**Historical Trends of Ecosystem Services in Canada, 1911-2011**

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November 2015

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Science.

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**ABSTRACT**

Ecosystem services (ES) refer to the flow of ecosystem benefits to people, and are classified as either provisioning, cultural, or regulating services. Canadian landscapes have been transformed by a land-use history that often prioritized provisioning services, at the expense of regulating and cultural services. Although the latest scholarship acknowledges the importance of assessing historical legacies to understand current ecosystem functioning, most studies are time and space static. This thesis considers a century of Canadian ecological history (15 time steps from 1911-2011) at a national scale and county-level resolution (*n*=293 in 2011). Data were obtained from a variety of archival sources including the Canadian Census of Agriculture, The Atlas of Canada Protected Areas data, and Parks Canada visitation records, and were used to quantify 16 ES. Historical county boundary maps were used to standardize the data relative to the changes of boundaries though time, and to produce a series of maps of ES bundles. A K-means analysis and mapping were used to assess changes in the composition and distribution of ES bundles. Finally, these long-term dynamics were evaluated qualitatively, through the lens of an historian. The political climate and social attitudes towards management and conservation were narrated in order to interpret quantitative trends, and to provide a more complete picture of ecological development during the twentieth century.

Overall, there was an increase in the number and complexity of ES bundles over time, and a trend towards regional specialization. Bundles generally transitioned according to three trends: (1) relatively unproductive bundles transitioning into service provisioning, (2) bundles transitioning to include a new dominant service, and (3) bundles that were replaced by different functional compositions entirely. Ninety-six percent of counties (*n*=273) experienced a transition in bundles at least once over the one hundred-year period. Eastern Canada was shown to be more dynamic in terms of the number of bundle transitions than other parts of Canada. Ultimately, the perspective provided by such a long history demonstrates the dynamism of ES in response to management decisions and the interactions between multiple ES and socio-political variables.

**RÉSUMÉ**

Le terme de service écologique (ES) se rapporte aux flux de bénéfices que la population reçoit des écosystèmes, et sont classés en services d'approvisionnement, culturels ou de regulation. Les paysages canadiens ont été transformés par une utilisation des terres qui a historiquement prioriser les services d'approvisionnement, aux dépens des services de régulation et culturels. Si les récentes recherches reconnaissent l'importance de prendre en compte l'héritage de l'histoire pour comprendre le fonctionnement actuel des écosystèmes, la plupart des études restent focalisées sur un point dans le temps et l'espace. Cette thèse porte sur un siècle d'histoire écologique canadienne (15 pas de temps de 1911 à 2011) à l'échelle nationale et à la résolution des comtés (*n*=293 en 2011). Les données ont été obtenues de divers documents d'archives, tels que le recensement de l'agriculture canadienne, le département des Ressources Naturelles Canada, l'atlas canadien des aires protégées et le registre des visites de Parc Canada, et utilisées pour quantifier 16 SE. Des cartes historiques montrant les limites administratives des comtés ont été utilisées pour standardiser les données relativement aux changements de ces limites au cours du temps, et pour produire des séries de cartes représentant les *bundles* de SE (groupes de SE corrélés positivement dans le temps et l'espace). Des méthodes d'analyses de K-moyenne et de cartographie ont été utilisées pour évaluer les changements dans la composition et la distribution spatiale des *bundles* de SE au cours du temps. Enfin, les dynamiques temporelles ont été évaluées qualitativement, avec le regard d'un historien. Le climat politique et les attitudes sociales envers la gestion et la conservation ont été narrés de manière à interpréter les résultats quantitatifs, et à fournir une image plus complète du développement de l'écologie canadienne au 20$^{ème}$ siècle.

De manière générale, le nombre et la complexité des *bundles* de SE ont augmenté au cours du temps, avec une tendance vers une spécialisation régionale de leur provision. Les transitions temporelles entre *bundles* suivent trois voies générales : (1) les *bundles* relativement peu productifs transitionnent vers la provision de services d'approvisionnement, (2) d'autres transitions impliquent l'incorporation d'un service dominant, (3) des *bundles* changent entièrement de composition fonctionnelle. Les *bundles* produits dans quatre-vingt-six pourcent des comtés (*n*=273) ont subi au moins une transition au cours des 100 années étudiées. L'est du Canada a montré plus de dynamisme en terme de nombre de transitions de *bundles* que les autres régions canadiennes. Au final, la perspective offerte par une longue histoire révèle la dynamique des SE en réponse aux décisions de gestion ainsi que les interactions entre plusieurs SE et des variables socio-politiques.

**ACKNOWLEDGEMENTS**

I would like to extend my sincere and abiding gratitude to my supervisor, Dr. Jeanine Rhemtulla. Thank-you for your guidance, encouragement, and inspiration over the last two years, for your willingness to explore history, and for believing in me as a scientist. I could not have asked for a more compassionate supervisor. You made my Master's experience a true joy. Thank-you to my co-supervisor, Dr. Benjamin Forest for his insights during committee meetings, thoughtful edits, and support of my thesis from McGill. Thanks, also, to Dr. Navin Rammankutty for his contributions to my research and presentations.

I wish to thank the members of the Rhemtulla and Rammankutty labs, Theraesa Coyle, Delphine Renard, Sylvia Wood, Thomas Fox, Sarah Wilson, Jordan Graesser, Verena Seufert, Larissa Jarvis, and Danny Plouffe, for their comments on my presentations, their motivation, and of course, their friendship. I am especially grateful for Delphine's mentorship during my Master's program. Thank-you for your advice, collaboration, and visits to Vancouver. I must also thank my diligent research assistants, Laura Dale and Jane Chow, for their hard work preparing data and researching sources.

Thank you to the McGill University and the Department of Geography for their support of my graduate education, for exposing me to new ideas, and introducing me to such exceptional peers. Thank you, also, to the University of British Columbia Department of Forest and Conservation Sciences for welcoming me into their labs and seminars.

I am very appreciative of financial assistance provided by the Quebec Center for Biodiversity Science, the Natural Sciences and Engineering Research Council of Canada, McGill University, and the Alexandra Irwin Cowie Fellowship. I am also deeply grateful for my correspondence with Mrs. Cowie whose devotion to McGill University I will always remember.

Jon Freedman, thank you for always being there for me no matter the distance, for listening patiently, for comforting me, for your humor, and your love.

Thank you to my Auntie Julie, Uncle Manolis, Zoë, and George for welcoming me to Vancouver, for sharing your home and many delicious meals with me.

And finally, thank you to my mom, dad, Harry, and Abbey for enduring another one of my theses, and for your unfailing love, reassurance, and confidence in everything that I do.

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## EXPLANATORY NOTES ON THE REGIONS OF CANADA

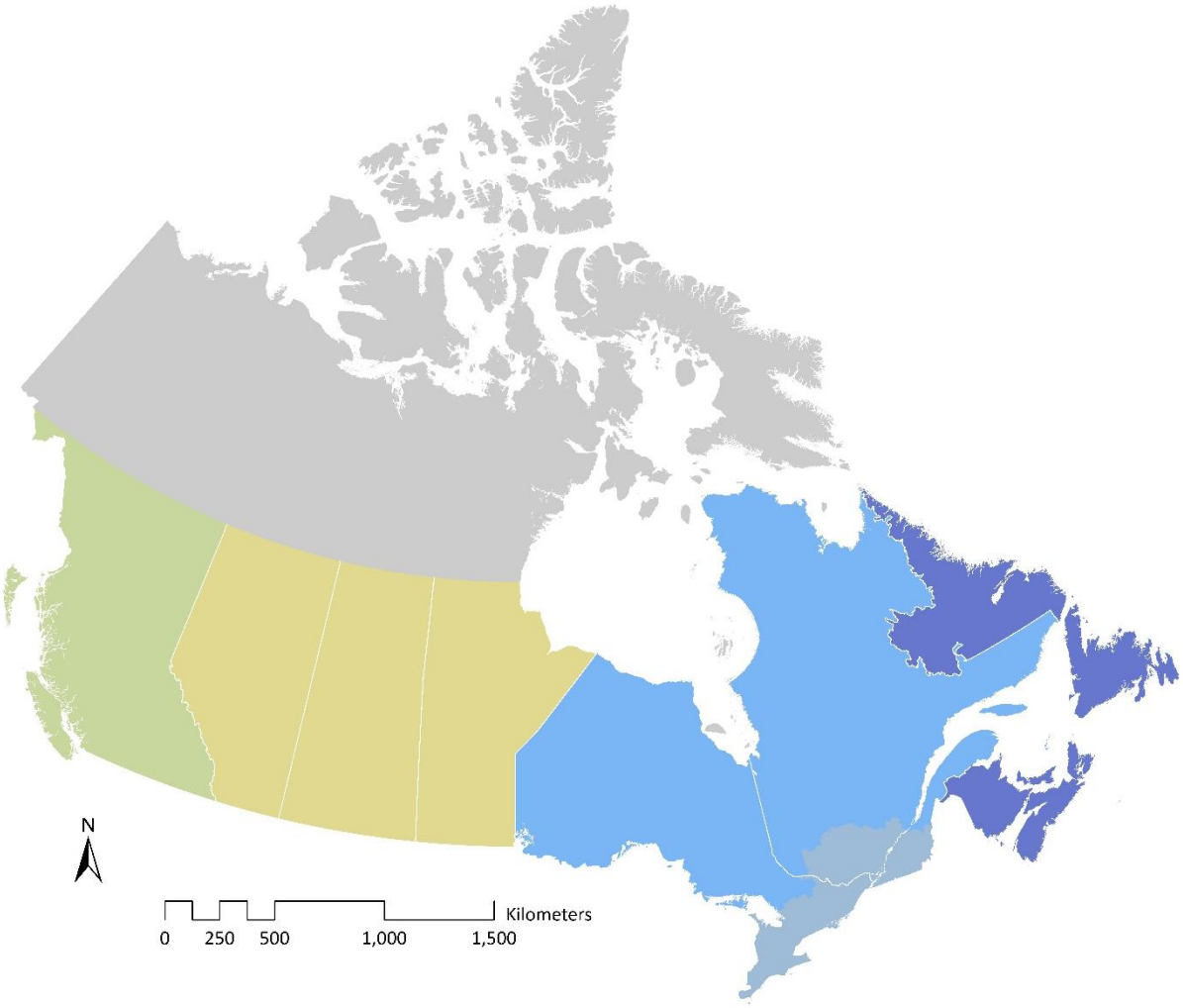



**Figure i** Regions of Canada referred to in the text

British Columbia
The Prairies
Western Canada
Central Canada
St. Lawrence Valley
The Maritimes
Eastern Canada

# CHAPTER 1. INTRODUCTION

Canada's place in history has long been defined by the immensity of its natural resources. The interdependency of the country's social and ecological systems, therefore, makes it a compelling example of the ecosystem services framework in practice. This thesis considers a period of one-hundred years, from 1911 to 2011, analyzes trends in multiple bundles of ecosystem services across Canada, and interprets the results qualitatively as informed by the historical narrative. Beginning in 1911, most populated counties in Canada provided the same few bundles of small-scale subsistence and frontier-agricultural services. These services that were staples at the beginning of the century were gradually made irrelevant by historical circumstances that included urbanization, agricultural innovation, war, and demand from new markets. Over time, the provision of services became spatially concentrated, and characterized by a suite of specialized bundles that optimized commercial crops, livestock, timber harvest, and protected areas. These changes occurred by way of regional transitions that brought the constellations of specialized bundles into a coordinated national ecology by 2011. This large temporal and geographic scope of this thesis reveals the striking dynamism of ecosystem services over time and the pathways of change that reconfigured the landscape.

## 1.1. Literature review

The ecosystem service framework is increasingly valued as a synthesis of diverse interests that can be used to address the challenges of managing multifunctional landscapes. The opportunity for methodological innovation and the integration of interdisciplinary influences that this concept represents, has inspired what Gretchen Daily and Pamela Matson called "a feeling of Renaissance in the conservation community" (Daily and Matson 2008).The proliferation of ecosystem service studies has devised new ways to approach and interpret the interface of social progress and environmental preservation. In the context of Canada, these advances can improve

understanding of the county's unique historical relationship with its "uncommon wealth of natural capital" (MacDowell 2012). However, there are a number of challenges to conducting historical studies of multiple ecosystem services. A review of the current literature will help to identify the limitations of the current literature, learn from its examples, and to define the terms of my thesis accordingly.

### 1.1.1. Defining ecosystem services

Establishing a standard terminology for ecosystem service concepts still remains a primary objective of the field. Although the basic typology of service groups has been defined (provisioning, regulating, and cultural services) by the Millennium Ecosystem Assessment, as Fisher *et al.* 2009 state, there needs to be a "clear, consistent and operational definition of what ecosystem services are" beyond these three categories (Duraiappah *et al.* 2005; Wallace 2007; Fisher *et al.* 2009; Sijtsma *et al.* 2013). Indeed, as the field progresses there is a need for greater distinction between concepts like ecosystem service capacity, demand, and flow, and more nuanced structures of ecosystem services, such as functional ecosystem services, realized ecosystem services, or recognized ecosystem services (Bürgi *et al.* 2015). The definition of terms of ecosystem service research is dependent on particular management scenarios that make standardization difficult; however, these limitations are preventing meaningful and consistent comparisons across studies and policy contexts (Fisher *et al.* 2009; de Groot *et al.* 2010; Seppelt *et al.* 2011). In this thesis, ecosystem services are defined, as far as possible, as the flow of ecosystem benefits to people. These could also be called Realized ES, "services that are consumed or utilized in some way in a specific landscape," according to the hierarchy established in Bürgi *et al.* (2015).

### 1.1.2. Quantification

The acquisition and quantification of empirical ecosystem service data poses one of the greatest practical challenges to researchers, especially those conducting historical research. Data collection is generally based on existing databases, proxies such as land-cover data, and derivatives of models (Naidoo *et al.* 2008; Eigenbrod *et al.* 2010). Other popular approaches assign monetary values to the service provided, in order to establish a familiar economic method of evaluating natural capital consumption that translates different types of services into a comparable unit (Troy and Wilson 2006; Brauman *et al.* 2007; Haines-Young and Potschin 2009; Zhang *et al.* 2010). Historical ecologists generally use a variety of sources and alternative perspectives to quantify ecosystem states. These may include primary sources, like oral histories (Wood *et al.* 2016) or government documents, repeat photography, land surveys (Rhemtulla *et al.* 2009), and historical narratives. This interdisciplinary style demands a "source-critical approach" and evaluation that compares multiple sources or utilizes statistical methods" (Bürgi and Gimmi 2007). And while historical ecologists are more frequently using these types of sources and methodologies to assess historical ecosystem change, very few have used these data to estimate ecosystem services, as opposed to ecosystem states, through time.

In spite of the resources available and the creative methods that can be used to describe a service, certain services are inherently more difficult to quantify than others, especially historically. Provisioning and regulating services, which can observed and measured, are the easiest to capture empirically. Because provisioning services represent essential human needs, they are often the most rigorously documented and easily accessible. Indeed, in studies evaluating multiple ecosystem services, especially historically, provisioning services are typically the largest group represented (Bürgi *et al.* 2015; Renard *et al.* 2015). Although quantifiable, regulating service data is the most difficult to obtain historically since unlike

provisioning and cultural services which require "a specific demand to exist," they operate "independently of being recognized by humans" and can function without being acknowledged or recorded (Bürgi *et al.* 2015). Cultural services, on the other hand, are expressions of subjective values that often defy quantification and are therefore difficult to estimate even though they were valued historically. In this thesis, data was compiled for provisioning and cultural services only, from a number of different sources from Census records, timber harvest statistics, inventory data, and Parks Canada accounts, and interpreted with the help of historical sources that include narratives, legislation, and news reports. Quantitative data were analyzed with multivariate statistics, and the results were compared against the historical narrative.

### 1.1.3. Interactions and spatial representations

Ecosystem services are known to be part of dynamic systems in which tradeoffs and synergies shape the provisioning landscape. Tradeoffs between services generally result in the increase of a few valuable provisioning services at the expense of regulating and cultural services and synergies produce a mutual improvement of two or more services (Foster *et al.* 2003; Raudsepp-Hearne *et al.* 2010; Haase *et al.* 2012; Macdonald *et al.* 2012) However, "most science implicitly uses as a simplifying assumption the notion that ecosystem services do not have significant and variable relationships with one another" (Bennett *et al.* 2009). Indeed, in a review of the current literature on ecosystem services, Seppelt *et al.* (2011) found that more than 50% of studies analyzed services in isolation (without considering any interactions between services) and 50% evaluated five or fewer services simultaneously. When relationships between services are studied, they typically address only two services at a time (Bennett *et al.* 2009; Seppelt *et al.* 2011).

Yet, Renard *et al.* (2015) found that at the regional scale, the relationships among all 12 of the ecosystem service quantified in their study changed through time, both in terms of the type

(tradeoff or synergy) and the strength of the relationship. Similarly, Raudsepp-Hearne *et al.* (2010) found that most of their study's 12 ecosystem services interacted; of the 66 possible pairs of ecosystem services, 34 were significantly correlated and landscape-scale patterns of trade-offs between services were observed. A study by Qiu and Turner (2013) also identified synergies and tradeoffs among 10 ecosystem services by factor analysis, and all but one of the services analyzed were shown to interact with one another. Common among these three studies was the negative correlation between livestock and/or crop production and regulating services—including ground and surface water quality, drinking water quality, soil organic matter, soil phosphors retention, and carbon sequestration—and a general positive correlation between cultural and regulating services (Raudsepp-Hearne *et al.* 2010; Qiu and Turner 2013; Renard *et al.* 2015). As such, it seems that research should prioritize studies that evaluate the relationships among multiple services, identify sets of positively correlated ecosystem services (bundles), and assess the situations (landscapes or management regimes) in which the services and bundles occur (Bennett *et al.* 2009).

The representation of such bundles across space has become a priority (Raudsepp-Hearne *et al.* 2010; Renard *et al.* 2015), however there remains a need for greater interdisciplinary collaboration and integrated social-ecological approaches, to collect and synthesize data for effective mapping of spatial trends (Hein *et al.* 2006; Troy and Wilson 2006; Naidoo *et al.* 2008; Bennett *et al.* 2009). Instead of analyzing ecosystem services using ecological units, using social units like administrative boundaries more effectively describe the processes that shape the production and consumption of services (Raudsepp-Hearne *et al.* 2010). In this thesis, multiple ecosystem services are analyzed as bundles and mapped across space. The maps are based on administrative boundaries (provinces and counties) that express the social dimensions of

ecosystem service trends in Canada. Moreover, the evolution of the bundle landscape was interpreted statistically as well as qualitatively through readings of history.

### 1.1.4. Temporal evaluations

In addition to representing ecosystem services on a spatial axis, analyzing their temporal trends is critical to understanding interactions and managing outcomes. Although a historical approach to ecosystem services represents a small minority of the current literature (but see Renard *et al.* 2015), and none at both the temporal and geographic extent of this thesis, it can reveal important explanatory variables for change, such as long-term demographic or economic trends, the origins of natural resource policies, and events like wars or cultural movements, that create unique demand scenarios for certain services. For instance, in a pioneering paper examining trends in nine ecosystem services over 35 years, Renard *et al.* (2015) provided empirical evidence for the dynamism of ecosystem services through time and space. The study found that "the most common types of ES bundles and their spatial distribution across the landscape changed through time," and that changes to ecosystem service bundles were related to "the spatial distribution of environmental, social, and economic characteristics" (Renard *et al.* 2015). Indeed, as Swetnam *et al.* (1999) explain, "If ecosystems are necessarily dynamic, then it may be misguided and fruitless to choose a single fixed point or period of time in the past" to evaluate ecosystem service provisioning. Rather, research should ideally consider the provision of services over an extended period of time to determine the historic range of variability and to account for the slow rates of some natural processes (Swetnam *et al.* 1999; Hein *et al.* 2006).

Engaging in the *longue durée* of ecological research provides an important contextualization of ecosystem service change that necessarily combines scientific and social factors, helping to improve current and future management of multifunctional environments (Foster *et al.* 2003; MacDonald and Bennett 2009; Lautenbach *et al.* 2011). This thesis evaluates

one hundred years, from 1911 to 2011 at ten and five year intervals, and analyzes long-term bundle dynamics. Ultimately, studying the large-scale spatiotemporal trends of ecosystem services with integrated social-ecological methods can address many of the gaps in the literature mentioned above, and achieve a more complete representation of the influences that have shaped the ecosystem service landscape in Canada.

### 1.2. Thesis objectives and research questions

In this thesis, I aim to develop a better understanding of the spatiotemporal dynamics of ecosystem services. By combining quantitative analyses and qualitative readings of history, I will address some of the major gaps in the literature, namely the shortage of temporal evaluations, the tendency to quantify limited and only currently important services, and the neglect of landscape and social histories. The large scope of this project intends to capture a greater diversity of the services that were valued over time, and permit a more comprehensive assessment of their evolution within a dynamic socio-ecological system. The two main questions motivating this research are:

1. What bundles of ecosystem services exist in Canada between 1911 and 2011?
2. How do these bundles change through time and across space?

To answer these questions I adopted a mixed methodology that combined archival research, statistical analyses, mapping, and historical narration. Analysis focused on defining service bundles, describing trends in demand, and mapping the bundles' spatial distribution. The results were then elucidated by political, economic, and cultural commentaries. Ultimately, I hope that this project contributes a perspective on ecosystem services that makes a case for engaging with historical sources in future research. Without the context and insight provided by these narratives, the study of ecosystem services is only ever half realized.

## CHAPTER 2. METHODOLOGY

The dimensions of this study are an attempt to assess Canada's ecological history as a provider of ecosystem services. For a country famously accused of having "too much geography," the contextual scope and methods required were similarly vast.[1] Ensuring consistency among the multiple variables and research parameters was the primary methodological objective.

### 2.1. Geographic scope and spatial resolution

Canada's ten provinces, covering an expanse just greater than 5.8 million square kilometers and spanning 86° of longitude from east to west, constituted the study area. Data were collected at the spatial resolution of the census division. These second-level geographic units, below provinces and above municipalities, will hereafter be referred to as counties. Counties were the smallest units for which data were consistently available across both the geographical and temporal scales. There were a total of 283 counties across the ten provinces with areas ranging from 196 to 820,284 square kilometers with an average of 20,531 square kilometers.

The three territories north of the 60$^{th}$ parallel were excluded from the study. The Canadian territories have a political evolution and ecological praxis all their own. Due to their northern latitudes and cultural heritage, the territories depended on a very different suite of ecosystem services (one which generally lacked agriculture-oriented services) than did the provinces. Administratively, the territories again diverged from the provinces, operating under different census geographic units and making comparable analysis unfeasible.[2] The territories' distinctiveness in Canada's history deserves more focused analysis, and therefore precluded them

1. In a speech to the House of Commons on June 18, 1936, Prime Minister William Lyon Mackenzie King declared that "If some countries have too much history, Canada has too much geography."

2. Only Nunavut's administrative regions are consistent with census divisions/counties. The Yukon Territory is treated as a single unit, while the Northwest Territories' administrative regions do not correspond with census divisions.

from this study. In contrast, the ten provinces share a more similar developmental history, both politically and environmentally. They represent a nested geographical unit that could be evaluated cumulatively at the national scale, as well as comparatively at the provincial level.


**Figure 1** Counties of Canada (*n*=283); excluded territories not shown.

## 2.2. Temporal period

The temporal period of study was 1911 to 2011, at ten year increments from 1911 to 1971, and five year increments from 1976 to 2011. This chronological structure, composed of 15 time-steps, corresponds to the records of the Canadian Census of Agriculture, which was a

primary source of data and organization for the project (data sources will be discussed in detail in a forthcoming section). The 1911 census year was established as the start date for the study due to inconsistencies between the 1901 records and the succeeding years. What is more, 1911 is the year that a new unit within the Department of the Interior, the Dominion Parks Branch, was created. This agency, the first of its kind anywhere in the world, was devoted to managing Canada's national parks (Campbell 2011).Therefore, the ecosystem service data provided by national parks were temporally consistent with that of the Census of Agriculture. The 2011 census concludes the century-long period, as it was the most recent record available at the time of study.

### 2.3. Spatial standardization

Over the course of the one hundred-year period, Canada's county boundaries changed substantially in every province. Historic digital boundary files were available through Statistics Canada for every census period except for 1971 and 1976; the 1981 boundary map was used as a substitute for these missing files (Statistics Canada, Cartographic Boundary Files). In order to render the data comparable across time and space, the 2011 county boundaries were used as the reference to which all previous boundaries (1911-2006) were adjusted. The county maps from 1911 to 2006 were individually overlaid with the 2011 reference map in ArcGIS (ESRI "ArcMap" 2015, Version 10.2.2), and the overlapping boundaries were clipped to create polygons representing the smallest units of discrete area and then aggregated according to the 2011 boundaries. The area of each constituent polygon was divided by the total area of the historic county it was derived from. Using R statistical software (R Development Core Team 2014, Version 3.0.2 ), this fraction was used to calculate the proportionate value of the ecosystem service associated with its area. Finally, the area-adjusted data were aggregated by the 2011 county names. Each of the 15 time steps now had the same name and number of counties

with data that was comparable across the entire time series. Water features and splices less than 0.004 square kilometers in area were deleted from the attributes.

### 2.4. Ecosystem services: data sources and standardization

The selection of ecosystem services was informed by historical knowledge of staple resources and important industries in Canada, and was constrained by the availability of consistent records. Ultimately, 16 services that met both the temporal and geographic requirements were chosen and quantified over the one hundred year period for every county: barley, canola, chickens, corn, cows, hay, horses, oats, national park attendance, pigs, potatoes, protected area, rye, soybeans, timber, and wheat. Two classes of ecosystem services, provisioning services ($n$=14) and cultural services ($n$=2), are represented by the chosen variables (Table 1).

**Table 1** Data sources and descriptions for the 16 ecosystem services and secondary data sources.

| Data Source | Dates | Ecosystem Services | Category | Units |
|---|---|---|---|---|
| Canadian Census of Agriculture | 1911-2011 | Barley, Canola, Chickens, Corn, Cows, Hay, Horses, Oats, Pigs, Potatoes, Rye, Soybeans, Wheat | Provisioning service | Crops: Area (acres) of land under crop; converted to percent of total county area ($km^2$)<br><br>Livestock: Number of animals; converted to density of animals per county area ($km^2$) |
| Canada Year Book | 1911-1961 | Timber harvested | Provisioning service | Volume of timber harvested ($m^3$) |
| National Forestry Database | 1971-2011 | Timber harvested | Provisioning service | Volume of timber harvested ($m^3$) |
| The Atlas of Canada protected areas shapefile | 1911-2011 | Protected areas | Cultural service | Area ($km^2$) protected; converted to percent of total county area<br><br>Date of establishment |
| Annual Reports of the Commissioner of Dominion Parks | 1911-1921 | National Park attendance | Cultural service | Number of visitors per park per year |
| Parks Canada annual attendance records | 1931-2011 | National Park attendance | Cultural service | Number of person-visits per park, per year |
| **Secondary data sources** | | | | |
| Global Forest Watch Canada | 2013 | Canada's commercial forest tenures | … | Area of timber tenure ($km^2$) |
| Natural Resources Canada/ National Forest Inventory | 2013 | Merchantable forest volume in Canada | … | Volume of merchantable timber ($m^3$/ha converted to $m^3/km^2$ ) |

### 2.4.1 Agriculture and livestock

Agricultural products and livestock data were taken from the Canadian Census of Agriculture. Data were entered for more than one hundred agricultural variables from which 13 ecosystem services were chosen for analysis based on the temporal consistency of the record, a relatively equal geographic distribution across the ten provinces, as well as the relevance of the services to Canadian history. As described in the preceding section, the standardization of county boundaries ensured that the raw data obtained from the census based on mutable county boundaries, would ultimately be comparable. From 1911 to 1951, Census data were manually entered into the database from hard-copy volumes (Canada, Dominion Bureau of Statistics 1911-1951), and from 1961 to 2011, the digital data from Statistics Canada (Statistics Canada 1961-1971) were edited and entered. Crops were recorded by acres planted, while livestock were tallied by the number of animals per county. To control for the disparities in county size, crop data were converted to the proportion of total county area (% of county $km^2$), and livestock data were converted to the density of animals per county (number of animals/$km^2$).

### 2.4.2 Timber harvest

Data for the volume of timber harvested was derived from multiple sources. A lack of administrative stability and uniformity in Canada's forest sector hindered the preparation of harvest records historically. In 1930, a series of measures known as the Natural Resources Acts transferred the control of forests in the Prairie Provinces and along the Railway Belt (a region along the main line of the transcontinental railway) in British Columbia from federal to provincial jurisdiction (Drushka 2003). The other Canadian provinces had each controlled their forests separately since Confederation in 1867, and from 1930 onwards all provinces kept independent records of their forestry activity. Indeed, so far as this research found, no consistent historical records exist at a scale smaller than that of the province. From 1911 to 1961, data on

the volume of timber harvested at the provincial level was obtained from the Canada Year Book, an annual review published since Confederation which "charts key trends and indicators in the nation's economy, population, society and environment" (Canada, Dominion Bureau of Statistics 1912-1964). As the units of volume reported in the Year Book differed from year to year, the data were all converted to a standard unit of cubic meters (Urquhart 1993). From 1971 to 2011, harvest volumes were obtained from the National Forestry Database (National Forestry Database 1970-2013). Provincial totals were calculated as the sum of the total volume of softwood and the total volume of hardwood harvested per year in cubic meters. The consistency of these measurements through were checked by plotting the trend of timber volume harvested; there were no discontinuities between 1961 and 1971 when the data source changed.

In order to create finer resolution data at the county scale, a digital vector of Canadian timber tenures and a raster map of merchantable timber volume ($m^3$/ha) (MODIS image, 250 km resolution) were obtained from The Global Forest Watch and Natural Resources Canada and The National Forest Inventory respectively (Global Forest Watch Canada 2013; Beaudoin *et al.* 2014; Canadian Council of Forest Ministers 2013). Timber tenure describes the areas within which logging activities are permitted while the merchantable timber volume describes in greater detail where, within the bounds of a tenure area, the volume of timber is the highest and therefore most likely to be extracted. Although both of these layers are based on the current state of Canada's forests and are therefore not entirely representative of the period of study, they were the best approximations of Canada's commercial forest areas available.

Using ArcGIS (ESRI "ArcMap" 2015, Version 10.2.2), I intersected the timber tenure shapefile and the merchantable timber volume map, and used Zonal Statistics to calculate the total amount of merchantable volume within each county (Figure 2). I then calculated the proportion of a province's total merchantable timber volume in each of its counties, and

multiplied this proportion by the total of volume harvested in the province for each of the 15 census years. Ultimately, this process dispersed the provincial harvest volumes derived from the primary-source material, to the counties within their bounds based on the proportion of merchantable volume they contained.

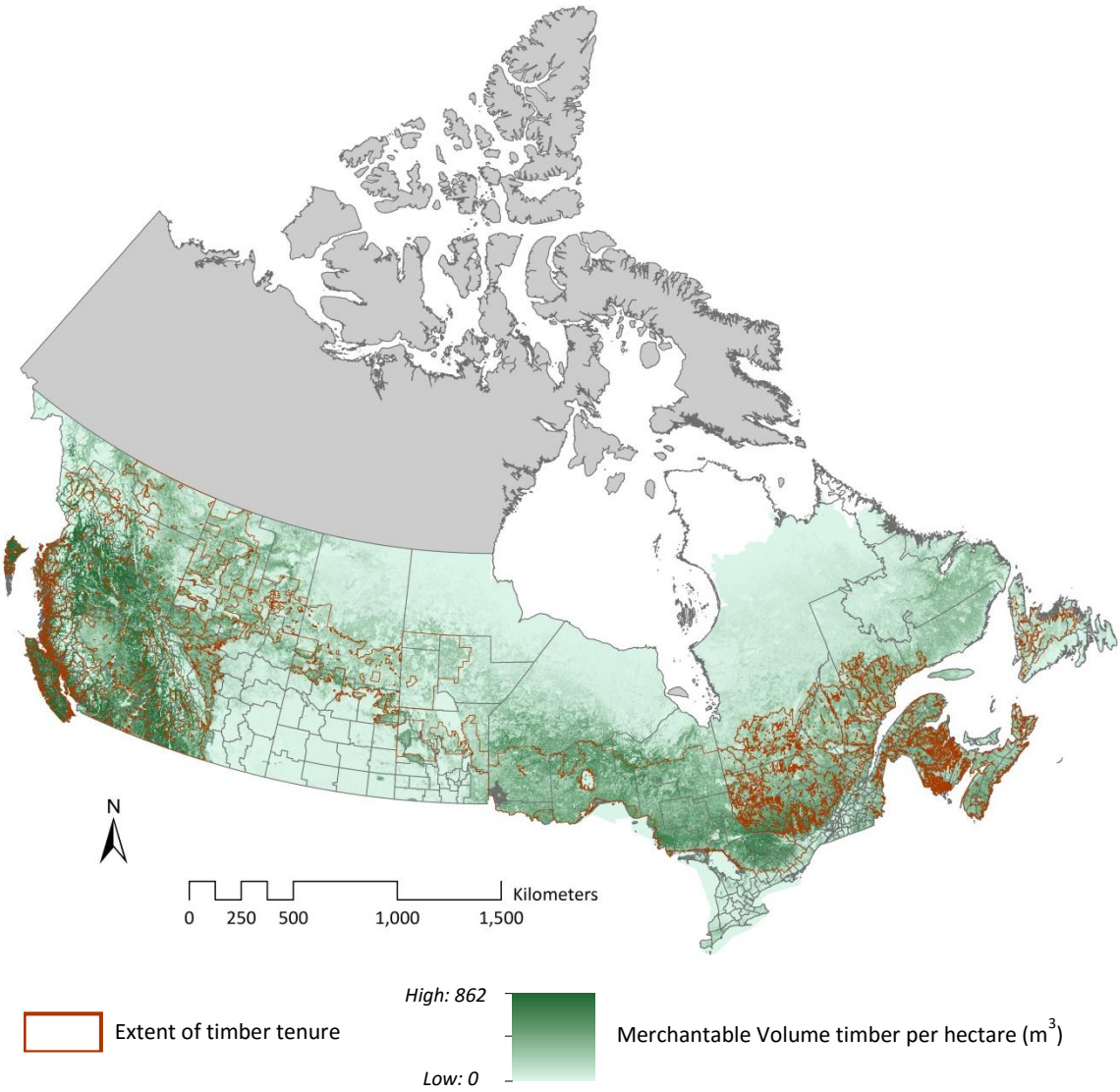



**Figure 2** Timber tenures and merchantable timber volume in Canada in 2013. Data were obtained from the Global Forest Watch and Natural Resources Canada and The National Forest Inventory respectively. Merchantable volume ranges from 0 to 862 cubic meters.

### 2.4.3 Protected areas

Similar to the timber harvest data, the process of quantifying ecosystem services from protected areas required multiple sources of data and a procedure to create finer spatial resolution. The area of terrestrial land designated protected was obtained from The Atlas of Canada in the form of a digital map (ArcGIS shapefile) of protected areas (The Atlas of Canada 2008) (Figure 3). This dataset detailed the area, name, legal status, and date of establishment of nearly five thousand protected areas in Canada from 1885 to the present. The types of protected areas included national and provincial parks, recreation areas, historic or cultural sites, wildlife preserves, game animal reserves, ecosystem management areas, and biological refuges. I calculated the cumulative area of each county that was designated protected for each of the15 census periods. The percentage of the county area that was designated protected was then calculated. Counties with no protected area within their boundaries received a value of zero. The creation of a protected area was attributed to the census year that immediately followed the date of establishment (data for a park established in 1948 was attributed to the 1951 census year). There were seven protected areas (provincial and national parks) that were established before 1911; these were attributed to the 1911 census period. Although the protected-areas shapefile included marine, coastal, and riverine protected areas, all non-terrestrial protected areas were eliminated from the analysis as including aquatic protected areas would have been inconsistent with the other land-based ecosystem services. All other area calculations were based on terrestrial land area which excluded water features such as lakes and rivers.

If the quantification of protected area measured the capacity of a cultural ecosystem service, the number of people visiting a protected area would be an expression of the service's flow. Annual records of the number of people visiting Canada's national parks were obtained from two sources. For 1911 and 1921, these registers were retrieved from the Sessional Papers of

Department of the Interior, within the Annual Report of the Commissioner of Dominion Parks (Canada 1914). Attendance tallies were missing for Jasper and Yoho in 1911 and for Kooteney in 1921. The missing values for Jasper and Yoho in were interpolated based on the rate of increase of nearby Banff National Park, and Kooteney's 1921 record was estimated based on the average rate of increase of the other Rocky Mountain parks between 1911 and 1921. From 1931 to 2011, the fiscal year person visits to national parks were available through the Parks Canada Agency (Parks Canada Agency 1930-2013).[3]

For each census year, the total number of visitors for a given national park was multiplied by the proportion of park area that fell within a county. This attributed the number of visitors to national parks proportionately to the counties that contained a portion of the park's area. Again, this process restored the spatial resolution of the county needed for analysis. Counties with no national parks were given a value of zero.

3. The Parks Canada Agency warns: trends in visitor data must be interpreted with caution. The very nature of national park and national historic site locations makes controlled access difficult to manage. Significant fluctuations in volume can be attributed to many ad hoc factors such as flooding, fire, special events, attendance measurement methodology upgrades, and weather extremes. The Parks Canada Agency officially defined the measurement of attendance as the person-visit statistic (definition below) in 1988/89. Data prior to this year may not be directly comparable to data reported after this date.

Person-Visit: Each time a person enters the land or marine part of a reporting unit for recreational, educational or cultural purposes during business hours. Through, local and commercial traffic are excluded. Same day re-entries and re-entries by visitors staying overnight in the reporting unit do not constitute new person-visits.

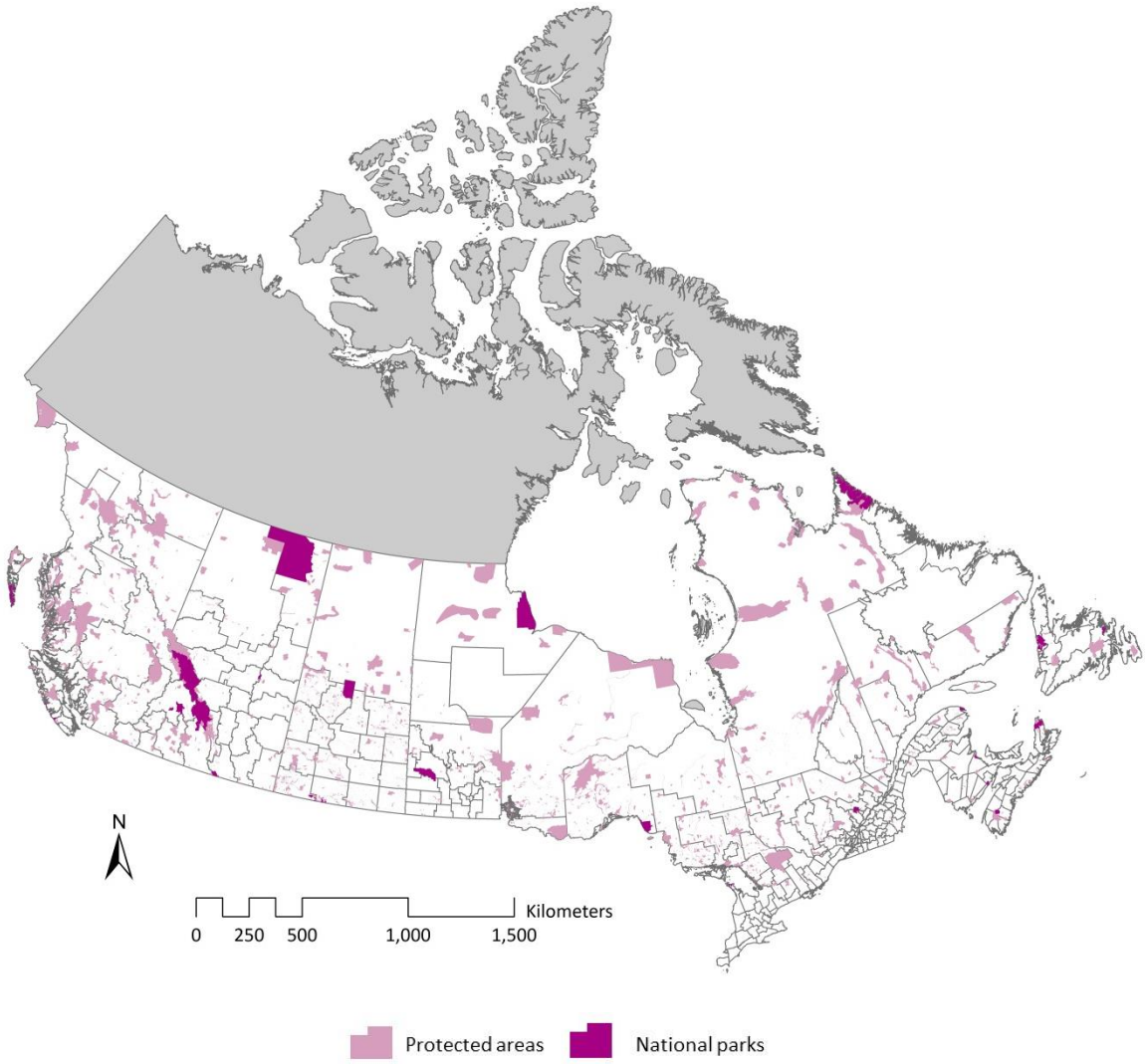



**Figure 3** Map of all protected areas in Canada (*n*=4,745) created between 1885 to 2011 are shown in light pink; National Parks are displayed in a darker shade (*n*=44). Attendance data was only available for National Parks.

### 2.5. Managing missing data and pre-processing

After quantifying and standardizing 16 ecosystem services, the data were compiled into a single dataset. Nine percent of the dataset had missing (NA) values. Since this was a small proportion of the total data, the NA values were interpolated rather than removed from the analysis. Using R (R Development Core Team 2014, Version 3.0.2 ), two methods were combined to replace NA values depending on their location in the time series. For missing values in the middle of the time series, NAs were filled using a linear interpolation method (average of the two values before and after a missing value.) For NA values at the beginning (1911) or end

(2011) of the time series, a rolling-fill method was used to replace the NA value with a copy of either the next available value in the series, or the preceding value in a series.

After filling all of the NA values, the entire data set was transformed using the x' = sqrt(sqrt(x)) transformation to meet assumptions of normality. The data were then standardized (x'= (x-m)/sd) to unit variance and zero-mean to remove the effect of differing units and ranges of variation across the ecosystem service data.

## 2.6. Analysis

### 2.6.1 R figures

Analysis of the dataset attempted to reveal patterns among the 16 ecosystem services across space and time. A series of initial graphs were made using R (R Development Core Team 2014, Version 3.0.2 ) that plotted the temporal trend and spatial variation of each ecosystem service at two different scales: (1) national averages of each service over time, (2) provincial averages relative to the national average.

### 2.6.2 K-means

I performed a K-means clustering analysis using R (R Development Core Team 2014, Version 3.0.2 ) to define ecosystem service bundles, groups of positively correlated ecosystem services that were provided together in the same place and at the same time. The entire dataset (all ecosystem services, for all counties and time steps) was evaluated and the number of bundles selected according to the highest value of the "simple structure index" (SSI). The SSI partitioned the data according to three criterions: the maximum difference of each data point (a measure of one ecosystem service in one county at one time step) between clusters, the sizes of the most contrasting clusters, and the deviation of a variable in the cluster compared to its overall mean. Ultimately, the K-means analysis defined the ideal number of bundles within the dataset and assigned each county to a bundle at each time step.

I illustrated these bundles by flower diagrams which depict the relative abundance (ranging from zero to one) of each ecosystem service as a petal within a bundle; the longer the petal, the higher the abundance of the service. The relative abundance of services was standardized in two ways: the first method standardized the data so that the ecosystem service petals within a bundle were comparable to each other, but not to the petals in other bundles (the most abundant service in each bundle had a value of one and all others ranged from zero to one), and the second method standardized the data so that the abundance of ecosystem services was compared between bundles (each ecosystem service had a value of one in whichever bundle it was most abundant; in all other bundles where that service was represented it had a value between zero and one.) I evaluated the composition of services that constituted each bundle and gave each one a qualitative description of the bundle's primary function (e.g. livestock, mixed farming, protected area).

### 2.6.3 Bundle mapping and analysis

According to the bundle number assigned to each county per time step by the K-means analysis, I mapped each of the fifteen time steps (1911-2011) in ArcMap (ESRI "ArcMap" 2015, Version 10.2.2). This time series of bundle maps was both qualitatively interpreted with the help of the historical narrative, and quantitatively analyzed for spatial patterns and trends through time in two ways. The first quantitative analysis addressed how the representation of bundles on the landscape changed from the beginning to the end of the century. The number of counties providing each bundle were counted and summarized in a table by census year. Using this table, I was able to show which bundles decreased, and which increased on the landscape over the time period. The counties that in 1911 provided a decreasing bundle were traced to 2011 to determine which bundles had replaced them one hundred years later, and what percentage of the counties were represented by each trajectory.

In the second analysis of the bundle maps, I illustrated the number of times a county changed the bundle it provided between 1911 and 2011 using ArcMap (ESRI "ArcMap" 2015, Version 10.2.2). To do this, I evaluated the bundle assigned to each county at each time step, summarized the number of unique bundles it provided over time, and mapped the counties according to the number of "bundle transitions" it experienced between 1911 and 2011. For example, if a county provided the same bundle for the entire period, I gave it a value of zero; if a county provided three different bundles over time, it was assigned a value of two to indicate that it changed twice between 1911 and 2011.

# CHAPTER 3. RESULTS

Over time and across space, the general trend was one of increased provision and spatial specialization of services, and an increase in both the number and complexity of bundles present on the landscape. In this chapter, I will begin by reporting the trajectories of individual ecosystem services at the national scale as well as selected provincial-level trajectories that illustrate the variability. The details of the main results will then be described in two sections corresponding to the two main research themes; the first addresses the composition and transitions of ecosystem service bundles, and the second is concerned with the spatial patterns of the bundles geographically.

## 3.1. Provision and spatial specialization increased through time for most services

Over the one hundred year period, the provision of eleven ecosystem services increased and five decreased. Although the total magnitude of change was relatively slight at the national scale, the change in variability among counties was pronounced whether a service was increasing or decreasing (Figure 4). In most cases, there was a marked transition in standard deviation (expressing a spatially concentrated provision of a service where high variability indicates a high degree of spatial specialization). For the five services that decreased through time—horses, cows, hay, potatoes, and oats—variability was high at the beginning of the time series and began to decrease along with the decrease in provision, around 1951. Similarly, for most services whose provision increased, variability increased with increased provision over time. Several services, however, showed consistently high spatial variability throughout the period: wheat, rye, and to a lesser extent, barley and timber (Figure 4(i), 4(g), 4(a), 4(p)).

The services whose national trends showed increasing variability over time over time—chickens, pigs, timber, canola, soybeans, and National Park attendance—revealed that provisioning became increasingly concentrated in fewer areas, not only at the provincial level but

at the county level as well (Figure 5(b), 5(c)). Indeed, subsets of provincial trends showed far more dynamic trajectories compared to the national averages. For example, although the provision of potatoes for all of Canada showed a modest increase over time, the provisioning for Prince Edward Island contributed enormous amounts to that average compared to provinces like Quebec whose low-level potato provision decreased somewhat through time (Figure 5).

What is more, both of the above examples suggest that not only was the provision of certain services increasingly concentrated in fewer provinces, but that there was an increase in variability within the provinces themselves over time. Overall these examples suggest that there was a trend occurring across Canada for fewer provinces, and fewer counties within provinces, to produce more of a service over time to sustain the national supply. The following two sections will elaborate on this result and provide more detailed insights into the relationships between services, as ecosystem service bundles, and how these groups transition over time and vary across space.

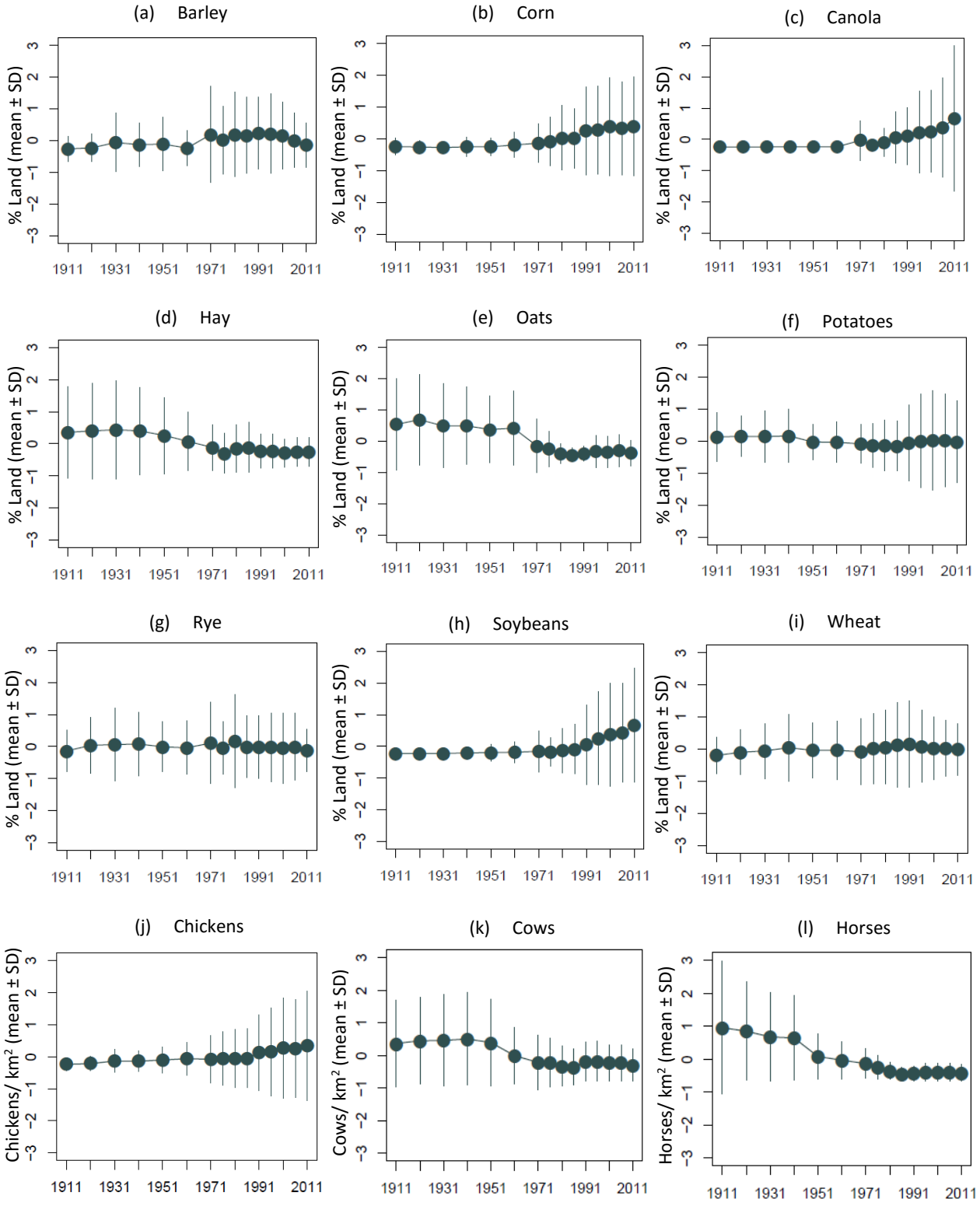



**Figure 4 (a-l)** National-scale trajectories of the 16 ecosystem services in Canada. The data were plotted at each of the 15 time steps according to each year's relation to the average provision over the entire time period (standardized average provision is zero). The standard deviation indicates the spatial variation of the provision of each service. A small standard deviation indicates a more uniform provision of the service across space; a large standard deviation indicates that the provision of a service was clustered.

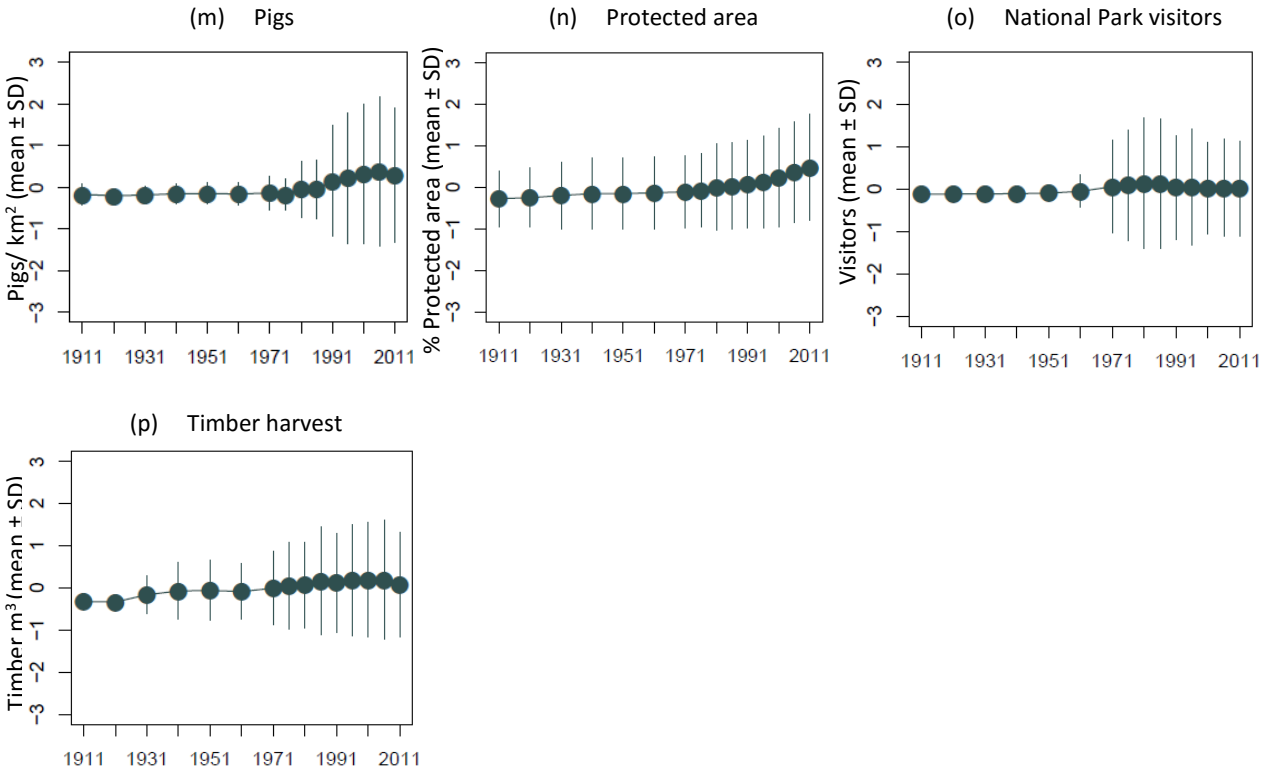



**Figure 4 (m-p)** National-scale trajectories of the 16 ecosystem services in Canada. The data were plotted at each of the 15 time steps according to each year's relation to the average provision over the entire time period (standardized average provision is zero). The standard deviation indicates the spatial variation of the provision of each service. A small standard deviation indicates a more uniform provision of the service across space; a large standard deviation indicates that the provision of a service was clustered.

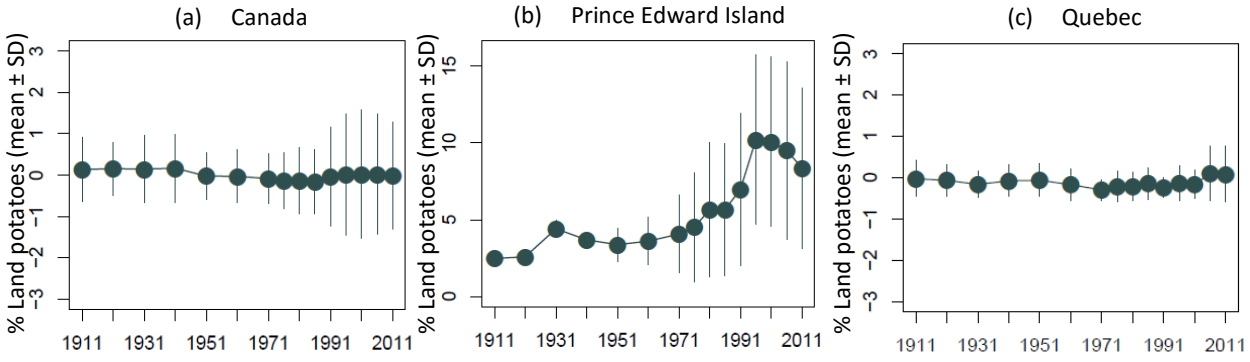



**Figure 5 (a-c)** Differences in the provincial trends of Prince Edward Island and Quebec (standardized relative to the national average) and the trajectory of potato provisioning at the scale of Canada. Most other provinces followed a similar trajectory to Quebec in terms of their provision of potatoes over time. All additional provincial-level graphs can be found in the Appendix.

## 3.2. Composition and transitions of ecosystem service bundles

### 3.2.1 Twelve bundles summarize the provision of ecosystem services in Canada from 1911-2011

A K-means clustering analysis identified twelve bundles of ecosystem services across Canada from 1911 to 2011 (Figure 6). The majority of bundles (*n*=9) were characterized by one or a few dominant provisioning services, and in the remaining bundles (*n*=3) cultural services were maximized. However, several of both types of bundles were multifunctional in their composition, and included a mix of provisioning and cultural services. The two standardization methods for the bundle rose diagrams highlighted different aspects of the bundles' functional identity. The set of bundles standardized for comparison between bundles (Figure 7) shows the productivity of each bundle's services relative and respective to those in the other bundles, while the set of bundles standardized for comparison internally (Figure 6), reveals the relative proportions of services within a single bundle.

The twelve bundles were named qualitatively according to their individual composition of services. Pairs of bundles with similar compositions but different magnitudes of provisioning, were distinguished from one another by the labels 'major' or 'minor' when necessary. The twelve bundles identified were: (B1) Frontier Forest, (B2) Livestock (major), (B3) Subsistence (major), (B4) Early Prairie Agriculture, (B5) Managed Forest, (B6) Late Prairie Agriculture, (B7) Popular Parks, (B8) Subsistence (minor), (B9) Multi-use protected area, (B10) Unmanaged Forest, (B11) Livestock (minor), and (B12) Tourism and Working Landscapes (Figure 6).

**Ecosystem Service Bundles identified using K-means analysis**
*(comparable within bundles)*

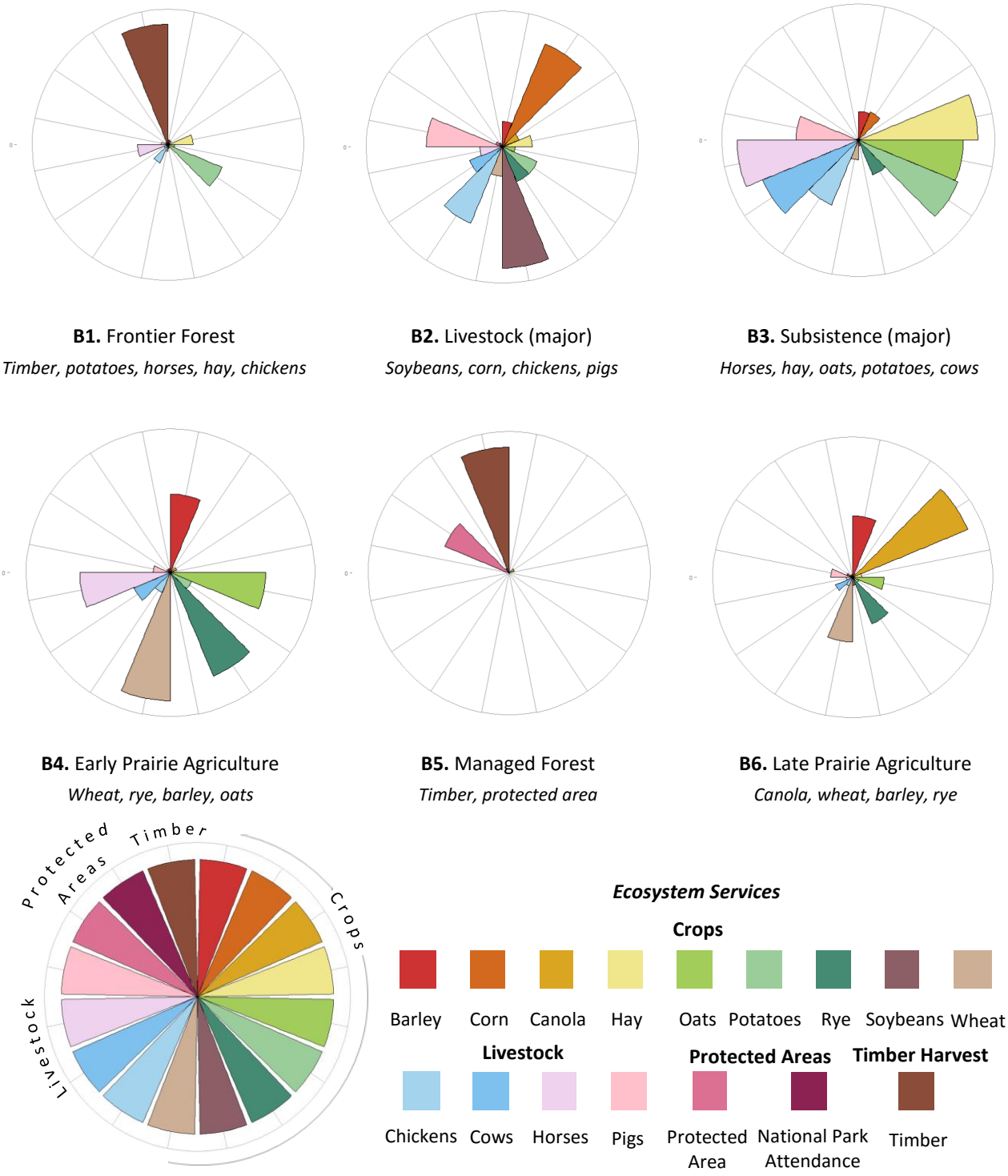
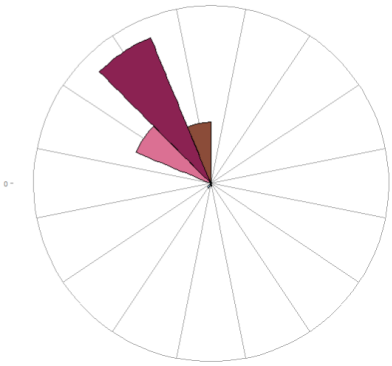
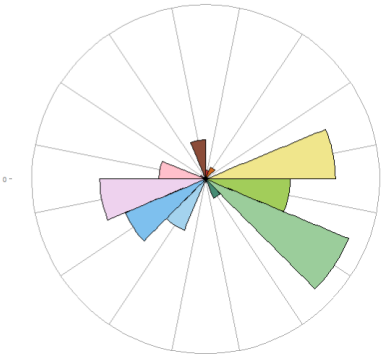



**Figure 6** Ecosystem service bundles standardized for comparison within bundles. The most abundant service in each bundle had a value of one and all other services in that bundle range from zero to one.

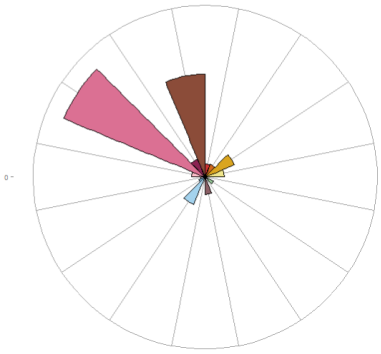
**Ecosystem Service Bundles identified using K-means analysis**
*(comparable within bundles)*



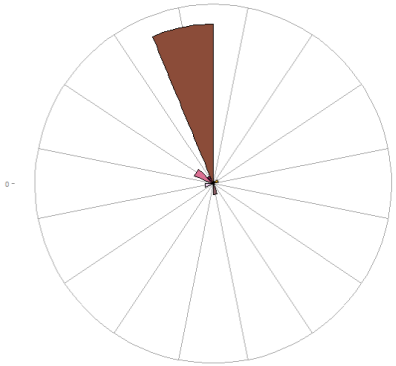
**B7.** Popular Parks
*National park attendance, protected area, timber*



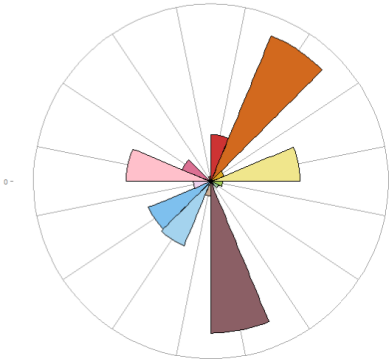
**B8.** Subsistence (minor)
*Potatoes, hay, horses, cows, oats*



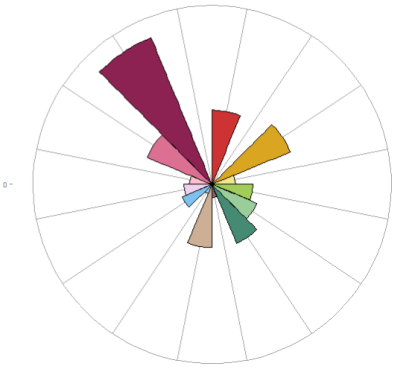
**B9.** Multi-use protected area
*Protected area, timber, chickens, corn*



**B10.** Unmanaged Forest
*Timber*



**B11.** Livestock (minor)
*Corn, soybeans, hay, pigs, cows, chickens*



**B12.** Tourism and Working Landscapes
*National park attendance, corn, barley, rye, wheat, protected area*

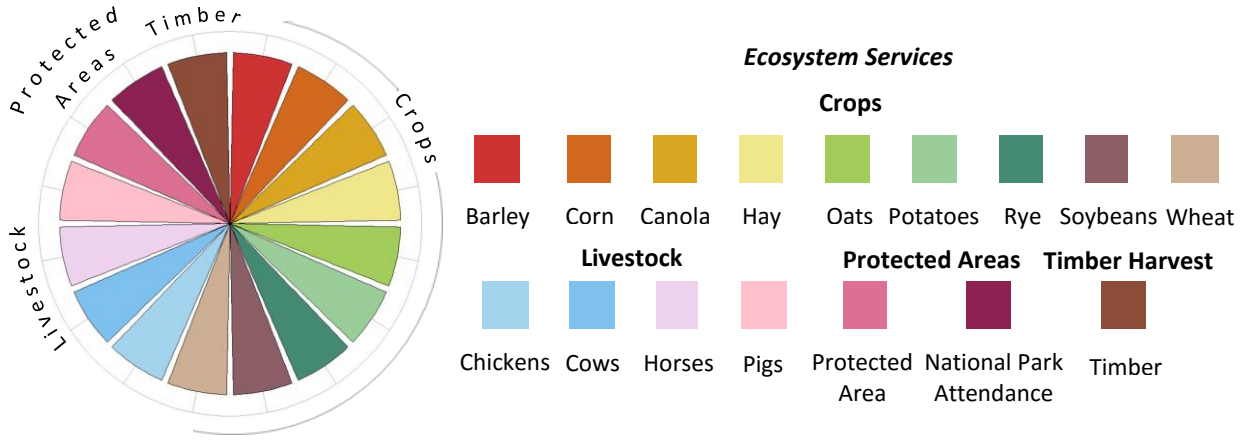



**Figure 6 (continued)** Ecosystem service bundles standardized for comparison within bundles. The most abundant service in each bundle had a value of one and all other services in that bundle range from zero to one.

**Ecosystem Service Bundles identified using K-means analysis**
*(comparable between bundles)*

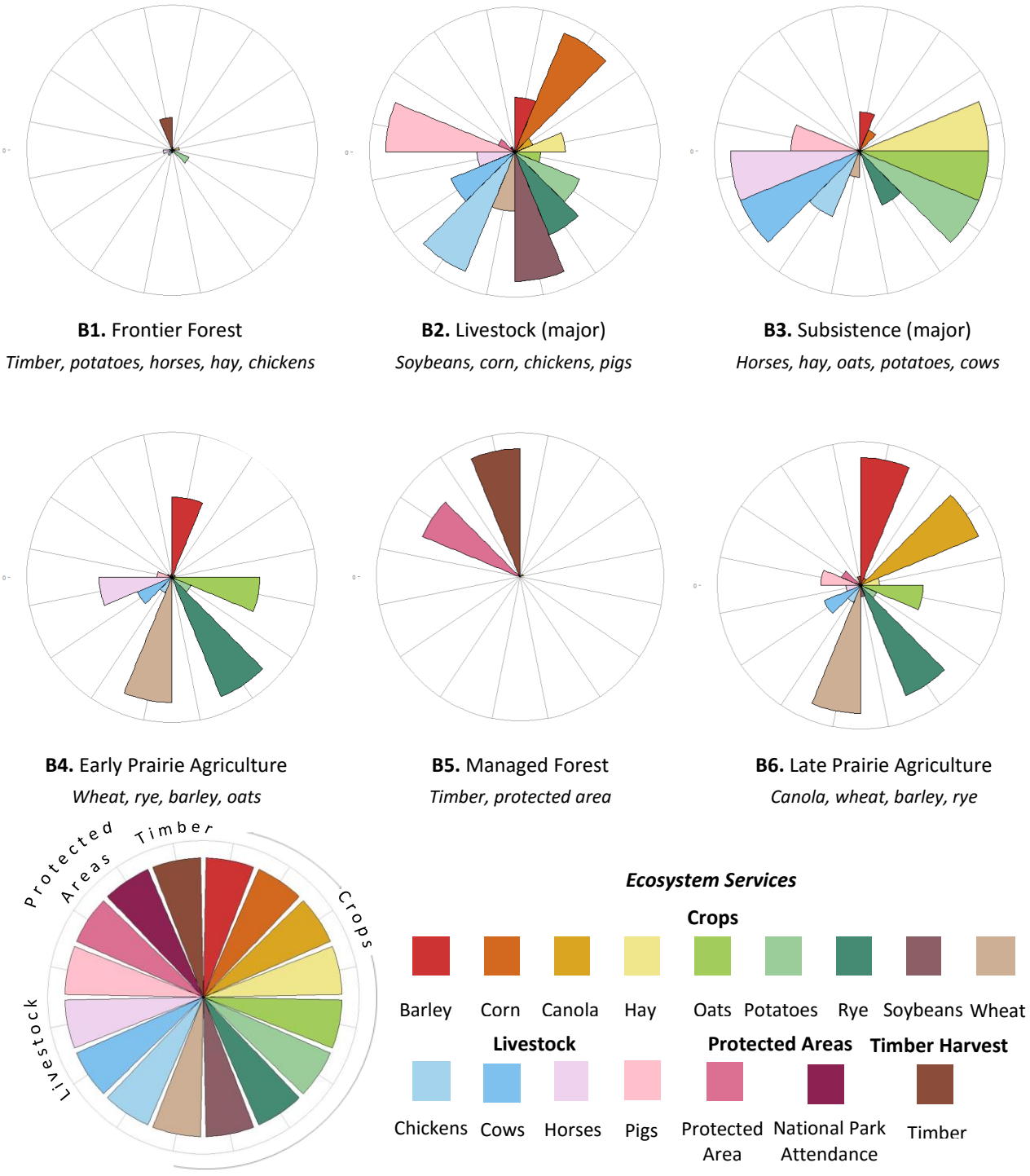
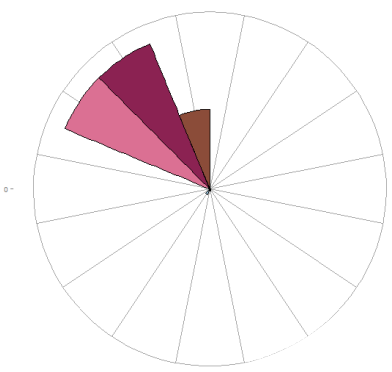
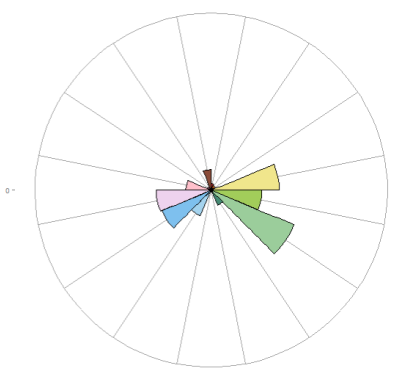



**Figure 7** Ecosystem service bundles standardized for comparison between bundles. In whichever bundle a servic in most abundant it has a value of one. In all other bundles where that service was represented it had a value between zero and one.

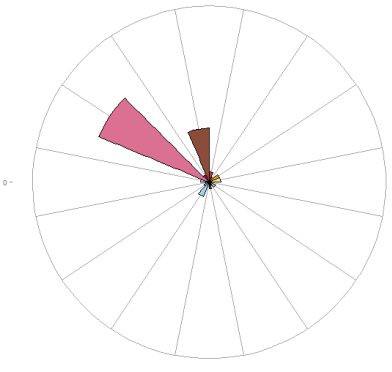
**Ecosystem Service Bundles identified using K-means analysis**
*(comparable between bundles)*



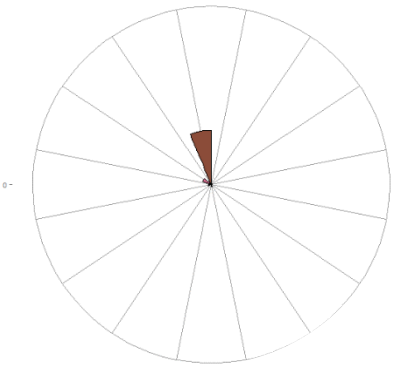
**B7.** Popular Parks
*National park attendance, protected area, timber*



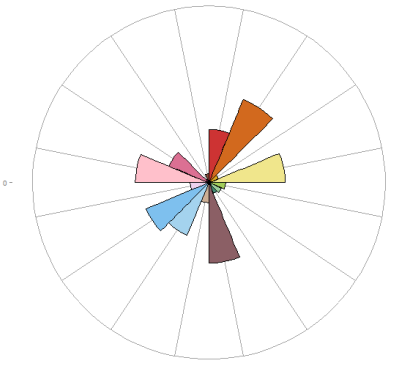
**B8.** Subsistence (minor)
*Potatoes, hay, horses, cows, oats*



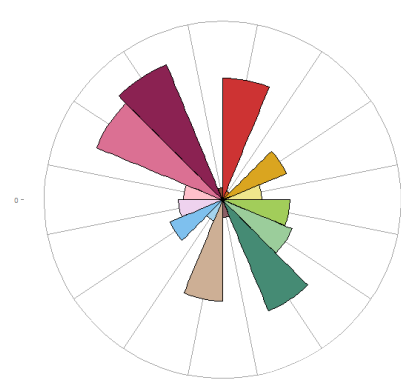
**B9.** Multi-use protected area
*Protected area, timber, chickens, corn*



**B10.** Unmanaged Forest
*Timber*



**B11.** Livestock (minor)
*Corn, soybeans, hay, pigs, cows, chickens*



**B12.** Tourism and Working Landscapes
*National park attendance, corn, barley, rye, wheat, protected area*

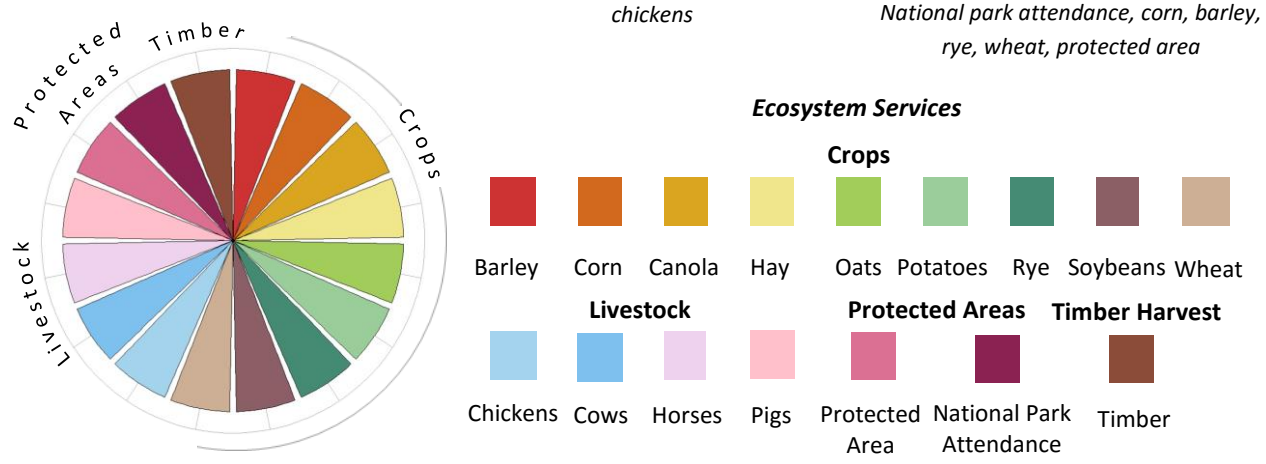



**Figure 7 (continued)** Ecosystem service bundles standardized for comparison between bundles. In whichever bundle a service is most abundant, it has a value of one. In all other bundles where that service was represented it had a value between zero and one.

### 3.2.2 Bundles transitioned along a temporal and regional gradient

Of the twelve bundles, seven increased and five decreased to varying degrees through time. B2 increased the most over the century, while B3 showed the greatest decline. What is more, all five of the decreasing bundles (B1, B3, B4, B8, and B10) were provisioning-service oriented while all three cultural service bundles (B7, B9, and B12) showed increases in county representation (Table 2).

Transitions through time between the five decreasing bundles and the seven increasing bundles showed a tendency to shift from low production and limited service diversity to bundles that generally provided higher amounts of more services (Figure 8). Bundles (standardized for comparison to each other) show three trends: (1) Relatively unproductive bundles transitioning into service provisioning: for example, Unmanaged Forest (B10), which is made up of a small amount of timber harvest and an almost imperceptible mixture of protected area and horses, was replaced by Managed Forest (B5), which included large amounts of both timber harvest and protected area; (2) Bundles transitioning to include a new dominant service: Early Prairie Agriculture (B4), for instance, which was predominantly composed of wheat, rye, and barley, was almost always replaced by Late Prairie Agriculture (B6) which had a similar composition of wheat, rye, and barley, but included a large amount of canola; (3) Bundles that were replaced by different functional compositions entirely; for example, Subsistence (major) (B3) which included horses, cows, hay, oats, and potatoes, was largely replaced by Livestock (major) (B2), which is characterized by soybeans, corn, pigs, and chickens. (Figure 8).

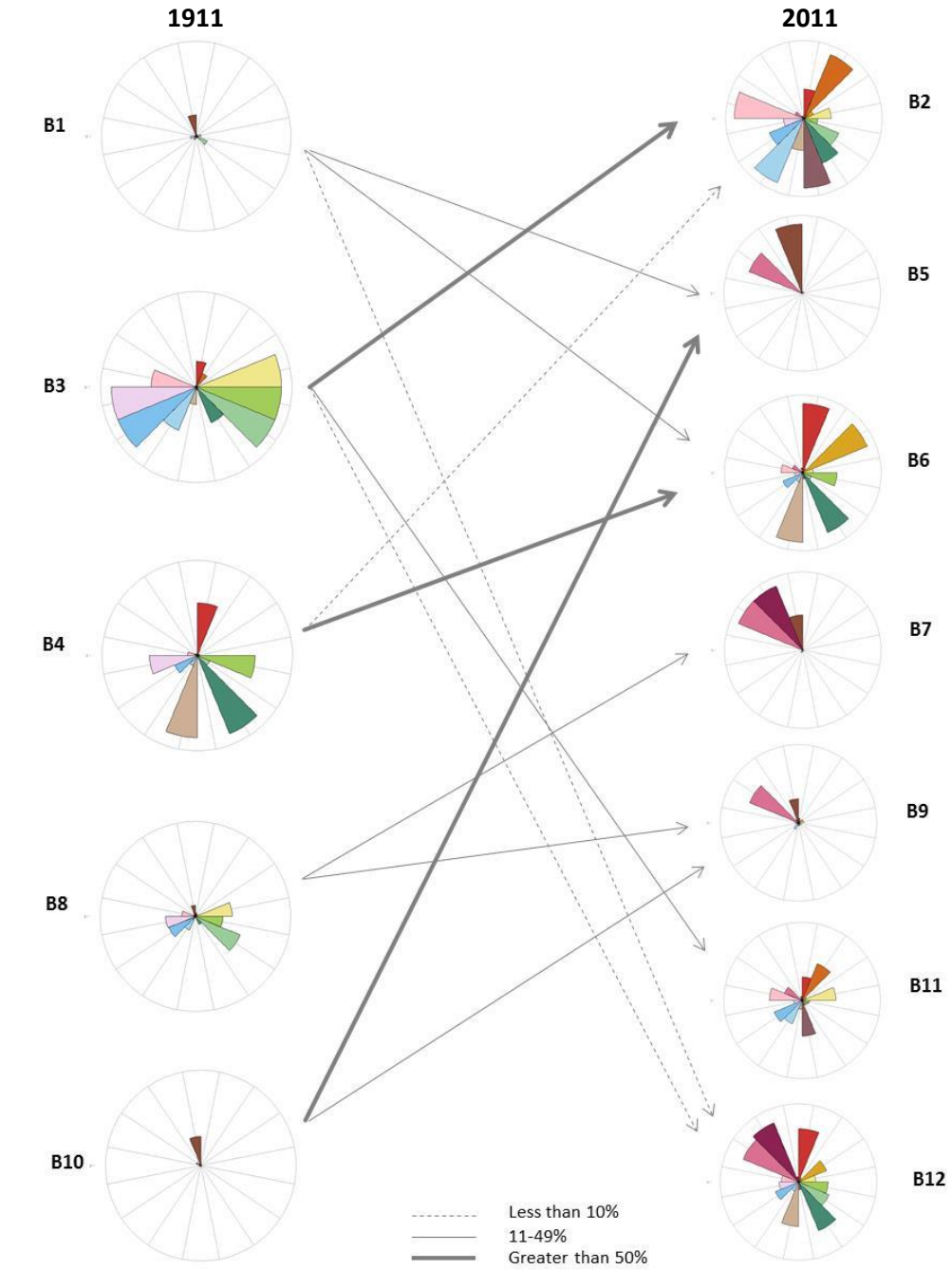
The bundle provided by any given county changed through time and the number of transitions a county experienced was largely regionally defined. Only three and a half per cent of counties ($n$=10) provided the same bundle of services for the entire one hundred year period, while eight per cent of counties ($n$=23) experienced four or more changes. The average number

of bundle transitions a county underwent over the study period was two. 90% of the counties that experienced a greater than average number of transitions were in the Central and Maritime Provinces, while 58% of the counties that experienced a below average number of transitions were in the Prairie Provinces and British Columbia (Figure 9).[4]

4. This analysis includes Newfoundland. Since the province entered confederation in 1949, Census data are only available from 1951 onward. The missing data from 1911 to 1941 were filled in with the first available records, and therefore, Newfoundland's bundles do not reflect change over time for the same period as the other provinces. Without Newfoundland, only one percent of counties ($n$=4) provided the same service for the entire century.

**Table 2** Number of counties (total counties= 283) providing each of the twelve bundles over time between the first and last appearance of each bundle.

| | *Number of counties per bundle per year* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bundle Year** | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** |
| **1911** | 62 | 0 | 76 | 22 | 3 | 0 | 0 | 67 | 3 | 49 | 0 | 1 |
| **1921** | 47 | 0 | 80 | 44 | 3 | 0 | 0 | 58 | 6 | 44 | 0 | 1 |
| **1931** | 55 | 0 | 70 | 43 | 4 | 0 | 2 | 62 | 9 | 34 | 0 | 4 |
| **1941** | 53 | 2 | 77 | 45 | 10 | 0 | 2 | 50 | 13 | 27 | 0 | 4 |
| **1951** | 58 | 4 | 63 | 43 | 13 | 0 | 2 | 57 | 13 | 25 | 0 | 5 |
| **1961** | 65 | 5 | 52 | 39 | 16 | 0 | 7 | 54 | 13 | 23 | 0 | 9 |
| **1971** | 69 | 8 | 25 | 3 | 23 | 38 | 11 | 43 | 17 | 35 | 3 | 8 |
| **1976** | 51 | 15 | 12 | 15 | 27 | 25 | 15 | 29 | 19 | 58 | 8 | 9 |
| **1981** | 37 | 20 | 8 | 9 | 30 | 35 | 17 | 19 | 28 | 59 | 14 | 7 |
| **1986** | 34 | 20 | 1 | 6 | 35 | 38 | 18 | 11 | 30 | 59 | 24 | 7 |
| **1991** | 23 | 33 | 3 | 5 | 39 | 39 | 14 | 13 | 35 | 36 | 36 | 7 |
| **1996** | 17 | 39 | 3 | 1 | 47 | 42 | 14 | 7 | 40 | 32 | 34 | 7 |
| **2001** | 11 | 47 | 1 | 0 | 47 | 44 | 14 | 3 | 41 | 31 | 38 | 6 |
| **2006** | 7 | 51 | 1 | 0 | 55 | 41 | 15 | 3 | 48 | 18 | 38 | 6 |
| **2011** | 2 | 52 | 0 | 1 | 55 | 40 | 15 | 4 | 53 | 15 | 40 | 6 |



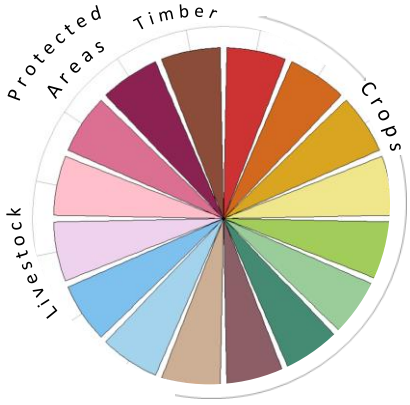




**Figure 8** Transitions of bundles (standardized for comparison between bundles) that decreased through time and the bundles that replaced them by 2011. The transition percentages were calculated by counting the number of counties that provided a given bundle through time. For example, a transition of "Greater than 50%" indicates that more than fifty percent of the counties that originally provided a bundle in 1911 (B1, B3, B4, B8, or B10) have transitioned to the bundle pointed to by the arrow by 2011.

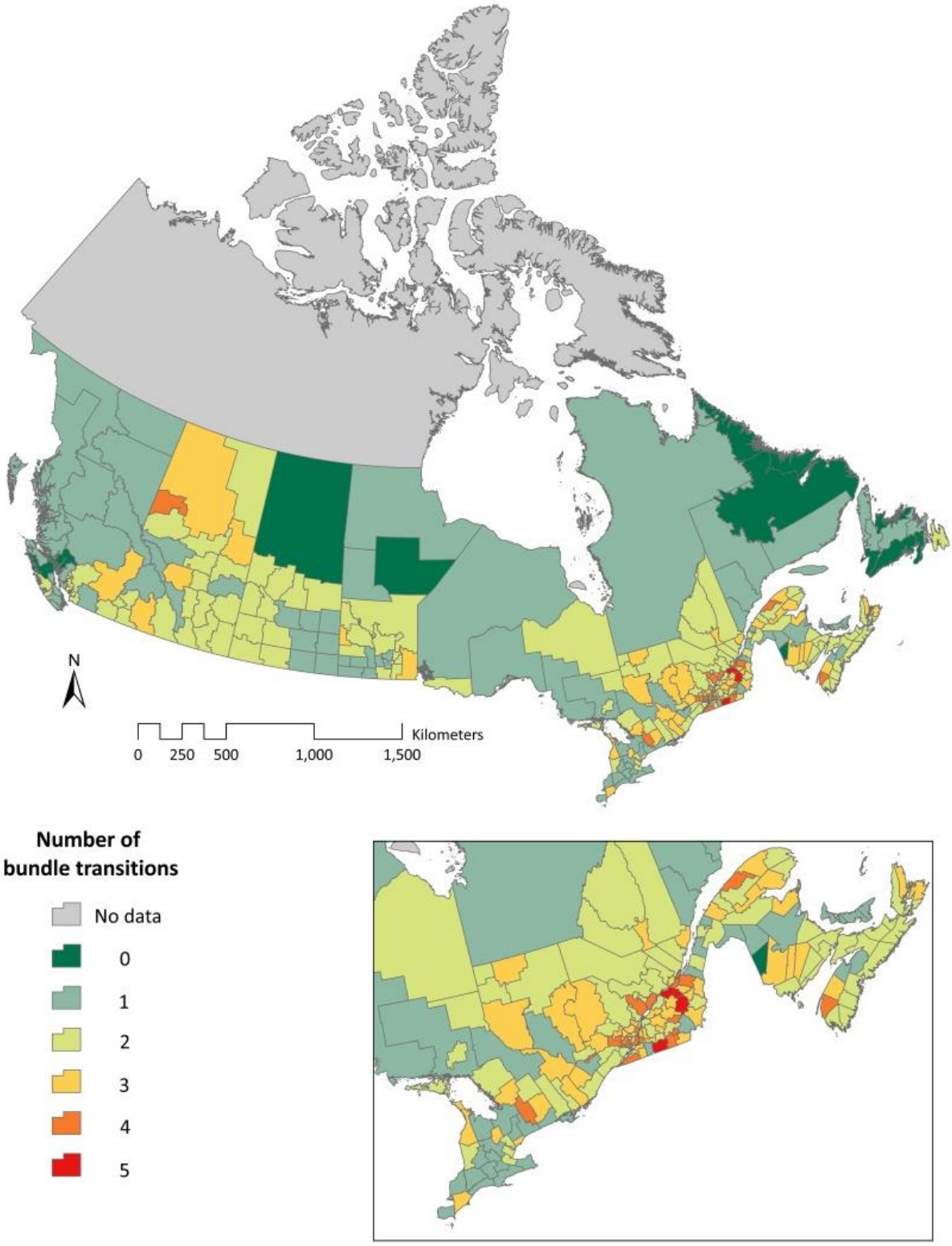


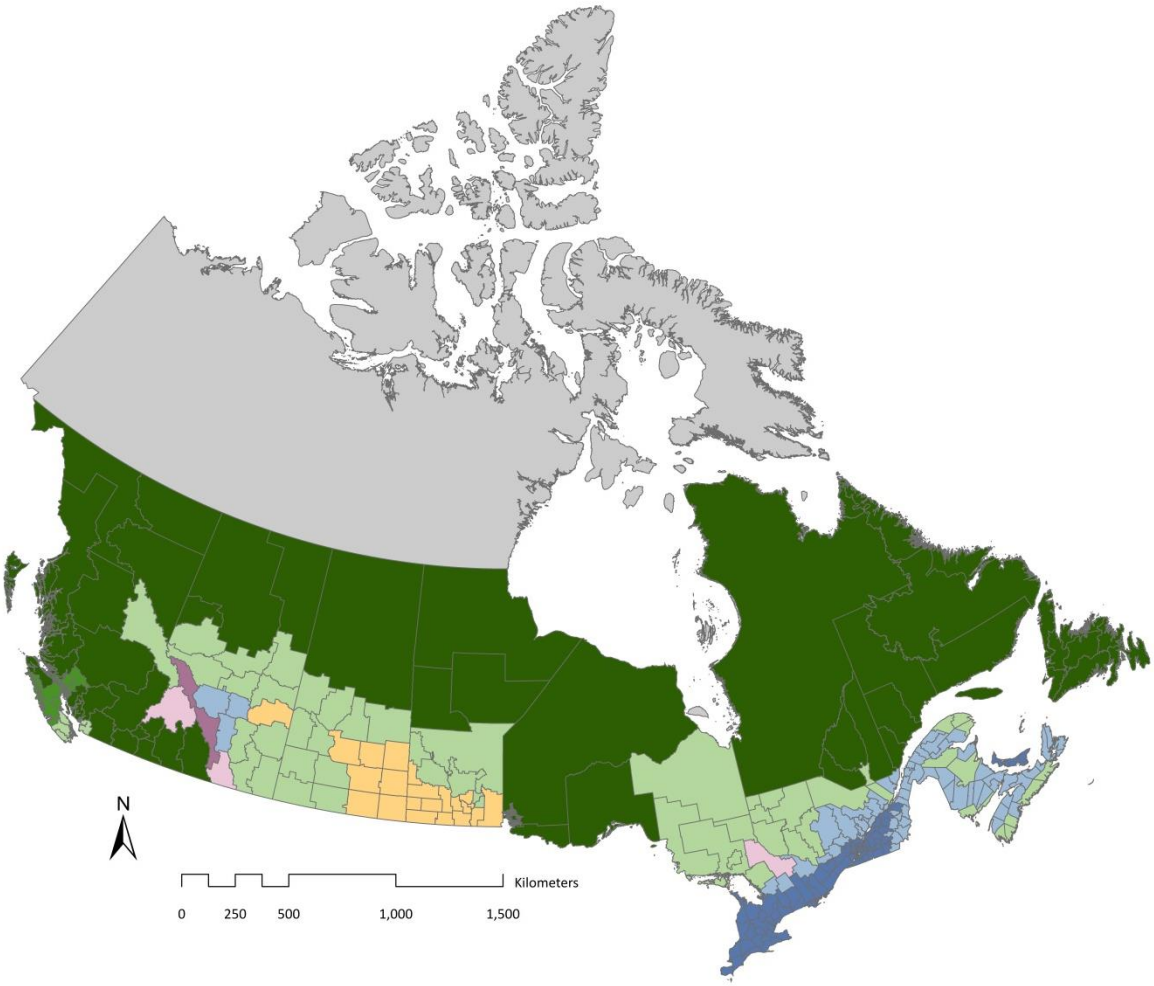

**Figure 9** Number of bundle transitions experienced by each county from 1911- 2011. A value of "1" indicates that a county transitioned once, providing two bundles over the course of the time period.

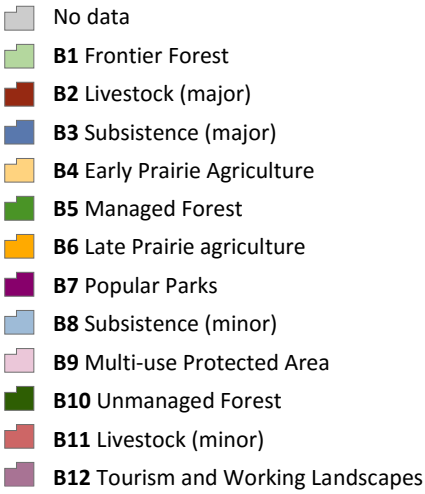
## 3.3. Spatial distribution of ecosystem service bundles

### 3.3.1 Over time there was an increase in the number and complexity of bundles present on the landscape

Maps of ecosystem service bundles from 1911 to 2011 show that at the beginning of the time series, fewer bundles were represented on the landscape (*n*=8) and over time there was a steady increase in the number of bundles (*n*=12, 1971-1996) and only a slight decrease by the end of the century (*n*=10, 2001-2011) (Figures 10-25). B3 (Subsistence (major)) and B4 (Early Prairie Agriculture), had all but disappeared from the landscape by 2001 (Figure 22). For the last three time steps (Figures 23-25), these two bundles were present in only three counties across all of Canada. In contrast, four bundles that were not present in 1911 (B2 Livestock (major), B3 Subsistence (major), B6 Late Prairie Agriculture, and B11 Livestock (minor)) had established themselves on the landscape along with an ever increasing, and marked presence of protected areas. Overall, there was a marked expansion of the Prairie bundles (B4, B6), protected areas (B7, B9, B12), and livestock (B2, B11), with decreases in subsistence farming (B3, B8), low-level timber provisioning (B10), and mixed farming (B1).

As previously mentioned, counties in eastern Canada were more dynamic over the one hundred year period, transitioning to several different bundles over time. Consequently, a far more complex and diverse patchwork of bundles had developed in the St. Lawrence Valley of Quebec and Ontario than anywhere else in the country (Figure 9). Other dynamic regions were the Maritime Provinces, and to a lesser extent, the outer limits of the Prairie agricultural region.



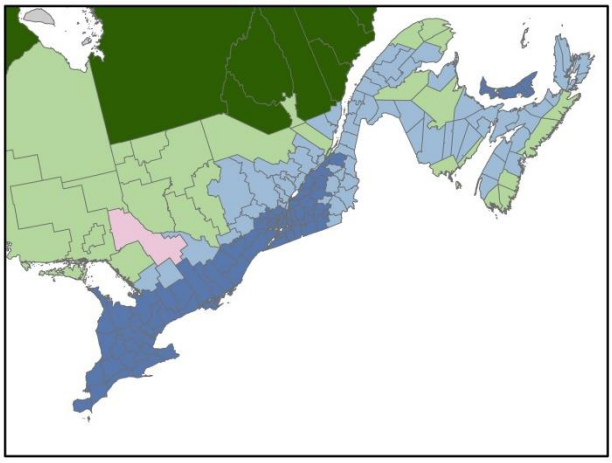



**Figure 10 Ecosystem Service Bundles in Canada, 1911** Eight bundles are represented on the landscape. Early regional specialization is apparent in Eastern Canada and the southern Prairies. Subsistence-based bundles (B3 and B8) dominate many of the eastern counties, while Early Prairie Agriculture (B4) characterizes the Prairie region. Counties on the boundaries of these two regions are defined by Frontier Forest (B1). The majority of remaining counties are represented by Unmanaged Forest (B10.) Only a few counties, mostly in the Rocky Mountains, are characterized by protected area bundles (B9 and B12.)

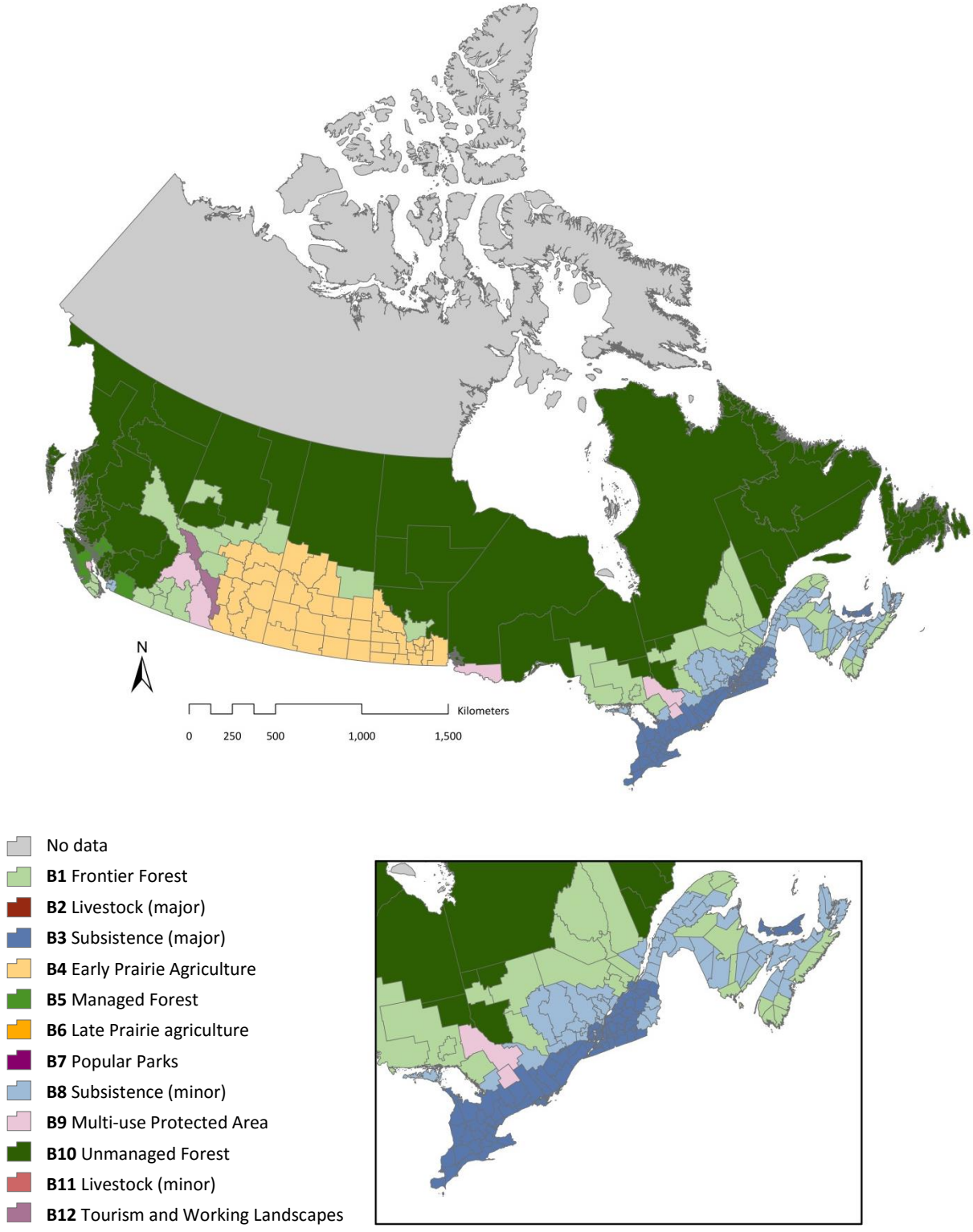
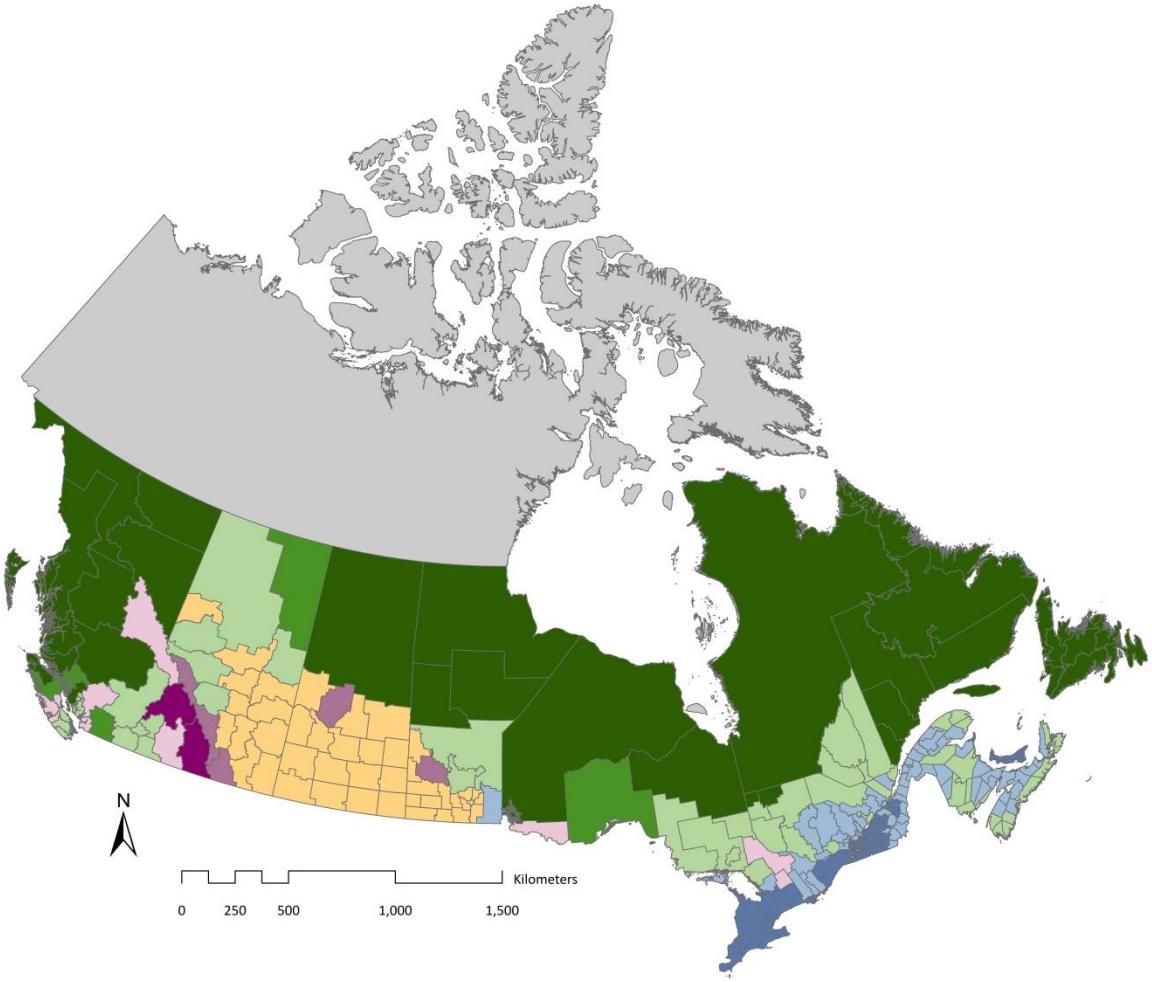
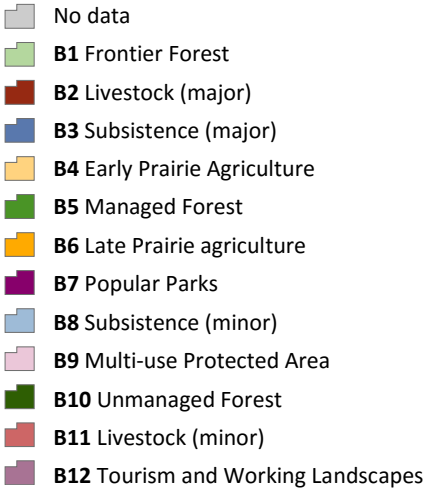



**Figure 11 Ecosystem Service Bundles in Canada, 1921** Early Prairie Agriculture (B4) expands markedly, replacing many of the Frontier Forest (B1) bundles in the Prairies.



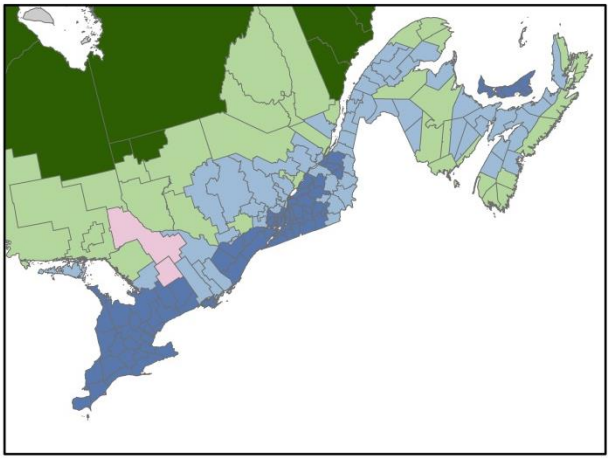



**Figure 12 Ecosystem Service Bundles in Canada, 1931** Several counties in Western Canada and the Prairies transition to multiple-use protected area bundles (B9 and B12) from Frontier Forest (B1.) Two Rocky-Mountain counties transition from multiple-use protected areas, to Popular Parks (B7.) Service provisioning gradually shifts north, replacing the low-level timber harvest of Unmanaged Forest (B10) with Frontier Forest (B1) and Managed Forest (B5.)

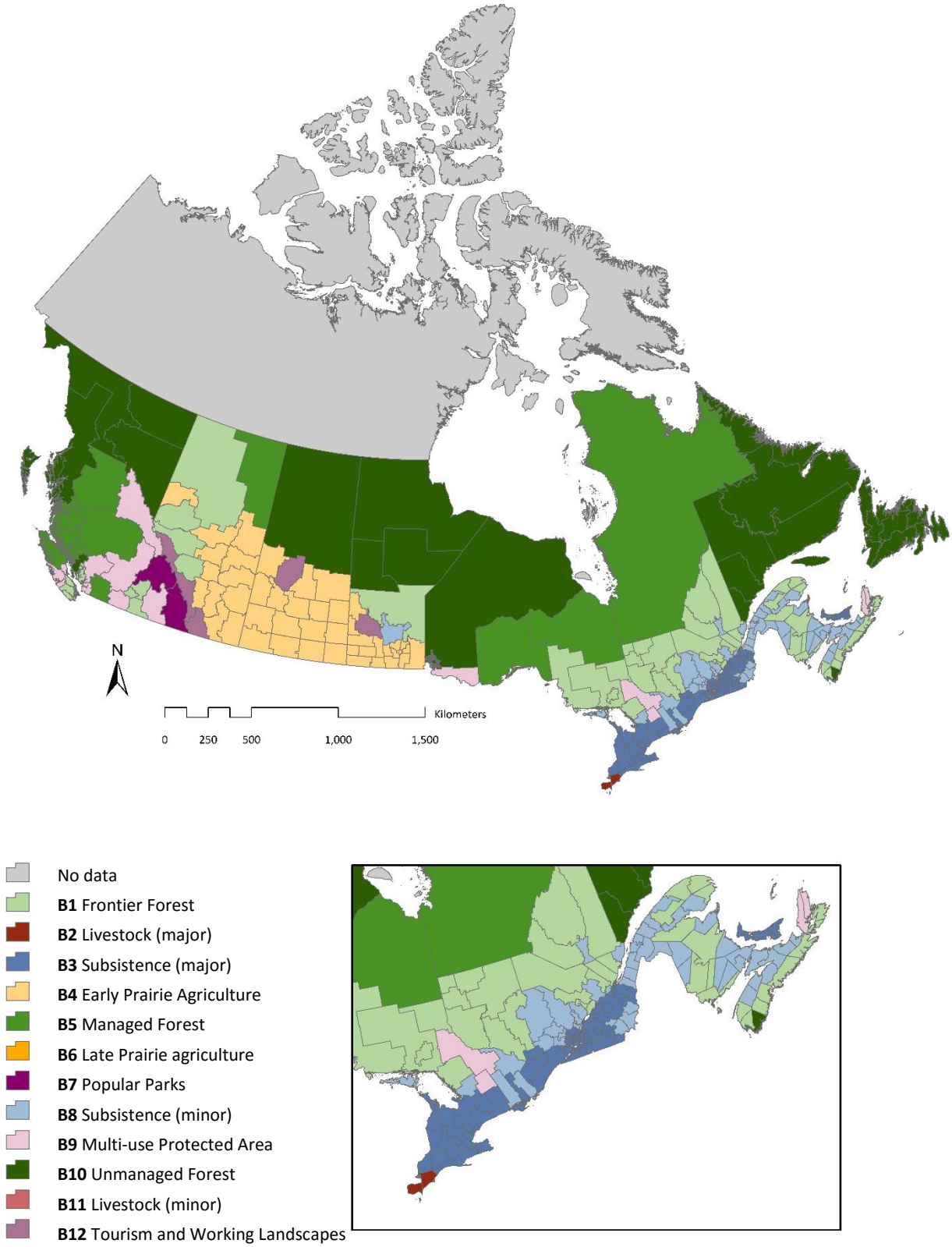
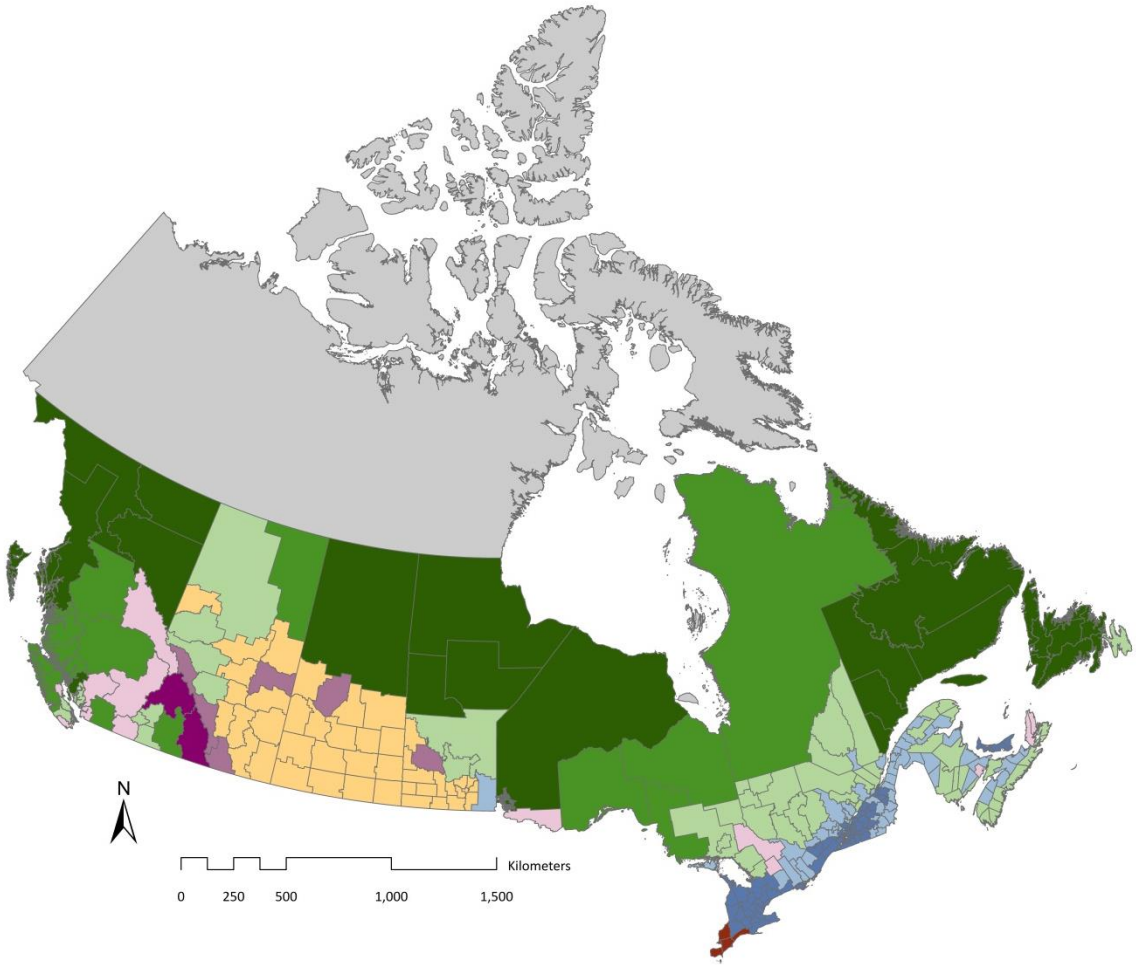
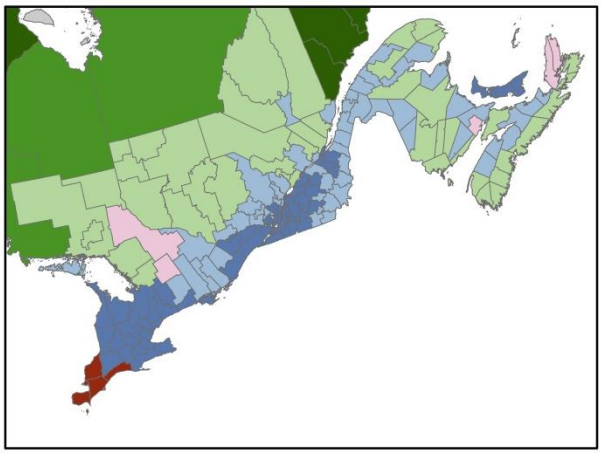


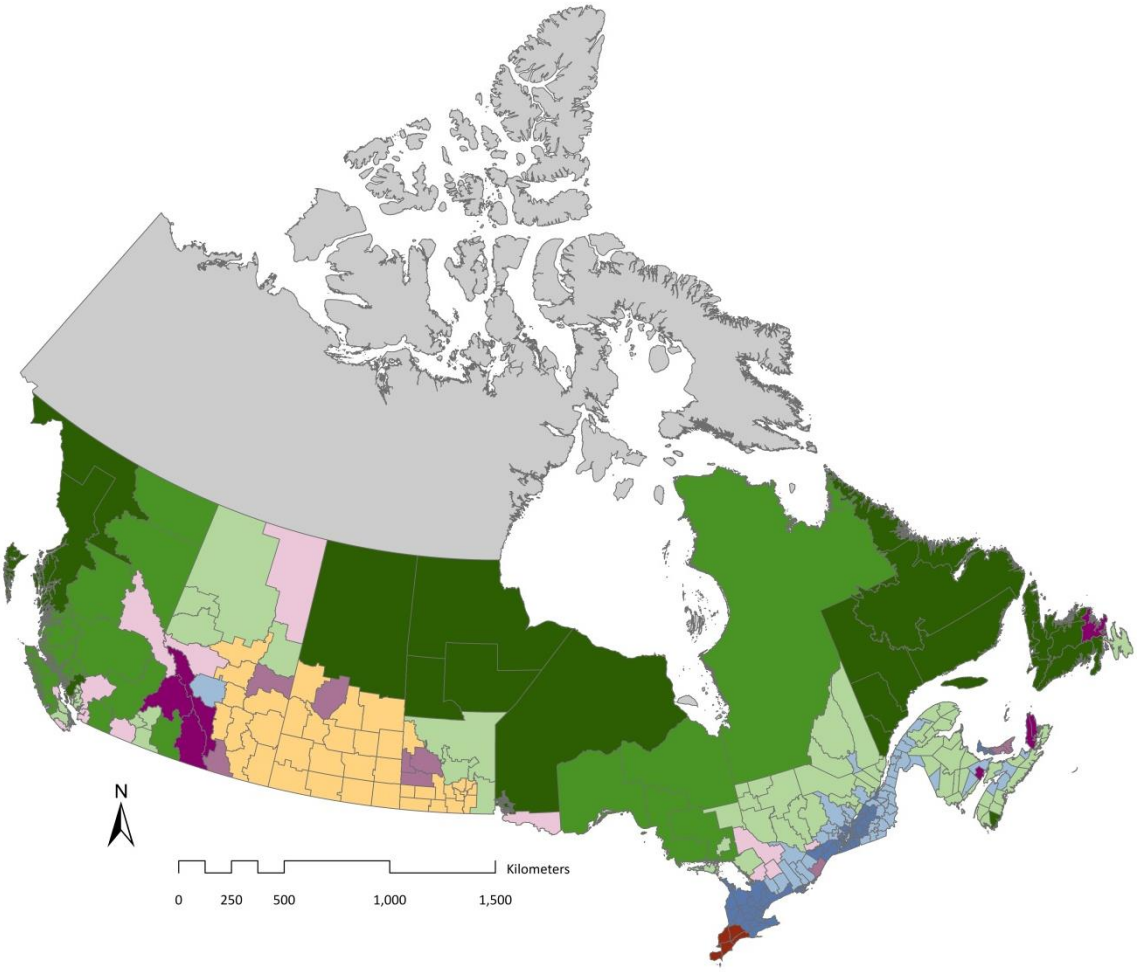

**Figure 13 Ecosystem Service Bundles in Canada, 1941** Large northern counties across the country transition from low-level timber harvest (B10) to managed forest (B5.) High magnitude livestock production (B2) appears in southern Ontario.



- No data
- **B1** Frontier Forest
- **B2** Livestock (major)
- **B3** Subsistence (major)
- **B4** Early Prairie Agriculture
- **B5** Managed Forest
- **B6** Late Prairie agriculture
- **B7** Popular Parks
- **B8** Subsistence (minor)
- **B9** Multi-use Protected Area
- **B10** Unmanaged Forest
- **B11** Livestock (minor)
- **B12** Tourism and Working Landscapes

**Figure 14 Ecosystem Service Bundles in Canada, 1951** Livestock production (B2) expands in southern Ontario. Subsistence bundles in eastern Canada decline in magnitude (from B3 to B8.) Several multiple-use protected areas (B9) are replaced by managed forest (B5) which maintains protected area but eliminates agricultural activity from the bundle.




No data
**B1** Frontier Forest
**B2** Livestock (major)
**B3** Subsistence (major)
**B4** Early Prairie Agriculture
**B5** Managed Forest
**B6** Late Prairie agriculture
**B7** Popular Parks
**B8** Subsistence (minor)
**B9** Multi-use Protected Area
**B10** Unmanaged Forest
**B11** Livestock (minor)
**B12** Tourism and Working Landscapes

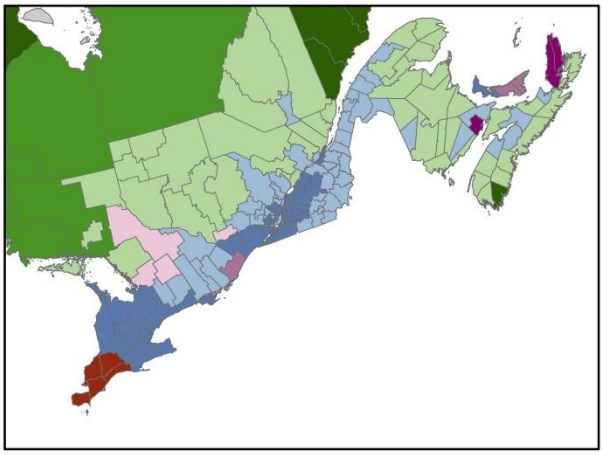
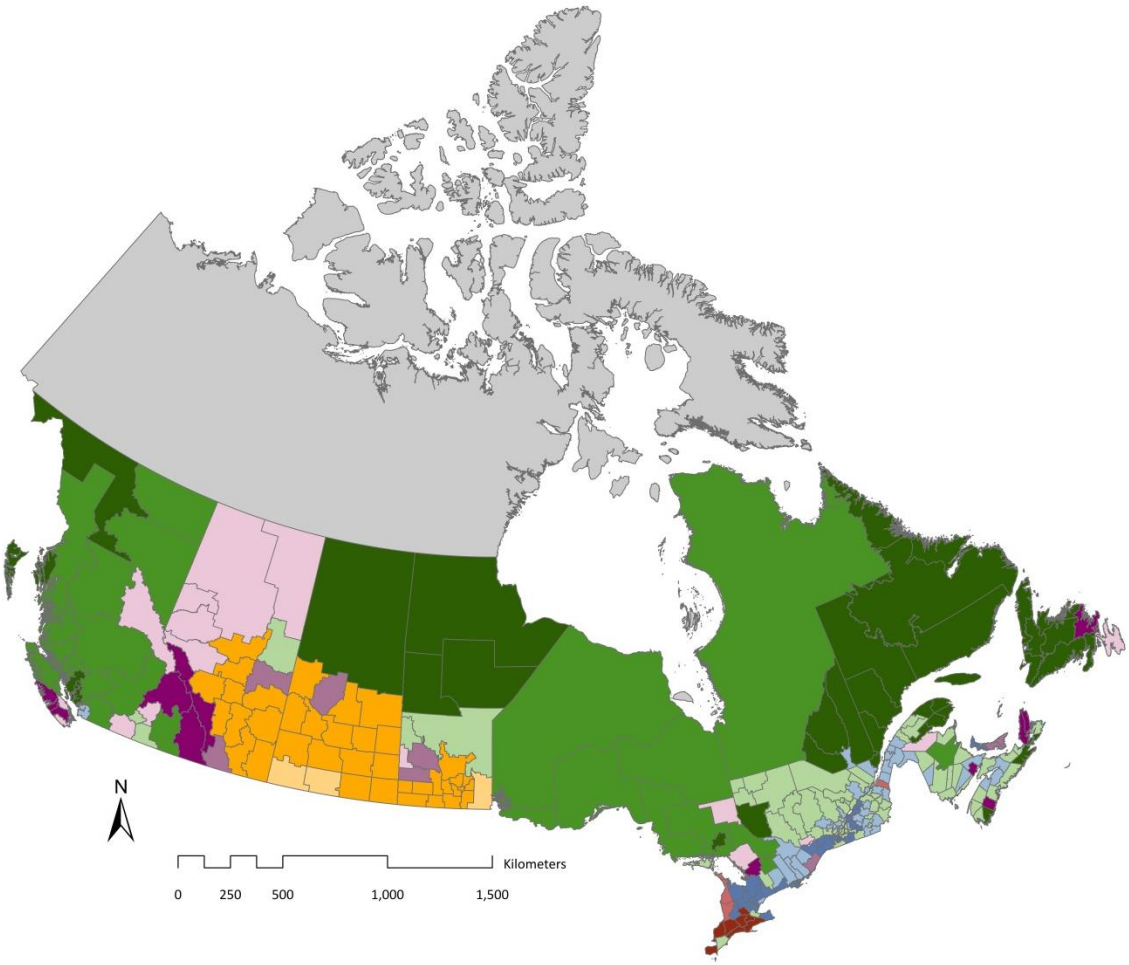
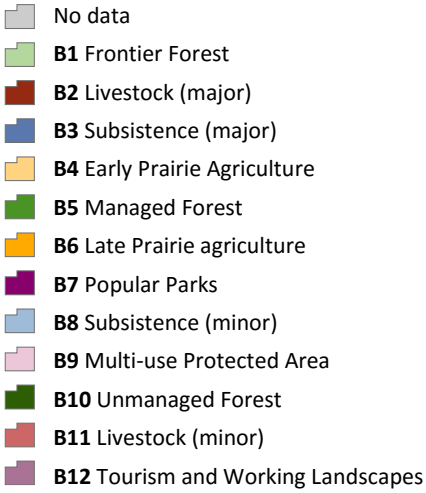


**Figure 15 Ecosystem Service Bundles in Canada, 1961** Protected areas and managed forest multiply across the country. Several counties transition to National Parks and tourism (B7), which were previously multiple-use protected areas (B9 and B12.) B12 counties also contain National Parks, however, they provide agriculture and livestock services as well. The transition to B7 focused service provisioning on protected area, tourism, and timber harvest only. Subsistence bundles continue to decline.



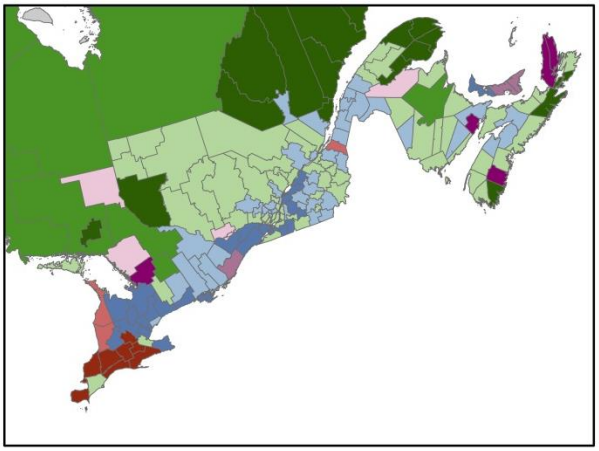
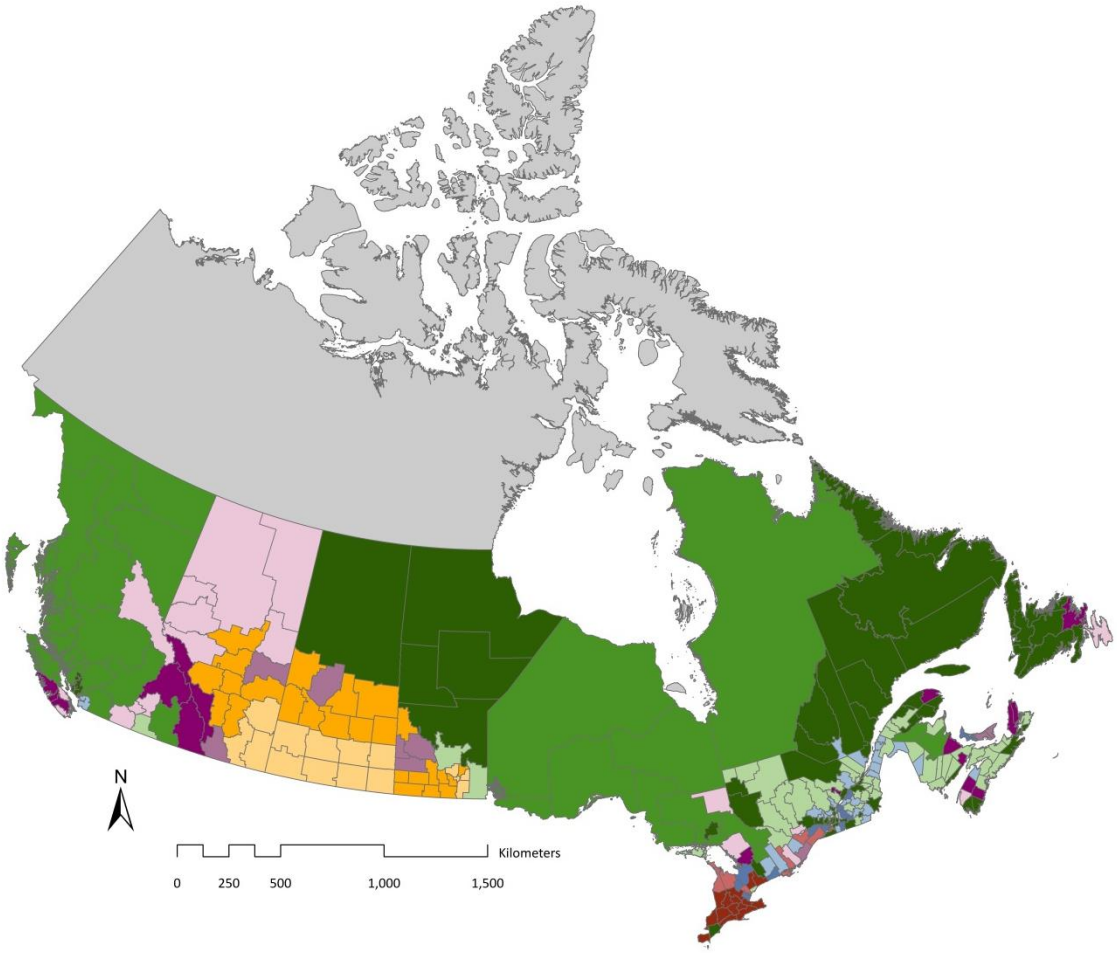



**Figure 16 Ecosystem Service Bundles in Canada, 1971** All twelve bundles are represented on the landscape for the first time. The bundle of Prairie grains that had dominated since 1911 (B4), is transformed by the addition of canola (B6.) Protected areas of all kinds and Managed Forest continue to expand across the country (B7, B9, and B5.) Livestock services increase in southern Ontario (B2 and B11.) Subsistence bundles (B3 and B8) continue to decline. Several counties in eastern Canada and the Maritimes become relatively unproductive as their mixed farming bundles (B1) are replaced by Unmanaged Forest (B10).



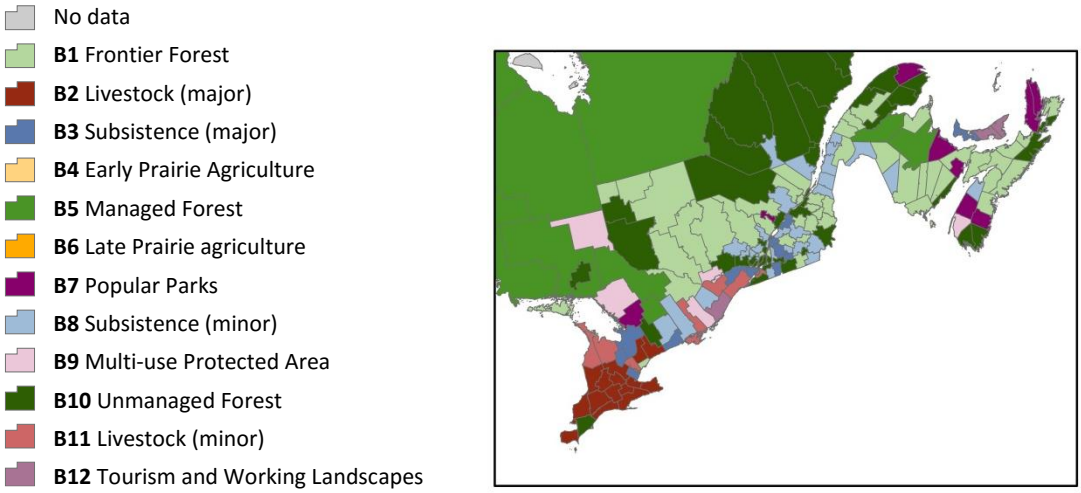
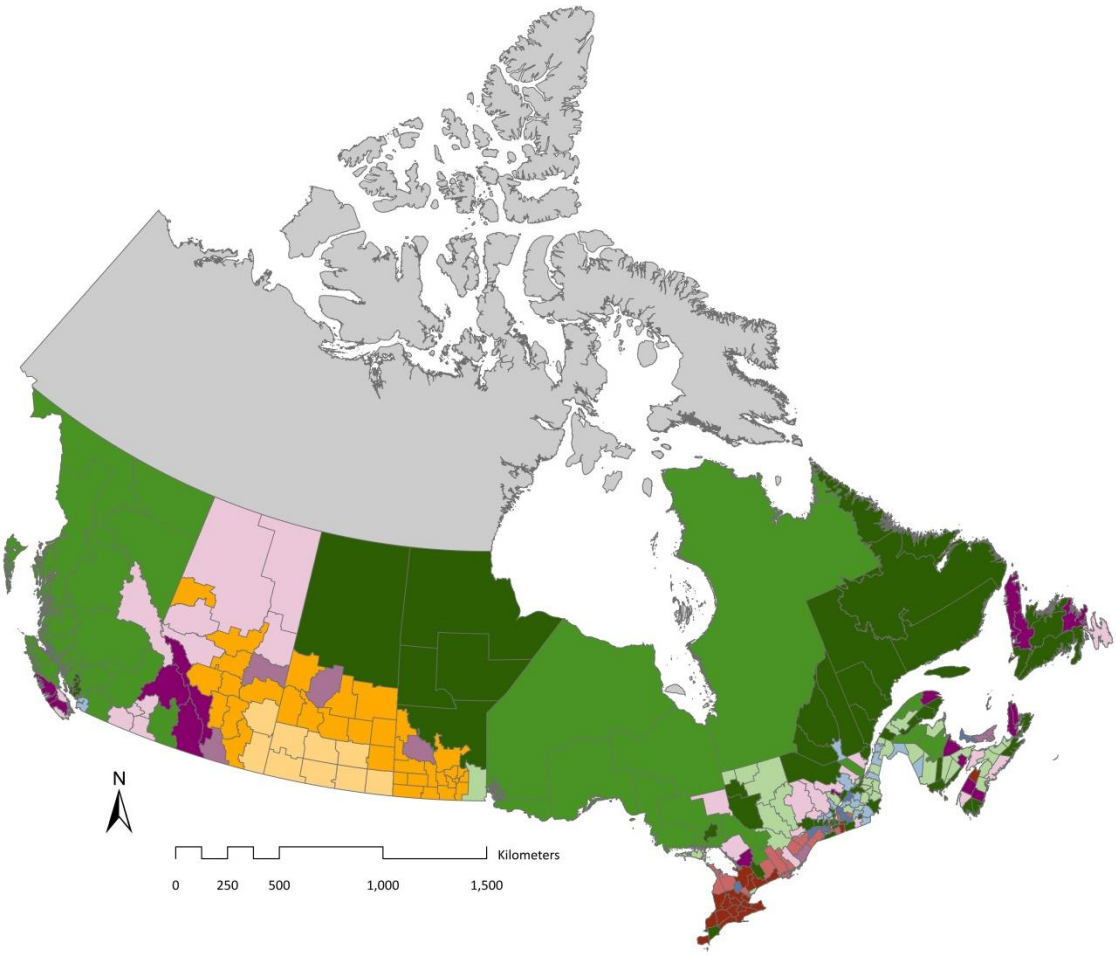




**Figure 17 Ecosystem Service Bundles in Canada, 1976** The Prairies bundle dominated by canola (B6) transitions back to the original suite of grains (B4) in several southern counties. Livestock (B2 and B11) multiplies in southern Ontario and sporadically throughout the St. Lawrence Valley replacing many remaining subsistence bundles (B3 and B8.) Several more counties, in Eastern Canada and Manitoba, transition to low-level provisioning (B10) from mixed farming (B1).




No data
**B1** Frontier Forest
**B2** Livestock (major)
**B3** Subsistence (major)
**B4** Early Prairie Agriculture
**B5** Managed Forest
**B6** Late Prairie agriculture
**B7** Popular Parks
**B8** Subsistence (minor)
**B9** Multi-use Protected Area
**B10** Unmanaged Forest
**B11** Livestock (minor)
**B12** Tourism and Working Landscapes

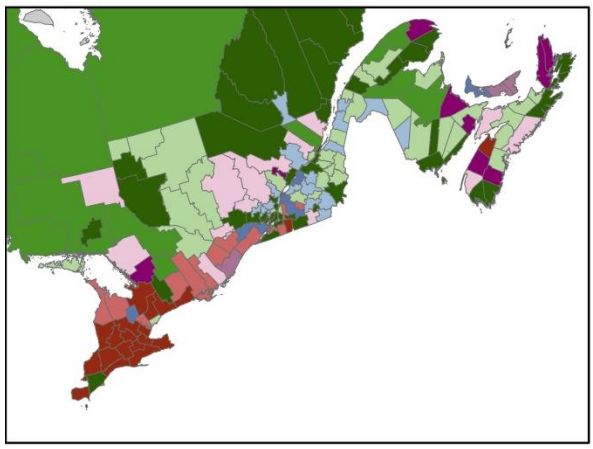
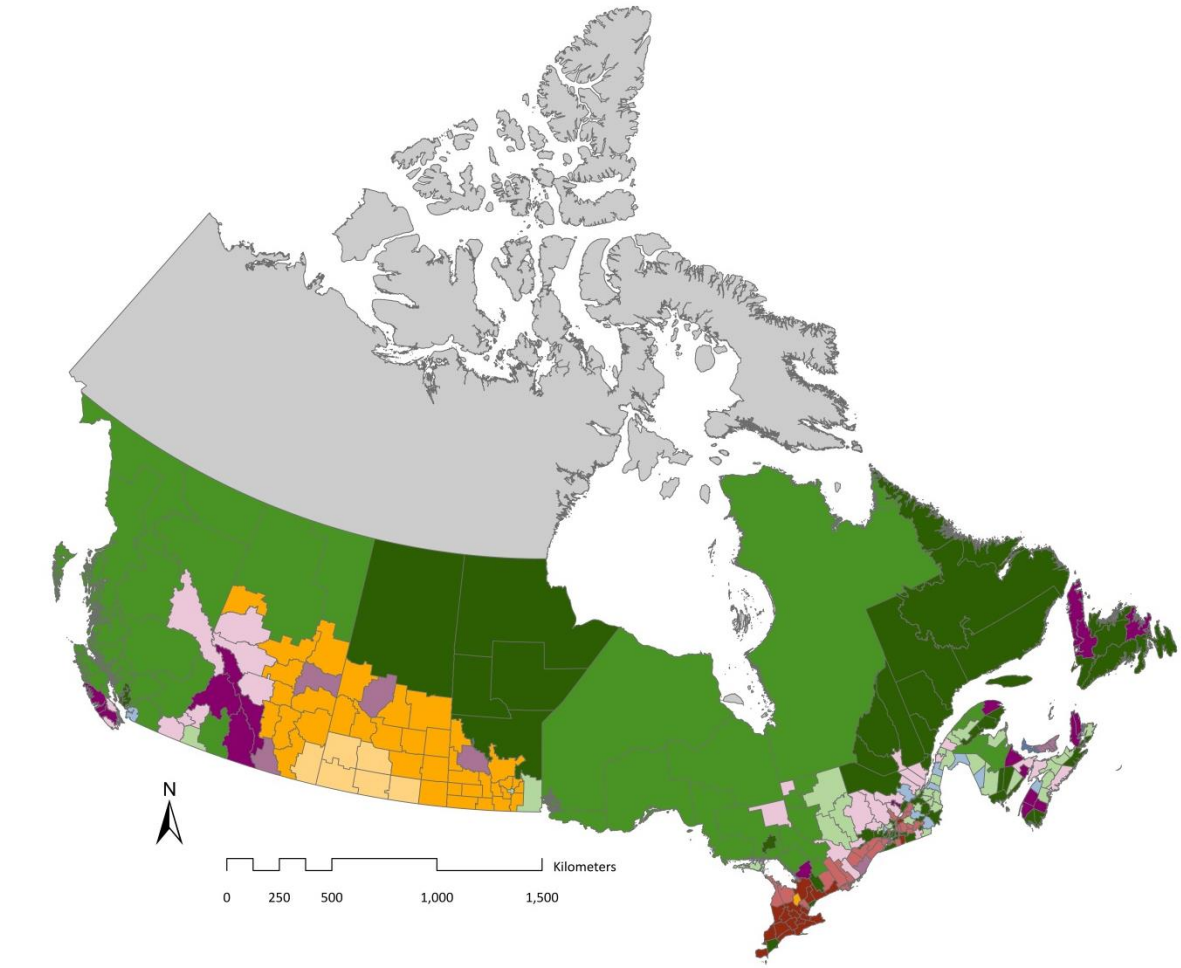


**Figure 18 Ecosystem Service Bundles in Canada, 1981** Livestock services proliferate throughout southern Ontario and the St. Lawrence Valley (B2 and B11.) Canola and grains (B6) regain ground in the Prairies. More timber and mixed farming bundles (B1) are taken out of production in Eastern Canada. The number of high-magnitude subsistence bundles (B3) is very few.




No data
**B1** Frontier Forest
**B2** Livestock (major)
**B3** Subsistence (major)
**B4** Early Prairie Agriculture
**B5** Managed Forest
**B6** Late Prairie agriculture
**B7** Popular Parks
**B8** Subsistence (minor)
**B9** Multi-use Protected Area
**B10** Unmanaged Forest
**B11** Livestock (minor)
**B12** Tourism and Working Landscapes

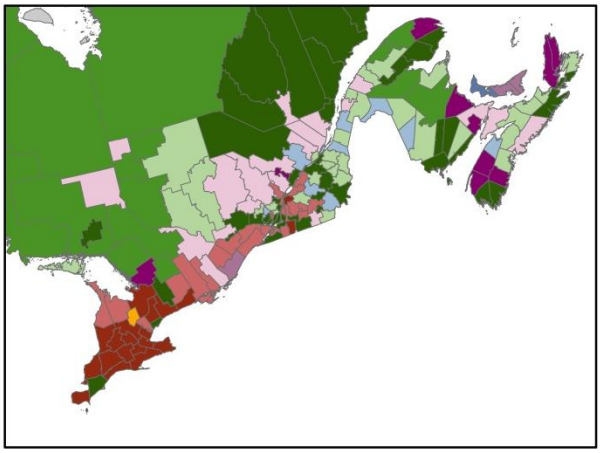


**Figure 19 Ecosystem Service Bundles in Canada, 1986** Managed Forest (B5) expands replacing bundles that included agricultural and livestock services (B9) as well as low-magnitude provisioning (B10). Canola and grains (B6) expands in the Prairies.

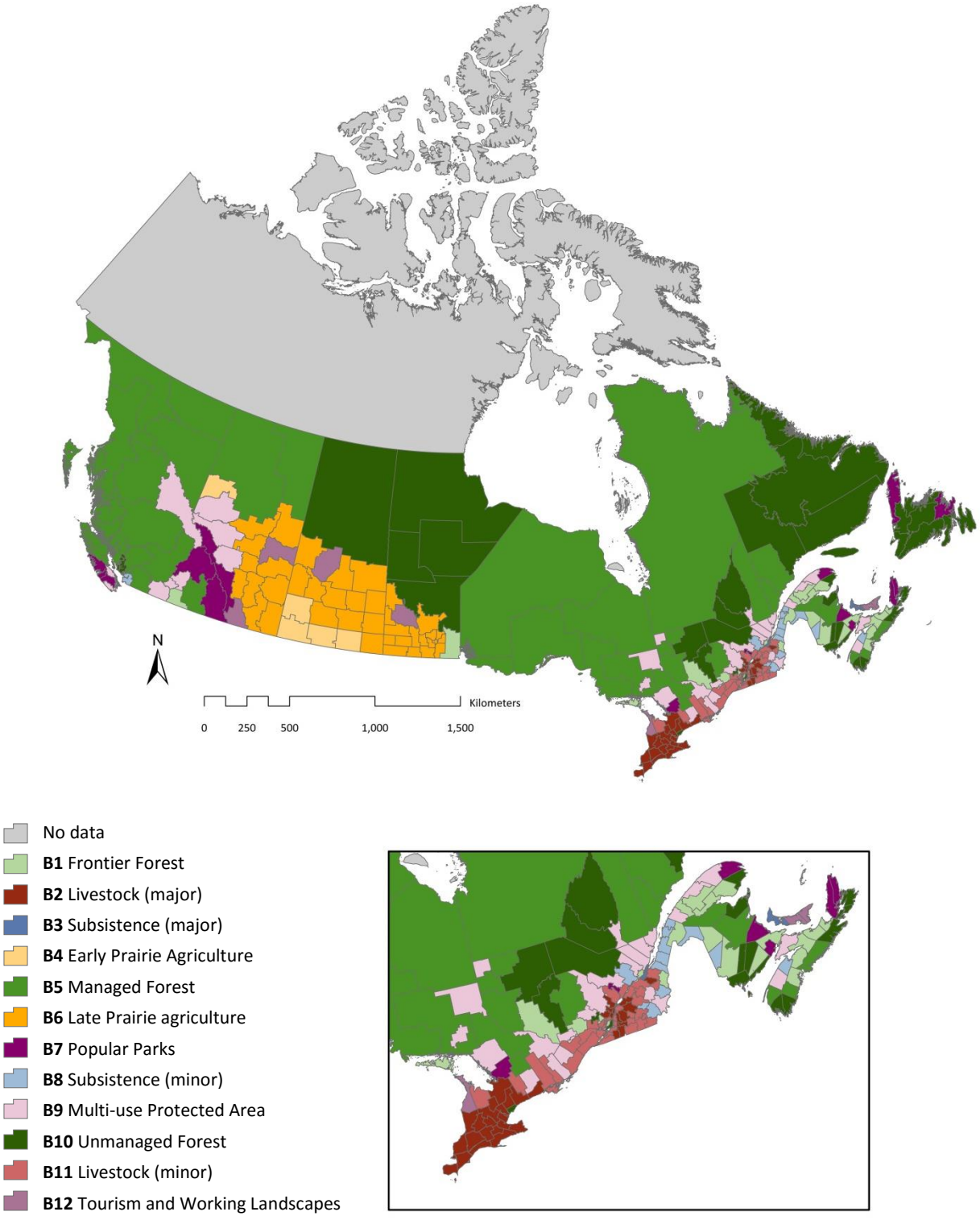



**Figure 20 Ecosystem Service Bundles in Canada, 1991** Livestock intensifies throughout southern Ontario and the St. Lawrence Valley (B2 and B11). Managed forest (B5) expands into a few counties in Eastern Canada and the Maritimes.

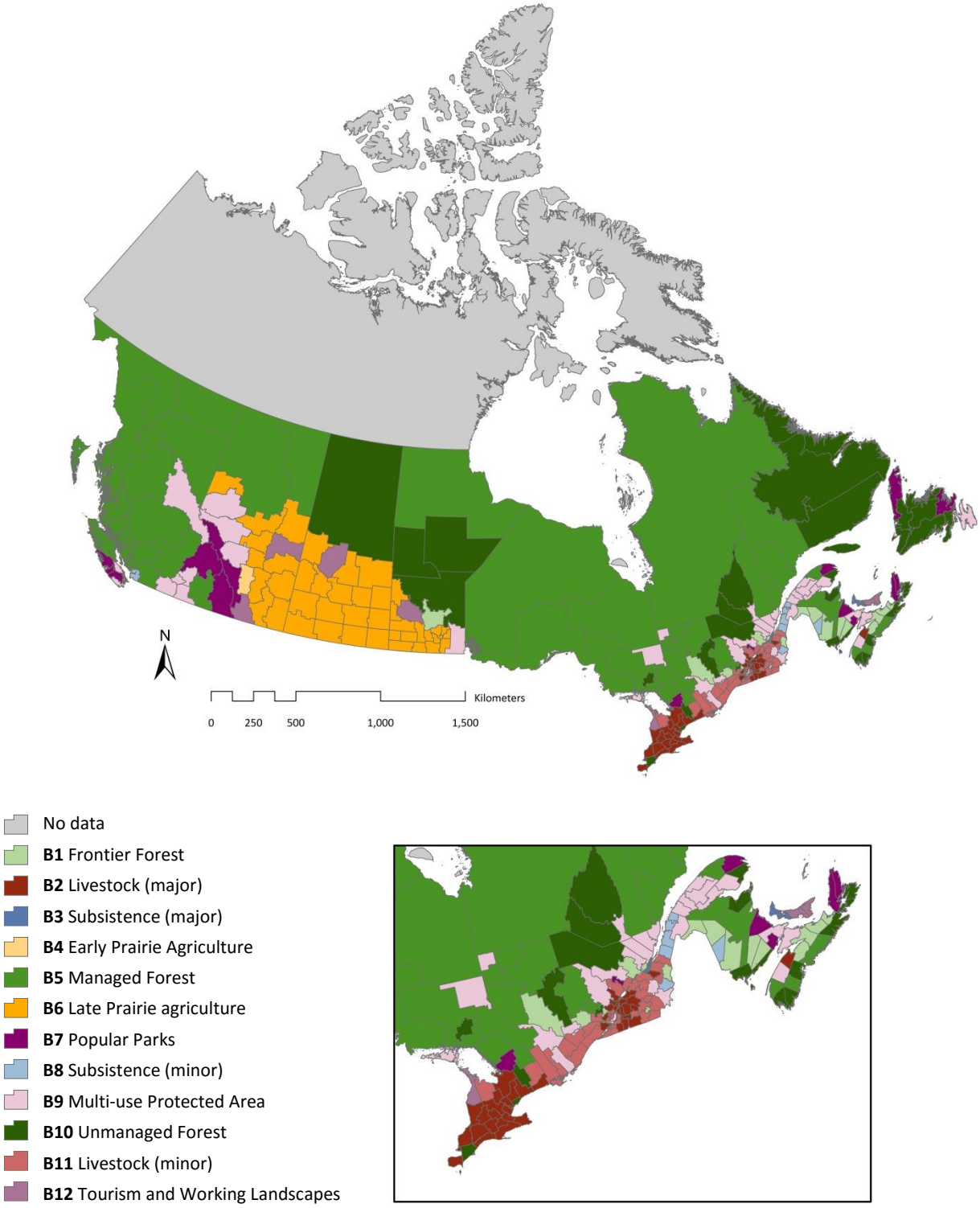
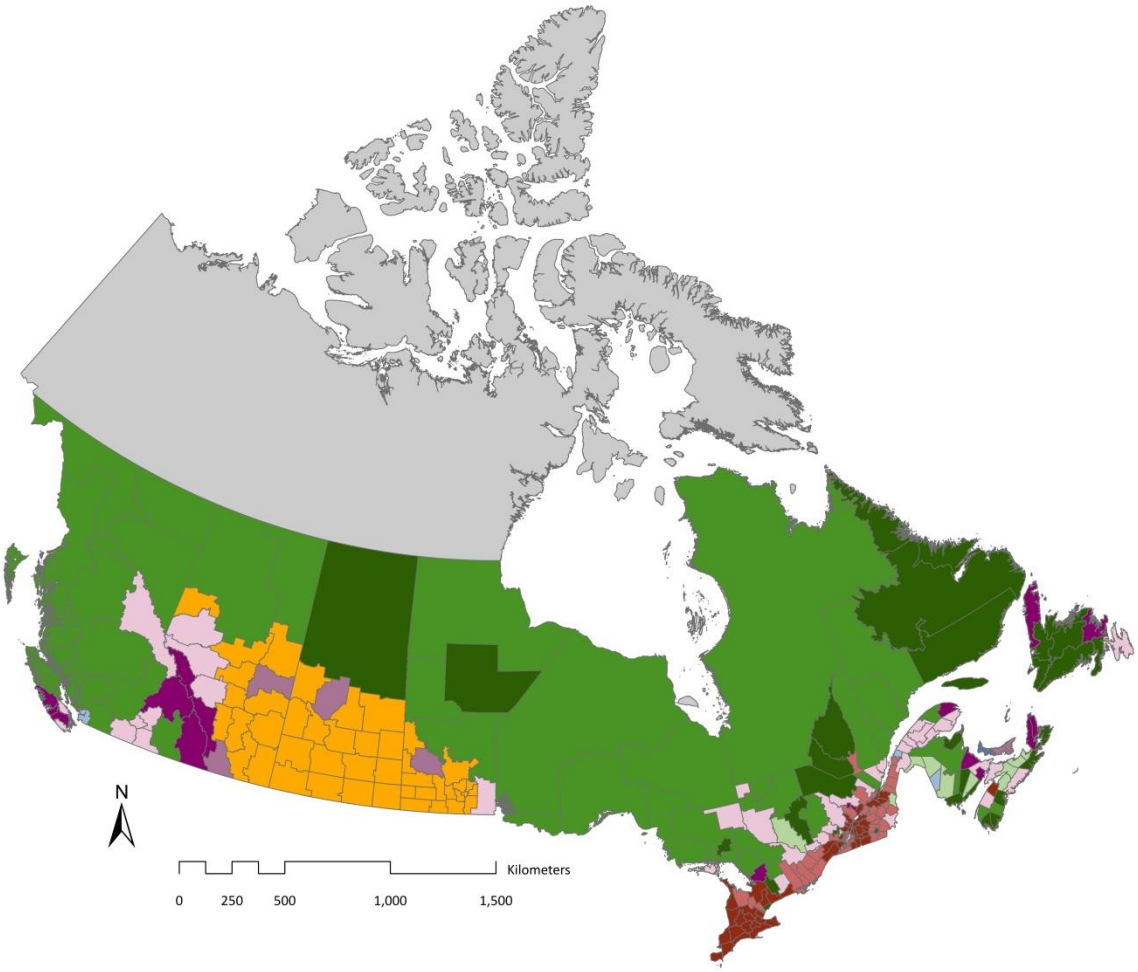
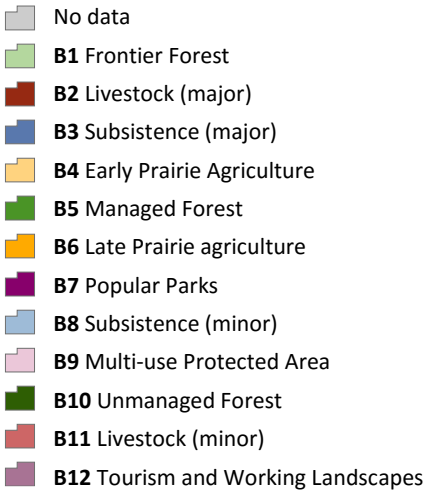



**Figure 21 Ecosystem Service Bundles in Canada, 1996** Managed forest (B5) and Canola and Prairie grains (B6) expand. Livestock (B2) continues to intensify.



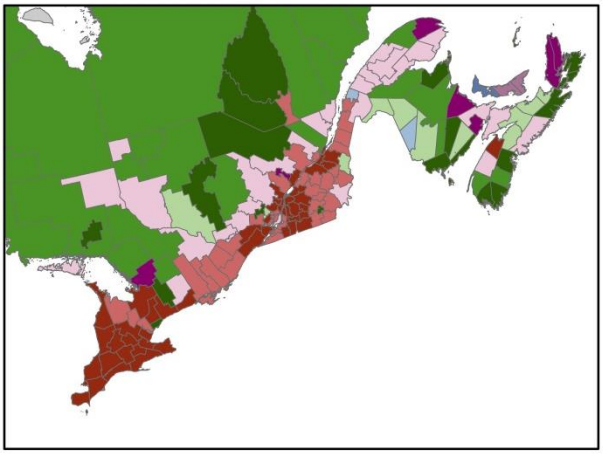
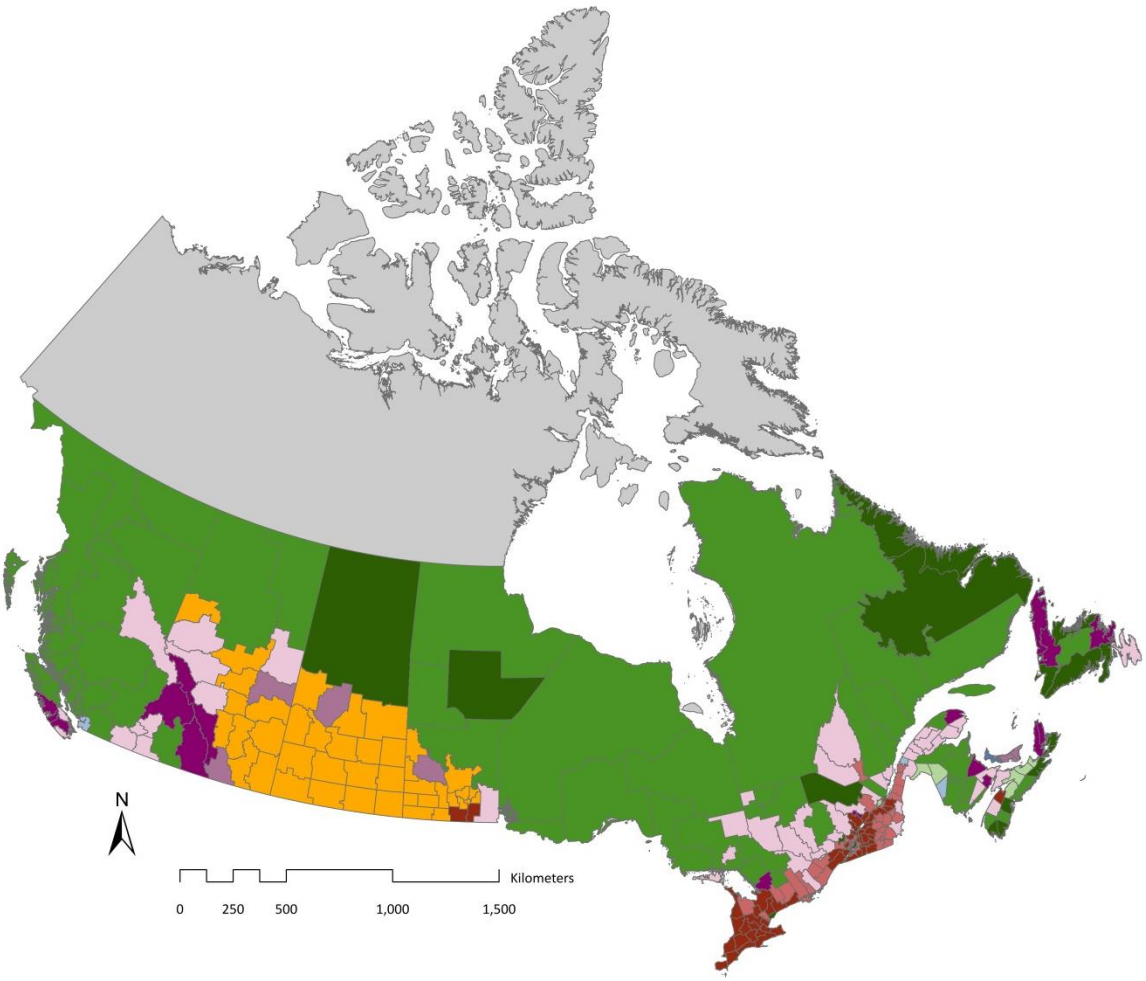
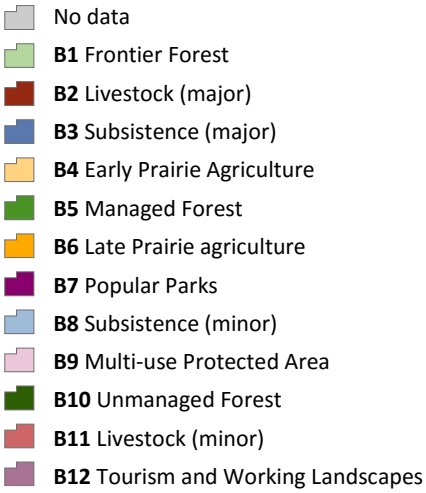



**Figure 22 Ecosystem Service Bundles in Canada, 2001** Managed forest (B5) expands in Eastern Canada. Only four subsistence bundles (B3, *n*=1, and B8, *n*=3) remain in counties in eastern Quebec, British Columbia, and the Maritimes. No bundles of Prairie grains that dominated the region at the beginning of the century remain on the landscape, reducing the number of bundles present to eleven.



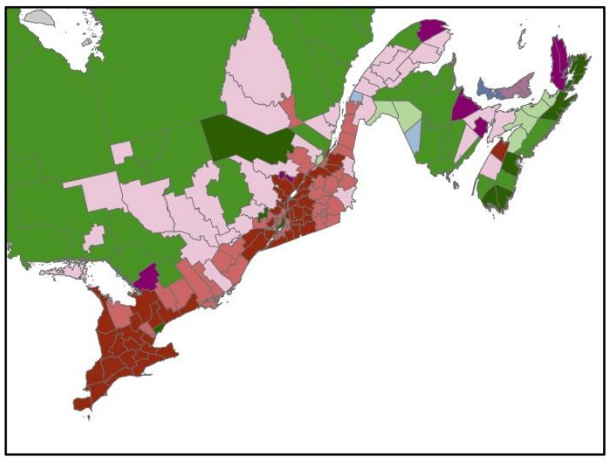



**Figure 23 Ecosystem Service Bundles in Canada, 2006** Protected areas combined with low-magnitude agriculture (B9) replace several low-magnitude provisioning and timber harvest bundles in Quebec. High-magnitude livestock provisioning (B2) appears in southern Manitoba. Managed forest (B5) expands replacing the few remaining timber and mixed farming bundles (B1) in the Maritimes.

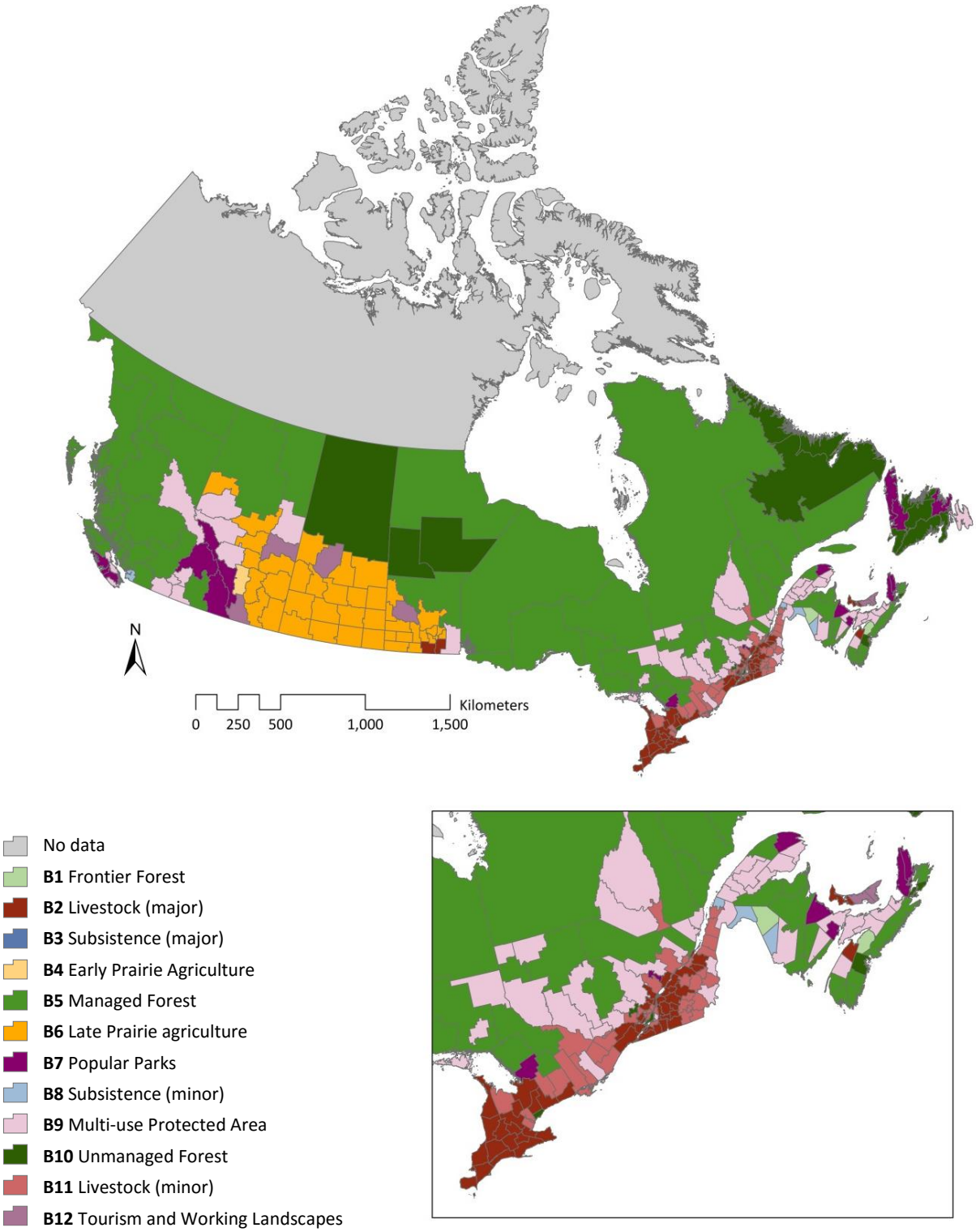



**Figure 24 Ecosystem Service Bundles in Canada, 2011** No more high-magnitude subsistence bundles (B3) remain on the landscape. Only four low-level subsistence bundles are present in the Maritimes (*n*=3) and in British Columbia (*n*=1). Regional specialization is characterized by livestock provisioning (B2 and B11) in Eastern Canada, grain and canola production in the Prairies (B6), and timber harvest (B5 and B10) distributed across the northern counties and western Canada. Protected areas and National Parks (B7, B9, and B12) are dispersed across the country.

### 3.4. Protected areas became a predominant feature on the landscape

The protected area bundles (B7, B9, and B12) deserve particular attention, not only for their distinctiveness among the other bundles, but for their unique development on the Canadian landscape. Unlike the provisioning-oriented bundles which developed according to a strong regional effect, the proliferation of protected areas was spread far more evenly across the county. This is consistent with results reported by Raudsepp-Hearne *et al.* (2010) in which all ecosystem services, except for tourism, were significantly clustered in space. The top two provinces in terms of total area designated protected by 2011, span the country from British Columbia to Quebec (Figure 25). Of course, there was a steady increase in the cumulative area of protected area over time; however, the periodicity of the newly protected area at each time step was more irregular than the provision of the other services through time (Figure 26).

At the provincial level, the contribution of protected areas, in area and in number, varied over time with the majority of provinces creating more, and larger protected areas near the end of the time series. British Columbia, Ontario, and Alberta, however, were early and relatively consistent providers of these bundles over the course of the century. Yet in terms of the cumulative number of protected areas, Quebec had the most by the end of the century, followed closely by British Columbia (Figure 25 and Table 3.) Proportionate to their respective sizes, the provinces contributed protected areas far more uniformly over time than they did for any other ecosystem service.

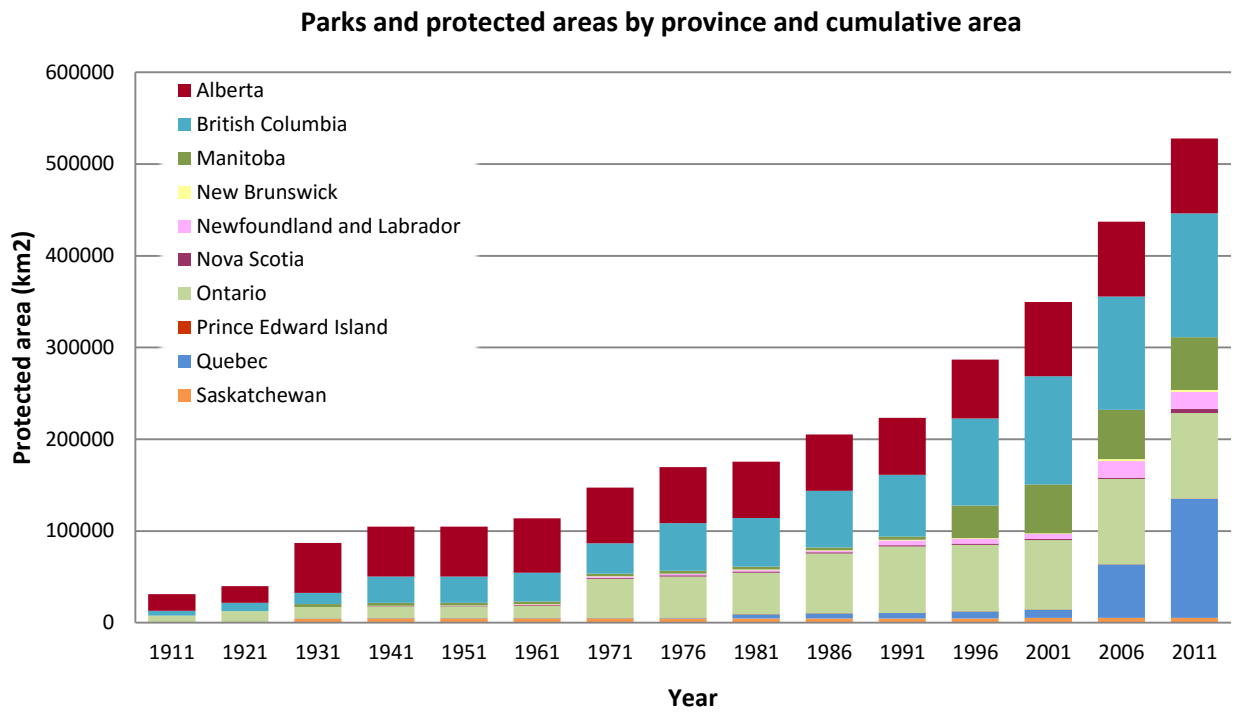



**Figure 25** Cumulative protected area by province from 1911-2011. In order from greatest area to least, the provinces with the highest aggregate protected area are: British Columbia, Quebec, Ontario, Alberta, Manitoba, Newfoundland and Labrador, Saskatchewan, Nova Scotia, New Brunswick, and Prince Edward Island.

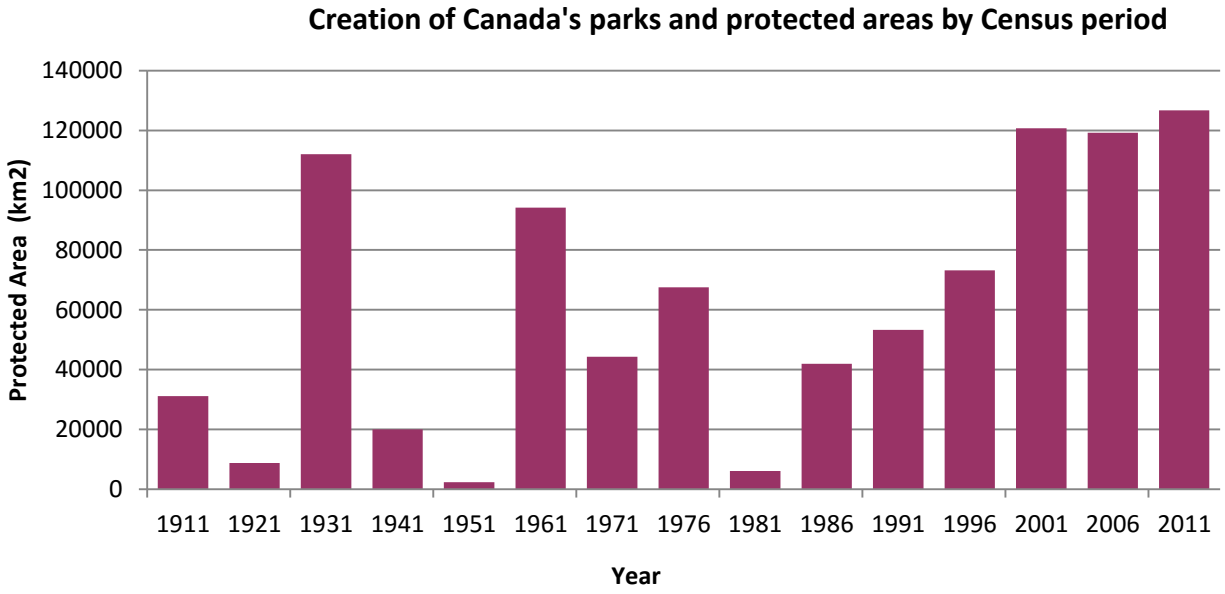



**Figure 26** Newly protected area at each time step from 1911-2011. Total areas were calculated for the period immediately preceding the Census year. The area newly protected in 1921, for instance, represents those parks created between 1911 and 1921.

**Table 3** Summary of the number of protected areas created by province. By 2011, the provinces that had the highest number of protected areas in total were (in decreasing order): Quebec, British Columbia, Ontario, Alberta, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Saskatchewan, and Prince Edward Island.

| ***Number of parks and protected areas created by Census period*** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year/ Province** | **1911** | **1921** | **1931** | **1941** | **1951** | **1961** | **1971** | **1976** | **1981** | **1986** | **1991** | **1996** | **2001** | **2006** | **2011** |
| **Alberta** | 4 | 3 | 5 | 5 | 5 | 16 | 17 | 5 | 7 | 5 | 18 | 15 | 17 | 7 | 3 |
| **British Columbia** | 7 | 4 | 8 | 20 | 11 | 23 | 27 | 26 | 28 | 15 | 24 | 28 | 27 | 18 | 16 |
| **Manitoba** | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 5 | 3 | 4 | 2 | 20 | 16 | 9 |
| **New Brunswick** | 0 | 0 | 1 | 0 | 3 | 1 | 3 | 1 | 4 | 3 | 0 | 9 | 2 | 12 | 9 |
| **Newfoundland and Labrador** | 0 | 0 | 0 | 0 | 0 | 6 | 7 | 3 | 5 | 4 | 7 | 1 | 2 | 6 | 4 |
| **Nova Scotia** | 0 | 0 | 1 | 6 | 0 | 0 | 0 | 3 | 5 | 2 | 1 | 0 | 0 | 0 | 18 |
| **Ontario** | 7 | 7 | 3 | 1 | 2 | 24 | 29 | 14 | 11 | 24 | 19 | 6 | 21 | 21 | 5 |
| **Prince Edward Island** | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 1 | 0 | 3 | 3 | 3 | 2 | 0 |
| **Quebec** | 0 | 2 | 3 | 6 | 0 | 2 | 1 | 4 | 24 | 27 | 20 | 36 | 48 | 80 | 44 |
| **Saskatchewan** | 1 | 0 | 7 | 0 | 5 | 4 | 2 | 0 | 9 | 1 | 1 | 0 | 3 | 0 | 0 |

# CHAPTER 4. DISCUSSION

Between 1911 and 2011, Canada's ecosystem services were at the confluence of decisive biological, political, and demographic influences that reconfigured the landscape of service provisioning. At the beginning of the century, most counties in Canada provided the same few bundles of small-scale subsistence and frontier-agricultural services. Increasingly, the provision of services became spatially concentrated, and represented by a suite of specialized bundles that optimized commercial crops, livestock, timber harvest, and protected areas in different regions across the country. This diversification was a response to demands on the various systems that were historically unprecedented in Canada. Population pressures, global conflict, bureaucratic initiatives, and cultural aspirations required certain services in greater quantities and at greater rapidity than ever before. Other services that were staples in the colonial and early-sovereignty periods gradually became irrelevant in the modern milieu. Ultimately, the transformation of Canada's ecosystem-service profile occurred by way of regional transitions that brought the constellations of specialized bundles into a coordinated national ecology.

## 4.1. Broad trends in ecosystem service provisioning

The increases and decreases of services, individually and as bundles, reveal important themes in the evolution of Canada's ecosystem service provisioning. As individual services, the five that declined over the course of the century—horses, cows, hay, potatoes, and oats—are representative of long-standing, subsistence-oriented activities that once dominated central and eastern Canada. During most of the nineteenth century, farmers in the St. Lawrence Valley relied on "wheat, corn, oats, potatoes, and hay," while the addition of a few livestock "evinced a farmer's rising income" (Forkey 2012). By 1911, the bundles characterized by subsistence services (B3 and B8) were facing imminent decline. Indeed, the analyses showed that

Subsistence (major) (B3), decreased the most in terms of county representation over the one hundred year period, effectively disappearing from the landscape in the 1980s.

In contrast, the eleven services that increased over the time period—barley, corn, canola, rye, soybeans, wheat, chickens, pigs, protected areas, National Park attendance, and timber—were services with capacity for commercialization and modern significance. Interestingly, many bundles of these services that came to dominate the contemporary Canadian landscape did not exist in 1911. The bundle that increased the most over the time period, Livestock (major) (B2), is composed of several of the high-yield, emergent services (soybeans, corn, pigs, and chickens) and only appeared on the landscape for the first time in 1941. Like many ecosystem services that increased over time, the livestock-oriented bundles were radically transformed by the demands placed on Canada's resources during the World Wars. The time-series maps showed that other bundles burgeoned similarly during the war years, modifying existing bundles, or replacing redundant bundles entirely.

With reference to the historical narrative, this observation suggests that the recession of the five subsistence provisioning services was precipitated by the intensification and redistribution of the other provisioning and cultural services during the World Wars. The service provided by horses for instance, was becoming obsolete by the 1920s. The increasing accessibility of "tractors, motor trucks, and other automotive equipment…was associated with a slowly declining horse population" (Britnell and Fowke 1962). Subsequently, during the Second World War and early post-war years, Canada's horses were often sold for meat to meet the urgent food requirements of liberated countries. Indeed, on February 4, 1947 the *Globe and Mail* reported that 11,500,000 pounds of canned Canadian horsemeat was ordered by the United Nations Relief and Rehabilitation Administration (UNNRA), "earmarked to relieve hunger in Poland, Czechoslovakia and Austria" (*The Globe and Mail* 1947). For the decline of subsistence

farming, horses are something of a keystone service within the two bundles. Their decline in itself is less important than the change its loss signals. The service provided by horses was the power for the hard labor of a rural economy, ploughing fields, pulling wagons, and harvesting crops. They determined the kind of agriculture that could be practiced, and horse-powered agriculture was inherently small-scale and local. Crops associated with this kind of agriculture, potatoes, hay, and oats, trailed accordingly with the transition. Automotive and mechanical advances made production more efficient, enabling ever-intensifying agricultural production; i.e. the rise of commercial livestock production.

Although the oats provided by Subsistence bundles (B3 and B8) began a fairly steady decline by the beginning of the Second World War, they remained a part of the provisioning landscape in the Prairies. This was due in part to a freight subsidy policy introduced in early 1941 that provided for "free freight on all grains used for feed moving from Lakehead[5] to the Eastern Provinces and from Calgary and Edmonton (in Alberta) to British Columbia" (Britnell and Fowke 1962). The invigoration of feed-grain production in the Prairies was a direct response to the new high-yield Livestock bundles (B2 and B11) that were replacing the subsistence bundles in the east. At the outbreak of World War II, "the livestock industry was assuming a stronger relative position in the agricultural economy of Canada" as export markets for wheat shrunk (Britnell and Fowke 1962). The shortness of the hog cycle offered the greatest opportunity to produce the quantities of meat required by the British. However, the new livestock bundle contained a negligible amount of oats and although hay remained, albeit significantly lower than pre-war magnitudes, the Eastern Provinces were considered feed-deficient. Yet, with government subsidies, hog production in the Eastern Provinces could be

5. Lakehead (Thunder Bay) was the beginning of the Great Lakes transportation route. A terminal elevator existed at the Lakehead for the purpose of receiving Prairie grain and loading it into ships for transport to central and eastern Canada, and the United States.

combined with grain production in the Prairies to expand output rapidly. This coordination of specialized regions of production peaked in 1944, when the total exports of pork products were four times the pre-war average (Britnell and Fowke 1962). The interdependency of Prairie grain production and Eastern livestock represents an unconventional kind of ecosystem service bundle. Although we traditionally define bundles by services that overlap in space, here these services are operating as a bundle across space, at the national level.

Comparison of the opposites in bundle trajectories exemplified by Subsistence (major) B3 and Livestock (major) B2, provides a compelling example of the kinds of changes that were occurring broadly across the country. The disappearance of a high-magnitude subsistence bundle, and the precipitous rise of a high-magnitude livestock bundle, suggests that Canada was managing its provision of services in such a way that increasingly prioritized national, rather than local, use. The coordination of service provisioning among different regions is also apparent, with the Prairies producing the grain required for livestock in the feed-deficient East. The regional specialization of bundles was already a feature of the Canadian landscape at the time this study began, but this pattern was further crystallized over the course of the twentieth century.

### 4.2. Trends and transitions of ecosystem service bundles

In total, the K-means analysis identified twelve bundles which summarize the categories of ecosystem services that existed in Canada from 1911 to 2011. The tally of counties providing each bundle, year by year, indicate that five bundles decreased and seven bundles increased in general over the time period. The bundles that diminished from the landscape were all provisioning-oriented bundles characterized by local production for a relatively small, and still predominantly rural, population. The first half of the twentieth century was a transformative era demographically, politically, culturally, and by consequence, ecologically. Indeed, the rise and

fall of bundles on the landscape was influenced by such sociocultural factors that acted separate from, and sometimes even in spite of, natural processes. These effects are obscured in the quantitative results of the previous chapter and depend on converging social narratives to contextualize the trajectories of bundles within a more complete historical purview.

The transitions of bundles were shown to occur according to three main trends: (1) relatively unproductive bundles transitioning into service provisioning, (2) bundles transformed by the addition of a new dominant service, and (3) bundles that changed their functional composition entirely. These trends are best explained by the growth of the Canadian population, agricultural innovations, management schemes, and new markets that emerged as a result of the war years. These factors conspired to produce a landscape that was regionally specialized and organized at the national level, one that wavered along the spectrum of environmental morals, settling somewhere between utilitarian and preservationist ideals (Hessing *et al.* 2005). Ultimately, the seven bundles on the rise throughout the twentieth and early twenty-first suited the larger, concentrated, and modernizing Canadian nation (Population, urban and rural, by province and territory).

### 4.2.1 Unproductive bundles transitioning into service provisioning

By 1931, Canada's urban population edged out rural inhabitants for the first time in history, 54% to 46% respectively, and World War I had inflated Canada's Prairie economy and galvanized the country's production and transportation infrastructures. By 1951, the population balance was 62% urban to 38% rural, Canada had successfully mobilized for another World War, and thriving regional economies had been established that specialized in diverse provisioning and cultural bundles (Statistics Canada 2011). With increased domestic consumption, and even more significantly, increased demand from foreign markets, counties that were characterized by relatively low service provisioning, namely Unmanaged Forest (B10) and Frontier Forest (B1),

gradually began to transition to more productive service bundles. It is important to note that while these two bundles are considered unproductive relative to the other bundles, the services included in the Unmanaged Forest and Frontier Forest bundles are far from complete. Non-timber forest services data, especially regulating services, were unavailable considering the temporal and geographic scope of this project. The bias for agricultural provisioning services admittedly skews the analysis. The absence of regulating services, such as carbon sequestration, or water purification, is most conspicuous in these two bundles.

At the beginning of the century, the unmanaged forest bundle was dominant across the northern, sparsely populated counties across Canada, while frontier forest defined a buffer between the wooded north and the more populated, agricultural cores in the south. The frontier forest zones delimiting the Prairies and St. Lawrence Valley were the most responsive to changes in core areas of agricultural production. British demand for Canadian wheat in World War I saw the rapid expansion of wheat production which increased twenty times between 1901 and 1921(MacDowell 2012). The area dedicated to Early Prairie Agriculture (B4) increased markedly between 1911 and 1921and replaced much of the original frontier forest buffer.

In the decades that followed, frontier forest expanded outwards from the growing cores of production, often replacing Unmanaged Forest (B10) and marking transitional areas that would be brought into service provisioning of some kind. In the Prairies, the expanding frontier usually became more Early Prairie Agriculture (B4), protected areas (B9 and B12), or Managed Forest (B5). In the Eastern Provinces, the frontier transitioned into Multifunctional protected area (B9), Livestock (minor) (B11), and even back to Unmanaged Forest (B10). The trend of the frontier forest bundle was such that it increased in county representation between 1911 and 1971 as Canada's population and demand for agricultural ecosystem services increased and pushed the frontier gradually outward. The next phase saw a steady decline in the frontier bundle until it

existed in only two counties by 2011. It was the advances of the post-war era, mechanization and the loss of space-intensive draught animals, fertilizers and herbicides, which increased farm productivity and eased the pressure to convert forest to farmland. In fact, in the Eastern Provinces, “as productivity increased even more, marginal farmland was abandoned and began reverting to forest” in the three decades after 1971(Drushka 2003).

Unmanaged Forest was the bundle most often replaced during the pioneering phase of the frontier forest and the expansion of agricultural service provisioning. However, the majority of timbered B10 counties remained in forest-oriented provisioning of one kind or another. Forests in Eastern Canada had already undergone a major ecological transition by 1911, after mature woodlands were devastated by the logging industry and conversion to farmland. By the time the *Canadian Agriculturalist* reported that the rough era of chopping and clearing forests in central and eastern Canada was over in 1863, the soils were exhausted and old-growth forests had disappeared (*The Canadian Agriculturalist* 1863). By the end of World War I, the dwindling lumber industry in Eastern Canada “had liquidated the bulk of its available sawlog supply, particularly in the Atlantic provinces, and began to convert its forest economy to one based on pulp and paper” (Drushka 2003). Lumber production had been progressively shifting to British Columbia, and in 1917 it surpassed all other provinces (Forkey 2012).

The devastation of eastern forests at the turn of the century had dispelled the myth of Canada’s superabundance of resources and ushered in an era of conservationist thinking inspired by older European societies, especially the French and Germans, that had “experienced the consequences of deforestation earlier in their histories” (Drushka 2003). As a result, scientific management was embraced as the solution maintaining the “perpetual forest” through a utilitarian reserve policy which would theoretically provide society with a wide range of benefits “including fuel, timber, clean water, fish, wildlife, and recreation” (Drushka 2003). Management

of forests for multiple uses became the mandate, as seen by the marked transition from Unmanaged Forest (B10) to Managed Forest (B5), which represents increased timber harvest compared to the unmanaged forest bundle, along with protected areas.

Canada, and British Columbia in particular, enjoyed a postwar boom in the forest industry ushering in the second phase of forest mechanization. Machines powered by internal combustion engines were more affordable and efficient enabling a "more diverse logging sector to reach smaller stands of timber previously inaccessible" (Drushka 2003). In this way, many previously unproductive northern counties were brought into service provisioning characterized by the Managed forest bundle. The pro-business ethos of the Roaring Twenties spurred the already expanding production, which peaked in 1929. Although the forest sector suffered during the Depression, plummeting 60 percent below peak production, the outbreak of World War II revived the industry, creating an enormous demand for timber (Drushka 2003). Known as Great Britain's wood yard, Canada was a chief ally whose "most critical material contribution" was timber (Drushka 2003). The expansion of timber production as Managed Forest (B5) is evident in the decades after the Second World War. Production continued to grow precariously, in spite of a postwar policy that required sustainable yields to be established across Canada. These regulations, however, were only concerned with trees and timber production; sustaining "other forest values…was not part of the agenda" (Drushka 2003). By the 1970s, popular preservationist ideals overtook utilitarian conservationism, and raised concern over flawed sustained yield policies, due in large part to a lack of reliable inventory data and a disregard for the variation in forest histories across the country. Over time, the industry embraced more sustainable silvicultural practices, such as viable retention harvesting, which valued biodiversity and approached forests as complex systems.

### 4.2.2 Bundle transformed by a new dominant service

The World Wars have been introduced as catalysts for profound ecological change in Canada. Indeed, the mobilization of Canada's ecological resources during the Wars fundamentally transformed the landscape by requiring production that was "unprecedentedly heavy in quantity" (Britnell and Fowke 1962). At the outbreak of the First World War in 1914, Great Britain had long been established as a major market for Canadian agricultural exports. Wheat from the Early Prairie agriculture bundle "was not only the cornerstone but the entire foundation of British food policy from the tentative emergence of its first elements in the middle war years until the postwar restoration of the food supply problem to the private trade" (Britnell and Fowke 1962). Buoyed by the slogan "Wheat Will Win the War", the British breadstuffs policy contributed to a massive increase in wheat acreage in spite of weather variations in the Canadian Prairies; this is evident in the expansion of the Early Prairie Agriculture bundle between 1911 and 1921. By 1928, the peak year of production, Canada had a vast surplus of wheat.

Following ten years of severe drought and depression, which affected the Prairies most acutely, farmers seeded "two million extra acres of wheat in the spring of 1940 in the hope of recouping their fortunes in a wartime wheat boom like that of 1914-1918" (Britnell and Fowke 1962). However, the devastation of the German *Blitzkrieg* reached Canada as twelve of the thirteen European wheat-importing nations were cut off from the supply (Britnell and Fowke 1962). Record wheat yields contributed to a "prospective 500 million bushel carryover", and aggressive wheat reduction program was implemented, offering compensation for the diversion of wheat acreage (Britnell and Fowke 1962). The cry of Canadian propagandists was now, "Less Wheat Will Win the War."

With the contraction of exports to European wheat markets, and war in the Pacific cutting off imports of oilseeds, Canada embraced an entirely new crop into the Prairie bundle. In 1943, the Agricultural Supplies Board purchased all supplies of Large Black Argentinian Rapeseed from the United States to use as a lubricant for steam ship engines (Britnell and Fowke 1962). The successful wartime production of rapeseed in the Prairies warranted the construction of an oil extracting plant in Moose Jaw, Saskatchewan (Kneen 1992). However, the abundance of rapeseed posed a challenge in the postwar era as demand shrunk, and steam-powered engines were being replaced by diesel. High levels of erucic acid and Sulphur compounds made rapeseed nutritionally unviable, until plant breeders in Saskatchewan and Manitoba developed a food-grade variety by reducing undesirable compounds through cross breeding experiments in the 1960s and 1970s (Casséus 2009). The development of Canola (an abbreviation for "Canadian oil") is marked by the appearance of the Late Prairie Agriculture bundle (B6) in 1971. At the same time, wheat prices fluctuated leading, once again, to large surpluses. A wheat reduction plan was implemented and farmers were encouraged to diversify production and "grow barley and canola, not for environmental reasons but for commercial ones" (MacDowell 2012).

Canola production remained the dominant service of the new Prairie bundle for the rest of the century, effectively replacing the old wheat-dominant bundle by 1996. It is, however, important to remember that the quantification of these ecosystem services was based on area under cultivation, not yield. The greater abundance of canola relative to wheat in the Late Prairie Agriculture bundle is an expression of area only. What is more, the relative spatial stability of this bundle after the Second World War does not account for the increasing sophistication of agricultural technologies that enabled greater production from the same, or smaller, area of land. Still, the history of the Prairie bundles demonstrates the elasticity of ecosystem services under different political and economic circumstances. With regards to wheat, the World Wars imposed

enormous and opposite demands on the Prairie ecosystem in a relatively short period of time, often in spite of adverse climatic and commercial conditions. What is more, the introduction of rapeseed as an emergency measure during a wartime shortage irrevocably changed the Prairie landscape and established a new Canola industry as late as the 1970s.

### 4.2.3 Bundles that changed their functional composition entirely

The transition from subsistence agricultural services to intensive livestock production in the St. Lawrence Valley has already been described in a previous section detailing the greatest declining (B3) and the greatest increasing bundles (B2). It was, again, the impetus of world war that initiated this transition. Although British demand for pork products was the reason for the majority of livestock intensification, domestic markets also changed in important ways during the war that had a demonstrable effect on the provisioning landscape. In 1942, Canada's *Official Food Rules*, a guide to nutrition during wartime rationing, was published. These rules were updated throughout the war, but always encouraged "one serving of meat, fish, or poultry" every day, and "at least 3 or 4 eggs weekly" (Canada 1942) Increases estimated for 1943 over the prewar years were "12 per cent for meats" and "24 per cent for eggs" (Britnell and Fowke 1962)

Not only did Livestock (major) (B2) provide the large amounts of pork required by the British, the amount of chickens and their feedstock, soybeans and corn, increased relative to the subsistence bundles (B3 and B8). The postwar population boom and ever-increasing urbanization, especially in the metropolitan centers of Ontario and Quebec, ensured that meat, poultry, and egg production would remain part of the provisioning landscape in Eastern Canada. The transition of provisioning in the St. Lawrence Valley, from subsistence agriculture to intensive livestock production beginning in 1941, was a complete transformation of ecosystem service bundles. Here it is important to note that although no regulating services were quantified in this thesis, Raudsepp-Hearne *et al.* (2010) reported that pork production was negatively

correlated with all regulating services in the study—drinking water quality, soil organic matter, soil phosphorus retention, and carbon sequestration. Although the transition to livestock production was precipitated by the Second World War, this phenomenon was not unique to the twentieth century. As was previously discussed, the St. Lawrence Valley had experienced a similar transformation when the Eastern forests were replaced by the subsistence agriculture bundles that, starting in 1941, were replaced by intensive livestock production. What is more, in 1941 as in the 1860s, the landscape in Eastern Canada changed largely because of sociocultural factors rather than ecological ones.

### 4.2.4 Spatial variability of bundle transitions

The example provided by the preceding section, the complete and repeated transformation of ecosystem service bundles in the St. Lawrence Valley—from forest to subsistence agriculture to livestock production—suggests that there is a spatial variability in the proclivity for bundle transitions. Indeed, of the counties that experienced a greater than average number of bundle transitions, 90% were in the Central and Maritime Provinces of Eastern Canada, while 58% of the counties that experienced a below average number of transitions were in the Prairie Provinces and British Columbia. While Ontario, Quebec, and the Maritime Provinces enjoy the more productive Mixedwood and Atlantic Maritime ecozones, the Canadian North and the Prairies are born of more austere conditions. Moreover, differential patterns of settlement, population growth, and urbanization have no doubt had an effect.

When diversification was required at various points in history—when Eastern forests were finally liquidated at the turn of the twentieth century, when drought and depression struck in the 1930s, or when surpluses and new markets emerged during the Second World War—the differences in regional resilience are most apparent. Resilience here refers to the kind of social-ecological resilience in which the capacity of a system to adapt and transform in response to

social change, to persist by learning from experience, and to adjust to "changing external drivers and internal processes"(Gunderson and Holling 2002; Folke *et al.* 2010). Indeed, economists and Political Scientists George Britnell and Vernon Fowke observed, that "The superior ability of agricultural communities in older parts of the country to weather the adversities of the 1930's rested more on the diligence, thrift, and capital accumulation of past generations than on any degree of independence of the cash market of urban centers" (Britnell and Fowke 1962). Communities in the St. Lawrence Valley had an extensive cultural memory of agriculture and resource industries that included cycles of depletion, diversification, and reinvention. In contrast, Prairie farmers had only a memory of monoculture. Indeed, even the celebrated wheat crop, "a short-season, rust-resistant variety" known as Marquis Wheat, had to be specially developed for the unyielding Prairie ecozone (MacDowell 2012). So intensively specialized were the Prairies, that in 1941 the Minister of Agriculture, James Garfield Gardiner, sympathized, "It is not only difficult for farmers in the wheat-growing area of Canada to change from wheat growing to any other occupation, but in many of those areas it is almost impossible for them to do anything else to advantage but grow wheat."

That some regions of Canada have been more prone to shifts in ecosystem service provisioning historically is intriguing; but the fact that three and a half percent of counties, just ten out of two hundred and eighty-three, provided the same bundle for the entire study period is striking.[6] By taking a snapshot approach to ecosystem services, much of the current literature on ecosystem services assumes that provisioning is temporally static (but see Renard *et al.* 2015). The century of Canadian ecosystem service history mapped in the prior chapter greatly challenges that assumption. Any single year in Canadian history would have revealed a different

6. This includes Newfoundland which accounts for six of the ten static counties. Since data for Newfoundland was only available from 1951 onwards, this results is due in part to the shortened time scale. Without Newfoundland, only four counties provided the same bundle for the one hundred-year period.

landscape, and without even a small chronological preamble or postscript, the patterns and relationships among bundles would be dislocated and inscrutable. The evolution of the twelve Canadian bundles reveals ecosystem services to be highly dynamic; susceptible to demands as far afield as Europe and the Pacific, and sensitive enough to respond to the changes in Canadians' moral and ethical ideas about their ecosystems.

### 4.2.5 The rise of cultural services: protected areas and popular parks

During the century of study, it was Canada's environmental ethos that transformed the landscape most extraordinarily. While all five of the decreasing bundles were provisioning-service oriented, all three cultural-service bundles were among the seven that increased. This is similar to the results reported by Renard *et al.* (2015), in which cultural services in Quebec showed the greatest magnitude of change through time, and Bürgi *et al.* (2015), in which cultural services in mountain pastures in Switzerland gained importance over the twentieth century. As the analyses in the previous chapter suggest, the emergence and distribution of Popular Parks (B7), Multifunctional Protected Area (B9), and Tourism and Working Landscapes (B12), were unique among all other bundles. As cultural services, these three bundles are barometers of Canadians' relationship to their environment and are the best ambassadors of the century of ecological change in Canada. The periodicity of their appearance on the landscape reflects the phases of exploitation, economic slumps, utilitarian conservationism, consumerism, preservationist ideals, and the embrace of an ecological integrity mandate.

The early foundations for this evolving landscape of ecosystem service provisioning were laid along with the tracks of the Canadian Pacific Railway (CPR), completed in 1885. The connection of Canada's vast territory by the railway and its feeder lines had important nation-building implications; first enabling the establishment of the wheat economy which was seen as a way of linking "British North America and British Columbia into a new Canadian nation", and

later, leading to the creation of Canada's first national park at Banff when railway workers discovered hot springs at the site in 1883 (Campbell 2011; MacDowell 2012). During this era, concerns over the finiteness of resources were beginning to be voiced, and efforts to reorganize patterns of use ensued (Forkey 2012). The competing impulses of conservationism and preservationism existed simultaneously throughout the twentieth century, and debated the form environmental management should take. Conservationist thought argued that "the natural environment remains a resource to be used by human beings, with its value primarily derived from the marketplace. In contrast, preservationism "reflects a non-consumptive approach to resource management [;] one that would maintain natural systems for purposes additional to extraction, production and consumption" (Hessing *et al.* 2005).

In 1911, "what began as a minor bureaucratic shuffle, simply to provide better management for the forest reserves" led to the creation of the Dominion Parks Branch. This agency, the first of its kind in the world, was tasked with managing national parks (Campbell 2011). In line with the conservationist ideology of the time, the parks were viewed as "useful places with exploitable resources that [could be] regulated in partnership with private enterprise (MacDowell 2012). Primary industries like lumbering or mining, or facilities for tourism were not excluded because it was believed that these activities "enhanced the park's usefulness in the nation's interest" (MacDowell 2012). By 1911, several counties in the Rocky Mountains were characterized by Multifunctional Protected Areas (B9) and Tourism embedded in working, landscapes (B12).

In the 1920s, the accessibility of automobiles "democratized mobility and leisure, enabling more Canadians to travel to their cottages, visit and camp in national parks, and take cross-country road trips" (MacDowell 2012). The automobile culture of the interwar years popularized Canada's national parks and facilitated large numbers of visitors and the creation of

new protected areas; this is expressed by the upsurge in newly protected area for the 1931 Census year. Depression and war slowed the creation of parks, but the experience of the Second World War in particular nurtured a proud national identity that was increasingly invested in symbols of Canada's natural beauty. The wilderness of Canada's parks and protected also represented an experience of the environment that was rapidly disappearing in Canada's growing postwar metropolitan centers. The publication of Rachel Carson's *Silent Spring* in 1962 ushered in an era of ardent preservationism that saw the world's first Earth Day, in 1970, and the foundation of Greenpeace in 1971 in Vancouver, British Columbia. Park attendance surged and more, diverse protected areas were designated.

In 1970 the Parks Branch adopted the National Parks System Plan "which divided the country into thirty-nine 'natural regions' and promised to someday have at least one park representative of each. This meant not only more parks, but parks with a concrete basis in ecological diversity rather than (or at least in addition to) scenery and political advantage" (Campbell 2011). It is important to note, here, that the federal government was especially concerned with "showing the flag" in the north and created enormous parks in the Territories as a political statement; unfortunately, due to the data limitations mentioned earlier, the Territories and their parks were excluded from this study (Campbell 2011). In the Provinces, the emergence of protected area bundles is shown to increase more uniformly across the map, unlike provisioning service bundles which emerged according to a strong regional effect. The kind of park and protected area also changed during this period. The creation of protected areas that were multifunctional, embedded in working landscapes (B12), were less frequent compared to Popular Parks (B7) and Protected Areas (B9).

Yet as environmental historian Claire Campbell reflects it was "Despite—or because of—a new climate of green politics and a new fashion for green living, [that] national parks were

more popular than ever and were eroding under the strain of our enthusiasm for them; environmentalists began to talk about 'loving the parks to death'" (Campbell 2011). Concern for the ecological integrity of Canada's parks, combined with a decade of economic recovery slowed the creation of new protected areas. With a growing awareness of global environmental degradation, Canada's National Parks Act was amended, first in 1988, "to ensure that natural ecological processes continued to function with minimal interference," and again in 2000, making the "restoration and maintenance of ecological integrity the *first* priority" (Campbell 2011). The preservation of Canada's forests was also declared "essential to the health of the planet" by the United Nations (Campbell 2011).

In 1911, James Bernard Harkin, the first commissioner of Canada's Dominion Parks Branch, declared, national parks and protected area are "the property of all the people of Canada…they should not be developed for the benefit of any one section of the country or for private interests." The history of Canada's cultural ecosystem services reveals the struggle to balance human use and ecological integrity that colored all ecosystem service histories. The idea of a national park or protected area, that was to be "unimpaired for future generations," was the product of a post-scarcity society that had been confronted with the devastation of unfettered resource exploitation and the disappearance of wild spaces in the rush towards modernity.

### 4.3. Limitations of the results

Although this project endeavored to take a comprehensive approach to ecosystem service change across Canada from 1911 to 2011, the availability of data that were temporally and geographically consistent imposed important limitations on the analysis and the interpretation of results. The discussion above made note of several examples of such constraints, which include a lack of regulating services, a narrow scope of cultural services, and the exclusion of the First Nations perspective. Whether these limitations are a result of methodological conflicts, the

paucity or complete lack of quantitative data, they can still provide valuable insights into ecosystem service history.

The most conspicuous limitation of this project is the absence of regulating services within the ecosystem service bundles. Although every attempt was made to identify regulating services that could be quantified historically and were represented equally across the Provinces, none were found that satisfied both conditions, or that could be calculated in a reasonable amount of time. The lack of regulating services is perhaps most conspicuous in northern and western counties where timber harvest is the dominant activity within relatively sparse bundles that contain either negligible amounts of other services (B10), or only one other service, protected area (B5). In reality, these regions provide many important ecosystem services including high levels of carbon stocks in trees and soils, First Nations cultural spaces, and water purification. The dearth of historical data on non-timber forest values limits the complexity of these bundles and prevents the level of interpretation that is possible for the more southerly bundles. Carbon sequestration and water purification held the most promise during the data acquisition phase, however, given the historical dimension of this project it was not entirely surprising to discover that databases for such services do not exist.

The valuation of regulating services is a largely modern apperception. As Bürgi *et al.* (2015) point out, regulating ecosystem services "operate independently of being recognized by humans." Indeed, the level of scientific or traditional knowledge and insights into underlying ecological processes, determine what society can perceive as an ecosystem service (Bürgi *et al.* 2015). No carbon sequestration data was recorded in 1911 because the existence of such a thing was not recognized, much less valued by society enough to monitor its fluxes. The gradual emergence of regulating service data, either as part of the ecosystem service framework or as discrete processes, is a marker of scientific progress and the development of social values

concerned with maintaining ecological systems. This example should remind us that a goal of historical ecology should always be to approach research with an evolving historical consciousness, rather than imposing modern values onto past ecosystems. The absence of regulating service data may render a map of ecosystem services incomplete as we know it, but it does represent the reality of services as an early twentieth-century mind would understand them. If regulating services are eventually quantified historically, they must be carefully interpreted. By inserting a modern concept into a historical context, ecologists should avoid conflating distinct time periods.

Similarly, the limited scope of cultural services included in this project is a commentary on the creation of historical data and the power structures that shape it. Unlike the observable phenomena of provisioning and regulating services, cultural services describe notions of heritage, spirituality, and leisure that often defy quantification and mean many different things to many people. Therefore, the myriad cultural values invested in ecosystems across Canada over one hundred years, are at best expressed by proxy. Again, the documentation of cultural services that is available historically comes with an inherent bias. Because cultural services are the most qualitative ecosystem services, their historical record is determined by the dominant elements in society.

As such, the cultural services quantified in this project, National Parks and a variety of protected areas, are principally representations of the Euro-Canadian experience. The exclusion of the Canadian Territories, described in Chapter Two, certainly precluded alternative cultural perspectives and important cultural landscapes. However, even in the Provinces, First Nations values across the country were eclipsed by Canadian society which frequently excluded and undermined them. The conflicting cultural values of these groups are exemplified in the creation of Canada's National Parks. As historian Neil Forkey explains:

> Aboriginals in Ontario and the Rockies found themselves excluded from the commons to make way for parks. The prevailing attitude among parks planners… was that Aboriginals would take fish and game out of season, not only going against the idea of a pristine park, but, more to the point, disrupting the tourist economies that were linked to these spaces (Forkey 2012)

If data were available for a greater variety of cultural services, perhaps we would see more complex trends that capture these kinds of cultural disparities within Canada. Instead of seeing the categorical rise of all cultural services over time, perhaps we would see the decline and recovery of cultural resources associated with indigenous societies as their place in the larger Canadian society evolved over the century.

### 4.4. Summary

The results discussed in this chapter reveal several important insights to the historical dynamics of ecosystem services in Canada and some generalizable lessons for historical ecology. Broadly, the bundles that declined from the landscape were provisioning-oriented bundles characterized by local production for small, predominantly rural populations: Frontier Forest (B1), Subsistence (major) (B3), Early Prairie Agriculture (B4), Subsistence (minor) (B8), and Unmanaged Forest (B10). In contrast, the bundles that proliferated were increasingly culturally-oriented, or characterized by industrialized agricultural services that suited the growing and urbanizing Canadian population: Livestock (major) (B2), Managed Forest (B5), Late Prairie Agriculture (B6), Popular Parks (B7), Multifunctional Protected Areas (B9), Livestock (minor) B11), and Tourism and Working Landscapes (B12).

Contrary to the snapshot approach taken by many current studies (Raudsepp-Hearne *et al.* 2010; Qiu and Turner 2013), my analysis revealed that ecosystem services are highly dynamic over time. Only one percent of counties, just three out of two hundred and eighty-three, provided the same bundle of services for the entire study period. Moreover, certain regions seem to be more resilient to regional transitions in ecosystem service bundles. Eastern Canada represented a

disproportionate number of these highly dynamic counties that were able to adapt to resource depletion and changes in market demand in a way that other regions could not. Whether this resilience is due to biophysical factors inherent in the Eastern ecozones, traditional knowledge developed over longer settlement histories, or some combination, the spatial patterns of resiliency is something that should be investigated in future research.

The conventional spatial parameters of ecosystem service bundles were challenged by the apparent coordination of bundles at large scales. Although bundles were shown to become regionally specialized over time, they interacted with each other across the landscape. For instance, Prairie feed grains and pork production in the St. Lawrence Valley essentially formed their own complete bundle, but when we only consider bundles where services overlap in space, these relationships are obscured. This network of cooperative bundles speaks to the idea that over time, the various bundles were organized into a national ecology unique to the Canadian experience. Ultimately, this exemplifies the interdependency of social and ecological systems that is at the cornerstone of the ecosystem service framework.

# CHAPTER 5. CONCLUSION

In 1904, Prime Minister Wilfrid Laurier addressed the Canadian Club of Ottawa: "My fellow countrymen," he declared, "the twentieth century shall be the century of Canada and of Canadian development…Remember from this day forth, never to look simply at the horizon as it may be limited by the limits of the Province, but look abroad all over the continent"(Morton 2001). In many ways, this thesis is an expression of the nation-building process that Laurier prophesized. The expansion of Canada was fundamentally achieved through ecological modifications that produced specialized and coordinated regions of ecosystem services. Between 1911 and 2011, almost all counties in Canada experienced a transition in service provisioning and most experienced multiple changes. Over time, the small-scale subsistence and frontier services that were prevalent at the beginning of the century were replaced by highly-specialized bundles, including cultural services, that operated regionally and even within a network of bundles at the national scale. This offers a new perspective on the traditionally spatially-explicit definition of ecosystem service bundles, and emphasizes the importance of scope, both temporal and spatial, in ecosystem service research. Indeed, the results indicate that there may be a sort of synergistic relationship between overlapping spatial and temporal factors. In terms of the number of bundle transitions, Eastern Canada was shown to be the most dynamic. Considering the longevity of the region's settlement history and the accumulation of local knowledge, the coincidence of historical complexity and a moderate ecozone seems to permit greater resilience to socioeconomic variations.

Ultimately, by embracing archival source materials and combining them with rigorous analyses, this thesis contributes an example of how ecosystem services can be quantified and interpreted historically. The results provide insights to the long-term dynamics of bundles across space, and offer a commentary on the evolving historical consciousness that shapes ecosystem

management. At any single point in time between 1911 and 2011, the Canadian landscape would have revealed a different arrangement of bundles, and no single configuration would be justly representative. Instead, it is the variability captured by continuous analysis that best expresses the complexity of Canadian ecosystem services within a unique historical experience.

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# APPENDIX

**Alberta**

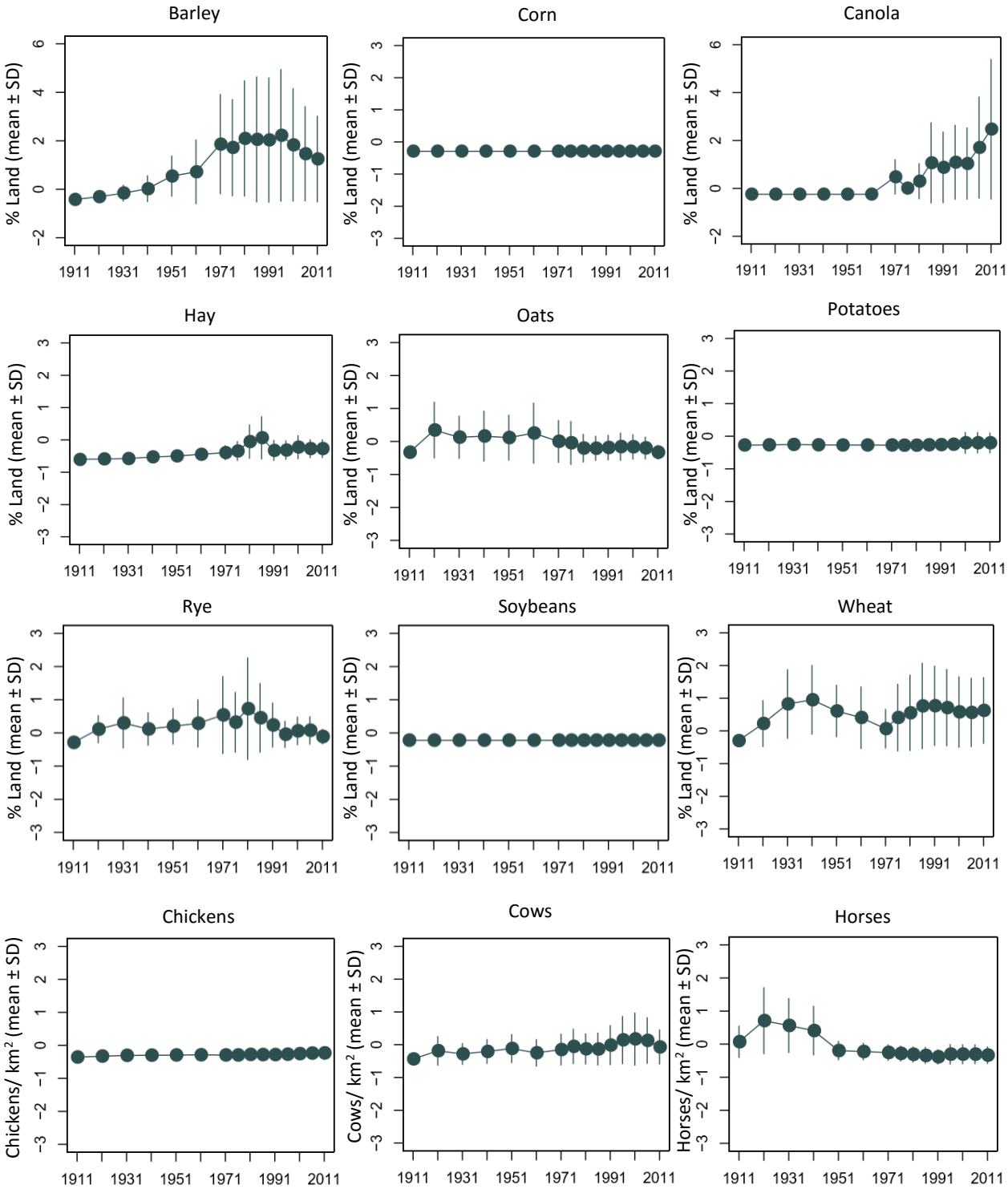


**Figure 27** Alberta's provision of ecosystem services compared to the national average. Results are comparable between provinces.

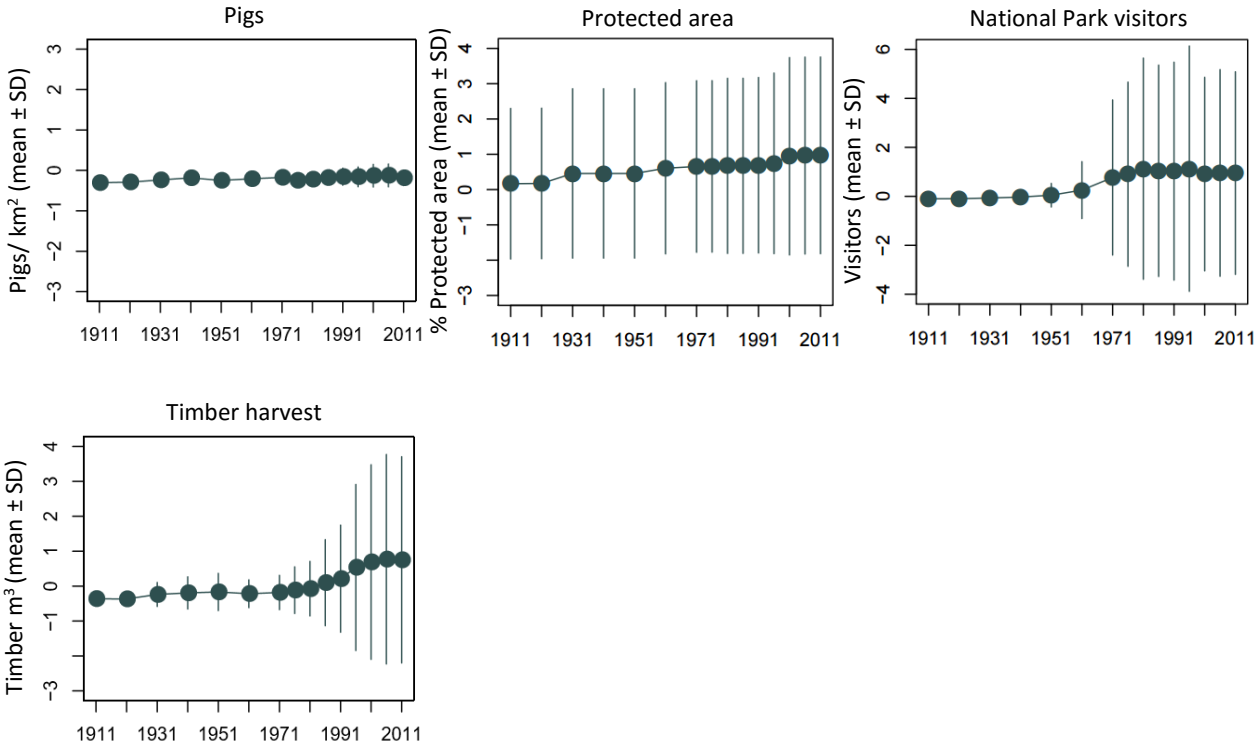


**Figure 27 (continued)** Alberta's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**British Columbia**

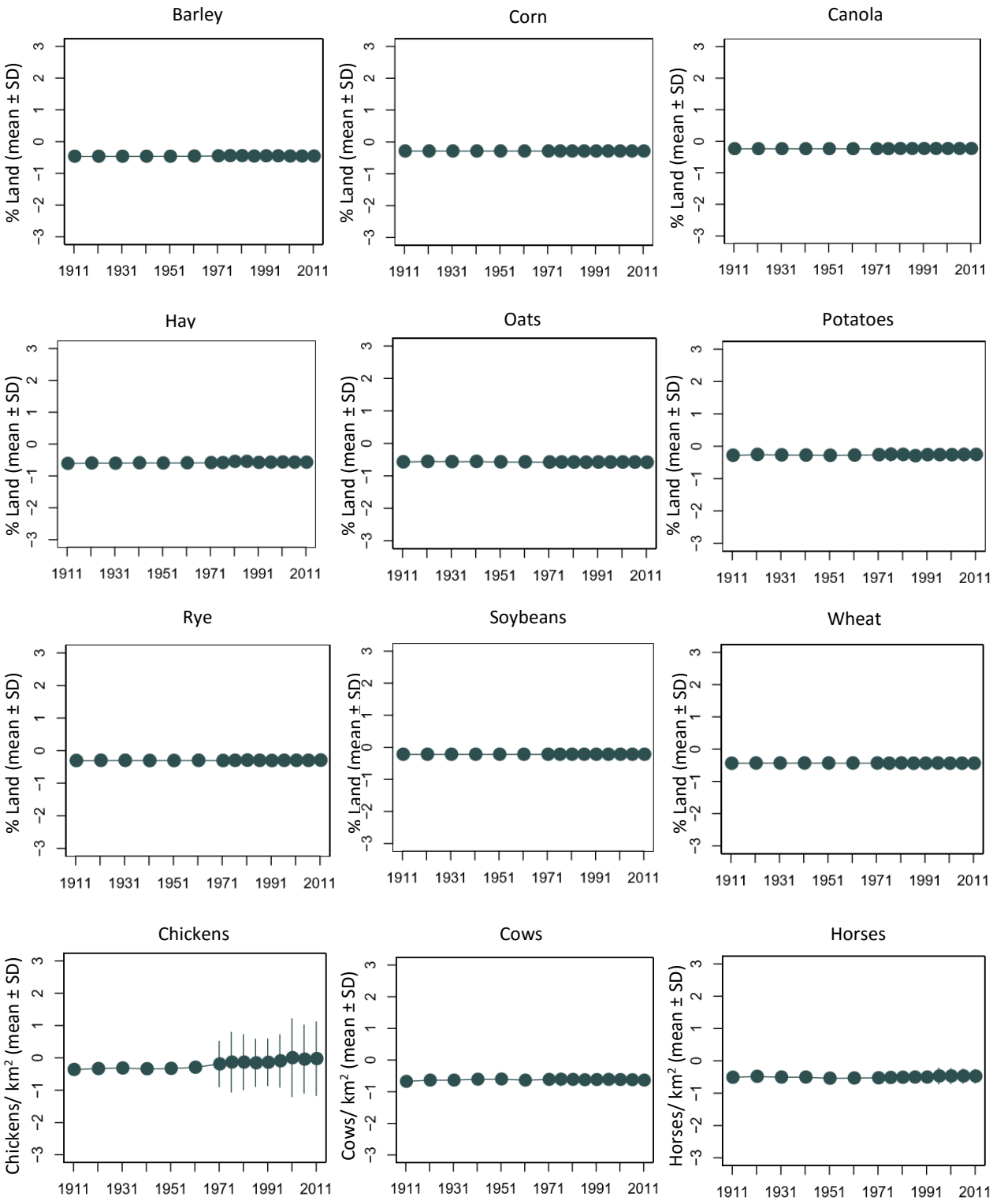


**Figure 28** British Columbia's provision of ecosystem services compared to the national average. Results are comparable between provinces.

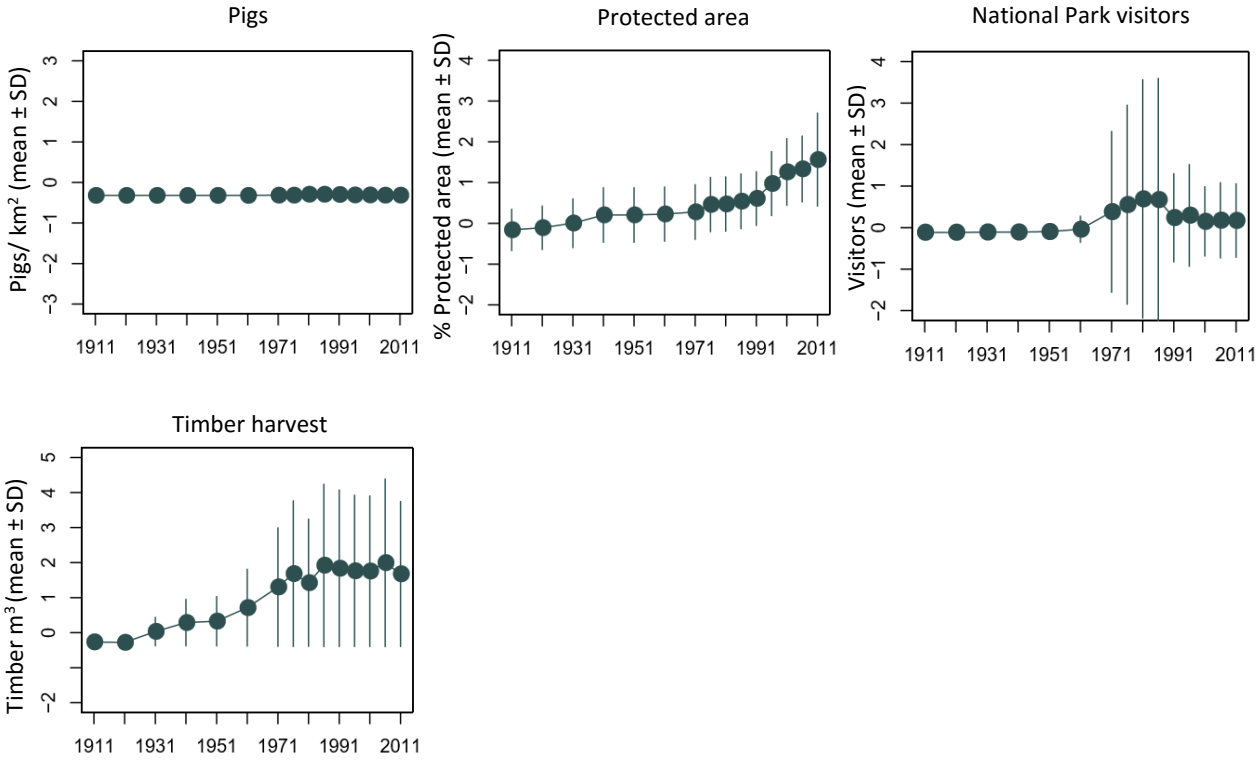


**Figure 28 (continued)** British Columbia's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Manitoba**

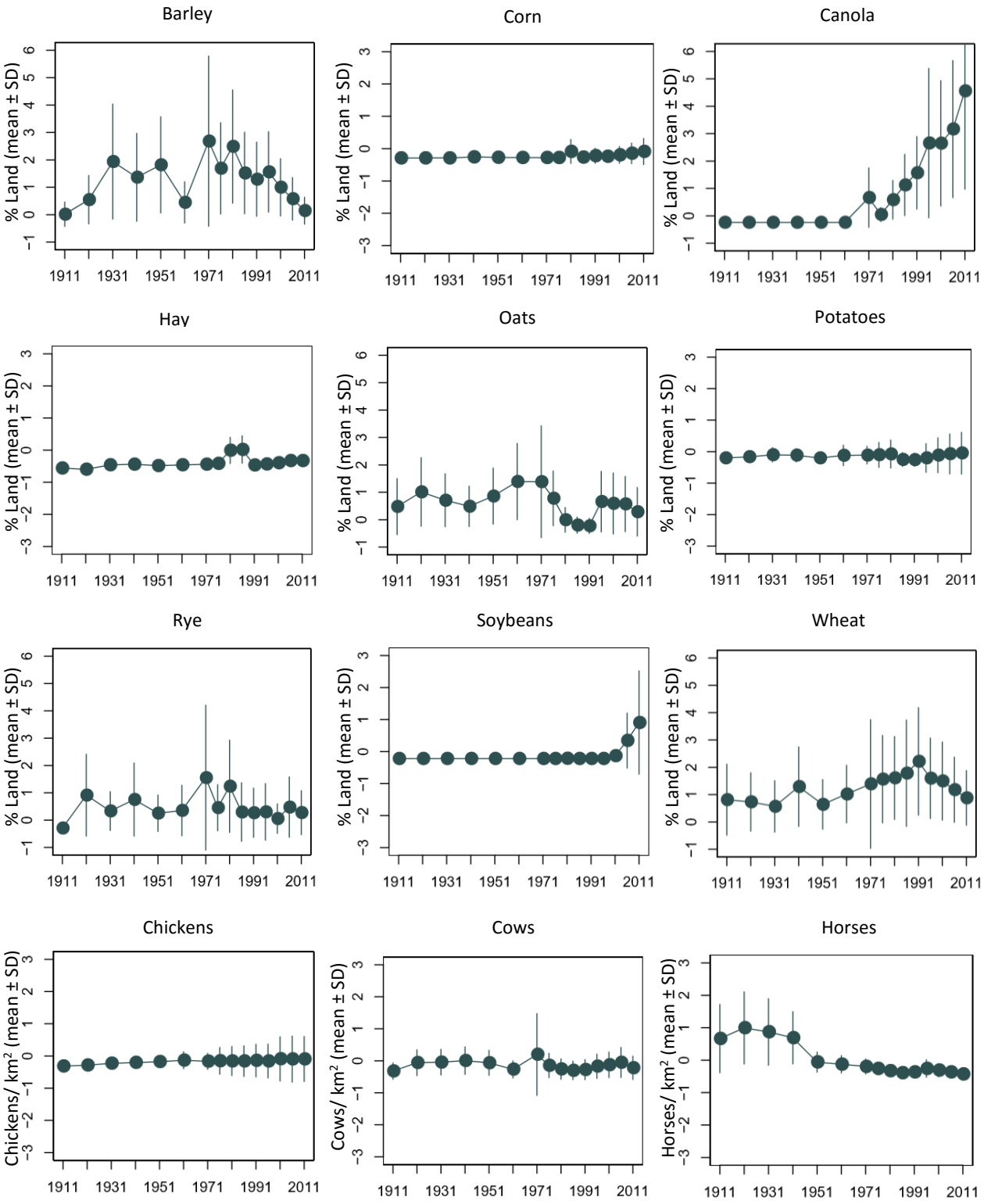


**Figure 29** Manitoba's provision of ecosystem services compared to the national average. Results are comparable between provinces.

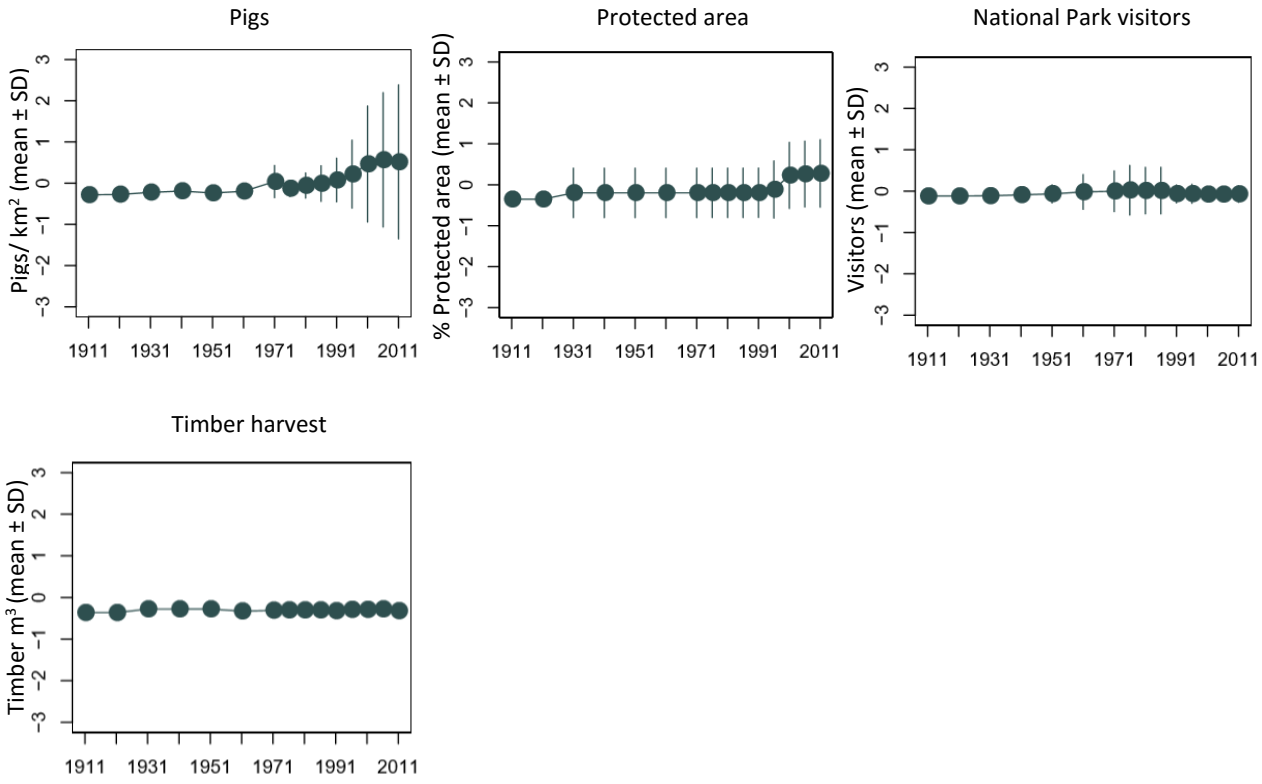


**Figure 29 (continued)** Manitoba's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**New Brunswick**

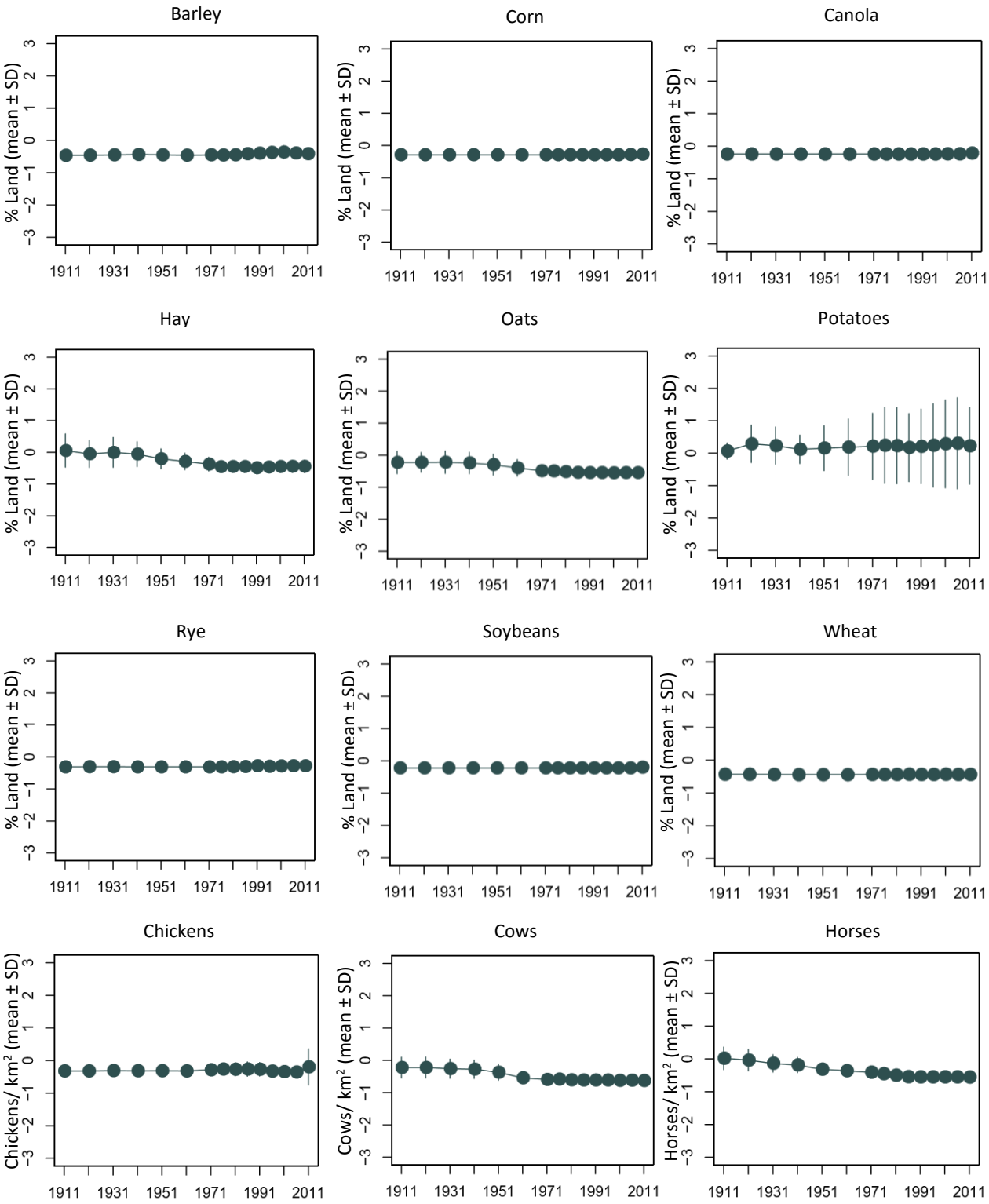


**Figure 30** New Brunswick's provision of ecosystem services compared to the national average. Results are comparable between provinces.

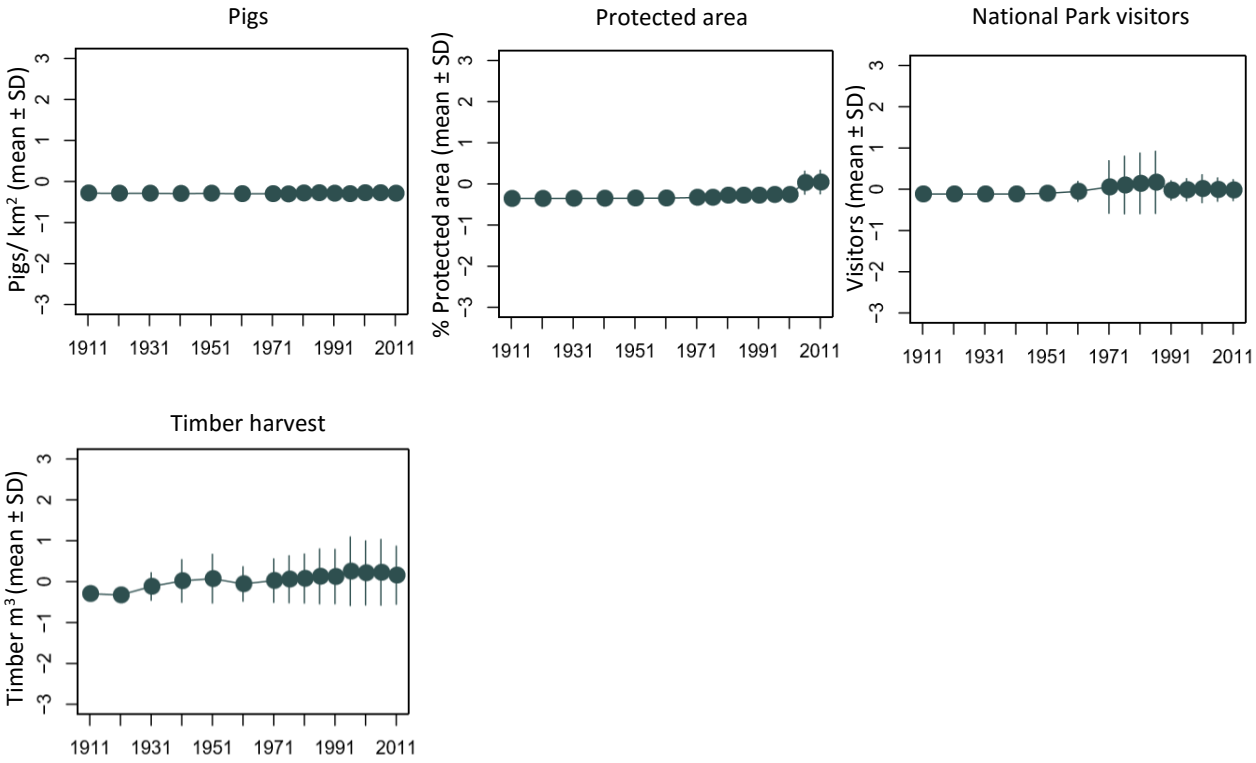


**Figure 30 (continued)** New Brunswick's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Newfoundland**

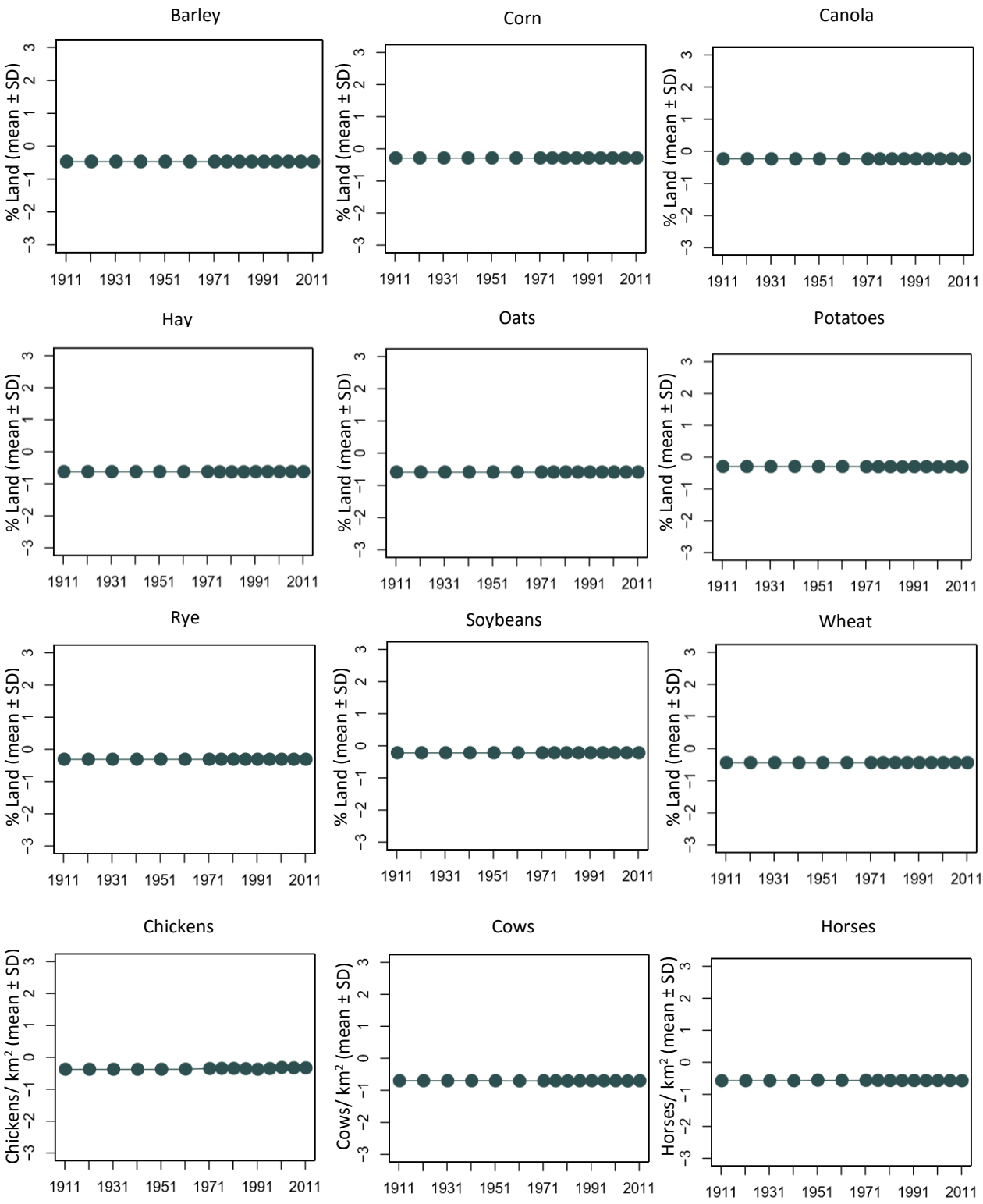


**Figure 31** Newfoundland's provision of ecosystem services compared to the national average. Results are comparable between provinces.

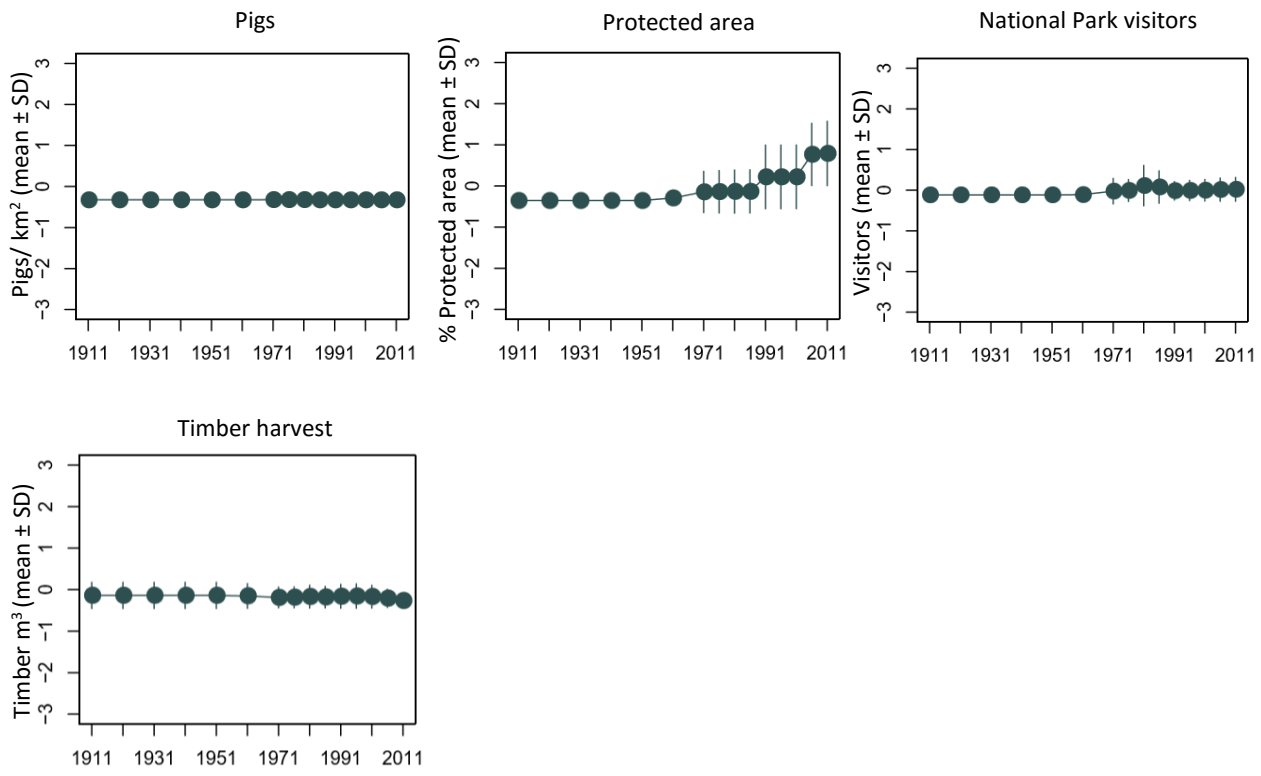


**Figure 31 (continued)** Newfoundland's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Nova Scotia**

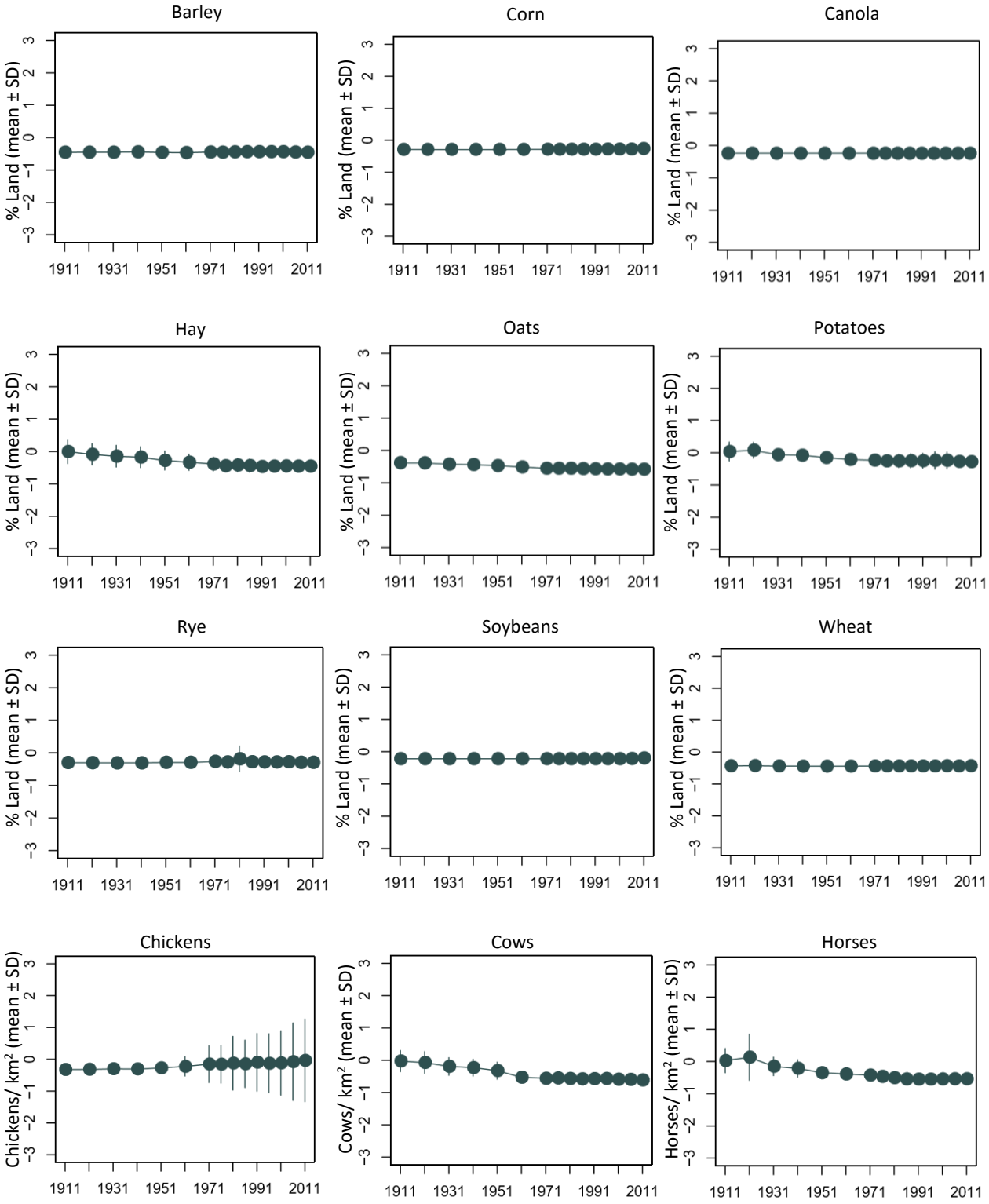


**Figure 32** Nova Scotia's provision of ecosystem services compared to the national average. Results are comparable between provinces.

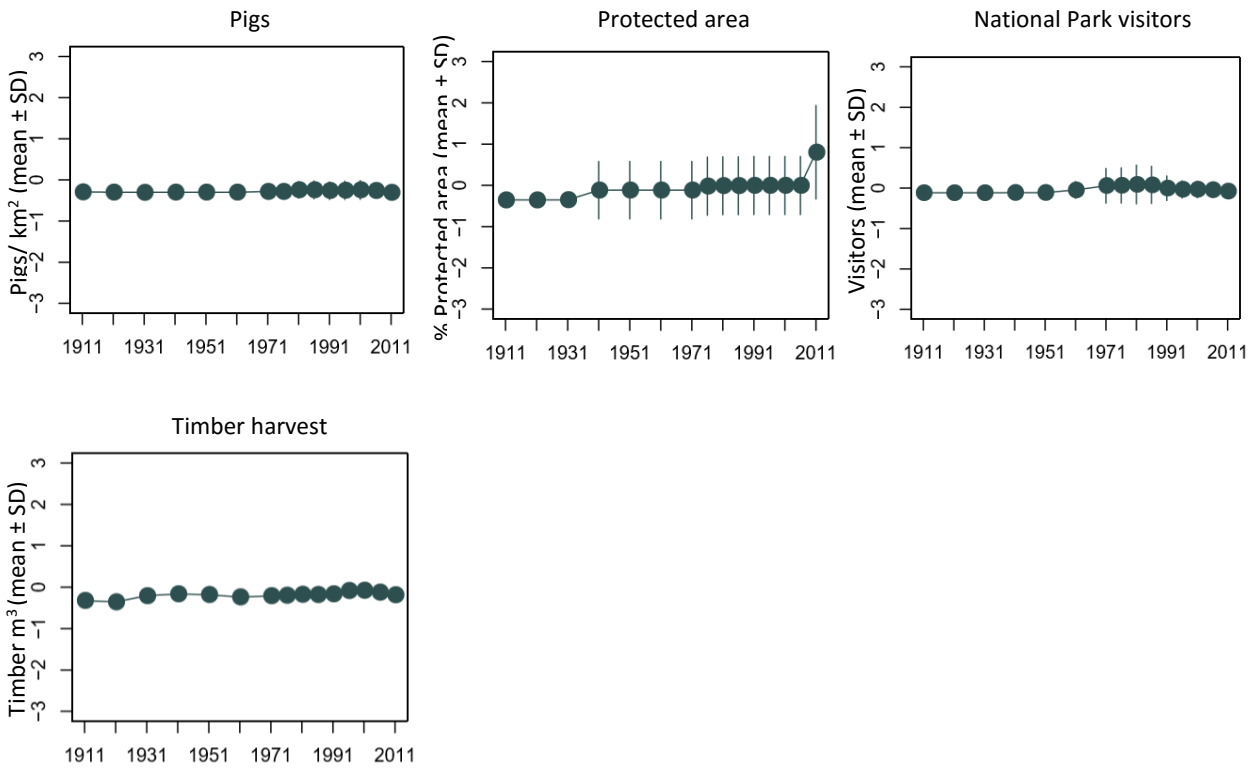


**Figure 32 (continued)** Nova Scotia's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Ontario**

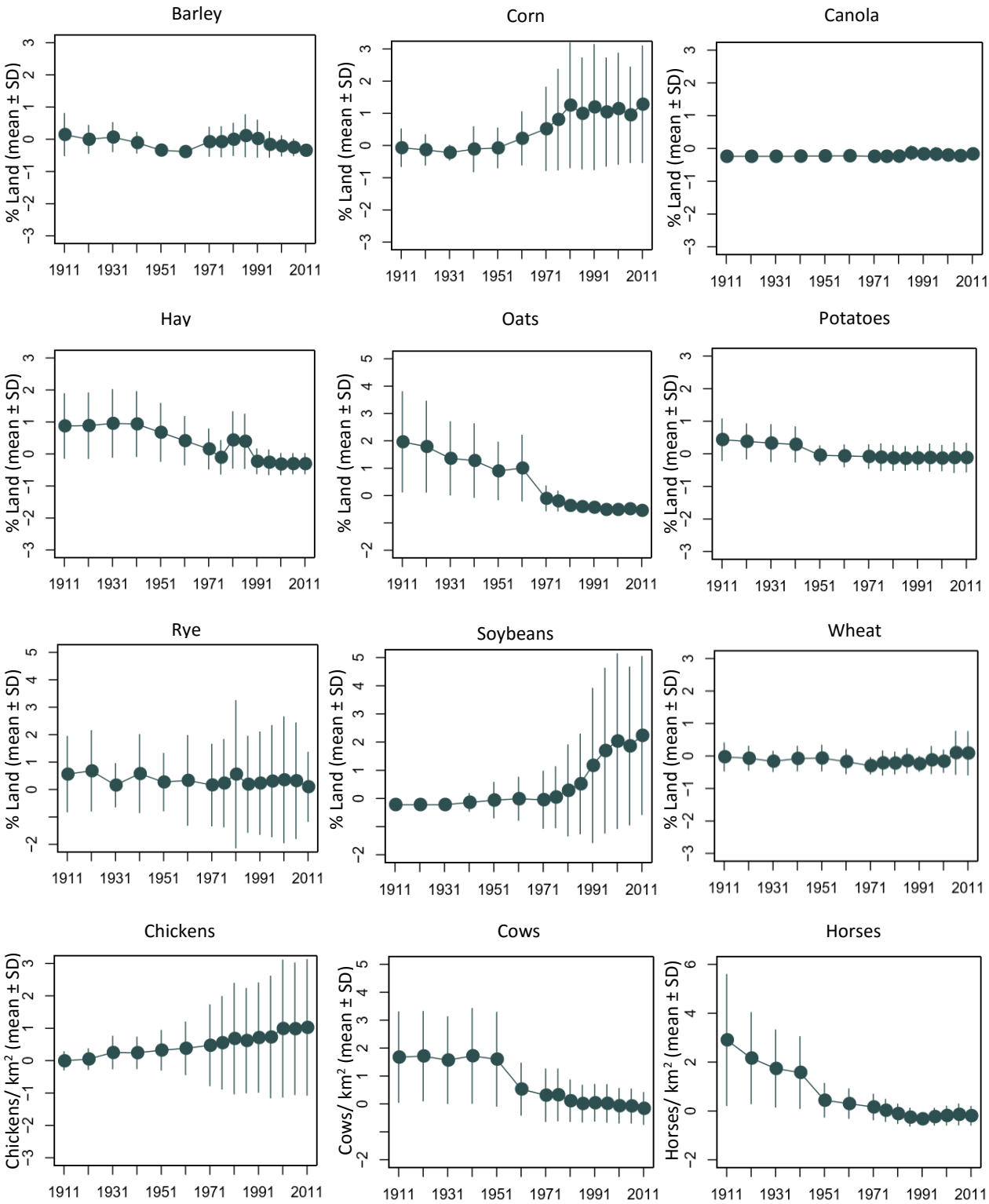


**Figure 33** Ontario's provision of ecosystem services compared to the national average. Results are comparable between provinces.

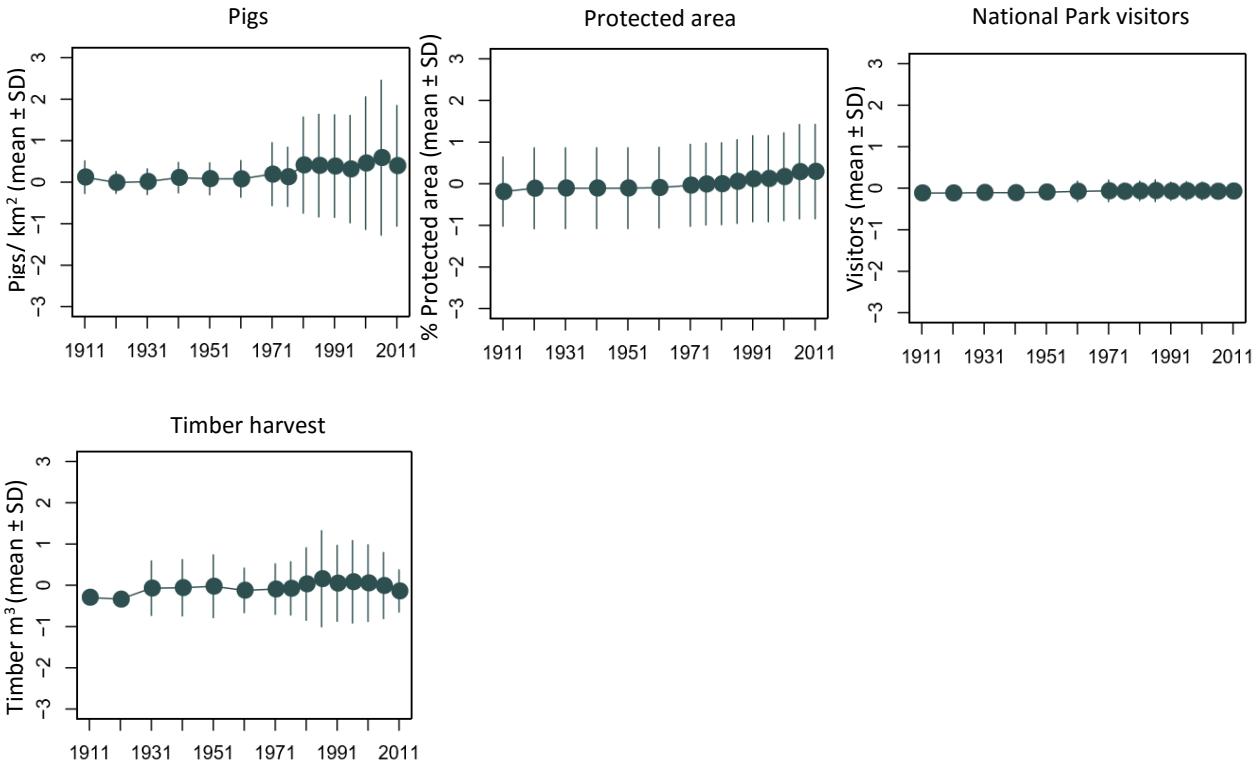


**Figure 33 (continued)** Ontario's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Prince Edward Island**

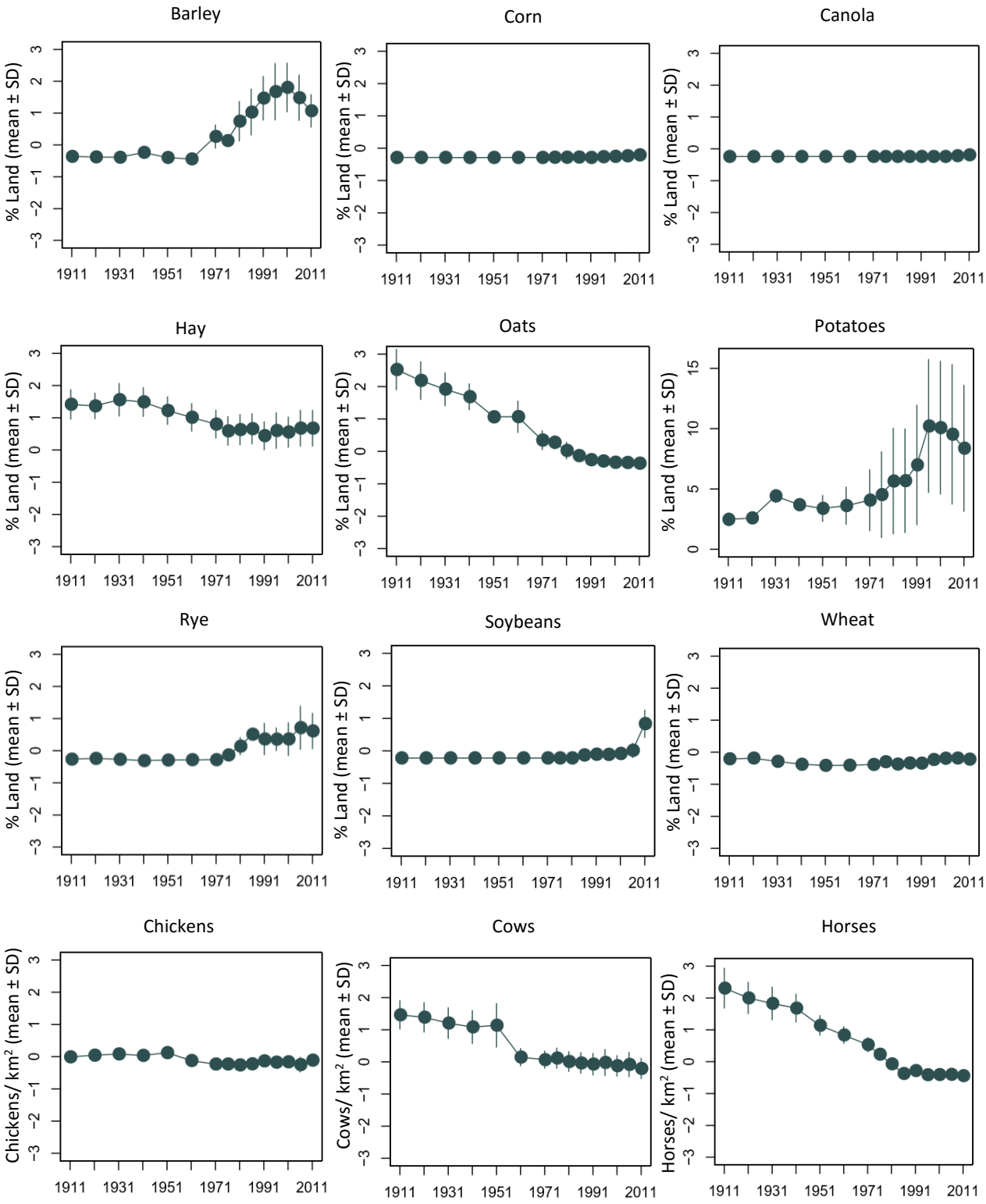


**Figure 34** Prince Edward Island's provision of ecosystem services compared to the national average. Results are comparable between provinces.

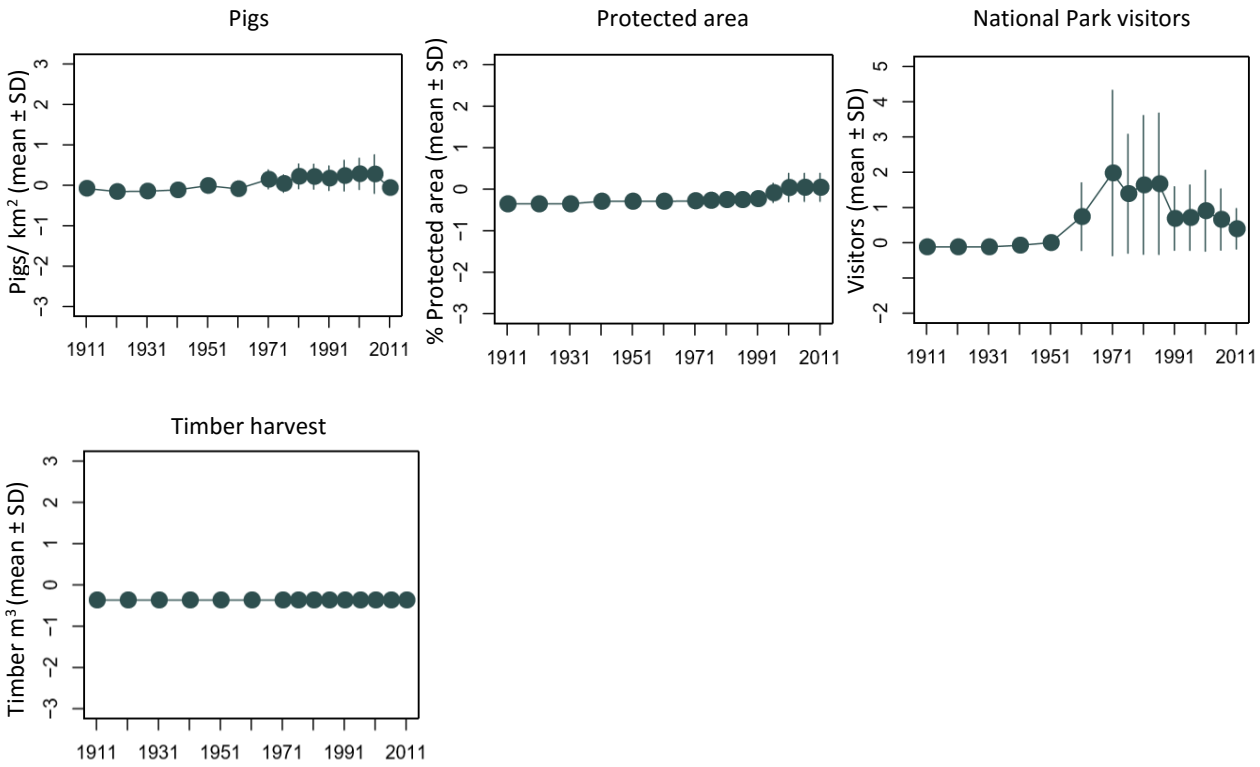


**Figure 34 (continued)** Prince Edward Island's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Quebec**

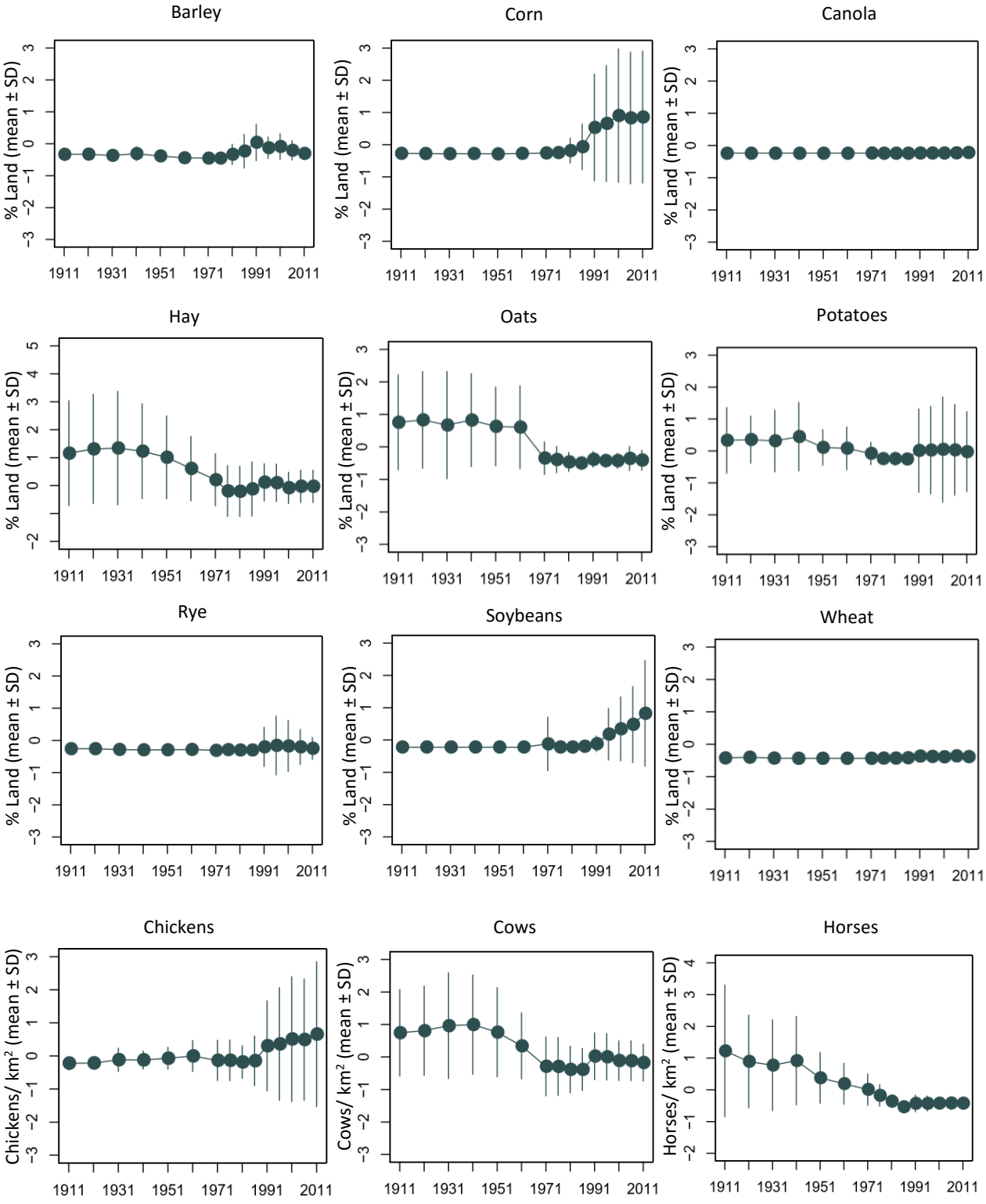


**Figure 35** Quebec's provision of ecosystem services compared to the national average. Results are comparable between provinces.

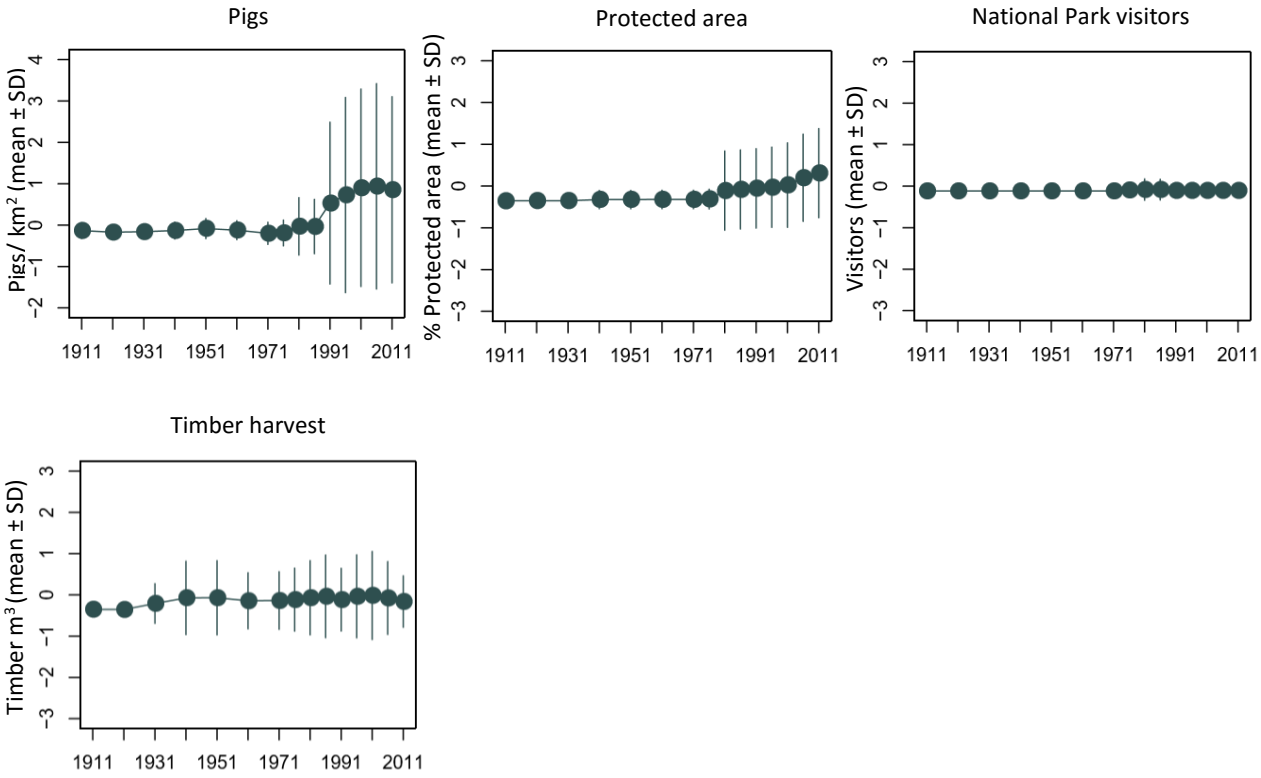


**Figure 35 (continued)** Quebec's provision of ecosystem services compared to the national average. Results are comparable between provinces.

**Saskatchewan**

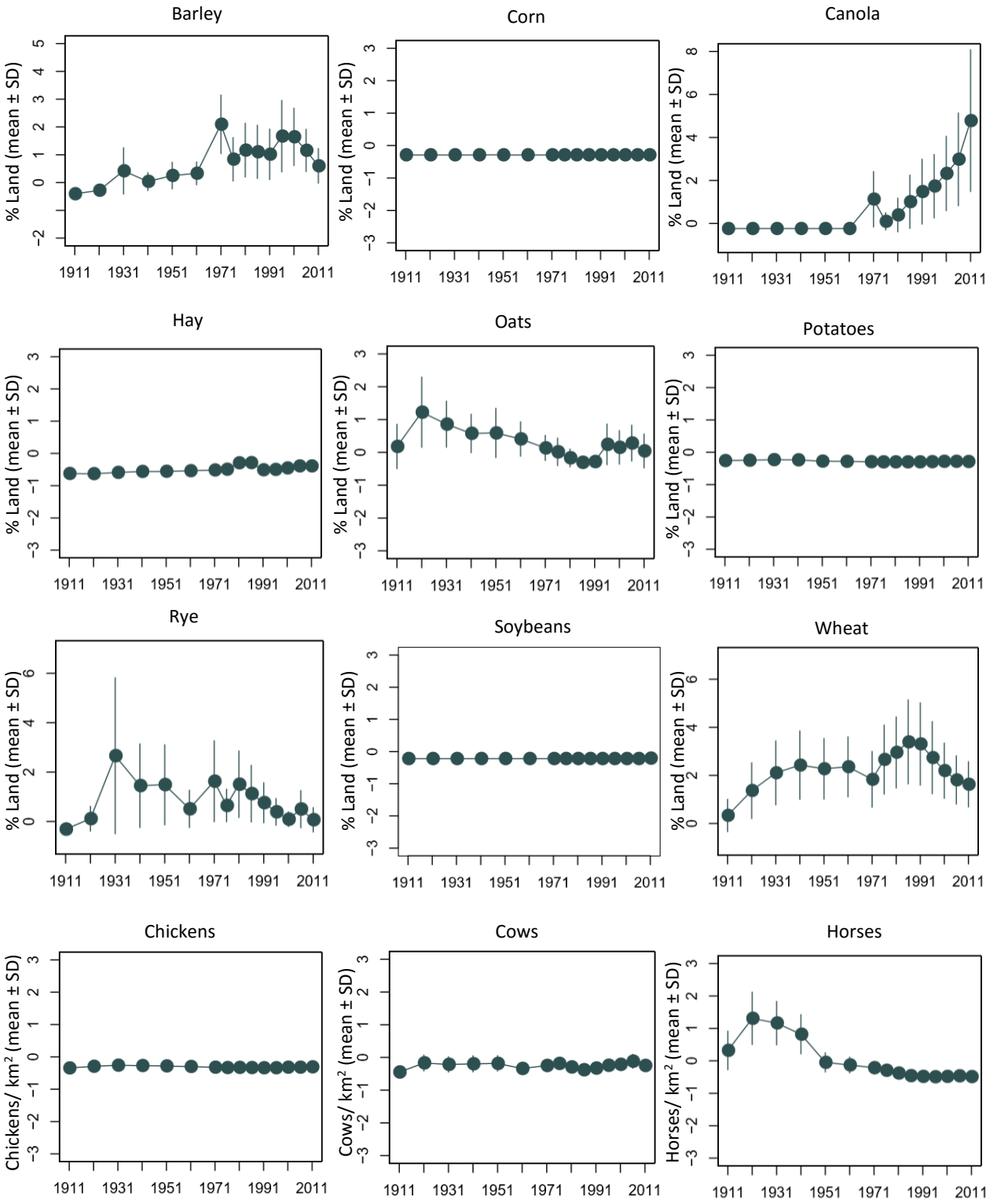


**Figure 36** Saskatchewan's provision of ecosystem services compared to the national average. Results are comparable between provinces.

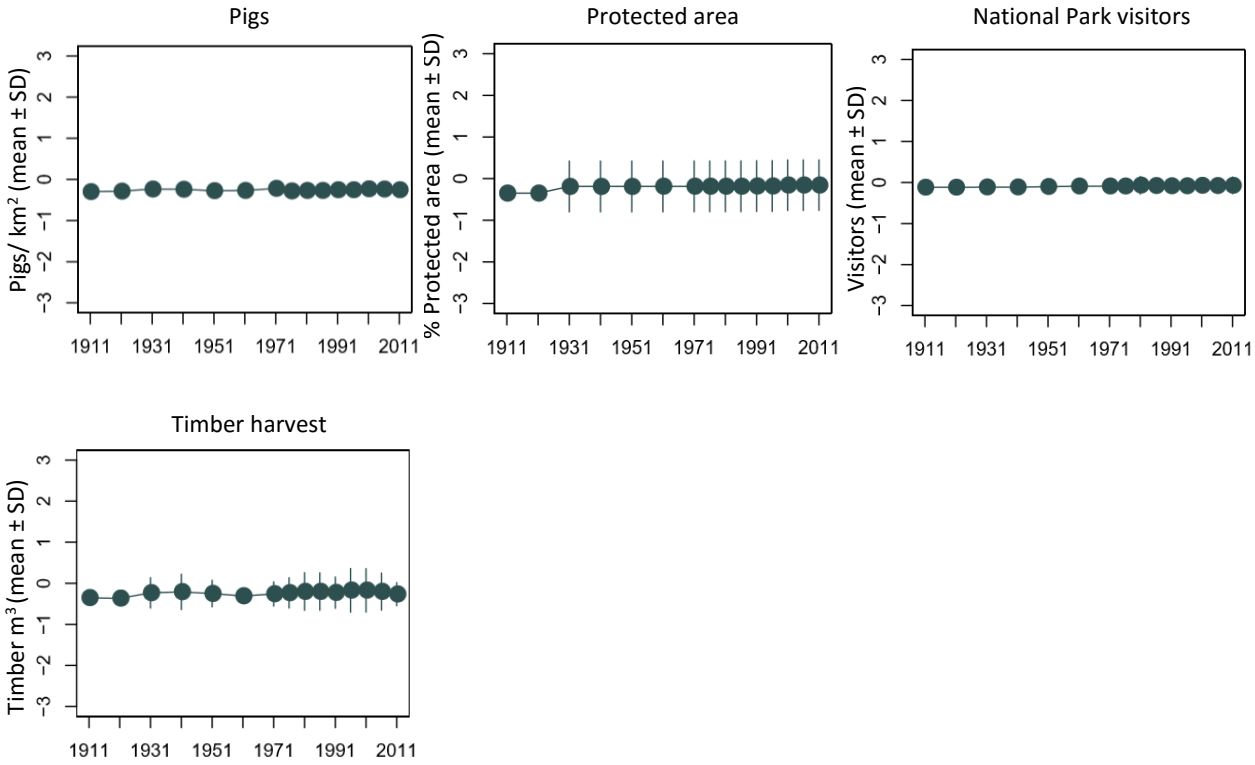


**Figure 36 (continued)** Saskatchewan's provision of ecosystem services compared to the national average. Results are comparable between provinces.