build spatially explicit predictive models for Alberta's species at the provincial scale. Currently, we have detailed predictive models for 922 species in six major taxonomic groups. These models help in understanding the basic land cover associations and spatial distributions of the species. In doing so, they aid biodiversity conservation and provide valuable information with broad applications in management. Species-specific data and results from the ABMI and BAM have been used in species status assessments (e.g., Ball et al. 2013, Stehelin et al. 2016). The ABMI's intactness index, either as spatial intactness maps or regional indices for species and taxa, has been used as a biodiversity indicator in Alberta to present the overall effect of human disturbance on species abundance. The results from sector effects analysis support the attribution of the regional effects of anthropogenic disturbance to specific industrial activities.

Besides species, habitat structural elements can also change because of natural and anthropogenic disturbances in the landscape; thus, modelling these in a similar framework to what we do for individual species can provide insights into expected effects under different human footprints or management scenarios. Detailed results for the habitat elements sampled by the ABMI are also provided through the ABMI's Data & Analytics Portal (**abmi.ca/data**).

Many factors influence the efficacy of the models, including accuracy and comprehensiveness of collected data, appropriateness of sampling design, and the relevance of predictive variables and modelling algorithms (Elith & Leathwick 2009). We use a flexible and generic analysis that could be adapted to address specific questions, such as the effects of particular industrial sectors. The diversity of products facilitates applying our results to resource management (see **Chapter 7**).

The ABMI strives to develop data and reporting products that are actively used by managers in Alberta and beyond. We have successfully produced information that stakeholder groups have used to explore alternative management options in land-use planning under various hypothetical scenarios. To ensure our models provide accurate information, the ABMI conducts rigorous quality evaluation including assessing model fit and measures of uncertainty for model coefficients and predictive maps. It will be important to incorporate these uncertainty estimates into scenario modelling and other management tools. Validating our modelling results for specific footprint types would allow model refinement and increase confidence in the results. This work is ongoing.

After multiple pilot studies (e.g., Mahon et al. 2014, Schieck et al. 2013), our products are being applied in forestry planning in association with the provincial government, BAM, and other partners. These currently focus mostly on birds, but we expect the applications to broaden to other taxa and industrial sectors in the future. The models for birds generally outperform the models built for other taxa in terms of our validation metrics. This, however, is a result of a large dataset made available through collaborations. Increasing sample size for other taxa is expected to lead to more refined models for species currently modelled, and to more species being modelled due to increased detections. Mammal models are currently based on winter tracking and only provide information on winter habitat use. This protocol for mammals has been superseded by trail cameras and we expect to have models for the spring and summer habitat use and population density of mammals in the next 2 years.

In comparing the predictive model component of the ABMI to that of other monitoring programs (see **Biodiversity Programs Review** document), there is a trade-off between the breadth of taxonomic groups surveyed and the depth at which the data are analyzed. For example, local monitoring programs or regional programs focusing on few taxa derive more detailed summaries or build more detailed models of relative abundance. A few other broad-scale biodiversity monitoring programs relate species' abundances to land cover or other landscape features quantitatively, but their management applications are not always clear. Consequently, quantitative models in other monitoring programs are used mostly to describe the distribution of species. As an exception, programs focusing on birds often have access to extensive and detailed population assessments across large areas.

The ABMI's sampling design, which is complemented by targeted sampling along disturbance gradients and combined with a unique geospatial dataset describing human footprint, makes the program and its predictive analytical results globally unique. Although originally designed to detect trend, additional targeted sampling has facilitated analyses of how species vary among habitat types of human disturbance at broad regional scales (Haughland et al. 2010, Burton et al. 2014). In comparison to other monitoring programs, the ABMI thus has a unique, and uniquely versatile, approach to assessing biodiversity.

4.7 References

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5 Trend—Land-base change, expected precision and initial results from revisited sites.

Prepared by Dave Huggard for the ABMI

5.1 Executive Summary

The ABMI is an integrated monitoring program tracking trend in biodiversity across Alberta and its regions. An extensive set of verified 3 × 7-km GIS plots allows us to track changes in land cover (human footprint and native vegetation) from 1999 to 2015, with high precision at the regional scale. Simulations have shown that field monitoring will produce precise trend estimates for many species over time, if assumptions are met. Most common species will meet the ABMI's stringent performance targets after 20 years at the large regional scale, and many more species after 30 years. Initial trend estimates based on revisited sites are presented for the breadth of taxa and habitat elements surveyed by the ABMI. With only two years of revisits so far, the emphasis is on using the initial results for scientific assessment, testing, and improvement of methodologies, to ensure reliable trends in the long term.

5.2 General introduction

Monitoring long-term regional and provincial trend in biodiversity is a primary goal of the ABMI. Biodiversity is measured at the coarse-filter level by native vegetation types and human footprint; at the medium-filter by habitat elements and water physiochemistry variables; and at the fine-filter level by species across a range of taxa. Trends in species are a strong emphasis of the ABMI, and the main reason for its use of systematic field sampling with a panel-revisit design (Boutin et al. 2009).

ABMI trend estimates rely on revisiting the same sites over time. Although trend can be estimated from different random or otherwise representative sites visited each year[3], revisiting sites is more efficient (Underwood 1981). Statistically, revisits eliminate the extra uncertainty due to different sites being visited each time period. Revisits allow a "Before-After-Control-Impact" (BACI; Green 1979) design to help ascribe trends to land cover changes. Revisiting sites

[3] Prior to the start of revisits, the ABMI explored estimating trends from different sites sampled over time. The method produced weak results. Trying to compensate for the non-random sampling using habitat and spatial models for the species added large uncertainty to many of the resulting trend estimates.

can also help to detect and correct problems in field protocols or species identifications in early years of monitoring.

In this chapter we summarize initial trend estimates for the indicators, with an emphasis on the results for species based on revisited sites. We use initial trend results as parameters in a simulation to estimate the precision we can expect in trend estimates with different sampling options and durations of monitoring. This simulation is used to evaluate expected success at meeting the ABMI's stated goal of being able to estimate trend to within ±3%/yr after three visits to each site (i.e., approximately a 30% change in a decade) (Nielsen et al. 2009).

Due to incomplete funding, the ABMI is not yet at full operational capacity, and it has not been possible to sample at the frequency needed to deliver revisits every 5th year as initially planned. With revisits to only ~30% of the sites, it is too early to interpret the results as meaningful trends. Thus, the main focus of the present evaluation is to support simulations of expected trend, and to use the initial results to critically evaluate field and identification protocols to ensure valid trend estimates are achieved in the long-term. This process is ongoing, with some adjustments already made, and other tests, calibrations and changes being designed.

5.3 Trend of land cover types

5.3.1 Methods

We summarized trends of native vegetation types and human footprints from 1999 to 2015 (see **Technical Report 5.1**), using the 3 × 7-km plots of detailed mapping centred near each of the 1,656 systematic ABMI sites (**Chapter 3**). The province-wide 3 × 7-km plots are a unique resource allowing the ABMI to track land cover change over time.

Human footprint types were summarized into seven classes: urban/rural and residential/industrial (these types cannot be separated reliably where they occur together); mines; agriculture; forestry; soft linear (vegetated features, including seismic lines, powerlines, pipelines, road margins); hard linear (roads, railways); and human-created waterbodies. For forestry, which recovers with time after disturbance, we also summarized "recovered forestry", prorating older harvested areas using biotic recovery curves based on a literature review (see **Technical Report 5.2**). Other successional footprint can also recover when abandoned, but we do not yet have good information on the age since abandonment for those features.

Native land cover was summarized into 11 classes: deciduous, mixedwood, pine, upland spruce, treed bog, treed fen, treed swamp, upland grass/herb, upland shrub, open wet, and wet shrub. Old stands (80+ years) were also summarized for the four upland stand types that are suitable for forestry.

5.3.2 Results

Total human footprint is much higher in the Parkland and Grassland natural regions than in the forested regions (**Figure 5-1**). Agriculture is dominant in these southern regions and the Boreal (along the southern fringe).

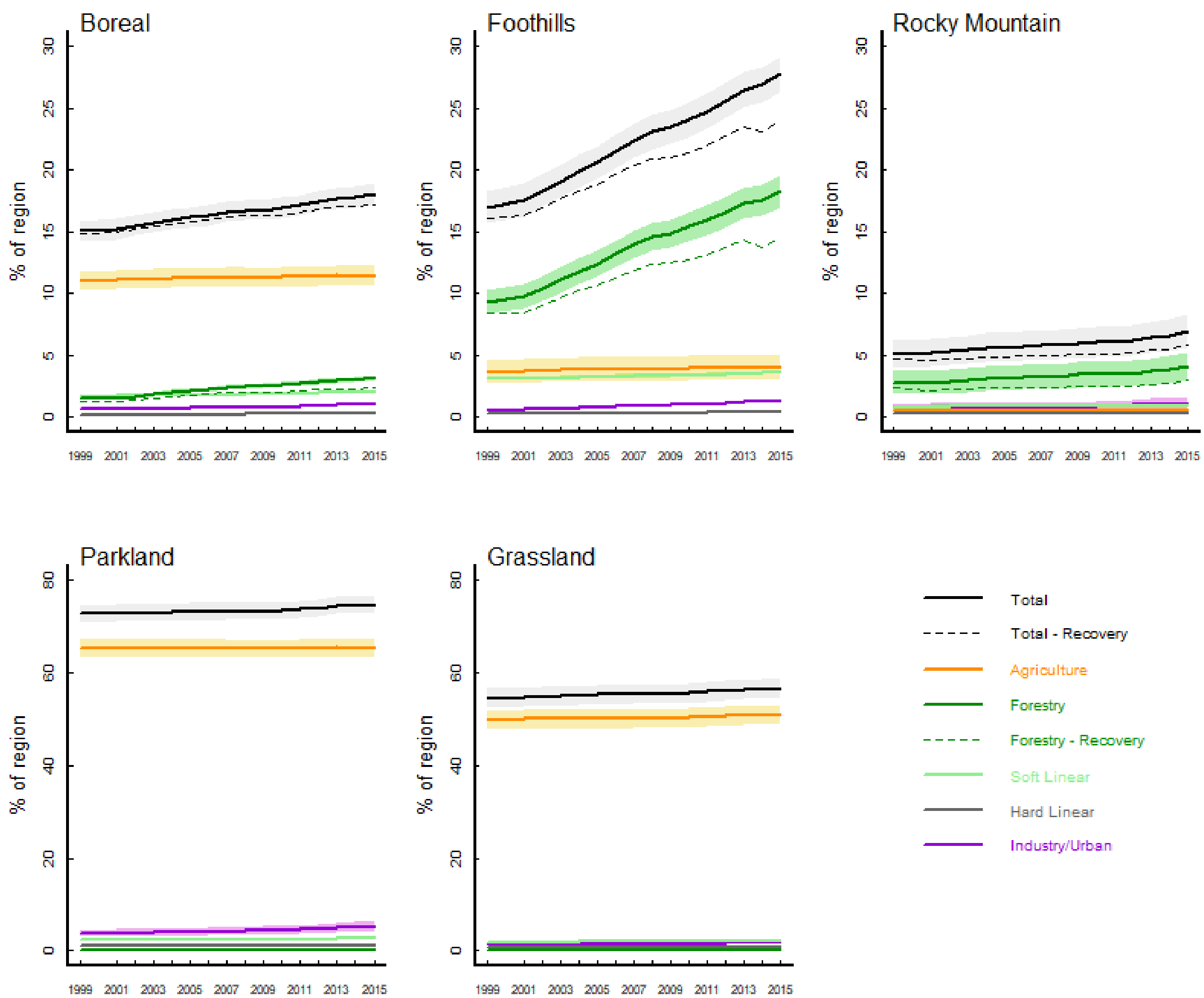

Figure 5-1 Area of human footprint types over time from 3 × 7-km areas in each region. The dotted "recovery" curves account for biotic recovery of aging forestry areas. Note the different y-axis scaling between the top and bottom figures. Shading associated with each line shows 90% confidence intervals. (These intervals are calculated for each year separately—statistically, they include the uncertainty in the intercept—so they do not account for the repeated-measures design.) The Canadian Shield natural region is not shown, because it has < 0.1% footprint.

Forestry is the main footprint type in the Foothills, and total human footprint is increasing most strongly in this region due to forest harvesting. Forestry is also increasing total footprint to lesser extents in the Boreal region and in small parts of the Rocky Mountain region. Since there is some older forestry area in the Foothills, recovery of that partially mitigates increases from new harvesting. Forestry is not as long-established in the Boreal, but more of it is in aspen forest, which recovers quickly, reducing the net effect of new harvesting there.

Urban and industrial footprint contributes small incremental increases to total footprint in all five regions. Agricultural area, a dominant footprint type in the Boreal, Parkland and Grassland, has increased only slightly during the past 16 years.

Pine forest in the Foothills region is showing the greatest decline among native land cover types (**Figure 5-2**), because it is the focus of forestry there. The other three upland forest types (deciduous, spruce, mixedwood) are declining at slower rates. In the Boreal region, deciduous forest is declining at the greatest rate, because it is the main harvested stand type in that region, with small declines in other forest types. Declines in lowland forest and all open vegetation types (not shown) are very slight, and are driven by scattered energy footprint and some minor expansion of agriculture and rural development in the south.

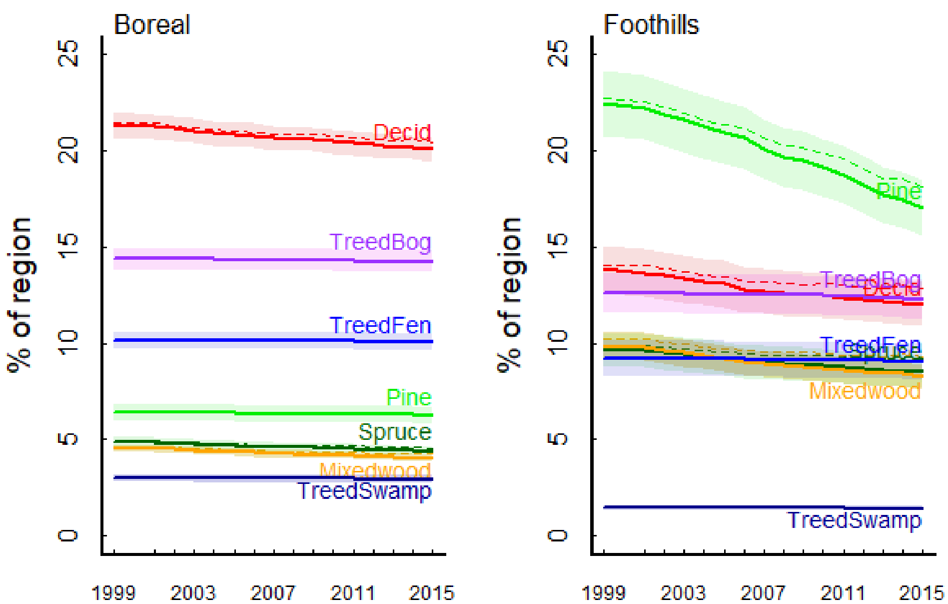

Figure 5-2 Area of broad stand types over time in the two main forested regions (left: Boreal; right: Foothills). Dotted lines account for contributions from recovering forestry areas. Shading associated with each line shows 90% confidence intervals. (These intervals are calculated for each year separately—statistically, they include the uncertainty in the intercept—so they do not account for the repeated-measures design.)

Bootstrapping the results of land cover change from the 3 × 7-km plots produces narrow confidence intervals (see **Technical Report 5.1**) for total amount of change at the regional level, except for moderately wide intervals for forestry, which occurs in aggregated patches. Uncertainty is greater for smaller sub-regions or rarer footprint types, such as urban areas (not shown).

Overall, the yearly 3 × 7-km plots provide a reliable way to track change in human footprint and broad native vegetation land cover at the provincial and regional scales. This is a resource that is unprecedented in many areas of the world (see **Biodiversity Programs Review** document. Priority areas for field monitoring would include Foothills (highest rate of footprint increase), Parkland (highest current amounts of footprint), and conifer forestry areas (largest potential driver of change and recovery).

5.4 Revisit-based trend

5.4.1 Introduction

The ABMI is designed to estimate trends of species using revisits to sites. To date, 1,039 of the 1,656 systematic sites have been surveyed, and, as revisits only began in 2015, 273 (16.4%) sites have revisit information that could be used in our analyses (**Figure 2-7**). The revisited sites were first surveyed between 2007 and 2013, with a range of 2–9 years and an average of 5.9 years between visits. Unfortunately, one revisit approximately six years after the first survey is too short a time period to effectively evaluate how well the ABMI can meet its objective of estimating trends to within ±3%/yr after 10–20 years for common species[4].

Here, we use simulations to predict the expected precision of our trend estimates for different reporting areas (number of sites) and years of sampling, as well as to examine effects of different options for revisit schedules (**Section 5.4.2**). We apply the simulation results to species monitored by the ABMI using the initial revisit results, to show expected ABMI performance in the future. We then present the actual results from the revisits we already have. We summarize the rate of land cover change—from human footprint and fires—at our revisited sites, and use simulations to estimate the variation we can expect in sampled disturbances due to sampling error (**Section 5.4.3**). This habitat change at revisited sites is a principle driver of trend for species that are affected by disturbances. We then summarize initial trend for each of seven main taxa, as well as habitat elements and water physiochemistry. For convenience, we refer to the change as "trend", but with only two years of revisits, it may be more appropriate to consider it "temporal fluctuation". With annual and multi-annual variation common in populations, and particularly with the sampling error discussed below, these early results should not be interpreted as showing trends that are expected to persist in the long-term. Meaningful information on long-term trends that are relevant to conservation will require at least three revisits, which will not be achieved for an additional 13 years with full ABMI sampling. This is particularly true with the slow rate of human footprint change in the areas that are currently a priority for ABMI field monitoring.

A second focus of these initial summaries is to identify and begin resolving problems revealed by the results, to ensure that our data produce reliable, unbiased estimates of trend in the long term. We include measures of "quadrat consistency" where possible, reporting how consistently individual species are found in quadrats between the first and second visits. We also investigate unexpected changes in individual species, groups of species, and overall taxon abundance to look for issues in field and lab methods that could bias trends. We summarize ways that we have tested, calibrated, and corrected the issues, or what we plan to do in the future. This detailed

[4] Technically, the ABMI goal is to be able to declare that a trend of +3%/yr or -3%/yr is statistically significantly different from a trend of 0%/yr with a probability of error of 0.1. However, it is equally important for an objective monitoring program to be able to confidently report that a species is showing no trend, or a trend of 1%/yr, etc. For this reason, it is preferable to speak of precision, rather than a power analysis approach that is specifically seeking differences from 0%/yr.

critical review of initial results and adaptive monitoring is an essential part of the ABMI's ongoing objective to provide rigorous scientific data on long-term trends of biodiversity.

5.4.2 Expected precision of trend in the future

5.4.2.1 Methods for simulating expected precision

We used Monte Carlo simulations of a revisited panel design similar to the ABMI's to estimate the expected future precision of trend estimates with different monitoring efforts and duration (see **Technical Report 5.3**). Simulations used a range of abundances and variance components (site-to-site, annual, site*annual and variations between panels) extracted from the initial data on ABMI species at revisited sites. In addition to those species characteristics, we also examined how the expected precision of the trend estimates was affected by the number of sites, duration of monitoring, revisit cycle (e.g., 5- versus 10-year cycle), and the true trend of the species. The simulations have been run for taxa that are indexed with 0–4 quadrat occupancy per site (plants, bryophytes, lichens, mites) and for mammals where the abundance index at a camera station has a highly skewed distribution (a few cameras with very high abundances). The simulations broadly involve generating abundances of each species at each site over time using the species parameters, sampling these abundances using the various sampling schemes, and calculating trend from the resulting "data". Monte Carlo iterations are used to incorporate the different sources of variation for the species, sampling error, and measurement error, showing how that uncertainty is expected to create uncertainty in the trend estimates. Parameter values for ABMI vascular plant, bryophyte, lichen, and mite species were derived from the initial two years of revisits. For the mammals, we have no revisits, and therefore had to assume some of the parameters, making the mammal projections speculative until we have revisit information. Details of the simulation methods available in **Technical Report 5.3**.

Precision for bird trends was calculated using a different approach, due to the larger time series in the ABMI + BAM composite dataset (see **Section 3.1.2.2.2**). Instead, the current SE of the trend estimates based on 19 years of data was extrapolated to additional years of sampling using the relationship of SEµ1/duration$^{1.5}$. This relationship with duration is what we have found in all trend precision simulations we have conducted to date.

We also examined expected precision if we report on average trend of a group of species, using an inverse-variance weighted mean. The assumption is that each species is providing an independent estimate of the average group trend. We calculated this precision for groups of 5, 10, 20, 40, and 80 random species from the ABMI's analyzed vascular plant species.

5.4.2.2 Results for simulated expected precision

Detailed results are found in **Technical Report 5.3**. A summary of the main conclusions follows.

5.4.2.2.1 Effect of true trend

Species with strongly negative trends show lower precision (wider SE of the trend estimate) than stable or increasing species, because of the increased role of binomial sampling error as the species becomes uncommon (see **Technical Report 5.3**).

5.4.2.2.2 Duration of monitoring

Duration of monitoring is the dominant factor determining precision. The SE of the trend estimate decreases as 1/monitoring duration$^{1.5}$ (see **Technical Report 5.3**). For example, after 20 years of monitoring, the SE of the trend estimate is 0.35× as large as it was at 10 years. The same relationship applied as duration increased from 7 years (i.e., 2/5 of a revisit on a 5-year cycle, similar to the current ABMI situation) to 10, 15, or more years. Completing one cycle of revisits (10 years of monitoring at full effort levels) is expected to reduce the SE of the trend estimates to 0.59× current levels, on average.

5.4.2.2.3 Number of sites

Increasing the number of sites monitored, or expanding the reporting region to include more sites, decreases the SE of the trend estimate in about the familiar $1/n^{0.5}$ relationship (see **Technical Report 5.3**). Trend reporting for a region that is four times larger than another is expected to produce SE's about ½ the size.

5.4.2.2.4 Species abundance and variability

Species abundance also affects precision, with common species having much lower SE's of the trend estimate for a given number of sites and monitoring duration. Annual variability increases SE's, especially for shorter durations of monitoring. Other variance parameters have lesser or no effect, because the revisit panel design removes those effects (see **Technical Report 5.3**).

5.4.2.2.5 Revisit cycles

Five-year and 10-year revisit cycles produce similar SE's on the trend estimate, if the same total number of sites is monitored each year (i.e., if there are twice as many sites overall with the 10-year cycle). Additionally, monitoring for 20 years with a continuous 5-year revisit cycle produces SE's that are only very slightly smaller than monitoring for the first 5 years (one visit of all sites), skipping 10 years, then completing a 5-year cycle between years 16 and 20. The expected precision is almost entirely determined by the time between the first and last completed cycle, not the intervening cycles (see **Technical Report 5.3**).

5.4.2.2.5.1 The "ABAB" option

The previous result opens up the possibility for designs that sample taxon A or use method A for one cycle, switch to taxon B or method B for a cycle, complete a revisit cycle for taxon or method A, then finally complete a revisit cycle for taxon or method B. This "ABAB" design provides 15 years of monitoring for two taxa or methods over a 20-year period, with negligible loss of precision. It is an option for questions about which taxa to monitor, or how not to lose existing data when new protocols are proposed. Intermittent sampling, however, has logistical problems that need to be considered, and prevents interim trend estimates or evaluation of changing trend over time.

5.4.2.2.6 Expected precision of trend for ABMI species

We applied the simulation results to the real ABMI species we have analyzed in the taxa with the 0–4 quadrat index, to show how the number of species that we expect will meet certain precision targets changes as the duration of monitoring and number of sites in a reporting region increase (see **Technical Report 5.3**). Example results are shown for ABMI plant species in **Figure 5-3**. The same patterns apply for lichens, bryophytes, and mites (results for mammals and birds are presented separately below). As monitoring duration increases from the current ~7 years of monitoring (top row) through 10, 15, 20, and 30 years (bottom row), more and more species (y-axis) have lower expected SE's on the trend estimate (x-axis).

The ABMI aims to be able to detect a ± 3%/year trend for a common species at the regional level. To declare that a true trend of ± 3%/year is "significantly" different from 0%/year at $p < 0.1$, the SE needs to be < 1.83%/year[5]. At year 7, 49 of 460 analyzed ABMI plant species (10.7%) are expected to meet this goal in a region of 800 sites (approximately half the province), rising to 76 species (16.5%) at year 10, 195 species (42.4%) at year 15, 322 species (70.0%) at year 20, and 435 species (94.6%) at year 30.

Precision is also higher for larger regions (800 sites, or ~half the province; right column) than for 200 sites (middle column) or a small region of 50 sites (left column). At year 20, 85 species (18.5%) would have expected SE < 1.8%/year for a small region of 50 sites, 198 species (43.0%) would be that precise across 200 sites, and 322 species (70.0%) across the 800-site half-province.

Results for the 18 species of mammals show wider expected SE's of trend estimates, due to the highly skewed distribution of the abundance index (a few cameras with high values, most with no records of a species). Depending on which assumed values of unknown parameters are used, it is possible that no mammals will reach the precision targets until 15 or 20 years with 800 sites, and most species will not reach the targets until 30 years. Less than half of the 18 species are currently projected to meet those targets after 30 years at the 100- or 200-site scale. Again, these projection results are highly dependent on assumed parameters, which will only be known when we have camera revisits.

Since the ABMI + BAM composite dataset (see **Section 3.1.2.2.2**) includes 19 years of data, the resulting trend estimates meet the precision target for 90% of the 98 analyzed songbird species[6]. That percentage is predicted to rise to 96% after 5 more years, 98% after 10 more years and 100% after 15 more years (34 total years at that point) (see **Technical Report 5.3**).

Using inverse-variance weighted averaging, the average trend for a group of species is expected to be much more precise than for individual species. Groups of 10 species should meet the ABMI's precision targets after only 10 years, even for regions of only 200 sites (see **Technical**

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[5] $3\%/yr/z_{0.1} = 3\%/yr/1.64 = 1.83\%/yr$

[6] BAM uses a different analysis philosophy, bootstrapping with the individual point count station or BBS stop as the resampling unit, and so is looking at measurement error within the sampled sites, rather than the larger sampling error. The precision of BAM results is therefore not directly comparable to the precision we report for ABMI revisits, or to results from the Breeding Bird Survey.

Report 5.3). Groups of 5 species should meet the target in 10 years at the half-province scale, or 15 years in regions of 200 sites. Groups should also reach the target in small subregions of 50 sites after 15 years. These results apply to a random set of species. Precision is increased because the group estimate is dominated by the most precise species, which is often the most common species. Thus, using a group average is most appropriate where the species in a group are being used as (interchangeable) environmental indicators. The results would not apply to a set of rare species. However, it would not make sense to talk about the average trend of a group of rare species, because the reason for interest in rare species is usually to conserve each one of them. Therefore, rare species need to be tracked individually, rather than as a group.

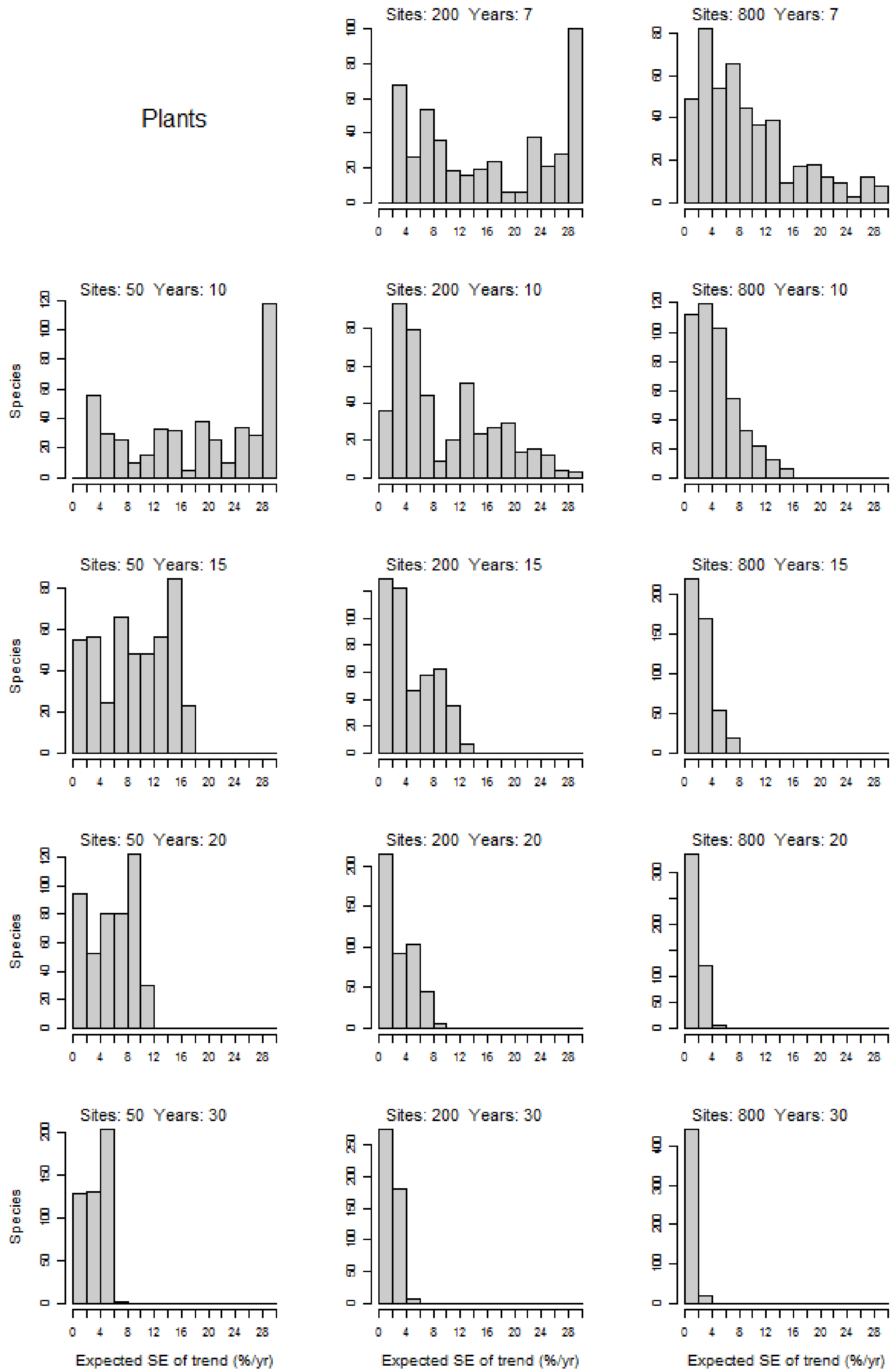

Figure 5-3 Number of ABMI analyzed species with different levels of expected SE of trend (%/year) across a range of numbers of sites (columns) and monitoring durations (rows), for vascular plants.

5.4.2.3 Discussion of expected precision

The simulations above are useful for understanding how many ABMI species are expected to attain precision targets for trend estimates over time and for differently sized areas. They emphasize the importance of long-term monitoring for precise trend estimation, and the pool of common species that will have precise estimates in larger regions. The simulation results show that the ABMI will meet its precision goals for estimating trend for increasing numbers of species over time, even as soon as the completion of the first revisit (expected in 3 years for ~40% of the province). Most currently analyzed species are expected to meet that goal by 20 years at the half-province scale. A majority will meet the goal in 30 years for a typical 200-site region, and approximately 25% should reach that goal by years 20 or 30 even for small 50-site sub-regions. Mammals are currently predicted to have less precise trend estimates due to the high measurement error at individual cameras, but revisit information is needed to estimate the simulation parameters for them. Bird trend estimates using the composite BAM + ABMI dataset (see **Section 3.1.2.2.2**) already have 19 years of data, and have precise estimates for many species. The average trend for groups of randomly-chosen species is expected to be much more precise, in part because it is dominated by the most common (and therefore precise) species in the group.

The simulations conducted in this review were complex, to realistically account for the different sources of variation in species' abundances and different sources of sampling error. However, we made several simplifying assumptions with the two largest being, first, that trend stays the same over the duration of the monitoring span. Major changes in trend over the monitoring span would add to uncertainty. This also means that if after 20 years, for example, someone wants to know the trend "in the last 10 years" because they believe it is different over that span, then the simulation results for only 10 years of monitoring would apply. Second, methods provide consistent abundance measures over time. If important aspects of field or lab methods change over time, that would add additional uncertainty to the results. More critically, if the changes are directional—such as better microphones for recording birds, or more ef3.1.2.2.2ficient search for plants by better-trained technicians—then that would introduce a bias into the trend estimates. The estimates would then be inaccurate to some degree, regardless of how precise they are. Concern about the possibility of bias is the reason for the strong ABMI emphasis on checking for possible methods changes in the initial revisit results (part of **Section 5.4.4**) and standardizing or calibrating methods. Previous simulations have shown that calibration itself needs to be well-designed and have sufficient sample size to avoid adding extra uncertainty to trend estimates (see **Technical Report 5.4**).

5.4.3 Land-base change at revisited sites

Loss and alteration of habitat to human footprint and natural disturbances is a main driver of population changes. These events are rare at any particular point, and could add substantial sampling error to ABMI trends, even with relatively large numbers of revisited sites. We may need to use our more precise sample of land cover change (from the 3 × 7-km plots) to adjust for this sampling error at revisited sites (for example, by weighting disturbed field sites based on overall disturbance rates in the 3 × 7-km plots).

Based on GIS summaries of the land cover in the central 1-ha plot in the initial visit and the revisit, the 273 revisited sites included: 4 sites completely converted to human footprint, 4 sites partially (10–90%) converted, 3 sites completely burned, and 1 site partially burned (see **Technical Report 5.5**). Treating the partially disturbed sites as 50% disturbed, these values equal disturbance rates of 0.37%/year by human footprint and 0.22%/year by fire. The human footprint rate is moderately higher than the recent rate of human footprint increase seen in the 3 × 7 summaries (section 2). The fire rate may be low, but much of Alberta has active fire suppression, including the prairies.

Simple binomial simulations using the observed disturbance rates showed the expected distribution of disturbance rates over a 5-year revisit period for 680 sites (the area currently monitored fully by the ABMI) and a sub-region of 100 sites (see **Technical Report 5.5**). The distribution is fairly wide (**Table 5-1**). For example, in the 680 sites, 90% confidence intervals on the sampled total (human footprint + fire) disturbance rate ranged ± 30% around the median, and ± 80% for 100 sites. Given that habitat disturbance is a main driver of species change, that sampling error will create substantial uncertainty in trend estimates for species, particularly in smaller sub-regions.

Table 5-1 Expected distribution of human footprint and fire disturbances at revisited sites over one revisit period.

		Mean	Percentiles of Distribution of Disturbance (%/5yr)						
Sites	**Type**	**(%/5yr**	**2.5**	**5**	**10**	**Median**	**90**	**95**	**97.5**
100	Human footprint	1.86	0.00	0.00	0.42	1.69	3.39	3.81	4.24
	Fire	1.09	0.00	0.00	0.00	0.85	2.54	2.97	3.39
	Total	2.95	0.42	0.85	1.27	2.97	5.08	5.51	6.36
680	Human footprint	1.86	1.06	1.18	1.31	1.87	2.43	2.62	2.80
	Fire	1.09	0.44	0.56	0.62	1.06	1.56	1.68	1.81
	Total	2.95	1.87	2.06	2.24	2.93	3.68	3.93	4.11

Note: Human footprint and fire were modelled independently, so the percentiles for the total disturbance are closer to the median than the sum of each disturbance would be—total disturbance benefits from averaging the two independent sources of variation.

5.4.4 Summary of revisit trend after 2 revisit years

5.4.4.1 Methods

We used a simple measure of change from prior visit to revisit (see **Technical Report 5.5**):

Change (%/year) = [(total count in revisit/total count in prior visit)$^{1/\text{mean span}}$ – 1] x 100%

This is simply the ratio of abundances in the revisit to the prior visit, pooled over the whole reporting area, converted to an annual rate (%/year). The reporting area is the entire area sampled with revisits by the ABMI so far, but the same approach could be used for any sub-region. A few sites have been visited more than once during the first round of sampling. Only results from the most recent of those years were used. When we have multiple revisit periods in the future, we anticipate using a log-linear regression for this estimate, with model selection used where the data allow us to check for non-log-linear relationships (i.e., substantial changes in trend within the sampling span).

The revisit trend value was calculated for all species that occurred at at least one site in both visits, and at least four sites overall. These are minimal criteria, and the estimates for the rarer species have large uncertainty. Confidence intervals were placed on the estimate using 1,000 bootstrap iterations, with the site as the resampling unit.

5.4.4.2 3.4.2 Overview of revisit results

The distribution of initial revisit trend for the species in each taxon shows an exaggerated normal distribution (example for lichens, **Figure 5-4**; see also **Technical Report 5.5**). Rarer species, those present at < 10 sites, show extreme results that account for most of the exaggerated tails (very large increases and decreases). They also have very wide confidence intervals. Common species, present at 20+ sites, show a less pronounced spread and narrower confidence intervals. Although we focus on the scientific process of identifying and correcting possible problems here, many common species have estimates near 0%/year, as would be expected over a short period with few sites disturbed, and many of those species already have fairly tight confidence intervals.

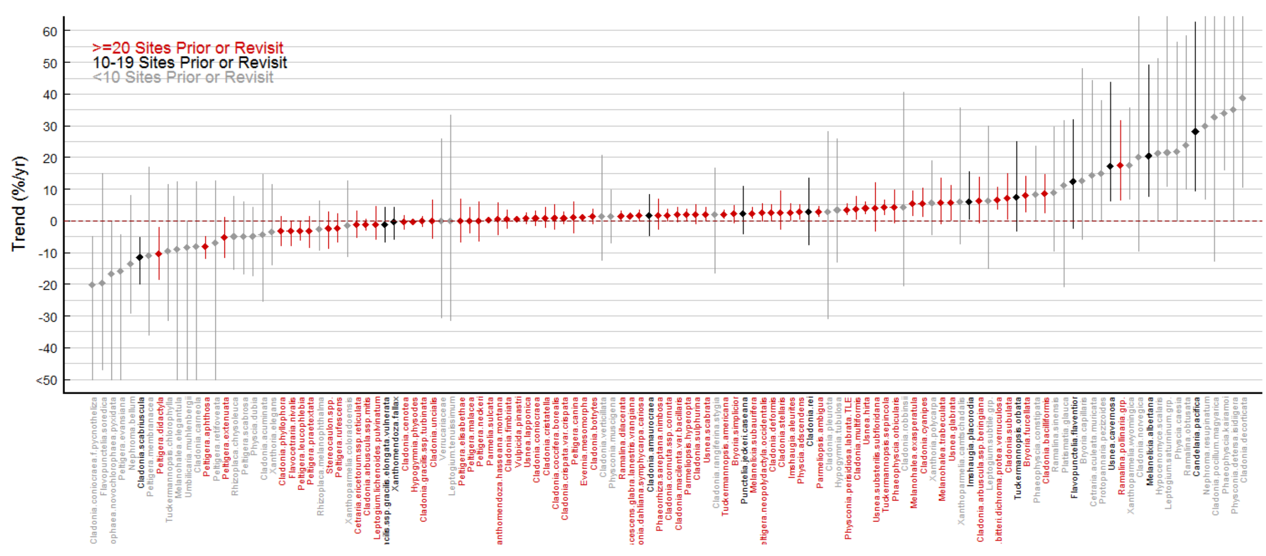

Figure 5-4 Trend estimates (after only 2 revisit years) for all analyzed lichen species. Colours show abundance classes; grey: < 10 sites, black: 10–19 sites, red: 20+ sites. Error bars are 90% confidence intervals.

In the technical report, we include diagnostic information on trend for species, such as quantile-quantile plots to assess how much the observed distribution exceeds the expected distribution for such a large number of species with uncertain estimates, and plots of the species' results based on 2015 versus 2016 revisits to illustrate yearly variation (see **Technical Report 5.5**). Below, we summarize some aspects of the results for each taxon, separately for the three abundance groups and for some ecological groups within taxa:

- Number of species or species groups analyzed for that grouping,
- Mean trend and its SE across the species,
- Mean absolute trend (how much the trend differs from 0%/year, whether positive or negative),
- Width of the 90% confidence intervals,
- Percentage of species with trends significantly different from 0%/year ($p < 0.05$ one-tailed),
- Percentage of species with trends more extreme than ± 3%/year,
- Percentage with trends more extreme than ± 10/year

5.4.4.3 Investigating revisit trend and consistency

Data collection methods that remain consistent over the years are critical to unbiased trend estimates. Because we do not have any "gold standard"[7] information on what species are truly present in ABMI sites at any time, we currently identify problems mainly by investigating unexpected results from the revisits. We generally expect little overall change over one revisit period since only a few sites are directly disturbed and the change in natural vegetation over a short period is usually small. Thus, we highlight changes across a taxon or group of species that are unexpected, as well as individual species that show unexpectedly large changes.

An initial examination looked for pairs or groups of closely related species that are difficult to identify reliably and that showed large opposite trends—e.g., a decrease in one species accompanied by a large increase in one or more related species—which most probably indicate changes in species identification in the field or lab. This is particularly likely if the species change within quadrats between visits. Any such sets of species were lumped into groups and the revisit summaries re-run for the species group. This is an ongoing, iterative process.

The lichen example (**Figure 5-4** above) also illustrates several examples of features that we are investigating to improve the consistency of our results in the long term. For example, these include overall change in the taxon (e.g., a median trend of 1.59%/year, with 70% of species showing increases), consistent changes of particular groups (e.g., decreasing species in genus *Peltigera*), and additional species to consider for grouping (e.g., *Cladonia scabriuscula* showing

[7] We use "gold standard" to refer to results from a field method that gives a high degree of accuracy and repeatability. For species occurrence on a plot, that means that there is a high probability of recording the species if it is present (e.g., > 90%). Quicker, less accurate methods could then be checked against and calibrated to this gold standard.

unexpected large decreases). The specific lichen changes, possible causes, and proposed solutions are discussed in **Section 5.4.4.4.4**.

We also calculated an index of the consistency of a species' occurrence in each quadrat in the first visit and revisit: Number of quadrats with the species in both visits / number of quadrats with the species in either (or both) units × 100%. This is not a measure of accuracy or detectability, because we do not know the true occurrence of species at the plots, and it is not strictly a measure of repeatability, because we do not know the extent to which species truly changed between visits. Nonetheless, we expected little to moderate true change in occurrence of most species, so low quadrat consistency can indicate problems in field methods or identification.

5.4.4.4 Results for each taxon

5.4.4.4.1 Mammals

In 2014, the ABMI switched from snow transects to remote cameras for surveying mammals. As a result, we do not have revisit data for mammals using comparable methods. Under the present sampling design, it will be eight years before we have a complete set of camera revisits in the fully-sampled region. We may also revisit snow transects, benefiting from the "ABAB" design. With cameras, we anticipate precise trend estimates at the scale of large regions for the two deer species, moose, black bears, and coyotes, and useable estimates for a variety of moderately rare ungulates, carnivores and snowshoe hares.

→ ABMI camera surveys will provide valuable trend information on mammals when revisits are completed.

5.4.4.4.2 Birds

Trend estimates for birds are made using the composite BAM + ABMI dataset (see **Section 3.1.2.2.2**).

Here, we summarize bird trends only from revisited ABMI sites. As with all other taxa, our main purpose is to check for problems in the ABMI data that need to be addressed to ensure reliable long-term trends (or, for this taxon, a reliable contribution to the larger composite dataset).

Simple revisit trend estimates for birds are complicated by the fact that the ABMI bird protocol changed between the first visit and the revisit: birds are now recorded using automatic recording units (ARUs) deployed at four stations per site in the winter and collected in the late summer, whereas in the first visit humans operated the recorders for a single 10-minute session at each of nine stations per site. For this comparison, we matched the duration of the interpreted sample of the recording, time of day, and time of year as closely as possible between first visit and revisit (see also **Section 3.1.2.2.2**). We used available 3.33-minute segments of the original 10-minute recordings and 3-minute subsamples for the new ARU's, correcting for the different duration based on each species' singing rate derived by BAM (see also Solymos et al. 2013). Initial direct tests suggested that the old and new recording devices have similar sensitivity across the range of frequencies (Yip et al. 2017). We therefore have not made any other adjustments for the protocol changes.

The resulting trend estimates for most birds were strongly positive—species relative abundance was estimated to be much greater in the revisits (**Table 5-2**). The average species increased 38% between visits. This occurred for all abundance groups (but was larger for species with few detections), migration strategies (but was strongest for resident species), habitat associations, and for songbirds, waterfowl, raptors, etc. (see **Technical Report 5.5**).

Table 5-2 Summary of initial revisit trend for birds (ABMI data only).

BIRDS		Trend (%/yr)							
Group	# Species	Mean	SE of mean	Mean Absolute[1]	CI Width[2]	"Significant"[3]	% > ±3%/yr[4]	% > ±10%/yr[5]
<10 Sites	21	32.6	20.3	43.6	282.1	38.1	100.0	61.9
10-19 Sites	18	7.1	6.3	14.0	34.4	22.2	66.7	22.2
20+ Sites	99	6.2	1.0	8.3	25.2	60.6	79.8	29.3
Migration								
Resident	13	17.1	8.0	20.4	29.3	61.5	92.3	53.8
Short-distance	68	3.8	1.1	7.5	17.1	52.9	79.4	23.5
Neotropical	36	7.4	1.9	8.4	43.7	55.6	66.7	27.8

1 Mean of the absolute trend for each species = mean($|trend_{sp}|$)
2 Mean width of 90% confidence interval
3 Percent of species with 90% confidence intervals that do not overlap 0%/yr
4 Percent of species with trends more extreme than ±3%/yr
5 Percent of species with trends more extreme than ±10%/yr

Many bird species may be showing large long-term increases across Alberta, or the two years for which we currently have revisits could have been exceptionally good conditions for birds. However, we doubt that simultaneous large increases would happen across such a wide range of species and habitats. We are therefore designing tests to evaluate potential reasons for the increases:

First, we know from direct tests that human interpreters of recordings record more birds as they become more confident over time (see **Technical Report 5.6**). (Note: We do not know what birds were actually present at a site for these tests, and many vocalizations on the recordings are ambiguous. Thus, we cannot say whether the increase means that the interpreters became more accurate or, conversely, that they inaccurately indicated that more species/individuals were present). Current recording interpretation uses computer-assisted tools not previously available. Noise reduction and audio compression technology improves over time, making recent digital audio files clearer. Interpreters of the original 10-minute recordings reported species in each 3.33-minute third of the recording (we used the first of these), but may not have been rigorous about recording each species in each third. Those factors would all reduce the records in the original recordings compared to the current ones and would produce an upward tendency in the revisit trend estimates.

→ We will have current interpreters reinterpret a subsample of 3-minute segments from the original recordings, using current computer-assistance, to measure the influence of some of these effects.

Second, although the old and new recording units did not differ greatly in controlled tests, they may still differ in the field. One complicating factor is that humans were present during the original recordings, which could have suppressed vocalizations nearby, especially in the first third of the recording used for the revisit calculation.

→ We will conduct simultaneous recordings using the original recorders with a person present immediately beside operating ARU's to compare and calibrate the two recorder types under field conditions. ARU recordings with and without humans present will be used to calibrate the effect of human presence. We are implementing initial comparisons for the 2017/2018 field season and will assess what additional work is needed the following year, including sample sizes needed to produce a precise calibration.

Third, the subsamples of ARU recordings that were interpreted were selected to exclude excessive rainy or windy conditions that reduce bird singing rates or detections in recordings. The original recordings were made under a broader range of conditions when the crews visited the site (although they also did not sample during heavy rain or wind). Additionally, half of the ARU subsamples used in the comparisons were made at the peak song time of 30 minutes after sunrise, compared to only 1/9 of the original recordings (the 9 stations were spread over the period from sunrise to 10:00 am).

→ We will compare ARU subsamples that match the calendar date of the original visits, to randomize weather and time of day effects equally. ARU recordings are made at limited times of day, so we cannot match that aspect.

The initial ABMI trend estimates for birds are much higher than the BBS estimates, and uncorrelated across species (see **Technical Report 5.5**). This is compatible with uncorrected factors raising the ABMI revisit estimates, although the ABMI surveys differ from BBS in the period they cover, the regions and habitats they survey, and their analysis methods. However, the BBS may not be an accurate estimate of trend because those samples are all along roads (Matsuoka et al. 2011). We have not yet looked at revisit data from the Grassland region.

→ Conclusion: The planned tests will allow us to calibrate the original ABMI visit and revisits, which will allow ABMI/BAM to provide the first fully representative trend estimates for birds in Alberta.

5.4.4.4.3 Vascular plants

Vascular plants are the most diverse taxon monitored by the ABMI, with 473 analyzed species, including a wealth of important indicator species, non-natives that are a critical concern in Alberta, plants valued by people, and many others. Thirty-three species groupings and 15 genera were used to accommodate similar species with obvious identification problems. More species groups will likely be created as we continue to examine results for individual species (see **Technical Report 5.5**).

Like all taxa, the rarer plant species have greater mean absolute trends and much wider confidence intervals than the moderately common or common species (**Table 5-3**). Most species in all three abundance groups have trends > ± 3%/yr. Quadrat consistency is low—species are unlikely to be recorded on the same quadrat in the first visit and revisit.

Many of the plant results reflect the difficultly field technicians have in finding and identifying, or at least recognizing for collection, the many species of plants found in a 50 × 50 m plot during a 20-minute search. Extreme results and confidence interval widths decrease from annual/biennial plants to perennial herbs to shrubs to trees, and quadrat consistency increases, reflecting the increased visibility of the larger woody species. For example, one test showed that ABMI technicians doing 20-minute searches detected only 57% of species found by more experienced observers in time-unlimited searches on the same quadrats (Zhang et al. 2014). In addition, the number of species detected per quadrat was similar for all four sites in the ABMI results, but varied widely in the time-unlimited surveys, suggesting that the number of species that technicians can record within 20 minutes is limited.

The incomplete species list and low consistency increase opportunities for inaccurate trends due to changes in training and differences in observer ability. Diversity of *Carex* species per site, for example, increased 32% between visits, probably due to increased training in recognizing these species (see **Technical Report 5.5**). With a relatively fixed number of species recorded per quadrat, increased attention to *Carex* implies fewer records of some other species. We saw an overall tendency for rarer species to show declines, which may be due to increased recent emphasis on collecting voucher specimens of unlikely species. Many of the extreme revisit trends for individual species could be caused by differences between individual observers or training effects (e.g., increases in species specifically pointed out during training). The subjective element of the 20-minute searches is an important focus in pursuit of reliable data for trend estimation in the long term.

Table 5-3 Summary of initial revisit trend for vascular plants (see also **Technical Report 5.5**).

VASCULAR PLANTS		Trend (%/yr)							Quadrat
Group	# Species	Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]	Consistency (%)
Abundance									
<10 Sites	166	-2.94	1.40	13.55	58.6	22.3	84.3	50.0	16.9
10-19 Sites	132	0.97	1.21	9.92	27.4	33.3	71.2	38.6	23.7
20+ Sites	175	0.85	0.54	4.95	10.3	42.3	51.4	14.9	43.0
Growth form (≥10 sites)									
Nonperennial	33	-0.54	2.33	8.78	22.3	39.4	72.7	33.3	22.1
Perennial Herbs	184	1.24	0.80	7.42	18.0	42.4	61.4	26.1	35.2
Shrubs	45	1.98	1.10	4.31	11.5	24.4	40.0	11.1	44.5
Trees	11	-0.57	0.84	2.01	6.0	36.4	27.3	0.0	61.8

[1] Width of 90% confidence intervals (%/yr)
[2] 90% confidence intervals do not cross 0%/yr

[3] Percent of species with trend estimates > 3%/yr or < –3%/yr
[4] Percent of species with trend estimates > 10%/yr or < –10%/yr

In addition to the 20-minute quadrat searches, the ABMI also surveys a set of 0.5 × 0.5-m plots at each prairie site, in which the cover of all species is estimated (see **Section 3.1.2**). Overall cover dropped 32.5% from the first visit to the revisit, which could be partly due to weather conditions in the two revisit years, but likely also reflects changes in subjective cover estimates (see **Technical Report 5.5**). Consistency was again low, with few species recorded in the same plot in the first visit and revisit, and differing cover estimates if they were. Due to land-owner restrictions, plots cannot be permanently marked on private land, so at least some of that inconsistency is due to slightly different locations when the small plots are relocated with GPS. Improving GPS technology may resolve that problem, but subjective cover estimates remain an issue.

Concern about obtaining consistent results for the many plant species has led us to consider several options for modifying the plant methodology: 1) Modifying the methods to improve the completeness and consistency of the species list, particularly reducing the plot size; 2) using expert observers on a set of sites to establish a gold standard to calibrate each year's crews; 3) changing to recording or reporting on only easy-to-detect and -identify species; 4) switching to alternative methods that have less subjectivity. These options all have their own challenges and need pilot studies and tests before implementation.

→ We piloted nested search quadrats of 5 × 5 m, 10 × 10 m, 25 × 25 m, and 50 × 50 m in the summer of 2017. Search times exceeded 20 minutes, but data tablet entries were time-coded to measure the effects of different time limits, and to allow rarefaction estimates of total species abundances. We also used expert botanists to assess some of the plots, as a gold standard to compare with the results from ABMI field techs. Results—still in analysis—will be used to design a statistical pilot study of the method that holds the most potential. Implementing any changes slowly will allow us to complete one full set of revisits in the fully-implemented region with the current method. That will help if the decision is ultimately made to alternate revisits with the old and new methods ("ABAB" approach). Although the low consistency of the current 20-minute searches of 50 × 50-m plots means that there is potential for biases in any one species or group of species, using that method in a future set of revisits might allow us to see very large changes (changes that we believe are greater than could be accounted for by differences between individual observers or training effects).

→ Methodological refinements will lead to good long-term trend estimates for this highly diverse and important ecological indicator taxon.

5.4.4.4.4 Lichens

The lichen protocol changed in 2009 after initial evaluation of results from the first two years. Only revisited sites that used the new protocol in the first visit were used in the revisit summaries. The 123 analyzed lichen species show trend results that are somewhat less extreme (mean absolute trend closer to 0%/yr) and more precise than vascular plants, with slightly greater consistency at the quadrat level (**Table 5-4**). Unlike plants, all lichen identifications are done by experts in the lab, so that only a few sets of taxonomically difficult species had to be grouped together. In addition, technician searches may be more efficient than for vascular plants, because they do not focus on species identifications in the field (see **Technical Report 5.5**).

Table 5-4 Summary of initial revisit trend for lichens (see **Technical Report 5.5**).

LICHENS			Trend (%/yr)							Quadrat
	Group	# Species	Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]	Consistency (%)
Abundance										
	<10 Sites	46	4.94	2.22	12.16	55.1	17.4	82.6	45.7	24.6
	10-19 Sites	12	7.05	3.14	9.33	24.2	33.3	58.3	41.7	33.2
	20+ Sites	65	1.59	0.48	2.97	7.4	38.5	33.8	3.1	49.6
Microhabitat (≥10 sites)										
	Epigeic	36	-0.35	0.67	2.84	9.2	25.0	33.3	5.6	42.2
	Epiphytic	36	5.18	1.06	5.23	11.2	52.8	44.4	13.9	52.8
	Epixylic	36	0.78	0.63	2.78	7.1	36.1	33.3	2.8	49.8
	Epilithic	3	1.60	0.72	1.60	5.0	33.3	0.0	0.0	62.6

[1] Width of 90% confidence intervals (%/yr)
[2] 90% confidence intervals do not cross 0%/yr
[3] Percent of species with trend estimates > 3%/yr or < –3%/yr
[4] Percent of species with trend estimates > 10%/yr or < –10%/yr

Lichen species tended to have positive trends, which are large for the rarer species but also seen across many common species. We believe that larger recent collections are the reason for the widespread increases. Field technicians may also have been trained better at recognizing lichen species in different habitats. Epiphytic (mostly arboreal) lichens showed especially large increases across many species.

→ The current collection size is considered adequate to ensure identifications, so the upward tendency should not continue (if training that affects search/collection efficiency has stabilized). We may apply a correction factor to the results from the initial visits that used smaller collections, although it will be difficult to determine how to do that on an individual species basis.

A few large *Peltigera* species showed declines, possibly caused by over-collecting the species on the plots. Short times between visits at some sites may have exacerbated that problem.

→ Photos of standard collection sizes are being used in training. Collecting the minimum necessary number of *Peltigera* species will be emphasized.

Lab tests have shown that rates of species being missed or misidentified in collection bags are low (4%), and are even lower for quadrat occurrence, because there are multiple bags per quadrat.

→ With the issues of collection size and over-collection now resolved, lichens are expected to be sensitive indicators of long-term trend.

5.4.4.4.5 Bryophytes

The bryophyte protocol was changed in 2009, after initial evaluation of data collected during the first two years. Only revisited sites that used the new protocol in the first visit were used here. All bryophytes are identified in the lab, with this identification currently lagging by one year, so that results are only available for sites revisited in 2015. With only 51 revisited sites, there are only 49 bryophyte species included in the analyses. The two most diverse moss genera, *Bryum* and *Brachythecium*, are only identified to genus, due to difficulties recognizing species in the field and identifying them in the lab if they do not have reproductive structures (see **Technical Report 5.5**).

Trend estimates for bryophytes are somewhat less extreme and more precise than for vascular plants, and quadrat consistency is moderately higher (**Table 5-5**).

Table 5-5 Summary of initial revisit trend for bryophytes (see **Technical Report 5.5**).

BRYOPHYTES		Trend (%/yr)							Quadrat
Group	# Species	Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]	Consistency (%)
<10 Sites	30	4.62	2.06	9.66	36.4	26.7	73.3	43.3	35.8
10-19 Sites	14	1.89	1.32	4.12	15.0	28.6	57.1	7.1	52.0
20+ Sites	5	-2.01	0.62	2.01	8.3	0.0	20.0	0.0	45.7

[1] Width of 90% confidence intervals (%/yr)
[2] 90% confidence intervals do not cross 0%/yr
[3] Percent of species with trend estimates > 3%/yr or < –3%/yr
[4] Percent of species with trend estimates > 10%/yr or < –10%/yr

Except for the five common species, bryophyte species tend to have positive trends. Weather conditions in the 2015 revisits may be a factor, but that would have required bryophyte species to colonize new quadrats in the revisit (because our measure is only quadrat occurrence, not cover or biomass). The increases are more likely due to recent training of field technicians to collect larger samples of species to allow better lab identification. We anticipate that this bias will not continue into the future as collection size has been standardized. We may correct results from initial visits to compensate for the smaller collection size during the first visit.

→ The ABMI identified and resolved a methodological issue to realize the long-term value of this taxon of sensitive indicator species.

5.4.4.4.6 Mites

The 120 analyzed mite species show somewhat less extreme trends than other taxa, but very low quadrat consistency (**Table 5-6**). "Quadrat" here refers to the location of an individual soil sample (out of the 4 taken at a site). These cannot be taken at exactly the same spot on the revisit, and the slight variation in location and microhabitat may account for the low overlap of species between visits. Mites may also be variable from year to year on the fine scale (see **Technical Report 5.5**).

Table 5-6 Summary of initial revisit trend for mites (see **Technical Report 5.5**).

MITES		Trend (%/yr)							Quadrat
Group	# Species	Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]	Consistency (%)
<10 Sites	41	-1.76	1.46	7.05	42.8	7.3	65.9	22.0	19.8
10-19 Sites	34	1.90	1.79	8.21	22.9	38.2	73.5	35.3	14.2
20+ Sites	45	-0.19	0.57	2.89	9.9	20.0	35.6	2.2	24.3

[1] Width of 90% confidence intervals (%/yr)
[2] 90% confidence intervals do not cross 0%/yr
[3] Percent of species with trend estimates > 3%/yr or < –3%/yr
[4] Percent of species with trend estimates > 10%/yr or < –10%/yr

With all specimens identified by an expert, and little subjective choice in the collection and processing of the soil sample, mites have fewer sources of potential bias in long-term trend than do other taxa. The bigger limitation with mites is the natural history knowledge and background on temporal and microhabitat variation to interpret results for individual species.

→ Mites may be a valuable indicator for unknown future changes.

5.4.4.4.7 Wetland plants

Wetland plants are summarized separately for the "open water" zone, with 19 floating and submersed species, and for the "wet" zone, with 276 species. The open water species are unique to wetlands, while many of the wet zone species are shared with ABMI's plant surveys at systematic terrestrial sites. The same groups of difficult-to-identify species are used for the wetland plants as for the systematic plots (see **Technical Report 5.5**).

There are some large increasers and decreasers in wetland zones that still need to be checked, and probably lumped into additional groups. Mean absolute trend and confidence interval widths in the three abundance groups in the wet zone are comparable to the systematic plant results, while the open water zone shows more variability (**Table 5-7**). Quadrat consistency was not calculated, because individual wetland transects are not necessarily in the same place in each revisit.

Table 5-7 Summary of initial revisit trend for wetland plants (see **Technical Report 5.5**).

WETLAND PLANTS - OPEN WATER

Group	# Species	Trend (%/yr) Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]
<10 Sites	7	-9.90	5.72	15.74	70.9	57.1	85.7	85.7
10-19 Sites	1	19.69	NA	19.69	25.2	100.0	100.0	100.0
20+ Sites	11	-1.16	2.70	4.71	16.1	36.4	36.4	18.2

WETLAND PLANTS - WET ZONE

Group	# Species	Trend (%/yr) Mean	SE of mean	Mean Absolute	CI Width[1]	"Significant"[2]	% > ±3%/yr[3]	% > ±10%/yr[4]
<10 Sites	90	-1.63	2.21	15.07	53.8	27.8	86.7	54.4
10-19 Sites	57	1.81	2.38	12.83	28.4	42.1	86.0	45.6
20+ Sites	129	3.74	0.88	6.59	12.8	39.5	60.5	17.8

[1] Width of 90% confidence intervals (%/yr)
[2] 90% confidence intervals do not cross 0%/yr
[3] Percent of species with trend estimates > 3%/yr or < –3%/yr
[4] Percent of species with trend estimates > 10%/yr or < –10%/yr

Common species in the wet zone show a preponderance of positive trends—meaning that species were present in more transects during the revisits. We do not yet have a hypothesis for why this occurred, and thus have not yet developed ways to test its validity.

Trends for 233 plant species analyzed in both the systematic plots and the wet zone showed no correlation across the two analyses (see **Technical Report 5.5**), supporting the conclusion that sampling error currently has a large influence on trend estimates. The influence of sampling error will diminish as the duration of monitoring increases (see above).

→ Wetland plants in the open water zone are a unique set of species. Plant species in the wet zone provide complementary information to the shared species in the systematic plots, allowing a broader assessment of trend in the long term.

5.4.4.4.8 Wetland invertebrates

The ABMI samples wetland invertebrates. Sorting and field sampling protocols have changed several times. Identifications are done to different taxonomic levels for each invertebrate group (see **Section 3.1.3**) and thus trend assessment will occur at a different taxonomic level for each group. The ABMI and Dr. J. Ciborowski are currently advertising for a post-doc to further these analyses.

→ We have not yet examined revisit trend for wetland invertebrates.

5.4.4.4.9 Priority species

Rare species and those hunted, trapped, and eaten by people are of particular interest in Alberta. We summarized results for these priority species, using the list provided by the Government of Alberta's Biodiversity Management Framework (BMF). Rare species are included based on

ACIMS (NatureServe[8]) rankings for the province. There are 1,861 species on the list, most of which are plants that are rare in the province or lichens that are either rare or of unknown status.

Initial trend estimates were produced for 115 rare species (**Figure 5-5**) and 20 eaten species (**Figure 5-6**), totalling 7.3% of the species on the BMF list. Most of the rare species are lichens of unknown status (86 of the 115), many of which the ABMI has shown are not actually rare. The two rare bird species also occur at > 20 sites. The rest of the rare species that the ABMI has detected occurred at < 20 sites and have wide confidence intervals on the initial trend estimates.

Nine consumed plant species and three hunted birds are also common and have fairly narrow confidence intervals on the initial trend, although the bird species show widely varying initial results. Additional hunted and trapped species will be added when mammal results are available.

Results for both rare and eaten groups show the same wide distribution as the overall results for all taxa, and the same upward tendency in the case of lichens and birds. We expect that this tendency for positive trends is a bias (see above) and that, with various revisions to the data collection and analyses being implemented, many of the positive trends will disappear.

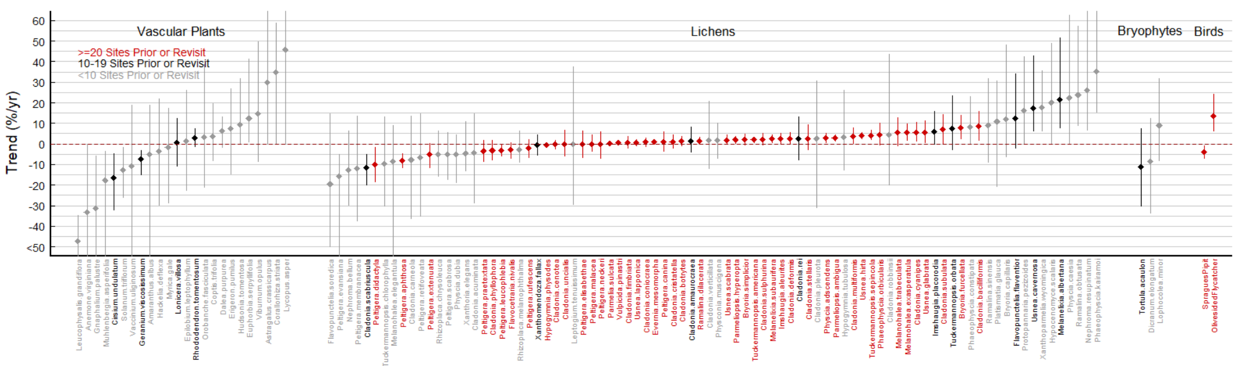

Figure 5-5 Trend estimates (after only 2 revisit years) for rare species of interest on the BMF list, sorted by taxon. Colours show abundance classes; grey: < 10 sites, black: 10–19 sites, red: 20+ sites. Error bars are 90% confidence intervals.

[8] http://www.albertaparks.ca/albertaparksca/management-land-use/alberta-conservation-information-management-system-acims/

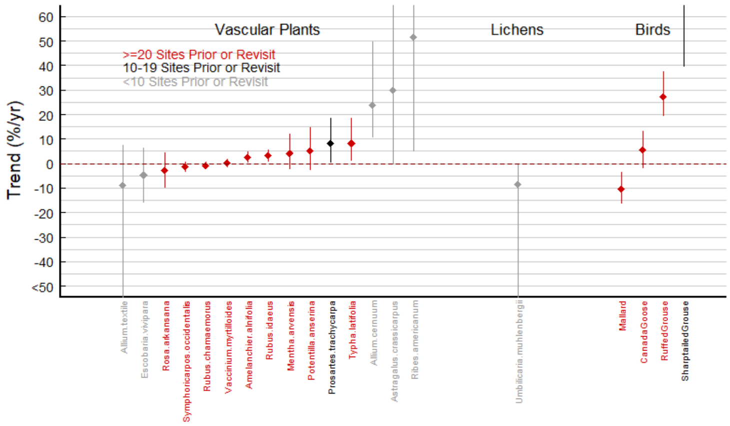

Figure 5-6 Trend estimates (after only 2 revisit years) for <u>eaten</u> species of interest on the BMF list, sorted by taxon. Colours show abundance classes; grey: < 10 sites, black: 10–19 sites, red: 20+ sites. Error bars are 90% confidence intervals.

→ Precision of trend estimates for priority species will increase with continued monitoring duration and when species are detected.

5.4.4.4.10 Habitat elements

Habitat elements can be important indicators for environmental monitoring, because they can be sensitive precursors of ecosystem changes (e.g., changes in growth rates or mortality of trees, or productivity of prairie plants), which affect numerous groups of species. The ABMI reports on trees, snags, and coarse woody debris (CWD) by size class, species groups, and overall basal area or volume, as well as a variety of cover layers. Revisit trend was calculated for these habitat elements in the same way as for species (see **Technical Report 5.5**).

Overall tree basal areas of different species groups showed consistent small decreases, while snag and stump basal areas increased (**Figure 5-7**). Those results held even when the few sites with stand-replacing disturbances were excluded. Several live tree classes showed positive or negative trends, which could be traced back to a few sites where cohorts of trees grew enough between visits to enter or exit a size class. The inconsistent stump results between visits probably reflect different criteria used to define countable stumps between the first visit and revisits. Snags may also have changed between the first visit and revisit due to method changes (e.g., short or highly decayed snags counted or not), or there may have been net recruitment from mortality exceeding fall rates. The ABMI does not tag trees and snags in plots, so we cannot look at the fate of individual stems to sort out the effects of recruitment, growth, mortality and measurement error. CWD also increased, but this patchy element has very wide confidence intervals, so no conclusions can be drawn yet.

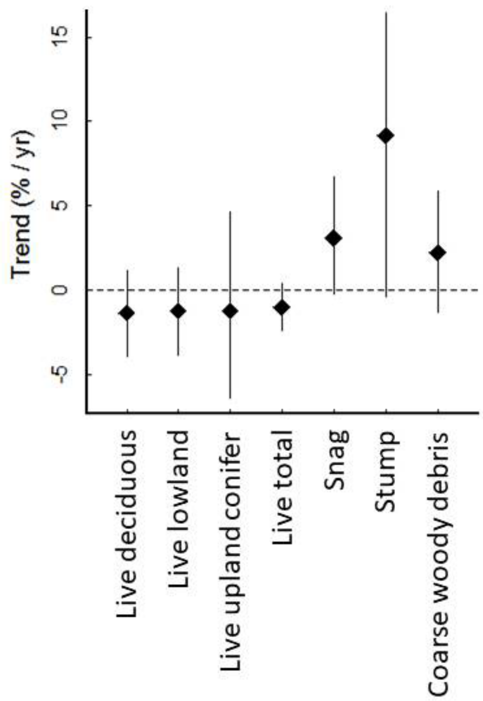

Figure 5-7 Trend estimates (after only 2 revisit years) for summary habitat elements. Error bars are 90% confidence intervals (see **Technical Report 5.5**).

Compared to permanent sample plots (PSPs) used for forestry monitoring, trees in ABMI plots show about twice as much variability over time. PSP's are more detailed, including tagged stems and field quality checks, but they also avoid habitat edges which might be more dynamic, unlike the ABMI's more representative systematic plots.

Canopy closure is the only cover layer that is measured, rather than estimated. It showed no change between visits (see **Technical Report 5.5**). Other cover layers showed large changes, positive or negative, and there was little consistency in cover estimates between visits at individual sites. Those changes likely include some effect due to individual field technicians' subjective estimates of cover, including a general drop in cover estimates for most of the vegetation layers (as was also seen for estimates of plant cover in the prairies).

→ Habitat elements are currently not a strong emphasis of ABMI sampling, and thus have relatively coarse measurements with low precision and repeatability. If this information becomes a higher priority, it will be valuable to refine the methods so results have higher repeatability.

5.4.4.4.11 Water physiochemistry

The ABMI's measurements of water physiochemistry are intended to characterize wetlands and be correlates for the plant and invertebrate analyses, rather than to rigorously monitor changes in water quality. Measurements are taken only on the day the site is visited, and only once near noon. Many physiochemical variables change over the season and throughout the day, creating high variability in the single measurements (see **Technical Report 5.5**).

Unexpectedly, all physiochemical variables increased between the first visit and the revisit, although some increases were small and/or accompanied by wide confidence intervals that made them not significantly different from 0%/year. Reasons for this are unknown, although there may be real fluctuations with only two years of revisits. In addition, for many variables, there were low correlations between visits across sites, showing that variability in the wetlands and/or in the field measurements is high (see **Technical Report 5.5**).

→ The ABMI is working with others in the Oil Sands region to develop a regional wetland monitoring program. This may allow more rigorous repeated measurements from wetlands that are more suited to reliable trend estimation. Additional resources would be needed to implement such a program.

5.5 What other programs are doing

Several well-known long-term trend monitoring programs have had substantial influence on management and conservation (see **Biodiversity Programs Review** document). Many of these monitor birds, conducted by competent bird-watchers using standardized protocols with annual visits, including the North American Breeding Bird Survey, the UK Breeding Bird Survey, and comparable programs in Sweden and other European countries. These long-running surveys have provided trend information on many species that have been important for bird conservation and for broader conservation and land management. The results have been complemented or corroborated by programs using alternative methods run by experts, such as mist-net and radar-based surveys, and by less rigorous volunteer-based surveys, such as Christmas Bird Counts and feeder watches. Breeding bird atlas programs, such as those run in all Canadian provinces except Alberta, provide additional information on long-term trend, but particularly on changes in spatial distribution of birds over time. In addition, the North American Waterfowl Breeding Population and Habitat Survey is a multi-decade standardized aerial survey of waterfowl populations across the continent providing annual population estimates as an integral part of an international treaty to manage those species. There are many more local projects monitoring bird populations, including other groups such as diurnal and nocturnal raptors, marsh birds and colonial seabirds.

Mammals are most commonly monitored at the individual population level, primarily for regulation of harvest of hunted and trapped species. The Finnish Wildlife Triangle program is one well-known exception that uses standardized volunteer track surveys to follow populations of all larger mammals in that country, along with a set of easily-surveyed birds. This long-term program has produced trend results that are useful for assessing changes in those communities and in the environment more generally. Other multi-species mammal surveys have either been more regional and/or have begun more recently (such as surveys using remote cameras).

The most influential long-term monitoring of plants has been through permanent sample plots in forestry. Very standardized and detailed information on tree growth, mortality, and recruitment has been essential to forestry management, but has also been a main source of information on biological effects of larger environmental changes, including acid rain and climate change. Forage production plots are a similar set of surveys focused on a particular management issue that could have broader potential for detecting environmental trends, although these usually have less broad-scale standardization than forest plots. Broader surveys of many plant species have been limited to locations such as the UK and parts of Europe where there is a high density of knowledgeable volunteers to conduct plant atlases (and similarly for butterflies, which are also of interest to some naturalists, and a few other taxa locally). These programs have detected changes in the distribution of individual species, including non-native invasions. Their ability to estimate trends in abundance for many species is less certain. There are also many examples of local monitoring of particular plant species and other taxa, generally focussed on small populations of rare species. Additionally, there are many local or small regional studies that use various taxa for monitoring particular environmental conditions (rather than for interest in biological diversity *per se*), such as lichens used for pollution monitoring or stream invertebrates for water quality. Some of these have been co-ordinated and standardized into larger-scale monitoring programs, such as the CABIN program for stream invertebrates.

In some cases, monitoring of multiple taxa is co-ordinated under the same program with different taxa monitored in the same sites, such as the Biodiversity Monitoring Switzerland program, the Biodiversity Monitoring and Reporting System for New Zealand, or on a more local scale, networks on long-term research sites, such as the Long-Term Ecological Research program. An alternative approach is used by programs that co-ordinate results from different monitoring programs in a region, using different sampling designs appropriate for the different taxa. Examples in the review include the Circumpolar Biodiversity Monitoring Program, the US National Parks Inventory and Monitoring Program, and the South African National Biodiversity Assessment. As well as basic trend estimates for individual species, these co-ordinated programs can report on trends of multi-taxa summary variables, comparable to the ABMI's intactness index. Such broad "state of biodiversity" reporting can play a high-level role in generating or maintaining interest in biodiversity conservation, which increases the value of species level trend estimates and relationships with management variables.

5.6 References

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6 Seeking Efficiencies in the ABMI's Monitoring Program

Prepared by Dave Huggard for the ABMI

6.1 Executive summary

We provide information to explore two possible ways to make the ABMI's program more efficient: 1) reducing effort in helicopter-access sites (and increasing effort correspondingly in cheaper ground-access sites); and 2) evaluating which biodiversity indicators to monitor, and particularly which taxonomic groups of species.

Helicopters double the costs of field work, but when all costs are factored in (i.e., including those not unique to helicopter sites, such as running the field program, processing the specimens and information, and presenting the results), helicopter sites cost 1.32 times as much as ground access sites overall. Reducing effort in helicopter sites and increasing it in ground-access sites would alter the representation of natural regions and some habitat and human footprint types, but would probably not significantly affect our modelling abilities. Simulations suggest only small changes in expected precision of trends with different effort allocation to the two access types. Other factors are listed that might be more important in decisions about allocating effort to the two strata.

Initial results are summarized for analyzable species in some of the main ABMI taxa, including relative abundance in different vegetation, ecosite and human footprint types and initial trend estimates. There is extensive overlap in the distribution of species' responses across taxa. Vascular plants, the most species-rich group, often encompass the distributions of species in other taxa, but there are some unique features of each group. The comparison of initial results is limited, because there are many relatively rare species in all taxa and these have wide uncertainty in their results, which tends to make distributions of species' results similar across taxa. Future value as indicators, practical concerns like costs and reliability of field methods, and importance to policy, management and public funding sources are key criteria for making decisions about which taxa to include.

Options to more efficiently continue with the current range of taxa include restricting surveys of some taxa to regions or habitats where they are most informative, especially if that allowed an entire site visit to be omitted, or using an "ABAB" revisit design, where two taxa are alternated in rounds of revisits.

6.2 Introduction

Two questions are often asked of the ABMI. First, is it necessary to sample with equal effort everywhere? A specific aspect of this question is whether we need equal effort in the more expensive helicopter-access sites. Second, does the ABMI have the right mix of biodiversity indicators? The ABMI uses native vegetation and human footprint as coarse-filter indicators, habitat elements and wetland physiochemistry as medium-filter indicators, and monitors many species from a range of taxa as fine-filter indicators. The main focus of this question is whether we have the right mix of taxa, but it also may be useful to consider the relative allocation of effort to the medium- and coarse-filter levels.

In the first part of this chapter, we address the possibility of stratifying by access—helicopter versus ground—and examine three effects of allocating more effort to the cheaper ground sites and less to the helicopter sites: 1) representation of ecosystem types in our sites; 2) expected precision of regional trend estimates for species; and 3) other aspects, including logistics.

In the second part, we provide information to help guide decisions about the best portfolio of indicators going forward. We compare current results for the habitat associations, spatial distribution, and trend of species in each ABMI taxon. Recognizing the preliminary nature of the trend estimates, we then present points about the possible future indicator value of the taxa for different environmental changes and monitoring questions, and challenges and opportunities for monitoring each taxon. We also discuss different options, such as alternating surveyed taxa in different revisit cycles or different regions, that may be useful for decisions about how to optimize the ABMI's portfolio of indicators.

6.3 Stratifying by access

6.3.1 Location and ecosystems of ground- versus helicopter-access sites

The ABMI classified all 1,656 of its systematic grid sites as being accessible by ground or helicopter (**Figure 6-1**). Helicopter-access sites occur mainly in the north of the province, especially the northeast, and in the Rocky Mountains. We expect that ground access will increase for some of these sites over time, but not so quickly that it will change planning over the next 20 years.

All sites in the Grassland and Parkland region are accessible by ground, as are 88.1% of the Foothills sites, 47.3% of Boreal sites, 28.5% of the Rocky Mountain sites, and none of the sites in the Canadian Shield. Sub-regions within the Boreal differ greatly, with 90.3% of sites in the highly developed Dry Mixedwood zone accessible by ground, 35.8–47.8% of sites in the large Central Mixedwood and Lower Boreal Highlands, and almost none in five smaller northern sub-regions. Broad habitat types that we use in species modelling are more dispersed geographically, so there is less of a range in percent ground access for these, although ground access is higher in deciduous, mixedwood, and black spruce wetlands, than in upland conifers and open habitat types (**Table 6-1**). Most human footprint is accessible by ground. More detailed summaries are presented in **Technical Report 6.1**.

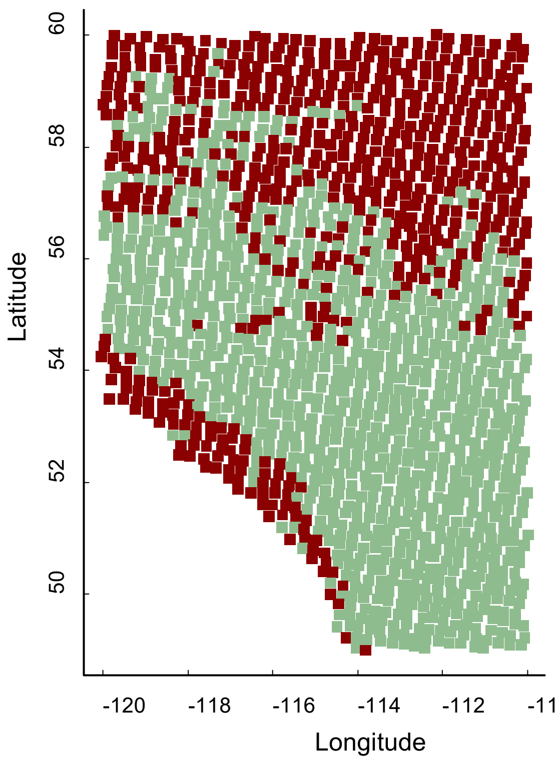

Figure 6-1 Mode of access required for ABMI systematic sites. Red = remote (helicopter) access, pale green = ground access.

Table 6-1 Percentage of Boreal and Foothills sites with ground access for each broad vegetation and human footprint type. Types underrepresented in ground-access sites are in bold.

	% Ground
Spruce	**36.6**
Pine	**33.8**
Deciduous	59.6
Mixedwood	56.8
Treed Bog	**35.6**
Treed Fen	**43.1**
Treed Swamp	52.2
Open Dry	**33.6**
Open Wet	**27.6**
Forestry HF	81.8
Other Successional HF	78.3
Alienating HF	98.6

6.3.2 *Costs of ground versus helicopter sites*

Detailed budgets from the ABMI indicate that the additional cost of helicopters doubles the field costs for helicopter-access sites (Table 2). However, there are additional fixed costs for all sites, including specimen processing and identification, data processing and analysis, GIS services, and management of the program. For this analysis, we included all the costs of the Monitoring and Processing Centres, half the costs of the Science Centre, and one-quarter of the costs of the Information and Geospatial centres as "processing, other" costs in **Table 6-2**. These additional costs are the same for each site, regardless of whether it is ground- or helicopter-access. The assumption is that if the number of sites were reduced or increased, these costs would also be reduced or increased proportionally (in fact, there are both fixed and variable costs; however, we use these broad-stroke assumptions here for simplicity). Including those additional costs means that helicopter sites, all told, cost only 1.32 times as much as ground-access sites. [Note: including only monitoring and processing centre costs—i.e., completely excluding Science, Information, and Geospatial Centre costs—makes the helicopter sites 1.40 times as expensive as ground sites. The difference between 1.32 and 1.40 is immaterial for the results and conclusions that follow.]

Table 6-2 Hypothetical costs of monitoring, processing and using the data from remote versus ground-access sites. Costs are based on simplified assumptions, are offered as 'ballpark' estimates only, and are subject to change.

	Cost per site ($)		Ratio
	Remote	**Ground**	**Remote:Ground**
Field work, equipment	23,217.94	11,328.62	2.05
Processing, other	26,291.39	26,291.39	
Total	49,509.33	37,620.01	**1.32**

6.3.3 *Expected precision of trends with stratification by access*

6.3.3.1 2.3.1 Simulation methods

We ran a simple simulation of trend precision to explore the implications of reducing sampling in the helicopter stratum and increasing it in the ground stratum, while maintaining a fixed budget. In the simulation, we used a hypothetical area with 200 ground access sites and 200 helicopter access sites. The Oil Sands Area in the northeast of the province has a similar total number of sites and proportion of ground versus helicopter access.

The simulation assumed that there was a fixed budget, enough to sample 40 ground and 40 helicopter sites every year (i.e., a 5-year rotation if no stratification was used), with helicopter sites costing 1.32 times as much as ground sites. With those costs, we looked at 4 levels of over-sampling the cheaper ground-access sites in each simulation: 1) 1:1 (40 ground and 40 helicopter sites each year); 2) 2:1 (56 ground and 28 helicopter sites), 3) 4:1 (70 ground and 17 helicopter sites) and 4) 10:1 (82 ground and 8 helicopter). Note that the total number of sites increases as relatively more effort is put into the cheaper ground sites, but that the total cost is the same in all cases. Because the remote:ground cost ratio is not huge, the total number of sites does not increase much—from 80 sites per year at 1:1 to 90 at 10:1.

We used Monte Carlo simulations with different levels of four variables that influence the expected precision to which species trend can be estimated in the stratified designs: 1) overall abundance of the species; 2) relative abundance of the species in the two strata; 3) difference in species trend between the strata; and 4) site-to-site variance in species abundance in the two strata. Precision estimates were calculated after 5, 10, and 20 years of data collection. This simple simulation assumed random sites were sampled each year, rather than a full revisit design, because our purpose was to compare the effects of different effort in the strata. A stratified mean trend for the whole region was calculated from the simulated data. Each simulation was run 1000 times to generate a SE showing the precision of the trend estimate. Details of the simulation methods are described in **Technical Report 6.1**.

6.3.3.2 Simulation results

Difference in trend between the strata and site-to-site variance in each stratum had little effect on results (see **Technical Report 6.1**). Monitoring duration (5, 10, and 20 years) had a large effect on precision for common and rare species at all levels of stratification between ground and helicopter sites (**Figure 6-2**). However, the relative differences in expected precision between helicopter and ground strata were similar at all durations. In addition, although overall abundance of the species affects the precision of the trend estimate, relative differences in expected precision between helicopter and ground strata were similar for rare and common species (**Figure 6-2**, panels a, b, and c).

For species that are twice as abundant in the ground stratum as in the helicopter stratum, precision increases slightly when there is twice as much effort in the ground stratum, and is similar with four times the effort and equal effort. For species with the same average abundance in the two strata, there is little difference in precision between equal effort and twice the effort in the ground stratum. However, for species that are twice as abundant in the helicopter stratum, any change towards more effort in the ground stratum reduces precision. Overall, for a fixed budget, the effects of increasing effort in the ground stratum by up to 4 times, at the expense of the helicopter stratum, are minor for species equally abundant or more abundant in the ground strata, and only slightly greater for species that are most abundant in the helicopter strata. Thus, there is little precision to be gained or lost from allocating unequal effort to the two strata. Increased monitoring duration has by far the largest effect on increasing precision.

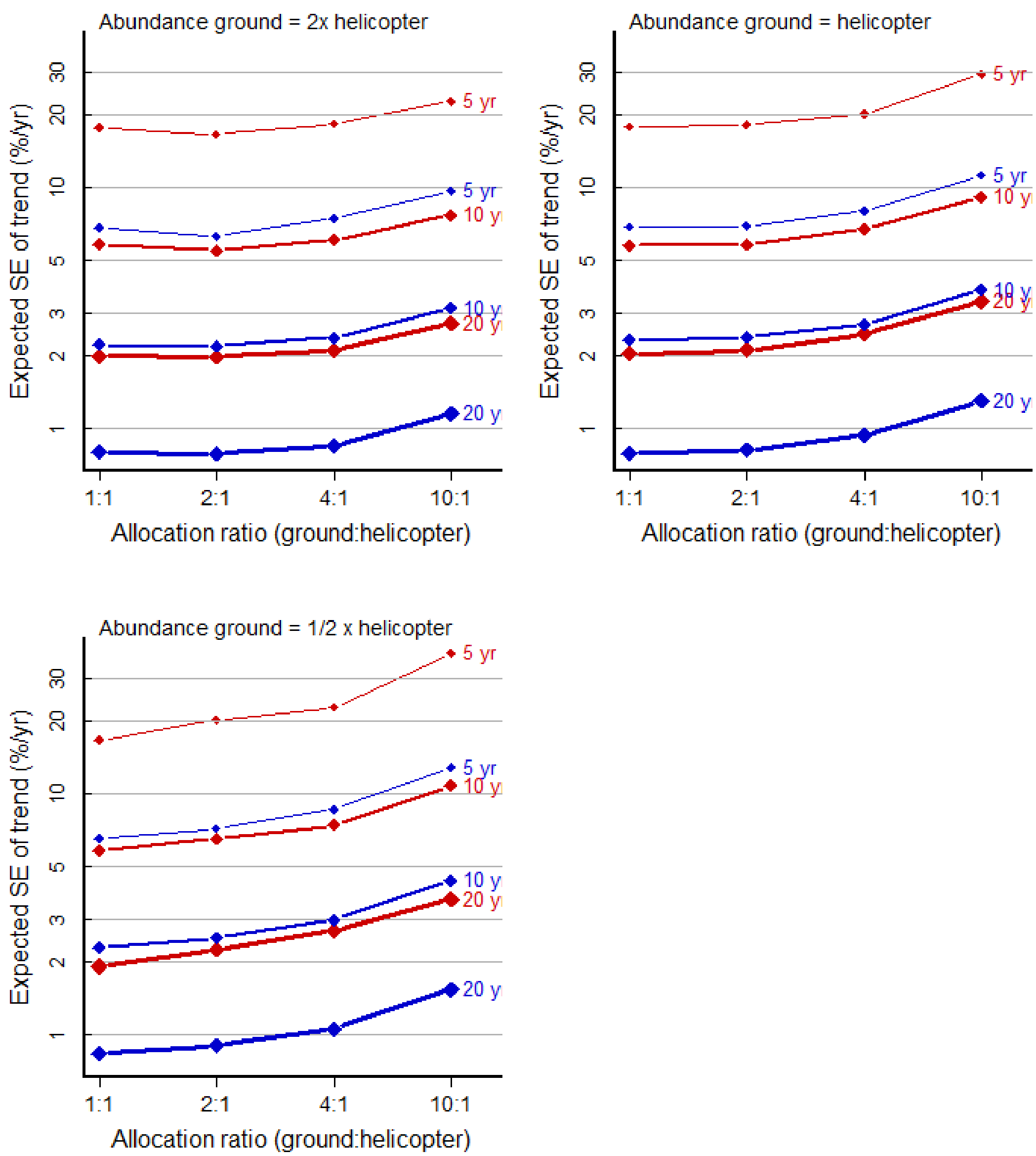

Figure 6-2 Expected SE of trend as a function of allocation of sites to cheaper ground access area versus helicopter area (for same total sampling cost), for a rarer (red) and more common (blue) species, after 5, 10, or 20 years of sampling.

6.3.4 Other considerations

With little gain or loss in trend precision expected from increased effort in the ground stratum relative to helicopter stratum, other considerations may be more important in deciding how to allocate sample effort. These considerations include:

1) Completing a province-wide baseline. Many sites in the under-sampled northwest of the province require helicopter access.

2) The large area of Wood Buffalo Park is under-sampled and requires helicopter access. As a large undisturbed area, it may provide an important comparison with more developed landscapes in the future.

3) Population changes of many species are driven by habitat change due to human footprint, which occurs almost entirely in the ground-access area. Increased sampling there will provide more revisited sites with human footprint to better estimate trend.

4) A main limitation for habitat modelling in the forested areas is that we have relatively few sites with footprint, which are almost all in the ground-access area.

5) In the future, several comparisons involving the under-sampled northern helicopter areas may be of interest, including comparisons with large low-disturbance landscapes, northern expansions of species with climate change, and possibly baseline information if new technologies allow greater resource exploitation in those areas (as happened over the last 40 years with the oil sands).

6) The logistics of ABMI field sampling that uses clusters of 9 sites may be made more difficult if there is unequal effort in the two strata.

6.3.5 What other programs are doing

The issue of allocation of effort to more expensive helicopter sites vs. cheaper ground sites is specific to the ABMI's situation. Other monitoring programs use variable effort between geographic or habitat strata, either intentionally (e.g., greater effort in the more heterogeneous mountains in the Swiss program) or by virtue of relying on volunteers who live in and have greater access to particular parts of a region. Unequal effort is addressed by stratified analyses, or more often by restricting interpretations to well-sampled areas.

6.4 A portfolio of indicators

6.4.1 Vegetation and human footprint

Although the ABMI's focus is on its broad suite of fine-filter species indicators, coarse-filter monitoring of vegetation types and human footprint is also an integral part of its monitoring. Human footprint types are tracked annually with the 3 × 7-km land-base samples (see **Section 3.2.4**; see also **Technical Report 5.1**), along with changes in native vegetation due to human footprint. Human Footprint Inventories that are updated biennially (see **Section 3.2.2**) provide province-wide context for those samples. Yearly reporting on change in human footprints is an important coarse-filter metric of ecological change to complement species monitoring and provides some information while we are waiting for complete revisits to report on species trends. The 3 × 7 plots also allow us to extend our reporting back to 1999, and to use our species-habitat models to predict the effects of human footprint change on species from 1999 to present.

The 3 × 7 plots are relatively inexpensive to update annually and provide good value for trend reporting and complementing species monitoring. Further improvements to accuracy and detail in the vegetation mapping, such as including rare ecosystem types or other ecological land classifications (e.g., ecosites) would extend the value of this coarse-filter indicator.

6.4.2 Habitat elements and wetland physiochemistry

Habitat elements and water physiochemistry are "medium-filter" indicators, in that changes in these elements can affect many species, including ones that we do not monitor (e.g., many insects living in dead wood, fish, etc.) These indicators have not been a strong focus of the ABMI, and have mostly been measured as covariates to help explain species results. Both habitat elements and wetland physiochemistry can be sensitive bellwethers of environmental changes (e.g., changes in tree growth or mortality, increasing water acidity). The ABMI's current field protocols and sampling intensities do not provide precise enough measurements for that purpose. Instead, the current methods are more suited to revealing larger changes in the long term. Budget and logistical constraints (tight schedule for field protocols, single visits per season) would have to be overcome if these medium-filter indicators were given more priority.

6.4.3 Species

The ABMI surveys species across a broad range of taxa to directly represent changes in biological diversity (Boutin et al. 2007). Taxa have been added and dropped over the ABMI's first 14 years (including pilot phase; see **Chapter 3**), and that process will continue as necessary. In this section, we present information that may help with decisions about which taxa to include in the ABMI's portfolio, including a statistical summary of initial results, an overview of the indicator values, monitoring challenges and opportunities for current taxa. The ABMI is open to including new taxa, while recognizing that doing so would require additional funding, diversion of resources from other taxa or ABMI activities, and/or the use of alternative options such as those included in the final section of this chapter.

Species habitat models and initial trend results have been estimated for species across ABMI taxa. Details are in a technical report for trend (see **Technical Report 5.1**) and in results for the habitat modelling chapter (see **Section 4.3**). We only provide a summary of those results here. Since all taxa include many moderately rare species with high uncertainty in current results, there is a tendency for all taxa to have the same distribution of results. As such, information about potential indicator values of each taxon (**Section 6.4.5**) may be more useful for making long-term decisions.

Analyses below are based on habitat coefficients derived from modelling for birds, vascular plants, bryophytes, lichens and mites. Habitat models for birds, developed in partnership with BAM, use a different set of habitat types, a different approach to the effects of linear features, and different analysis methods. When results for birds are included, they need to be considered cautiously, because differences from other taxa are confounded by analysis differences and may not indicate inherent biological differences. Habitat models for mammals are preliminary and several habitat types have not been sampled, so mammals could not be included in the comparison. The habitat models for wetland vascular plants reflect how habitat in the adjacent buffer area affects the wetland, and so have a different meaning than the habitat models for taxa in the systematic plots. Habitat models and trend are not yet available for wetland invertebrates.

6.4.3.1 Existing results - Vegetation or ecosite and human footprint relationships

6.4.3.1.1 Summary of relative abundance by land cover types

We tabulated in which land cover type (broad vegetation + HF types in the north, ecosite + HF in the south) the species in each taxon were most common (**Table 6-3**). The preferred habitat types of the 302 plant species in the north were fairly evenly spread across all land cover types, except that many species preferred soft linear features. (Linear features tend to have extreme estimates, high or low, for many species, because these types almost always occur as small areas in mixed sites and so are difficult to estimate.) Other footprint types, and black spruce, are preferred by the fewest plant species. Many lichen species are most common in the conifer or mixedwood stands, with few or no species most common in HF types. Similarly, few bryophyte species were most common in HF, but many species were most common in the three types of treed lowlands and in white spruce stands. Mite species had more varied preferences, with several species preferring pine, black spruce, deciduous cutblocks, and soft linear features, while few or no species preferred rural/industrial areas, other types of cutblocks, or swamps. Results for birds differ, probably because of different analysis methods. In particular, many bird species were modelled as being most abundant on roads (hard linear footprint). The composite BAM + ABMI dataset used for the analysis includes many road-based Breeding Bird Survey (BBS) data points. Bird species found more commonly in those roadside surveys may have ended up with highest predicted densities along roads.

In the south, all non-bird taxa had the most species preferring soft linear features, followed by either clay/saline or productive soils. Other footprint types were preferred by the fewest species, with the exception of 4 of 30 mite species preferring cultivation, and 17 of 236 plant species associated with roads (hard linear HF). Birds again differed, because of the strong association of many species with roads in the composite dataset.

Table 6-3 Percentage of species in each taxon that are most common in each vegetation or human footprint type in the north (left) or ecostie and human footprint type in the south (right). The four (left) or two (right) highest and lowest land cover types for each taxon are highlighted green and red, respectively.

	Bird	Plant	Lichen	Bryophyte	Mite
White Spruce	0.0	4.5	21.5	13.2	7.4
Pine	1.8	4.8	13.2	3.3	10.5
Deciduous	6.4	7.4	7.4	8.3	7.4
Mixedwood	5.5	5.2	10.7	8.3	4.2
Black Spruce	1.8	2.9	23.1	14.0	13.7
Treed Fen	4.6	7.7	5.0	16.5	9.5
Tree/Shrub Swamp	0.0	4.5	5.8	10.7	1.1
Grass	3.7	8.7	5.0	0.8	7.4
Shrub	0.9	4.8	3.3	6.6	6.3
Non-tree Fen/Marsh	0.9	5.2	1.7	4.1	4.2
Forestry White Spruce	0.9	2.6	0.0	0.8	1.1
Forestry Pine	0.9	3.2	0.0	1.7	1.1
Forestry Deciduous	6.4	5.8	1.7	3.3	12.6
Cultivated	0.0	4.5	0.0	0.8	3.2
Urban/Rural/Industrial	0.0	4.2	0.0	0.8	0.0
Soft Linear	13.8	19.0	0.8	2.5	8.4
Hard Linear	52.3	4.8	0.8	4.1	2.1

Soil+HF	Bird	Plant	Lichen	Bryophyte	Mite
Productive	20.8	13.1	10.6	19.2	20.0
Clay/Saline	6.9	16.9	25.5	15.4	20.0
RapidDrain	4.0	13.1	19.1	11.5	13.3
Cultivated	1.0	4.7	0.0	0.0	16.7
Urban/Rural/Industrial	6.9	2.5	0.0	3.8	0.0
Soft Linear	16.8	41.1	44.7	46.2	26.7
Hard Linear	43.6	8.5	0.0	3.8	3.3

6.4.3.1.2 Ordination of relative abundance in land cover types

We further summarized the habitat modelling results for species in each taxon using ordination of the predicted relative abundance of each species in broad habitat types (vegetation and human footprint in the north, ecosite and human footprint in the south). Two-dimensional NMDS solutions were generated, each species was plotted on the two ordination axes, and contours were plotted for kernel density smooths to show the smallest region of ordination space occupied by 90% and 50% of the species in each taxon (see **Technical Report 6.2**).

The main result in the forested north region is that the five taxa overlap extensively in ordination space (**Figure 6-3**)—i.e., the set of species in each taxon occupy a similarly complete range of habitat types. The overlap is extensive using the contours that contain 90% of the species in each taxon. There are more distinct differences when using the 50% contours that represent the core of each taxon's distribution. More plant species occur in open, dry habitats (northern grass and shrub) and in alienating human footprint (particularly agriculture) than do lichen, bryophyte, or mite species. Bird results are de-emphasized in these results, because the different analysis methods for that taxon confound the comparison. In particular, the modelling results showing that a majority of birds are most abundant along roads are reflected in the dominant area of the bird contour in the part of ordination space representing alienating human footprint. This is likely due to analysis differences, rather than inherent differences between the taxa. More detailed results confirm these general findings can be found in **Technical Report 6.2**.

NORTH – Broad veg+HF, 90% contours | NORTH – Broad veg+HF, 50% contours

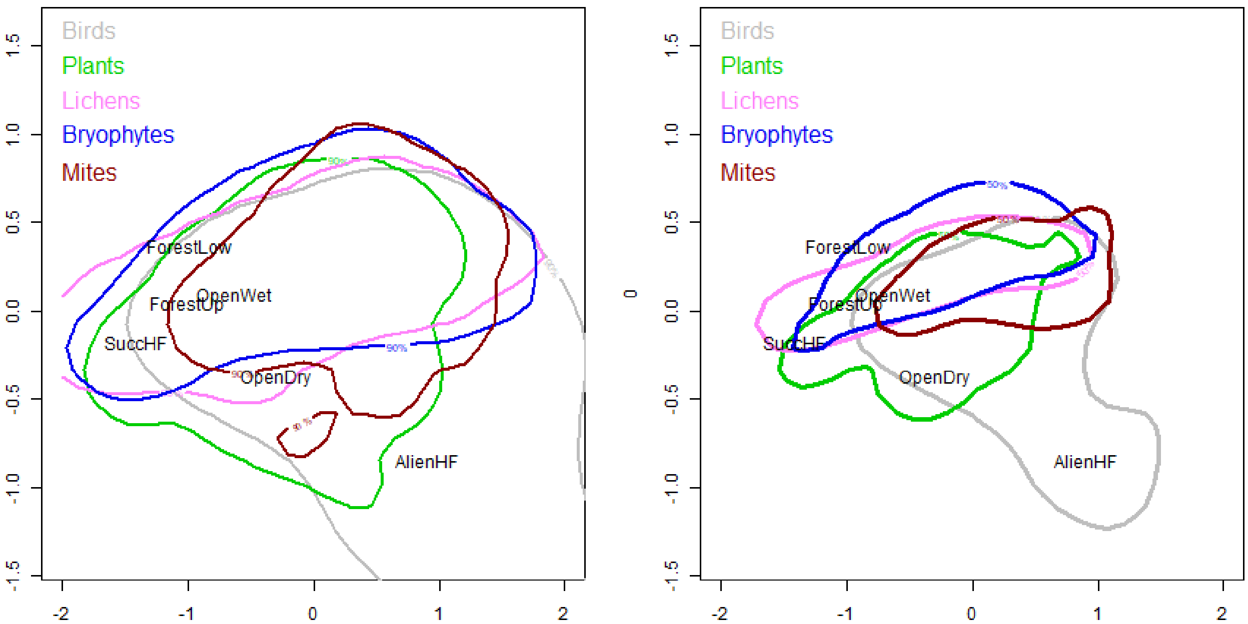

Figure 6-3 Contours encompassing 90% (left) or 50% (right) of species in each taxon in the two-dimensional ordination space based on six broad vegetation and human footprint types in the north analysis region.

SOUTH – Soil+HF, 90% contours | SOUTH – Soil+HF, 50% contours

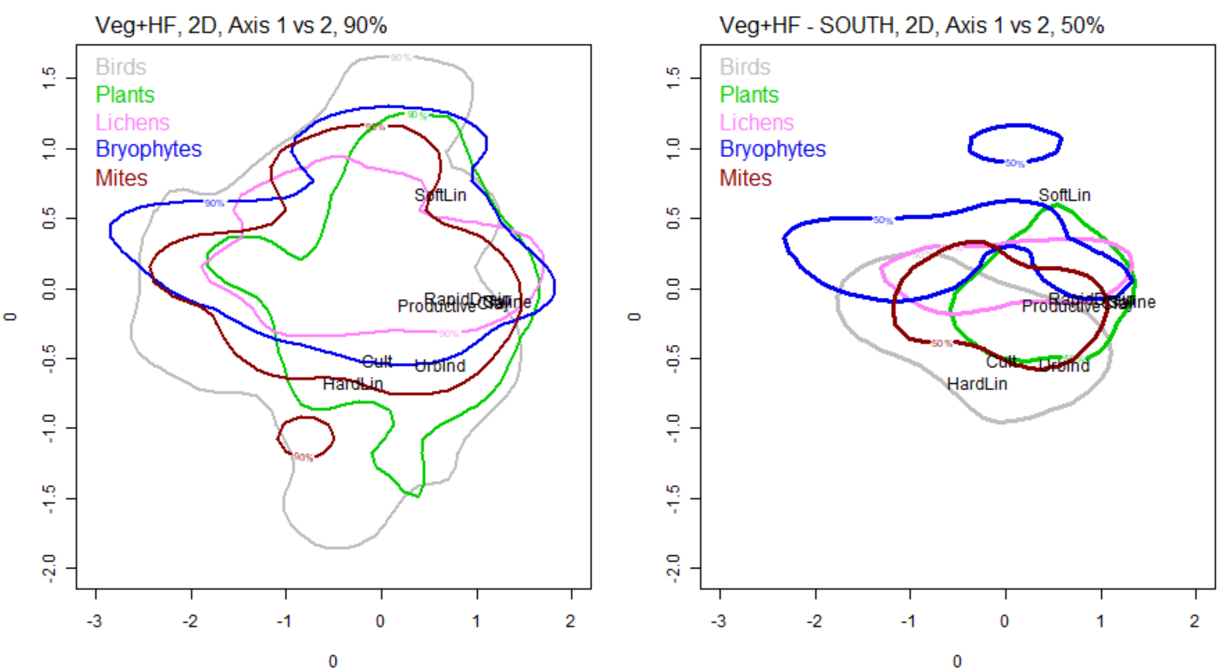

Figure 6-4 Contours encompassing 90% (left) or 50% (right) of species in each taxon in the two-dimensional ordination space based on three ecosite and human footprint types in the south analysis region.

In the south analysis region, ordination based on ecosite types and human footprint also showed extensive overlap of the species among taxa, although lichens and bryophytes are rarer in the south and occupied reduced areas of the ordination space compared to other taxa (**Figure 6-4**). Birds again show a strong association with roads (alienating human footprint) that may be an artefact of the analysis approach.

6.4.3.2 Existing results—Trend

The preliminary trend results are based on only 2 years of revisits. With wide uncertainty in estimates for many species, there is little to differentiate taxa—we do not yet know the extent to which species in the different taxa will show different long-term trends (see **Technical Report 6.2**). Additionally, most current overall differences in trend among taxa are attributed to changes in field protocols that have not yet been fully accounted for (e.g., larger collections for lichens and bryophytes, changes in the bird sampling, recording equipment and interpretation). The overall distribution of initial trend estimates across species therefore provides little information for evaluating overlap of taxa.

6.4.4 Discussion of existing results

The summary of results to date shows broad overlap between taxa. With so many species analyzed in each taxon, no taxon is highly restricted to species with any particular habitat preferences, spatial distribution, or trend. Much of the overlap is probably due to the use of the same generic set of habitat models for all taxa. Additionally, many of the results have high uncertainty, particularly for the rarer species in each taxon. Uncertainty in habitat models will decrease slowly with increasing sample sizes, and uncertainty in trend will decrease with increasing monitoring duration. However, we do not know yet how much that will lead to distinct responses between taxa.

There are a few general differences among taxa. Plants, with by far the most species, tend to encompass the full breadth of responses found in other (non-bird) taxa, in terms of habitat relationships, preferred habitat types, and spatial distributions. Plants also have many species that respond positively to human footprint, including non-native species. Lichens and bryophytes tend to be more restricted to particular habitat types in the north, including conifer forests for lichens and lowland forests for bryophytes. This makes them potentially more sensitive to changes in these habitat types, including regeneration after successional disturbances. Mites, like plants, tend to have a broad range of habitat associations, including species that prefer cultivated land. Birds have more habitat generalists than other taxa, but this may be due to the analysis approach used for this group. Mammals were not included in the comparison, because results are too preliminary with only two years of camera surveys. However, they are likely to show a limited range of habitat associations, simply because there are fewer mammal species surveyed, and many of these are wide-ranging habitat generalists.

Overall, initial ABMI results provide some guidance in selecting the best taxa to include in the ABMI's portfolio of indicators, but considering the uncertainty in many species' results so far, the following information on potential indicator value, budget and logistics constraints, and other values remains tentative.

6.4.5 Indicator value, constraints, and opportunities for different taxa

The ABMI's current set of taxa were chosen to represent a broad range of biodiversity with different temporal and spatial scales of response, and because they were species-rich, feasible to monitor quickly, and had other values, such as sensitivity to management or public interest. Chosen taxa include mammals, birds, vascular plants, bryophytes, lichens, mites, and aquatic invertebrates. Some other taxa were considered or explored but dropped, including:

▪ Springtails—originally identified along with mites, but dropped because of ultra-short scale temporal variance (e.g. rapid, localized population fluctuations following a rain event).

▪ Polypore fungi—dropped because of low species diversity and inconsistent sampling.

▪ Ground-dwelling beetles—methodology required multiple site visits and minimum sampling effort identified by local experts would have exceeded ABMI budgets.

▪ Fish—this separate program component has never been funded.

It may be beneficial to revise the ABMI's list of taxa to include those with high environmental indicator values that can be measured reliably. In a separate document, we have reviewed and summarized the potential values of each current ABMI taxon as an indicator of biodiversity and environmental conditions, for long-term trend monitoring and for more specific questions that could be added to ABMI. The document also lists constraints in monitoring the taxa, including whether current ABMI methods are adequate for realizing those potential values, and discusses opportunities for expanding monitoring of the taxa or making it more efficient. We urge reviewers involved in decisions about what taxa the ABMI should monitor to read that document (see **Technical Report 6.3**).

As an overall summary, every broad taxon has value as a biodiversity indicator. Species in each broad taxon are, by definition, taxonomically distinct from those in other taxa. Each current ABMI taxon contains many monitorable species. Each taxon also plays a range of ecological roles, with different taxa having varying degrees of importance for different roles and in different ecosystems. Those ecological criteria are therefore relatively unhelpful in deciding which taxa to include, because arguments of equal validity can be made for any broad taxon.

In general, the strongest argument for including a variety of taxa in a biodiversity monitoring program is that we do not know how species are going to change in the future—that is, after all, the reason we are monitoring in the first place! Having good information on a broad range of taxa increases our chances of finding unexpected effects. Some of these effects may be specific to the taxon being monitored, such as changes in plant communities due to sudden oak death and other diseases, or declines in corvids due to West Nile disease. Other changes first detected in a certain taxon may be general environmental problems affecting a range of species, as in the examples of acid rain and the ecological effects of pesticides. Monitoring for potentially critical unexpected changes is strengthened by a wide range of indicators. This forward-looking cautionary monitoring serves a very different function from choosing indicators with known cause-effect relationships to particular known stressors.

The review also indicates environmental and management conditions for which each taxon can serve as an indicator. While each taxon has indicator values, these values do differ among taxa. Lichens, for example, can be sensitive local-scale indicators of pollution effects, plants can indicate soil conditions and disturbance, wetland invertebrates can indicate changes in hydrology and water physiochemistry, and so on. Which taxa to include as indicators depends critically on the specific questions the ABMI chooses to focus on—local acute effects of particular developments, hydrological changes, broad regional changes due to climate changes, or some other process.

An additional important consideration is the limitations of current and potential future methods used by the ABMI in capturing the potential values of a taxon. ABMI methods are currently designed primarily to record many species in a brief single field visit. However, this may not be adequate, for example, to detect changes in biomass or growth of particular lichen species due to upwind pollution. Methods for other taxa, such as vascular plants, may have low repeatability, limiting our ability to measure long-term trends reliably and precisely (see **Chapter 5**). Taxa that rely on technology as an integral part of the monitoring, such as birds with recording units and mammals with cameras, may require increasingly large calibration programs as technology changes ever more rapidly. These considerations mean that choice of taxa, methods for each taxon, and the study design employing those methods (e.g, local designed comparisons vs. regional surveys, short-term impact studies vs. long-term monitoring) all need to be decided on as a coherent package.

From a practical point-of-view, taxa used in ABMI monitoring must also meet the assorted needs of policy, management, and the public. Large mammals and birds have the public's interest, and consequently the most obligations for management and the most monitoring effort by programs around the world. Some vascular plant species are also of interest to both public and management, including commercial species (trees, forage plants), non-native species, and some listed rare plants. Aquatic invertebrates are used in standardized, and in some places mandated, monitoring of streams, but not currently in wetlands. Lichens are monitored in the Oil Sands region as pollution indicators (albeit using precise chemical measurements of a few species). Other taxa include some listed species—often listed because they are data-deficient—but these do not generally attract the same public interest or policy requirements.

Other ways to increase efficiency, reduce costs, and maintain the current breadth monitoring portfolio may also be worth discussion. Possibilities for future consideration might include:

<u>1. Omitting taxa in regions or habitat types where they are less important</u>

Some taxa could be omitted in areas where they provide little information, such as wetland groups in the mountains, or mammal surveys in developed parts of the prairies (because cameras cannot be deployed in a representative way there). This strategy might reduce lab identification costs, but would only have a substantial effect if the remaining surveys at a site could be organized to avoid an entire field visit.

2. Alternating visits for some taxa ("ABAB" design)

For trend estimation, there is little benefit in intermediate revisits to sites (except for quicker reporting of initial trends). That opens up the option of alternating taxa in different revisit cycles—surveying taxon A in the first set of visits, taxon B in the next set, then A in the next visit, followed by B. (Practical problems of retaining taxonomic expertise can be resolved by doing half the sites on an ABAB schedule and the other half BABA.)

3. Focusing on particular taxa for particular questions

Particular taxa may be chosen for particular questions, such as arboreal lichens used to assess pollution effects. The specific methods and typically short-term comparisons used to address such questions could be modified to allow the information from the comparison to contribute to long-term trend estimation. For the lichen example, additional species could be surveyed in the same plots, control sites chosen to represent the local land base for long-term trend, and protocols, site locations, and data archived to allow future revisits. ABMI's data management system is well set up to allow short-term specific comparisons to contribute to long-term trend monitoring.

6.4.6 What other programs are doing

The few other large-scale integrated biodiversity monitoring programs (see **Biodiversity Programs Review** document) typically include birds, vascular plants, and a handful of other taxa. Birds and plants are included because of their indicator values, public and management interest, and the widespread availability of technicians or volunteers who can identify those species. The other taxa are chosen for their indicator values and typically because of local interest in the taxon, and sometimes for their diversity value itself—the greater probability of detecting unexpected environmental changes with a diverse range of organisms. The programs also include extensive tracking of the land cover, and also typically more precise measurements of indicative physical variables, such as water quality, tree growth, etc. Maintaining a portfolio of indicators to improve detection of unexpected environmental changes is a feature of the more advanced monitoring programs. Developed jurisdictions without integrated biodiversity monitoring programs usually have a series of programs covering this same range of elements, although with different degrees of intensity and expertise in monitoring. Without an integrated initiative, programs for individual taxa may be more prone to being reduced, cancelled, or severely modified over time as short-term priorities overpower the longer vision, and eroding the value of long-term continuity for providing precise trend estimates.

7 Conclusion

Over its first decade of operations, the ABMI has grown from an idea to a leader in biodiversity monitoring. We have developed a huge diversity of publicly available data on more than 3000 species across seven taxonomic groups, and on human footprint and native land-cover. We have also produced hundreds of peer-reviewed papers, technical reports, and other derived data products. These data and associated products have been used to inform management decisions around Alberta, from the local to the provincial scale.

In this 10-year review, we have attempted to evaluate the degree to which the ABMI has achieved its goal "to monitor and report on status and trend of biodiversity throughout Alberta". We have summarized the products created by the ABMI to describe status and trend in species, land cover, and human footprint elements; we have described the accuracy and precision obtained in these products; we have evaluated the degree to which multiple types of ABMI information corroborate each other; and we have compared the effectiveness of ABMI status and trend monitoring to monitoring conducted by comparable programs around the world.

Monitoring science evolves, and so do the needs of land managers and all Albertans. Over the past 10 years, the ABMI has continuously improved and updated its program to ensure best practices and to meet the changing needs of our partners. As we look ahead to the next 10 years, we will continue to seek new ways to deliver timely, relevant, scientifically rigorous, and cost-effective biodiversity data for Alberta's land-use decision makers—and for all Albertans.

The 10-year review is a testament to that commitment. Thank you for your contribution to this process.