# RESOURCE ECONOMICS AND ENVIRONMENTAL SOCIOLOGY

# Economic Benefits of Biodiversity to Crop Producers in Canada: A Literature Review

Violet Muringai and Ellen Goddard

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# Project Report

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DEPARTMENT OF RESOURCE ECONOMICS
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# EXECUTIVE SUMMARY

The objective of this report is to provide a literature review on the economic benefits of biodiversity to Canadian producers of cereals, oilseeds and special crops. The review focuses on the economic benefits of biodiversity to crop farmers that are undertaking farm practices that contribute to biodiversity. The farm practices include the maintenance of permanent and temporary wetlands, generation and renewal of soil and natural vegetation, maintenance of wildlife habitat and moderation of extremes of temperature and force of winds. Publicly available research is included in this report and it includes peer-reviewed academic journal articles and reports from various governmental and non-governmental sources. Studies on the economic benefits of biodiversity to crop farmers (or society in general) are mainly from Canada and the United States. In summary, the results generally show that biodiversity provides economic benefits to crop production in terms of providing pollination services, biocontrol of pests, soil formation, nitrogen fixation, improvements or maintenance of water quality, sequestration of carbon and the protection of crops from the force of winds (shelterbelts). Economic values of the benefits of biodiversity, to society and farmers, are also included in the report.

# 1. INTRODUCTION

Biodiversity, which is a short form for biological diversity, is defined as ‘the variability among living organisms from all sources, including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part’ (TEEB, 2010, p. xxxi). Canadian biodiversity ‘comprises the vast array of living organisms which have evolved and become an integral part of the Canadian landscape’ (Mineau & McLaughlin, 1996, p. 94). Biodiversity focuses on variability within and between species and of ecosystems and it also focuses on the richness, rarity and uniqueness of biological resources (TEEB, 2010). Biodiversity is more than just counting the number of species (Everard, 2009; Maclaurin & Sterelny, 2008); it includes interactions between species and habitats, generations, genetic variability in species, and climate among others. Different levels of ecological systems are included in biodiversity and these are genes, individuals, populations, species, communities, ecosystems and biomes (TEEB, 2010). In order to understand biodiversity, there is a need to recognize our (people and ecosystems) interdependencies and responsibilities (Everard, 2009).

Societies benefit directly and indirectly from biodiversity (Organization for Economic Co-operation and Development (OECD), 2002). Biodiversity is important for quality of life, including disease reduction (Keesing & Ostfeld, 2015) and economic activities, spiritual and religious reasons and landscapes among other outcomes (Everard, 2009) and it is important for both current and future generations (Convention on Biological Diversity, n.d.a). There are strong interdependencies between agriculture and biodiversity. Biodiversity is important to agriculture for the biocontrol of pests and diseases, cycling of nutrients, sequestration and conversion of nutrients, soil organic matter regulation and retention of water in the soil, soil fertility and biota maintenance and pollination services (Brussaard, de Ruiter, & Brown, 2007; Convention on Biological Diversity, n.d.b; Wratten, Gillespie, Decourtye, Mader, & Desneux, 2012).

However, human activities are resulting in losses in biodiversity (Convention on Biological Diversity, n.d.a; OECD, 2002). Some of the major causes of biodiversity loss are habitat degradation, pollution, unsustainable consumption of resources, introduction of alien species and diseases (Badgley, 2003; Clark & Downes, 1995). Agricultural activities can be a major cause of biodiversity losses through direct (use of pesticides and inorganic fertilizers) and indirect effects (for example, habitat degradation through drainage of wetlands) such that changes to agricultural production practices that support biodiversity are important for the preservation of biodiversity (Badgley, 2003; Rundlöf, Smith, & Birkhofer, 2016; Secretariat of Convention on Biological Diversity, 2008). The improvement of biodiversity on agricultural lands is important, for example, for the maintenance of water quality and quantity, supporting pollinators and allowing ecosystems to be more resilient and to adapt to stresses such as droughts (Convention on Biological Diversity, 2014).

The UN IPBES 2019 report (United Nations Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services https://www.ipbes.net/global-assessment-report-biodiversity-ecosystem-services) , tabled in May 2019, heightened concerns about global declines in biodiversity. A key part of declining biodiversity is seen to be changes in land and sea use and globally the report recognizes a decline of 20% in the average abundance of native species in major global land-based habitats. Almost simultaneously, the OECD released a report entitled Biodiversity: Finance and the Economic and Business Case for Action (OECD, 2019) for a May 2019 G7 Environmental Minsters Meeting. This report starts from the point that ecosystem services from biodiversity are 'vital to human well being' and 'worth more than 1.5 times global

GDP' (p. 9). Specifically, they reference the 'annual market value of crops dependent on animal pollination ranges from USD 235 billion to USD 577 billion' (p. 12). However, the focus of the report is on the business case for biodiversity conservation and the business benefits identified include resource sustainability, increases in operational efficiency arising from tracking biodiversity implications, consumer loyalty, new products, technologies, services (including ecosystem) and markets diversifying revenue streams for businesses and better relationships with stakeholders including suppliers, consumers and employees (OECD, 2019, p. 40). One recent example of businesses recognizing the importance of biodiversity and acting is the coalition of nineteen agriculture-centric companies called One Planet Business for Biodiversity (OP2B, https://www.foodincanada.com/food-in-canada/loblaw-mccain-danone-support-new-biodiversity-coalition-142691/ accessed October 28, 2019). The coalition is aimed at scaling up regenerative agriculture to protect soil health, boosting cultivated biodiversity and restoring and protecting high value natural ecosystems among other things. Similarly, General Mills has initiated a new focus on soil health in both Canada and the US (https://www.producer.com/2019/01/general-mills-promotes-focus-on-soil-health/ accessed October 28, 2019).

Two other recent studies from other parts of the world highlight the importance of enhancing biodiversity on agricultural lands. First, in Brazil, Metzger et. al. (2019) produced a white paper on 'Why Brazil Needs Its Legal Reserves' (legal reserves are areas required to be maintained in native vegetation, a fixed percentage of private lands), showing the "importance of these reserves for water, energy, food, and climate securities, in addition to their primary function of assisting in the maintenance of biodiversity in agricultural landscapes" (page 91). These legal reserve requirements are controversial, unsurprisingly, because producers would like to use these set aside lands for agricultural production. In a different study related to the hill farms of the UK, the RSPB commissioned a study on how these farms might be most profitable, without ecosystem payments. Their report highlights that for many farms, reducing output from cattle or sheep grazing to areas of natural grasslands (without fertilizer addition) might be the most profitable position given the significant reduction in variable costs that would result (Clark, Scanlon & Hart (2019)). These two studies are examples of studies that could be undertaken in different parts of Canada, and provide quality information for farmer decision making with respect to biodiversity on croplands.

At the same time, the science of biodiversity enhancement is growing and consolidating, providing a wealth of information on which farm and firm decisions can be made with much higher certainty about outcomes. For example, a recent major global synthesis report (Dainese et al., 2019) examined the relationship between biodiversity and crop production. Specifically, the report looked at the relationship between biodiversity, in terms of the evenness of ecosystem service providing insect species (relative abundance) and the total number of individual insects (abundance) as well as the actual number of species, and outcomes such as pollination, biological pest control and final crop yields. The report's conclusion is that maintaining biodiversity "ecosystem service providers (pollinators and natural pest enemies, for example) is … vital to sustain the flow of key agroecosystem benefits to society" (p. 1). In terms of grasslands, a large international team (Fraser et al., 2015) synthesized the literature on the relationship between plant productivity (biomass plus litter) and plant biodiversity. Their result showed that in grasslands, plant diversity is maximized at intermediate productivity – 'at low productivity many fewer plant species can tolerate the environmental stress and at higher productivity a few species dominate' (p. 302). This finding, if extended to croplands, could affect the volume of crop production (and revenues and profits), in an environment where farmers operate to simultaneously produce ecosystem services from biodiversity and to produce high crop yields. For example, Rosa-Schleich, Loos, Mußhoff, and Teja. (2019) undertook a systematic review of available literature on diversified farming (producing mixture of crops or crops and livestock) and noted that 'the ecological benefits for the farmer were partly insufficient to outbalance economic costs in the short term, even though many examples showed that diversified farming practices have the potential to lead to higher and more stable yields, increase profitability and reduce risks in the long-term' (p. 251).

The significant scientific literature is rich enough that much more specific biodiversity/relationships can be verified through studies like the above, which synthesize and reanalyze results from multiple individual studies in geographically variable locations, for findings that can be used practically by decision makers.

In this report, the literature on the economic benefits of biodiversity with a specific focus on benefits to Canadian producers of cereals, oilseeds and special crops is provided. The literature review focuses on farm practices that contribute to biodiversity such as purification of air and water through the maintenance of permanent and temporary wetlands, generation and renewal of soil and natural vegetation, maintenance of wildlife habitat and moderation of temperature extremes and forces of winds.

The valuation of biodiversity is critical since biodiversity is an important asset that provides society with a variety of services and the individual species that contribute to biodiversity also have intrinsic values themselves (Grafton et al., 2004). Economic non-market valuation measurements can be important in identifying the need to protect certain resources and can assist in assessing the value of conservation of resources to society (TEEB, 2009).

For this report, information was obtained from various sources and databases including government websites, GOOGLE Scholar, Web of Science and the Environmental Valuation Reference Inventory (EVRI) databases. The literature review is structured as follows: 1. Introduction 2. Background on crop production in Canada 3. Crop production and biodiversity 4. Crop farm management practices for protecting or enhancing biodiversity 5. Assessment of economic benefits of biodiversity 6. Economic benefits of biodiversity to crop production 7. Conclusions.

## 2. BACKGROUND ON CROP PRODUCTION IN CANADA

In Canada, agricultural land is used for crop and livestock production and the land also provides habitat for wildlife (for example, birds, mammals and reptiles). Ecosystem services such as pollination, degradation of contaminants, natural control against pests and mitigation against drought and floods are provided by natural habitats on farms (Canadian Wildlife Federation, 2019).

Table 1: Distribution of cropland and total field crop area in Canada by province in 2016, Census of Agriculture

| | Total farm area (acres) | Cropland area (acres) | % of total cropland area in the country[a] |
|---|---|---|---|
| Saskatchewan | 61.6 million | 40.5 million | 43.4 |
| Alberta | 50.3 million | 25.3 million | 27.1 |
| Manitoba | 17.6 million | 11.5 million | 12.3 |
| Ontario | 12.3 million | 9.0 million | 9.64 |
| Quebec | 8.1 million | 4.6 million | 4.93 |
| British Columbia | 6.4 million | 1.4 million | 1.50 |
| Nova Scotia | 915,657 | 267,447 | 0.29 |
| New Brunswick | 835,329 | 344,504 | 0.37 |
| Prince Edward Island | 575,490 | 400,322 | 0.43 |
| Newfoundland and Labrador | 70,747 | 19,619 | 0.02 |
| Yukon and Northwest Territories | 25,860 | 6,318 | 0.01 |

[a] calculated using data on cropland area in Table 1

Source: Statistics Canada (2018a, b, c, d, e, f g, h, i, j and k) and Government of Nova Scotia (2017)

The total cropland area in Canada in 2016 was 93.4 million acres and on average, the size of land used for crops for an average farm was 483 acres (33 acres in 1871) (Statistics Canada, 2017). Most of the cropland in Canada is found in the Prairie Provinces including Saskatchewan, Alberta and Manitoba (Table 1).

Field crops are mostly produced in Saskatchewan, Alberta, Ontario, Quebec and Prince Edward Island while hay is mostly produced in British Columbia, Nova Scotia, New Brunswick, Newfoundland and Labrador and Yukon and North West Territories (Table 2). Canola is the major field crop produced in Saskatchewan, Alberta and Manitoba. Soybeans are the major field crop in Ontario while corn is the largest crop produced in Quebec, Nova Scotia and Newfoundland and Labrador. Spring wheat is the major field crop produced in British Columbia while potatoes are the largest field crop produced in New Brunswick and Prince Edward Island. Lastly, oats are the major field crop produced in the Yukon and Northwest Territories.

Table 2: Components of cropland in Canada by province in 2011 and 2016

| | Year | Field crops | Hay | Vegetables | Fruits, berries and nuts | Sod and Nursery | Largest field crops |
|---|---|---|---|---|---|---|---|
| | | % | | | | | |
| Saskatchewan | 2011 | 87.4 | 12.6 | 0.00 | | | Canola, spring wheat (excluding durum) and lentils |
| | 2016 | 90.7 | 9.20 | 0.00 | | | |
| Alberta | 2011 | 78.6 | 21.3 | 0.10 | | | Canola, spring wheat and barley |
| | 2016 | 83.2 | 16.7 | 0.10 | | | |
| Manitoba | 2011 | 82.9 | 17.0 | 0.10 | | | Canola, spring wheat and soybeans |
| | 2016 | 86.8 | 13.1 | 0.10 | | | |
| Ontario | 2011 | 74.1 | 23.3 | 1.50 | 0.60 | 0.60 | Soybeans, corn for grain and winter wheat |
| | 2016 | 78.4 | 19.1 | 1.50 | 0.60 | 0.50 | |
| Quebec | 2011 | 54.5 | 40.9 | 2.00 | 2.10 | 0.50 | Corn for grain, soybeans and oats |
| | 2016 | 60.1 | 35.2 | 2.00 | 2.30 | 0.40 | |
| British Columbia | 2011 | 29.8 | 64.1 | 1.10 | 4.10 | 0.90 | Spring wheat, canola and oats |
| | 2016 | 33.7 | 60.0 | 1.10 | 4.40 | 0.80 | |
| Nova Scotia | 2011 | 18.8 | 58.9 | 2.40 | 18.7 | 1.20 | Corn (grain and silage) |
| | 2016 | 23.7 | 54.8 | 2.20 | 18.3 | 1.10 | |
| New Brunswick | 2011 | 40.8 | 49.7 | 0.50 | 8.50 | 0.40 | Potatoes, oats and barley |
| | 2016 | 39.2 | 46.6 | 0.50 | 13.2 | 0.40 | |
| Prince Edward Island | 2011 | 65.0 | 31.2 | 0.60 | 3.10 | 0.10 | Potatoes, barley and soybeans |
| | 2016 | 65.7 | 30.1 | 0.60 | 3.60 | 0.10 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Newfoundland and Labrador | 2011 | 7.90 | 76.2 | 4.30 | 6.90 | 4.60 | Corn for silage, potatoes and spring wheat |
| | 2016 | 8.40 | 79.2 | 4.10 | 4.40 | 3.80 | |
| Yukon and Northwest Territories | 2011 | 21.2 | 76.6 | 2.20 | | | Oats |
| | 2016 | 22.2 | 75.6 | 2.20 | | | |

Source: Statistics Canada (2018a, b, c, d, e, f g, h, i, j and k)

## 3. CROP PRODUCTION AND BIODIVERSITY

In 2016, 6.9% of the total land area in Canada was classified as agricultural land, down from 7% in 2011 and 7.3% in 2001. In Canada, cropland increased from 46% (3.6% of total land area) to 53% (3.9% of total land area) of the total agricultural land between 1986 and 2006 (Federal, Provincial and Territorial Governments of Canada, 2010). In 2011, the land devoted specifically to crops represented 3.8% of the total land area in the country and in 2016, this had risen to 4.1% of the total land area. Agricultural lands provide habitat for more than 550 species of terrestrial vertebrates (which includes half of the species that are at risk in the country) (Federal, Provincial and Territorial Governments of Canada, 2010; Statistics Canada, 2014). Of different land uses within the country, cropland provides the lowest biodiversity values while the highest values are provided by natural areas including wetlands, woodlands and unimproved pasture (Federal, Provincial and Territorial Governments of Canada, 2010). In Figure 1, the number of wildlife species using different land covers for reproduction and feeding are illustrated. The "all other land" category which includes woodlands, wetlands and all other agricultural land that is not explicitly mentioned in Figure 1 (for example, farmyard sites and gardens) is mostly used by wildlife species for breeding and feeding. Crop lands are mostly used for feeding while they are minimally used for reproduction.

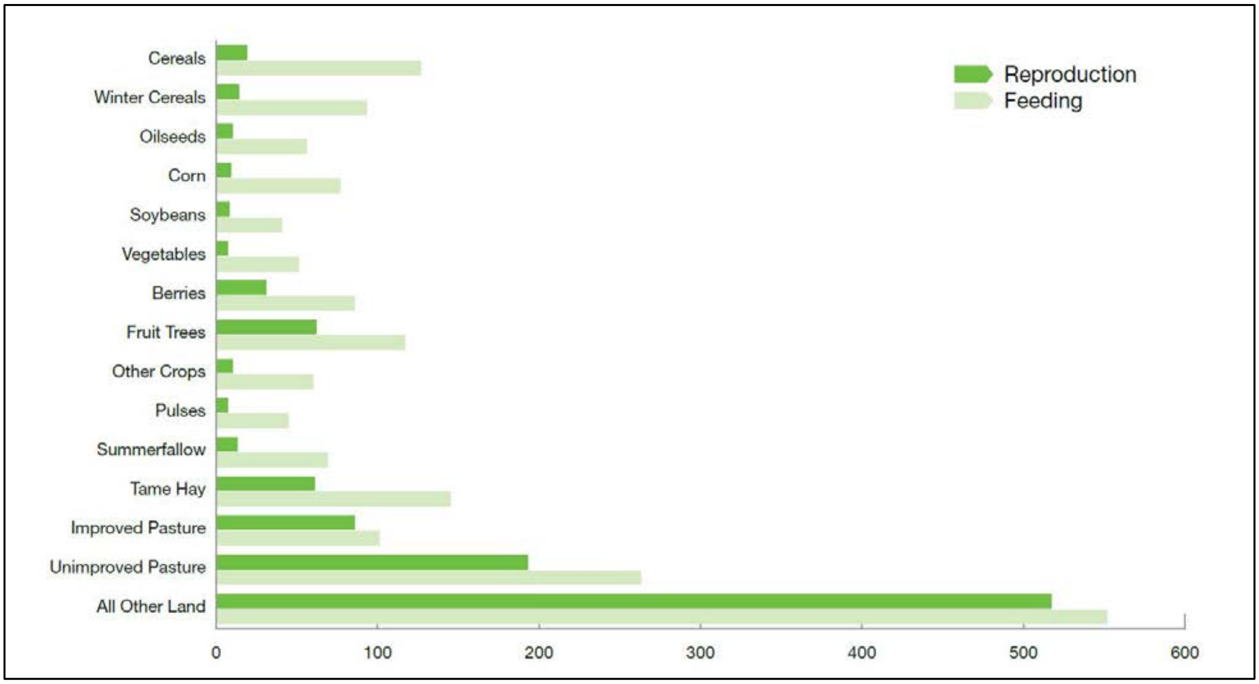


*Figure 1: Cover type and number of wildlife species on agricultural land in Canada*
Adapted from Agriculture and Agri-Food Canada (2016)

Figure 2 which was adapted from Alberta Agriculture and Food (2007) shows that biodiversity values for birds are highest in native habitats (e.g., communities that evolved in the region such as native grasslands). Therefore, conservation of native habitats is important for increasing the levels of biodiversity.

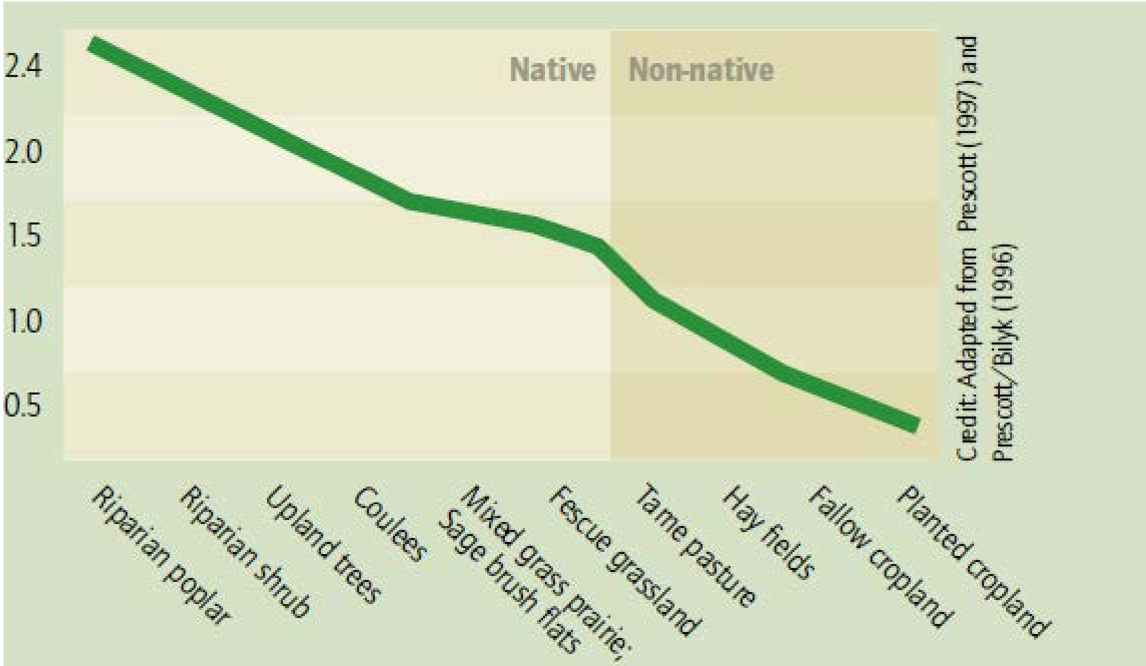


*Figure 2: Biodiversity values for birds*
Adapted from Alberta Agriculture and Food (2007)

Statistics Canada (2015) provides information on the number of farms in Canada that have woodlands and wetlands and the information is categorized by the type of farm (Table 3). About 47% of oilseed and grain farms have woodlands and wetlands and the size of the woodlands and wetlands are approximately 5% of the agricultural land area.

Table 3: Crop farms with woodlands and wetlands in Canada in 2011

| Farm type | All farms | Farms with woodlands and wetlands | Woodlands and wetlands | | |
|---|---|---|---|---|---|
| | Number | Number (%) | Area (ha) | Area per farm (ha) | Area as per % of agricultural land area |
| Oil seed and grain farming | 61,692 | 28,963 (46.9) | 1,483,879 | 51.2 | 4.7 |
| Vegetable and melon farming | 4,822 | 2,410 (50.0) | 96,694 | 40.1 | 14.4 |
| Fruit and tree nut farming | 8,253 | 3,587 (43.5) | 165,263 | 46.1 | 47.5 |
| Greenhouse, nursery and floriculture production | 7,946 | 3,361 (42.3) | 102,728 | 30.6 | 37.1 |
| Other crop farming | 37,402 | 22,137 (59.2) | 1,089,974 | 49.2 | 16.9 |

Source: Statistics Canada (2015)

*3.1 Crop production and its impact on biodiversity*

Crop production can have positive and negative effects on biodiversity depending on the practices used (Convention on Biological Diversity, 2008). Changing natural areas to cropland and intensification of agriculture has negatively affected the capacity of agricultural landscapes to provide habitat for wildlife (Federal, Provincial and Territorial Governments of Canada, 2010). Certain agricultural practices (for example residue management, crop rotation, and irrigation and drainage) influence habitats and foods for soil organisms (Food and Agriculture Organization of the United Nations (FAO), 2019). The physical and chemical environments for soils are also affected by tillage practices and use of fertilizers and pesticides among others farming practices (FAO, 2019). Crop rotation changes the composition of landscapes and host plants in fields which also affects pests and beneficial arthropods (Vankosky, Cárcamo, Catton, Costamagna, & De Clerck-Floate, 2017). Agricultural fertilizers impact biodiversity (McLaughlin and Mineau, 1995) because they can result in the accumulation of nutrients such as nitrogen in aquatic systems which can result in algal blooms (Federal, Provincial and Territorial Governments of Canada, 2010) and fertilizers and pesticides can disturb soil health since they affect the microflora of the soil (Prashar and Shah, 2016). Algal blooms produce toxic compounds, or they can use a lot of oxygen which affects other species (Federal, Provincial and Territorial Governments of Canada, 2010).

Crop production can negatively affect ecosystems. For example, it is possible that grasslands, forests and wetlands can be converted to cropland. Fragmentation of forests as a result of their conversion to agricultural activities among other human activities and natural processes can result in the reduction of neotropical birds that need interior forest habitat, reduction in species that require larger areas for habitat (e.g., grizzly bear and caribou), increased risk of predators for interior forest species among others (Federal, Provincial and Territorial Governments of Canada, 2010).

Wetlands which are lands that are always or most of the times saturated by water are also important ecosystems in Canada (Federal, Provincial and Territorial Governments of Canada, 2010). Wetlands are classified as follows: (i) organic or peatlands (bogs and fens) (ii) mineral (marshes and shallow water) (iii) swamps which are either peatlands or mineral wetlands (Federal, Provincial and Territorial Governments of Canada, 2010). Sixteen percent of the land area in Canada is wetlands and most losses of wetlands (Federal, Provincial and Territorial Governments of Canada, 2010) have occurred in southern Canada (an area that encompasses southern areas of BC, Alberta, Saskatchewan, Ontario, Quebec and all of the Maritimes https://www150.statcan.gc.ca/n1/daily-quotidien/190704/mc-a001-eng.htm). Wetlands have ecological (preservation of water quality) through the removal of nutrients and sediments, biological (habitat for fish, amphibians, plants, migratory birds and animal such as muskrat, beaver, otter, mink and raccoon) and hydrological functions (flood control and maintain the flow of streams) (Heimlich, Wiebe, Claassen, Gadsby, & House, 1998). Wetlands are also important for the sequestration of carbon, for example (Federal, Provincial and Territorial Governments of Canada, 2010). Wetlands are at risk of conversion to other land uses (to agriculture for example) and they are affected by hydroelectric development and changes in the climate, pollution, invasive species and urban development among others (Federal, Provincial and Territorial Governments of Canada, 2010). In Canada there continue to be losses in wetlands in different parts of the country, for example, 72% of the wetlands in Ontario were converted to other uses by 2002 (Federal, Provincial and Territorial Governments of Canada, 2010). Wong, van Kooten, and Clarke (2012) found the restoration of wetlands in one area increased the productivity of wetlands and habitat for ducks in other locations.  From a spatial autoregressive panel model, Wong et al. (2012) found that a 1% increase in cropland (measured by percentage of farm area in cropland) decreased duck density by 5% (direct impact). According to Pattison-Williams, Pomeroy, Badiou, and Gabor (2018) the prevention of more losses of wetlands is an important investment since wetlands have the capacity to reduce flood damages. Riparian vegetation reduces the negative effects of climate and water quality changes on the macroinvertebrate taxa richness (Mantyka-Pringle et al., 2019). Compared to natural wetlands, restored wetlands were found to have a lower beta diversity (which measures changes in species diversity between environments), highlighting the importance of maintaining original wetlands.

Grasslands which are open ecosystems with mostly herbaceous (non-wood) vegetation provide habitat for a variety of species, conserve soil and water, are important for cycling nutrients, pollination, grazing for livestock, providing genetic material for crops and store approximately 34% of terrestrial carbon globally among other benefits (Federal, Provincial and Territorial Governments of Canada, 2010). Grasslands are the most threatened ecosystem in Canada (Kraus, 2018) and most of the grasslands have been lost as a result of the conversion of the lands to cropland and losses of grasslands still continue with small areas of grasslands being mostly affected (Federal, Provincial and Territorial Governments of Canada, 2010). Mixed and fescue prairie which covers 25% of Prairie Provinces was largely converted to other uses in the 1990's (70%) while tallgrass prairie is the most threatened prairie and the small patches that remain are still threatened by being converted to other uses (Federal, Provincial and Territorial Governments of Canada, 2010). Bunchgrass and sagebrush areas in British Columbia have also suffered losses (15-19% before 1990) (Federal, Provincial and Territorial Governments of Canada, 2010). The health of grasslands is also affected by suppression of fires, cattle replacing free-ranging bison, cultivation of soils, invasive non-native species, overgrazing, encroachment of forest, fragmentation and agriculture intensification (Federal, Provincial and Territorial Governments of Canada, 2010). Roch and Jaeger (2014) found that the grasslands in the Canadian Prairies are fragmented to a great degree.

Lakes and rivers also provide habitat for a variety of species including plankton, plants, fish, amphibians and reptiles and species living in aquatic ecosystems have a higher risk of getting extinct as compared to species inhabiting other ecosystems (Federal, Provincial and Territorial Governments of Canada, 2010). Crop production can negatively affect aquatic ecosystems. For example, changes in agricultural use and practices such as reduced summer fallow, increase in conservation till and continuous cropping reduces runoff to the lakes (Federal, Provincial and Territorial Governments of Canada, 2010). Soil erosion reduces water quality by delivering sediments to waterways (Lobb, 2016) and agricultural activities can be an important cause of water pollution (Hassanzadeh et al., 2019).

In Table A1 in the appendix, information on ecozones in Canada where crops are produced is summarized. The information includes natural vegetation, wildlife, soils and water bodies found in the ecozones. The species that are at risk are provided in Table A2 and the information is by province. The ecosystems that are at risk in Canada (forests, grasslands, wetlands and lakes and rivers) are described in Table A3.

## 4. CROP FARM MANAGEMENT PRACTICES FOR PROTECTING OR ENHANCING BIODIVERSITY

Decisions about land use made by farmers have implications for conservation (for example, decisions about which crop varieties to plant, schedules for rotation, methods to till soil, cover crops, native habitat between fields and pastures) (Badgley, 2003; Mineau & Mclaughlin, 1996). Swinton, Lupi, Robertson & Hamilton (2007) provide an overview of the ecosystem services provided by and received or used by agriculture, which include many items related directly to biodiversity. According to Mineau and Mclaughlin (1996), enhanced biodiversity can potentially reduce costs of agricultural production. Two interventions that are important for conserving or enhancing biodiversity are land sharing (can include agricultural practices that are based on biodiversity, for example, moving from conventional to organic agriculture or the restoration or creation of elements that are beneficial to wildlife without reducing agricultural production) and land separation (restoration or creation of non-farmland habitat) (Benayas & Bullock, 2012). According to Gurr, Wratten, and Luna (2003), changing management practices in monocultures in order to benefit natural enemies and integrating annual and perennial non-crop vegetation with cropping can enhance biodiversity and benefit pest management. Non crop habitat near croplands is important for the conservation of the diversity of plant species, pollinating and predatory insects and birds (Mineau & Mclaughlin, 1996). Hedgerows, shelterbelts and field margins are some of the non-crop lands that provide habitat for many species including native pollinators (Mineau & Mclaughlin, 1996). Windbreaks have been found to be beneficial to native pollinators (Moisan-DeSerres, Chagnon, & Fournier, 2015). Jobin, Choinière, and Bélanger (2001) found that herbaceous field margins had fewer species of birds as compared to natural hedge rows and planted windbreaks.

Some of the soil management practices that have positive impacts on biodiversity include the reduction of summer fallow, reduced tillage, use of diverse crop rotations, application of chemical fertilizers in the amounts required by plants, use of organic fertilizers, reduction of pesticides, keeping crop residues on the soil surface, planting of shelterbelts, cover crops or winter crops and seeding perennial vegetation around wetlands and watercourses (Alberta Agriculture and Food, 2007; Nature Saskatchewan, 2006). Tillage practice, drainage of wetlands, intercropping, crop rotations, use of pesticides and fertilizers are also identified as farming practices that influence biodiversity by McLaughlin and Mineau (1995). Over the long term, soil biota can be greatly enhanced by for example, choice of crops and trees, improvement of natural pests, plant disease resistance, organic matter management and management of agricultural inputs such as fertilizers (Brussaard et al., 2007). Water management is also important for biodiversity and practices such as the maintenance or re-establishment of wetlands, grass or woody buffer and reduced use of agrochemicals benefit biodiversity (Nature Saskatchewan, 2006).

Organic agriculture and conservation tillage are practices that have been used to conserve biodiversity by farmers (Badgley, 2003). Organic agriculture in Canada is based on four principles, that are, health (sustenance and enhancement of soil plant, animal, human health and planet health), ecology (requires that organic agriculture be based, work with, emulate and assist in sustaining ecological systems and cycles), fairness (in relation to the environment and opportunities in life) and care (precautionary and responsible management for the protection of the health and well-being of generations (both current and future) and the environment) (Canadian General Standards Board, 2015). Soil fertility and biological activity can be maintained or enhanced through, for example, (i) varied crop rotations that involve plough-down, legumes, catch crops and plants with deep roots, use of animal and plant matter that is composted, non-composted plant matter and animal manure that is not processed (ii) use of tillage and cultivation methods that maintain or improve the physical, chemical and biological conditions of the soil and reduce soil erosion and damages to soil structure and tilth. Organic management practices are used in managing pests, disease and weeds and these include cultural methods such as crop rotation, setting up a balanced ecosystem and using resistant crop varieties), mechanical techniques (e.g., cultivation) and physical techniques (e.g., weed control through flaming) (Canadian General Standards Board, 2015). Organic crop production does not use synthetic pesticides and inorganic fertilizers (Bengtsson, Ahnström, & Weibull, 2005; Rundlöf et al., 2016). A meta-analysis by Bengtsson et al. (2005) showed that compared to conventional farming, organic farming increased the richness of species by 30% but the results varied across the various studies with 16% of the studies showing a negative impact of organic farming on the richness of the species. In the same study by Bengtsson et al. (2005), compared to conventional farming systems, species were 50% more abundant in organic farming systems and results also varied across studies (Bengtsson et al., 2005). Organic farming had a positive effect on abundance of birds, predatory insects, soil organisms and plants while this was not true for non-predatory insects and pests (Bengtsson et al., 2005). Organic farming has direct (as a result of reduced exposure to pesticides or inorganic fertilizers, for example) and indirect effects (as a result of the management practices that improve habitat diversity such as use of organic manure) on biodiversity (Rundlöf et al., 2016). A review of studies in Canada and the United States by Lynch (2009) found that organic farming had positive effects on floral and wildlife diversity as compared to conventional farming and yields were lower for organic farming as compared to conventional farming. Gabriel, Sait, Kunin, and Benton (2013) found that increases in biodiversity require approximately proportionate decreases in yield in agricultural systems that are highly productive and efforts to conserve biodiversity may be cost effective on lower productivity agricultural systems or land that is not used for agriculture. Although yield of grains was 54% lower in organic fields as compared to conventional fields (in a study in England), the diversity of species (bumblebees, butterflies, butterflies, hoverflies and epigeal arthropods) was not different between the fields after controlling for yields (Gabriel et al., 2013). Freemark and Kirk (2001) found that the richness of bird species was greater on organic farms as compared to conventional farms and that non-crop habitats, crop cover that is permanent and agricultural management practices that are less intensive are important for conserving bird species.

Research associated with potential linkages between biodiversity and ecosystem services (Watson, Galford, Sonter, Koh, & Rickett, 2019) highlight some important aspects of conservation efforts on biodiversity enhancement. First Watson et al. (2019) show that while ecosystem services and biodiversity are clearly linked, conservation efforts focused on ecosystem services may not necessarily increase biodiversity depending on the spatial overlap between areas of conservation focus in providing ecosystem services and those supporting biodiversity. They also identify distinctions in targeting the supply of ecosystem services in conservation efforts as opposed to targeting the supply of and demand for ecosystem services. For example, in looking at crop pollination ecosystem services, targeting supply would focus on characteristics such as wild bee abundance while targeting the ecosystem benefit would focus on the wild bees foraging on pollinator dependent crops (including the demand for pollination effectively). Their analysis shows that conservation focused on supply characteristics (easier to monitor perhaps) and conservation focused on both supply and demand characteristics may have different outcomes in terms of biodiversity enhanced. They also show that including ‘demand’ as a focus of conservation efforts may not necessarily skew the outcomes of those efforts to human dominated landscapes with lower potential to enhance biodiversity.

However even if the ecosystem benefits of enhancing biodiversity were uniformly positive for all farmers, in different geographies and for different products, it is unlikely that all farmers would take the same steps to enhancing biodiversity at the same time. Both farm and farmer characteristics, knowledge, attitude and values will result in different patterns of adoption of certain management practices. Very little research has been done on adoption of certain management practices in Canada but a lot has been done in the EU where agro-ecosystem payments have been a feature of agricultural policy for some time. In a study of dairy producers in Ireland, (Power, Kelly, & Stout, 2013) plant biodiversity was higher on organic versus conventional dairy farms (which may be linked to the reasons for becoming an organic farmer). In addition, plant biodiversity was higher on farms where the farmers had stronger environmental knowledge and more positive environmental attitudes, with the result that biodiversity is quite variable across farms even under government payments for agro-environmental services and other physical similarities across farms. In a focus group study of farmers in a number of different EU countries, farmer's perceptions about biodiversity informed their practices, with some slight variations between organic and conventional farmers. It is interesting that in this study farmers recognized all aspects of biodiversity, at the species level, at the habitat level and at the landscape and ecological systems level. Mills, Gaskell, Ingram, and Chaplin (2018) examined the different influences on UK farmer's adoption of subsidized ecosystem services (financial incentives play a role) and unsubsidized ecosystem services (agronomic and environmental attitudes play significant roles). Pan et al. (2017) identified all of the influences in farmer adoption of best management practices including whether the practices to be adopted are win-win, win-lose but also farmer agronomic knowledge, willingness to experiment and past experiences. Although these studies are purely illustrative, they provide a clue to the fact that biodiversity enhancements will be produced unevenly at first even given similarities in farm type and geography.

## 5. ASSESSMENT OF ECONOMIC BENEFITS OF BIODIVERSITY

The economic value of biodiversity reflects what the society is willing to trade off for the conservation of natural resources (TEEB, 2010). The total economic value of biodiversity and ecosystem services is the "sum of the values of all service flows that natural capital generates both now and, in the future, – appropriately discounted" (TEEB, 2010, p. 6). Biodiversity has both use and non-use values. Use values are classified into direct use (consumptive or non-consumptive) and indirect use (services such as control against floods, water purification, carbon sequestration, photosynthesis and pollination) and future values (options to utilize the resource in the future) (Adamowicz, Asafu-Adjaye, Boxall, & Phillips, 1991; Badgley, 2003; Clark & Downes, 1995; Grafton et al., 2004; TEEB, 2010). Non-use values include existence values (knowledge that the species or ecosystem exists), and bequest values (the resources will be available for use by individuals' descendants (Clark & Downes, 1995; Grafton et al., 2004)).

In the literature, different methods have been used to assess the economic value of biodiversity. The valuation of biodiversity and the ecosystem services provided by biodiversity is based on market valuation, revealed preference and non-market valuation, often stated preference methods (OECD, 2002; TEEB, 2010). Market valuation methods are price, cost and production-based approaches (TEEB, 2010). Price based methods use market prices, cost-based approaches use avoided costs, replacement costs or mitigation or restoration costs while production-based methods use a production economics approach or identify factor incomes (OECD, 2002; TEEB, 2010). In the production function approach, biological resources are treated as inputs and changes to environmental quality are observed and the changes are used to value biodiversity (OECD, 2002). Revealed preference methods “refer to a range of valuation techniques which all make use of the fact that many (non-market) environmental goods and services are implicitly traded in markets, which allows then for RP methods to uncover these values in a variety of ways, depending on the good in question and the market in which it is implicitly traded’ (OECD, 2018, p. 55). Revealed preference methods are the hedonic price method, travel cost method/recreational demand models and averting behaviour/defensive expenditure models (OECD, 2018). Stated preference methods are used in cases where the market of the goods or services does not exist and they involve the use of surveys, contingent valuation, choice experiments, conjoint analysis, contingent ranking and deliberative group valuation (OECD, 2002; TEEB, 2010). Most of these methods are aimed at identifying societal values for natural resources including biodiversity characteristics and the ecosystem services provided. OECD (2019) provides a chart highlighting the estimated economic values of different biodiversity aspects, at the local, national and global levels. The items valued include direct use values associated with food, fuel, water and natural products and indirect use values associated with carbon sequestration, shoreline erosion control, natural hazard protection, pollution buffering and recreation or tourism.

When looking at the economic benefits of natural resources, in this case, biodiversity, apart from the use of different methods, there is also a need to know the ‘value’ of a resource to particular groups. Although there are a variety of non-market valuation techniques that are often used to identify the value of biodiversity and various ecosystem services to the public, the best use of these studies is often in the design of public policy. For example, if there is a large non-market value associated with a particular ecosystem service that is not being provided through the marketplace, then there might be a market failure associated with the ecosystem service, perhaps from it being a public good. In that case, if the good is important, then public policies must be designed to regulate use or provide incentives for the provision of the ecosystem service. In the end the design of public policies may change the nature of the 'economics' for market participants such as farmers since they could be the recipient of either new regulations or ecosystem payments.

While not the focus of this particular literature review it must be recognized that the 'value' of biodiversity within a society will be affected by knowledge of biodiversity (specifically what it is) and also by attitudes towards the actually changing biodiversity conditions. The higher the public values (higher knowledge and more positive attitudes) biodiversity, the more likely the public is to support measures to enhance biodiversity, privately through personal decisions which can include purchasing products identified as improving biodiversity and through citizen decisions to support public policies aimed at enhancing biodiversity. Spash and Hanley (1995) investigated biodiversity knowledge in student and public samples in the UK. Their analysis showed a slightly higher level of knowledge of biodiversity amongst students but across their samples the ability to define biodiversity was not particularly good. Arbuthnott and Devoe (2014) examined knowledge and attitudes to biodiversity for a sample of university students in Western Canada. They also informed their student analysis with interviews of experts. Using the Spash and Hanley (1995) definitions of biodiversity (variety of plants and animals, genetic diversity and distribution of species), Arbuthnott and Devoe (2014) found that 'variety of plants and animals' was the most common definition agreed to by study participants. Their assessment was that their respondents identified biodiversity with discrete organisms more than with ecosystems (p. 151). In research we (Goddard and Muringai, unpublished data) have conducted with the Canadian public over the period 2012 to 2017, we have been examining Canadian attitudes and knowledge of biodiversity (as part of different studies on the use of genomics in agriculture). To illustrate the level of Canadian knowledge of biodiversity we asked Canadians whether they agreed with three definitions of biodiversity developed based on the Spash and Hanley definitions from 1995. From Figure 3, it is clear that our results are not dissimilar to the other Western Canadian study with more people identifying the number of species of plants and animals as representing biodiversity, than identifying genetic diversity or the ecosystems as biodiversity. It is worth noting that this is somewhat different from the original Spash and Hanley UK summary data also shown in Figure 3. Our initial analysis of this unpublished data suggests higher knowledge of biodiversity in 2016 2017 than in our earlier data.

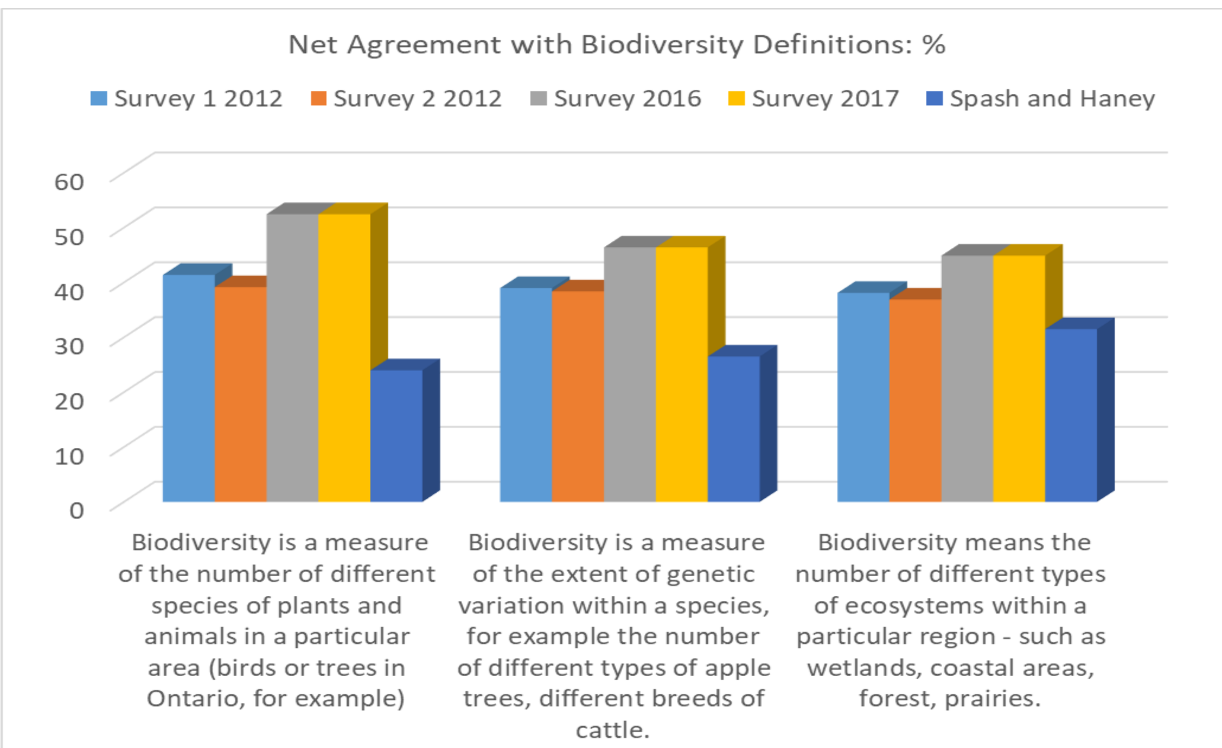


*Figure 3: Data on biodiversity definitions from various Canadian surveys (>1800 Canadian respondents) and original survey data by Spash and Hanley (1995)*

In our research we (Goddard and Muringai, unpublished data) also looked at a couple of basic attitudinal statements associated with biodiversity. We were interested in gauging whether or not the Canadian public was concerned about biodiversity but for these surveys we did not extend this analysis to nonmarket valuation of biodiversity within Canada, although this is something that could be undertaken in later studies. From Figure 4 , it is clear that the public agree that they are 'worried about the loss of nature plants and animals', disagree that 'we can afford to lose some biodiversity' and are a little more uncertain (although disagreeing that there is nothing they can do) about what they can do personally to help 'stop the losses in the world's biodiversity'. It is interesting that worries about biodiversity were slightly stronger in the earlier period but disagreement that there is nothing that could be done personally is a bit stronger in the later period.

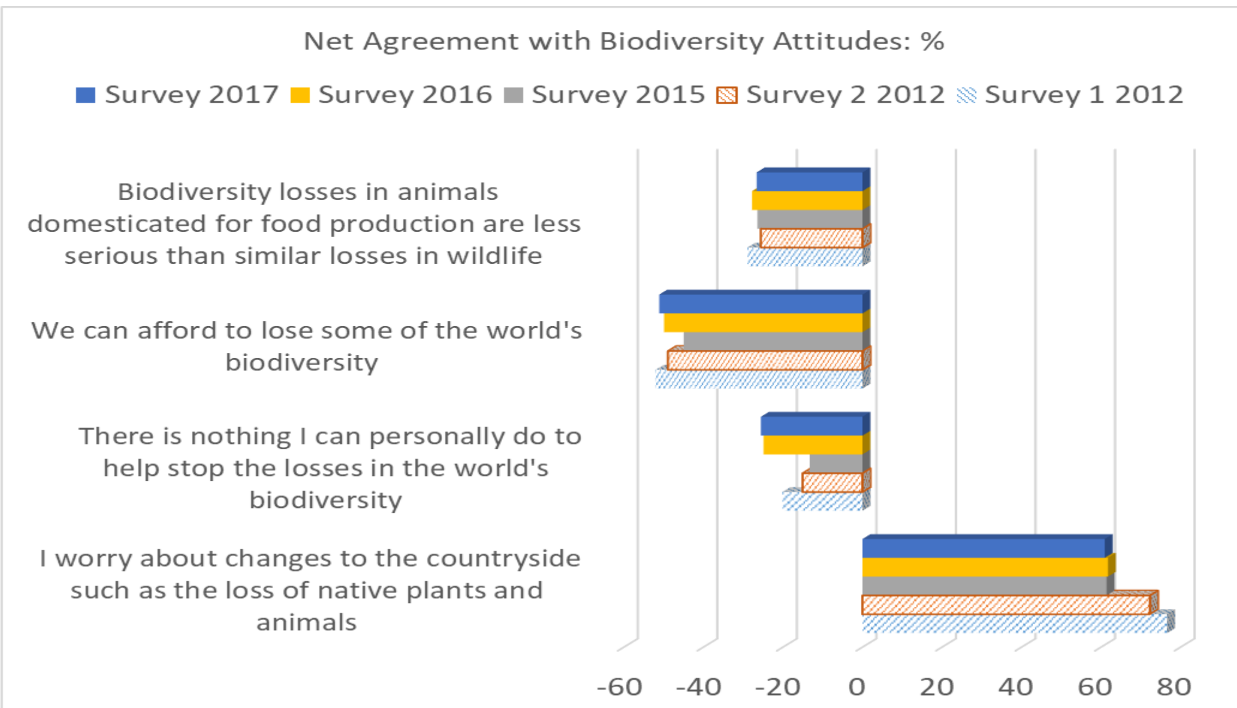


*Figure 4: Data on biodiversity attitudes from various Canadian surveys (>1800 Canadian respondents)*

Although far from conclusive, and related to biodiversity at its broadest level, the level of Canadian awareness is a little worrying if we expect the public to be one of the key supporters of initiatives to enhance biodiversity throughout Canada. Similar results are shown in the Table 4 from the OECD (2019) report. The ability for people to correctly define biodiversity is low, even in countries with a high percentage of the population having heard of it.

Table 4: Comparing knowledge and attitudes towards biodiversity across countries

| **OECD (2019 page 38) 'Table 4.1. Consumer awareness and understanding of biodiversity in selected G7 countries'** | | | | | | |
|---|---|---|---|---|---|---|
| **(Over the period 2009-18)** | | | | | | |
| | | France | United Kingdom | Japan | United States | Germany |
| Have heard of biodiversity | (%) | 90% | 66% | 62% | 55% | 53% |
| Correct definition of biodiversity | (%) | 34% | 22% | 29% | 25% | 25% |
| Source: (UEBT, 2018). | | | | | | |

## 6. ECONOMIC BENEFITS OF BIODIVERSITY TO CROP PRODUCTION

Results from economic valuation studies on biodiversity (both species and/or ecosystems) that are relevant to crop farmers of cereals, oilseeds and special crops are summarized in this section. More results on the economic benefits of ecosystems and species are summarized in Table A4 and A5 in the appendix. Benefits of biodiversity to crop production include pollination of crops such as canola, pest control by birds, beetles, parasitic wasps and spiders, resilience against droughts and floods. In addition, soil biodiversity is important for soil fertility, cycling and storage of nutrients higher crop yield and soil productivity for the long term (Alberta Agriculture and Food, 2007).

*6.1 Pollination services*

According to Statistics Canada (2015), crops that are dependent on pollinators such as sunflowers, buckwheat and mustard seed covered 289,792 hectares in 2011. Crops that are enhanced by pollination (canola, soybeans, dry white beans and other dry beans) covered 9,537,703 hectares in 2011 (Statistics Canada, 2015). While some farms rely on wild pollinators, other farms bring in pollinators for the achievement of adequate pollination (Statistics Canada, 2015).

Bees are the major pollinator and wasps, flies, butterflies, beetles, ants and birds, such as the hummingbird, also contribute to the pollination of crops in Canada (Agriculture and Agri-Food Canada, 2014a). Insects provide pollination services to two thirds of plant species (Jankielsohn, 2018). In the literature, the positive benefits of pollinators to crop production have been shown. According to Pimentel et al. (1997), the value of animal pollination to agricultural production is $40 billion per year in the United States and $200 billion per year for the whole world (for society). Wilson (2008) estimated that the total economic value of pollination services for agriculture (for society) in Ontario's Greenbelt is approximately $298.2 million per year. In the United States, honey bees and wild bees were estimated to pollinate ninety crops that are worth $30 billion each year for farmers (Myers, 1996).

Using worldwide data from 53 studies, Kleijn et al. (2015) found that, on average, the value of wild bee communities to crop production is $3,251 per ha which was similar to the contribution by managed honey bees (valued at $2,913 per ha) (Table 5). Individual wild bee species contribute up to $963 per ha (Kleijn et al., 2015). In Canada, honey bees pollinate crops such as canola, corn and soybeans and the value of honey bees to food and seed production is estimated at $44 million in New Brunswick, $80 million in Manitoba, $400 million in Saskatchewan and $10 million in British Columbia (The Standing Senate Committee on Agriculture and Forestry, 2015). Leaf cutter bees provide pollination services that are worth an additional $15 million in Manitoba (The Standing Senate Committee on Agriculture and Forestry, 2015). According to the Alberta Biodiversity Monitoring Institute (2018), canola flowers within roughly one kilometer from uncultivated lands benefit from pollination by wild bees and the value of pollination services provided by wild pollinators to the production of canola (based on increased yield) in Alberta is estimated to be $500 million per year.

Mallinger, Bradshaw, Varenhorst and Prasifka (2019) analysed the benefits of native solitary bees for the pollination of confection sunflowers (non-oil type of sunflowers) across the Northern Great Plains and results showed that pollination by insects enhanced sunflower yields by 45% (for farmers) which translates to more than $40 million and $56 million regional and national values respectively. Results varied by the genotypes of plants and location and wild bees had significant benefits to the production of confection sunflowers (Mallinger et al., 2019).

Table 5: Economic benefits of biodiversity for pollination of crops

| Species | Proxy | Country | Province/location | Valuation method | Units | Value | Source |
|---|---|---|---|---|---|---|---|
| Wild bees | Visitation to crop flowers by bees | Worldwide | | Production value method | $/ha | 3,251 | Kleijn et al. (2015) |
| Honey bees | Food and seed production | Canada | New Brunswick | | $ | 44 million | The Standing Senate Committee on Agriculture and Forestry (2015) |
| | | | Manitoba | | $ | 80 million | |
| | | | Saskatchewan | | $ | 400 million | |
| | | | British Columbia | | $ | 10 million | |
| Wild bees | Canola yield attributable to wild bee pollination | Canada | Alberta | Spatial model (preliminary) | $/year | 500 million | Alberta Biodiversity Monitoring Institute (2018) |
| Native solitary bees | Confection sunflower yield (frequency of visitation and efficacy on a per-visit basis) | United States | Great Plains | Yield increase | $ | $40.8 million in Great Plains and $56.7 million nationwide | Mallinger et al. (2019) |

Losey and Vaughan (2006) analysed the annual values of crop production that are attributable to natural bees, using data for the United States for fruits and nuts, vegetables and field crops. In this report, the results from Losey and Vaughan (2006) for field crops that are also grown in Canada are reported. Soybeans have the highest value that is attributable to pollination by native bees followed by alfalfa hay (Figure 5). Sugar beet has the highest proportion of pollinators that are native bees followed by soybean.

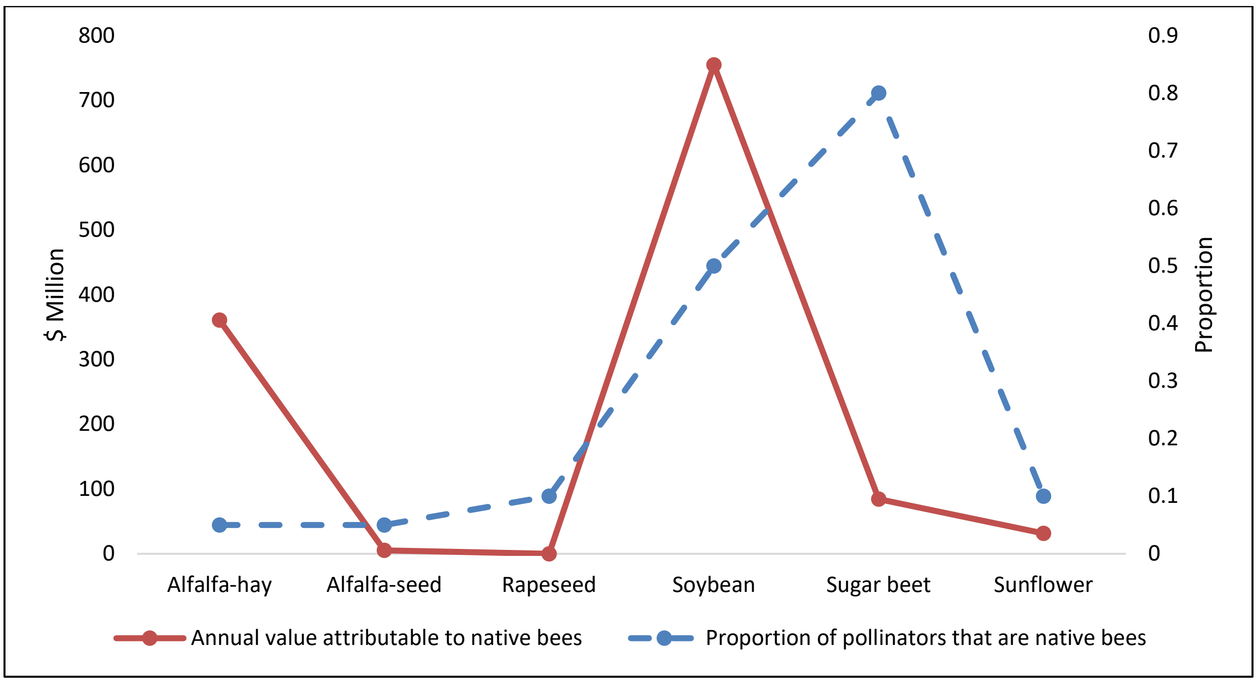


*Figure 5: Value of crops (per year) attributable to native bees in the United States*
Data are from Losey and Vaughan (2006)

Bartomeus et al. (2014) analysed the contribution of insect pollination on crop yield for four crops (spring oilseed rape, field bean, strawberry and buckwheat) in Europe. Although results varied across studies, crop yield was enhanced by adequate pollination by 18% to 71% and quality was also improved (Bertomeus et al., 2014). For example, the amount of oil in rapeseed was increased while the number of seeds that were empty in buckwheat were reduced.

Rader et al. (2016) analysed the contribution of non-bee insects to global crop pollination using data from 39 studies and results showed that the proportion of non-bee insect visits to flowers was 25 to 50% of the total number of visits. Non-bee insects made more visits to the flowers but bees were more effective in terms of pollination per each visit which resulted in similar pollination services between the bees and non-bee insects.

Garibaldi et al. (2013) analysed the impacts of visitation of flowers by wild insects and honey bees on pollination of crops using worldwide data on 41 cropping systems (including buckwheat) from 600 fields. Results showed that wild insects were more effective in increasing fruit set as compared to honey bees and that honey bees supplemented wild insects in the pollination of crops (Garibaldi et al., 2013).

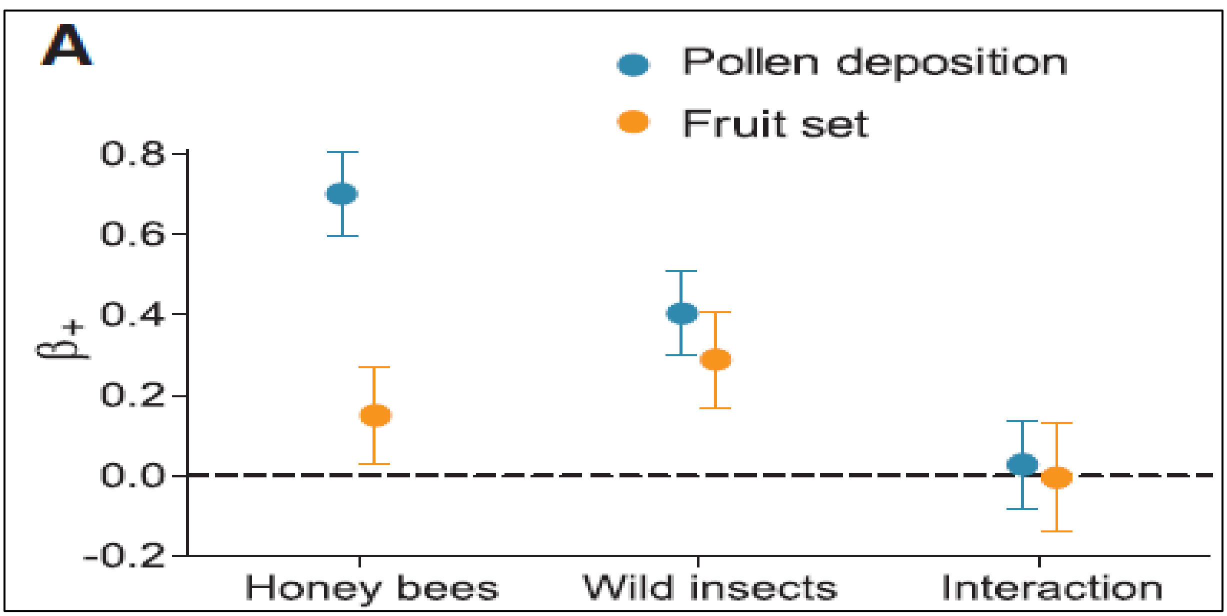

*Figure 6: Effects (direct and interaction) of visitation of flowers by honey bees and wild insects on fruit set and pollen deposition*
Source: Adapted from Garibaldi et al. (2013, p. 1610)

Visitation by honey bees increased fruit set in 14% of the cropping systems while fruit set from visitation by wild insects was double the amount of the increase for honey bees (Garibaldi et al., 2013). Figure 6 provides the results on the effects of visitation of flowers by honey bees and wild insects on fruit set and pollen deposition from the study by Garibaldi et al. (2013).

In a study conducted in Alberta (near La Crete), Canada, fields of canola that had more land that was not cultivated within 750 m of the field edges had the greatest wild bee abundance and those fields that had more bees were found to have higher levels of seed set (Morandin & Winston, 2006). Results also showed that yield and profits could be enhanced by the presence of 30% of uncultivated land within 750 m of the edges of the fields.

In their study in France, Catarino, Bretagnolle, Perrot, Vialloux, and Gaba (2019) found a 15% to 40% increase in yield and gross margins in oilseed rape fields with greater abundance of pollinators as compared to fields that had lower abundance of the pollinators.

Although research shows that biodiversity is important for crop production in terms of providing pollination services for crops, the abundance and diversity of wild insect pollinators is declining (Garibaldi et al., 2013). The yellow-banded bumble bee which is an important pollinator is of special concern in Canada (Saskatchewan, Alberta, Manitoba, Ontario, British Columbia, Nova Scotia, New Brunswick, Prince Edward Island and Yukon) (Table A2). According to COSEWIC (2015) the yellow-banded bumble bee might be threatened by factors such as pesticide use in agriculture, pathogens (from managed bee colonies), loss of habitat in urban areas and as a result of intensive agriculture and climate change.

*6.2 Biocontrol of pests*

Promoting biodiversity in crop fields and adjacent areas is important for pest regulation (Étilé, 2013). On-farm benefits of the biological control include reduced costs for pest control and improvements in yields (Naranjo, Ellsworth, & Frisvold, 2015).

Pimentel et al. (1997) estimated the value of biodiversity for pest control in crops (reductions in losses of crops) to be $12 billion for the United States and $100 billion worldwide per year. Losey and Vaughan (2006) report that the value of natural control of native pests (value of averted crop losses from predation or parasitism) was $13.60 billion and the value of the natural control that was attributable to insects was $4.49 billion in the United States. Jonsson et al. (2014) found reductions in crop damage of 45 to 70% as a result of biocontrol of pests by their natural enemies.

In four states (Iowa, Michigan, Minnesota and Wisconsin) in the United States, biocontrol of the soybean aphid in soybean was valued at $239 million per year ($33 per ha or $1,620 per farm per year) with integrated pest management and $1,407 million with biocontrol alone (Landis, Gardiner, Van Der Werf, & Swinton, 2008) (Table 6). Zhang and Swinton (2012) found that the biocontrol of the soy aphid in 5 states in the United States (to farmers) was $84 million for moderate infestation and $11 million for severe infestation. The values range from $4.20 to $32.60 per hectare (Zhang & Swinton, 2012).

Table 6: Economic benefits of biodiversity for controlling pests in crops

| Species | Proxy | Country | State/Province | Valuation method | Units | Value | Source |
|---|---|---|---|---|---|---|---|
| Natural enemies of the soy aphid | Median yields | United States | (Iowa, Michigan, Minnesota and Wisconsin) | Production function and input costs | $ | 239 million with integrated pest management (33/ha)<br>1,407 million for biocontrol alone | Landis et al. (2008) |
| Natural enemies of the soy aphid | Natural enemies and aphids per soy plant | United States | Iowa, Indiana, Illinois, Michigan and Minnesota | Production function and input cost | $ | 84 million for moderate infestation and 11 million for severe infestation (4.20 to 32.60/ha/year) | Zhang and Swinton (2012) |
| Natural enemies of agricultural pests | Averted crop losses | United States | | Cost of damage | $ | 13.60 billion for native pests and 4.49 billion attributable to insects | Losey and Vaughan (2006) |

Bengtsson (2015) found that the contribution of biological control of pests to yield increased by less than 20% and conventional farming had a higher impact on yield as compared to biological control of pests. In the United States, the annual value of bats (which includes reductions in costs of using pesticides) to the agricultural industry was estimated to be $22.9 billion (range is $3.7 billion to $53 billion) (Boyles, Cryan, McCracken, & Kunz, 2011).

Plaas et al. (2019) compared gross margins for three scenarios of winter wheat crop management in Lower Saxony in Germany and the scenarios were as follows: A: Wheat under conventional tillage with two fungicide applications B: Wheat under conventional tillage with 1 fungicide application and C: Wheat under conservation tillage with 1 fungicide application. The results for the standard gross margins for the three scenarios are illustrated in Figure 7.

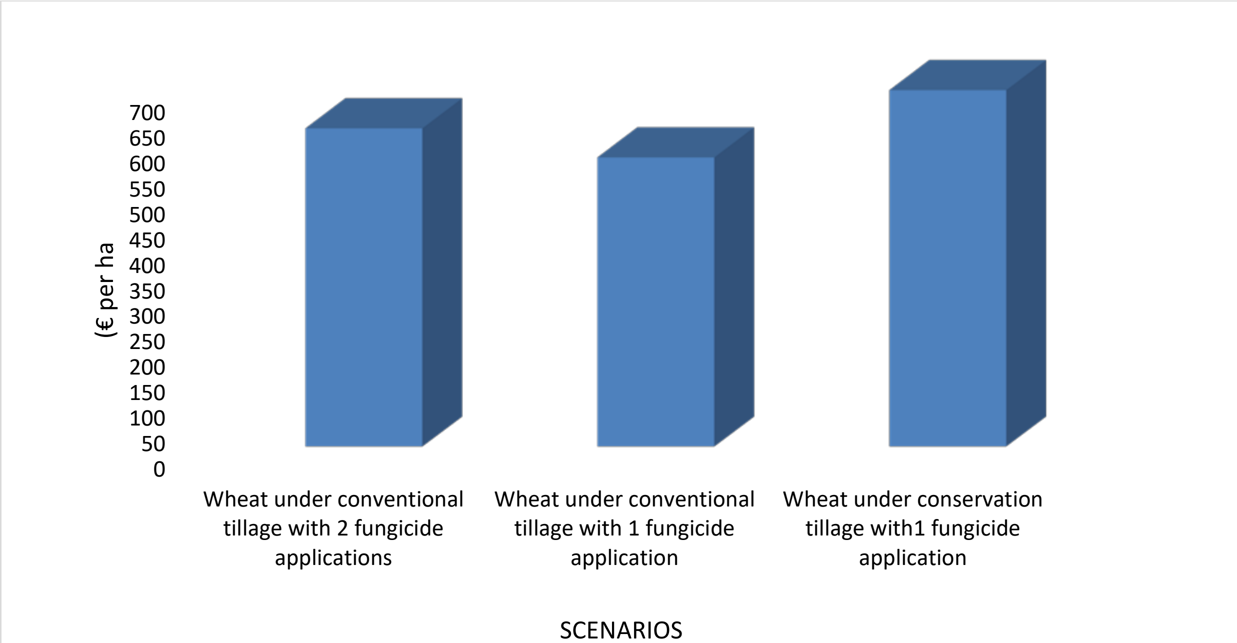


*Figure 7: Standard gross margins for different scenarios for tillage and fungicide application*
Data are from Plaas et al. (2019)

Results show that the difference in gross margins between wheat under conservation tillage with one fungicide application and wheat under conventional tillage with 2 application is 75 € per hectare (Figure 7). The difference between gross margins for wheat under conservation tillage with 1 fungicide application and wheat under conventional tillage and the same fungicide application is 132 € per hectare. The difference in standard gross margins is attributed to the presence of earthworms that control fungal plant pathogens.

The literature review conducted by Étilé (2012) showed that management strategies had different effects on biological control of pests in crops. Labrie (2010) in Étilé (2012) found that strip cropping of corn, soybeans, wheat and vetch had half of the aphids as compared to the monoculture of soybeans in Quebec.

*6.3 Soil formation, nitrogen fixation and water quality*

In Canada, soil loss has been shown to reduce crop production by 5 to 10% (a loss of $2 billion per year to agriculture and the economy). Soil biodiversity is important for suppressing crop diseases and the resilience of crops against disturbance and stress but there is need for further research (Brussaard et al., 2007). In addition to crop yield, soil biodiversity is important for the quality of food and potential benefits of food to health (Rillig, Lehmann, Lehmann, Camenzind, & Rauh, 2018). Pimentel et al. (1997) estimated the annual economic benefits of biodiversity for soil formation in agricultural lands to be $5 billion in the United States and $25 billion worldwide and nitrogen fixation to be $8 billion in the United States and $90 billion worldwide for agricultural and natural ecosystems. Soil biota such as earthworms and snails among others improve soils for the production of crops (Pimentel et al., 1997). Earthworms are important for soil structure improvements and the availability of nutrients for plants (Plaas et al., 2019). Pimentel et al. (1997) estimated the economic benefits of biodiversity for bioremediation of chemical pollution to society (using costs of remediation of chemical pollution) to be $22.5 billion and $121 billion for the world. Biodiversity is also important for recycling organic waste through decomposition and the economic benefits are valued at $62 billion for the United States and $760 billion for the world for society.

Martens, Entz, and Wonneck (2013) assessed the potential role of farming practices on environmental sustainability, profitability and resilience in the Canadian Prairies and also reported the strength of their assessment and the results are in Table 7. Reduced tillage and organic farming were rated highly in terms of soil health. Reduced tillage was rated highly in terms of reducing soil erosion.

Table 7: Farming practices and sustainable development of cropping systems in Canadian Prairies

| **Criteria** | Varieties and genetics | Crop selection and rotation | Cover crops | Annual polyculture | Perennial forages | Perennial grains | Three-based intercropping | Shelterbelts/ ecobuffers | Reducing tillage | Animal manure | Green manure | Soil biological fertility | Organic systems | Integrated crop-livestock | Farmscaping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sustainability criteria** | | | | | | | | | | | | | | | |
| Soil health | 2 M | 4 M | 6 S | 2 M | 8 S | 7 M | 6 M | 7 M | 8 S | 7 M | 7 M | 8 S | 8 S | 6 M | 6 M |
| Soil erosion | 2 W | 3 M | 7 S | 2 W | 8 S | 8 S | 7 M | 8 S | 8 S | 3 M | 4 M | 3 W | 5 S | 4 W | 6 S |
| Dewatering wet soils | 2 W | 5 S | 7 S | 2 W | 8 S | 8 W | 7 W | 7 M | 2 S | 2 W | 5 M | 2 W | 5 M | 3 W | 5 M |
| Storing water in dry soils | 2 W | 5 S | 2 W | 2 W | 2 S | 2 W | 5 W | 7 S | 8 S | 5 M | 4 M | 2 W | 5 M | 3 W | 7 M |
| Water quality protection | 2 W | 2 M | 5 M | 3 W | 8 S | 8 W | 7 W | 7 S | 7 S | 1 S | 5 M | 7 W | 7 M | 4 M | 8 M |
| Air quality protection | 1 W | 2 W | 2 W | 1 W | 2 W | 2 W | 5 W | 8 S | 6 W | 1 S | 1 W | 2 W | 4 W | 5 W | 6 M |
| Natural pollination services | 2 W | 4 M | 5 W | 4 W | 6 M | 6 W | 5 W | 8 S | 2 W | 1 W | 3 W | 1 W | 7 M | 4 W | 9 S |
| Natural pest suppression | 5 M | 5 S | 3 M | 3 M | 6 S | 6 M | 5 M | 6 M | 1 M | 5 M | 5 M | 6 M | 7 M | 5 W | 9 W |
| Natural disease resistance | 8 S | 6 S | 2 M | 5 S | 3 M | 6 M | 4 W | 4 W | 1 M | 5 M | 3 W | 6 M | 7 M | 4 W | 5 M |
| Greenhouse gas emissions | 1 M | 4 M | 5 W | 2 W | 8 S | 8 W | 5 M | 5 M | 5 S | 3 S | 6 M | 6 W | 7 S | 7 M | 6 W |
| Carbon sequestration | 1 M | 2 W | 5 W | 1 W | 7 S | 7 W | 8 S | 7 S | 6 S | 5 M | 5 M | 6 W | 6 S | 6 M | 7 M |
| Nutrient management | 3 M | 5 S | 6 S | 4 S | 8 S | 6 M | 5 M | 5 W | 3 S | 8 S | 8 S | 8 M | 8 S | 8 S | 6 W |
| **Profitability criteria** | | | | | | | | | | | | | | | |
| Profitability | 4 S | 6 S | 5 M | 3 M | 7 S | 5 M | 5 M | 5 M | 7 S | 3 S | 5 S | 5 W | 7 S | 8 S | 5 M |
| Protectable advantages | 5 S | 2 W | 1 W | 1 W | 4 M | 4 W | 1 M | 1 W | 1 W | 1 W | 1 W | 1 W | 7 S | 5 W | 5 W |
| Income stability/ reduced risk | 3 M | 6 S | 2 W | 4 M | 6 M | 7 M | 5 M | 4 M | 3 M | 4 W | 5 M | 5 W | 5 M | 7 M | 6 W |
| **Resilience criteria** | | | | | | | | | | | | | | | |
| Resilience to climate extremes | 5 M | 6 M | 5 M | 4 M | 7 M | 7 M | 5 M | 7 M | 5 M | 5 M | 4 M | 5 W | 5 M | 6 W | 7 M |
| Energy use/efficiency | 1 M | 4 S | 4 M | 3 M | 8 S | 8 M | 5 W | 5 W | 5 S | 5 M | 5 S | 8 M | 7 S | 6 M | 6 W |
| Enterprise diversity | 2 M | 5 S | 2 M | 3 M | 7 S | 7 W | 7 S | 5 M | 2 M | 2 W | 2 W | 2 W | 6 S | 8 S | 6 M |
| Agro-ecological integrity | 1 W | 5 M | 6 M | 4 M | 7 S | 7 S | 7 S | 7 S | 4 M | 7 M | 7 M | 8 S | 6 S | 8 S | 8 S |
| Adaptive capacity | 3 W | 5 M | 3 M | 3 W | 6 W | 6 W | 6 M | 5 M | 4 S | 5 M | 5 M | 5 W | 6 S | 8 S | 6 M |
| **Operational criteria** | | | | | | | | | | | | | | | |
| Technical feasibility | 9 S | 8 S | 5 M | 5 M | 8 S | 1 S | 4 W | 8 S | 8 S | 7 S | 8 S | 3 W | 5 M | 6 M | 4 M |
| Adoptability | 9 S | 7 S | 3 W | 2 S | 5 S | 1 W | 2 W | 4 M | 5 S | 3 S | 2 M | 2 W | 2 S | 3 M | 4 W |

Source: Martens at al. (2013, pp. 41)

Note: Scores for impact range from 1: no impact to 9: very large impact. Strength of assessment is coded as follows: S=strong, M=Moderate and W=weak.

Farmland LP in the United States assessed the value of benefits of ecosystem services from regenerative agricultural practices (Farmland LP, 2017). Regenerative agriculture practices integrate organic farming, agroecology and holistic management and they can be important in protecting biodiversity and reducing atmospheric carbon dioxide, soil erosion and water pollution. The practices include producing perennial crops, reducing the use of synthetic fertilizers, diversifying crop rotation, integrating livestock grazing with crop production and the establishing or improving functional natural areas. Social (air quality, aesthetics, disaster reduction and food), biodiversity (biological control, habitat, pollination and seed dispersal), climate and energy (soil carbon dioxide and nitrogen dioxide and soil formation), water (water capture, conveyance and supply and water quality) and soils (soil retention and soil quality) were the impact areas included in the analysis. Ecosystem service values were calculated using historical management data for farmed filed (crop type, tillage, soil type, organic status among others). Ecosystem values were also calculated for the same farmed fields under the assumption of conventional management and common crop types in the area. In Figure 8, the ecosystem service values for Farmland LP and conventional management are illustrated. The total economic service benefits are $12.9 million ($2,261/acre or $1.6 million per year) for Farmland LP managed farmed fields as compared to the damage under conventional management which is defined as management practices commonly found in the area (economic service value is -$8.5 million or -$1,500/acre).

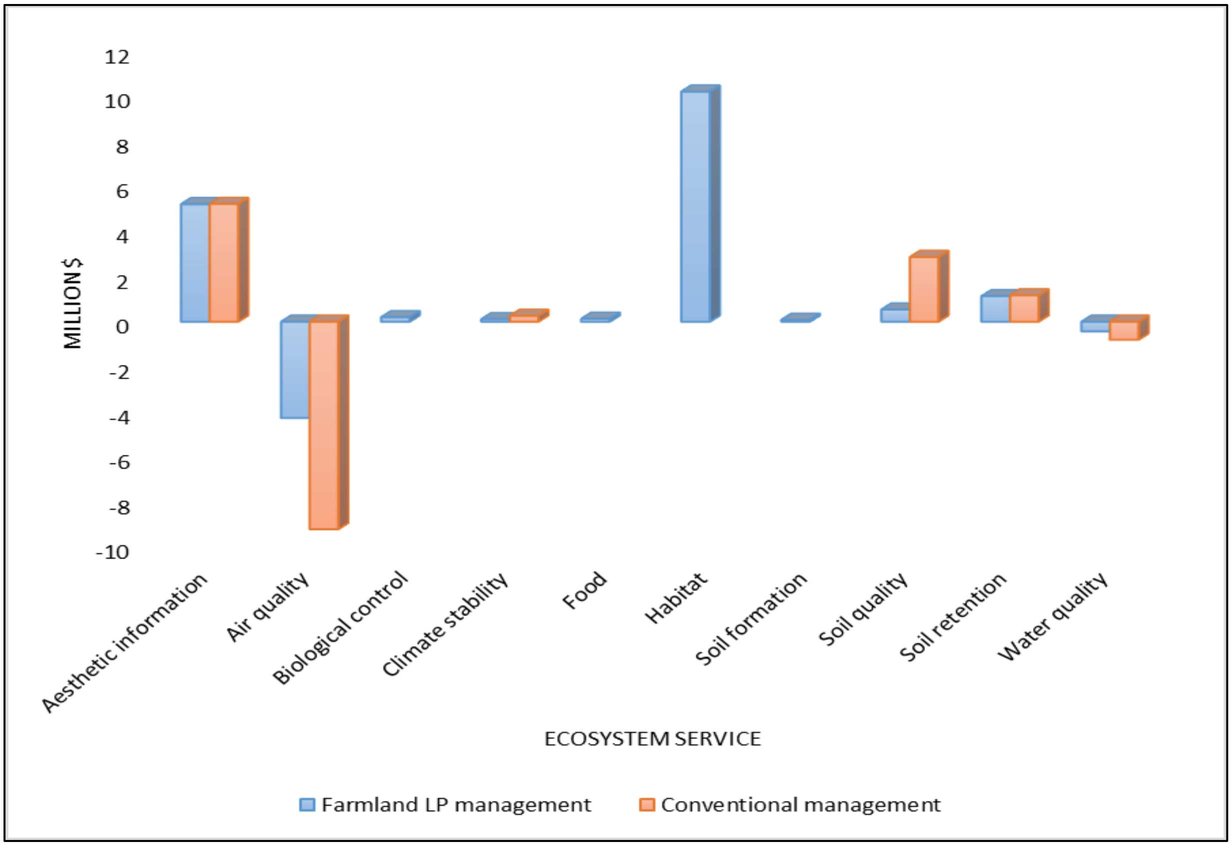


*Figure 8: Ecosystem service values for Farmland LP and conventional management*
Data are from Farmland LP (2017)

The largest economic benefit for Farmland LP management is habitat. Both Farmland LP and conventional management are beneficial in terms of aesthetic information (measured by housing prices which is not a benefit for farmers). Conventional management was rated highly in terms of soil quality but lower in terms of water quality as compared to the Farmland LP managed farms.

*6.4 Carbon sequestration*

The previous literature has shown that biodiversity is important for carbon sequestration. The economic value of carbon sequestration by forests was estimated to be US $6 billion and US

$135 billion for the United States and the world respectively (for society, Pimentel et al. 1997). Harris, Crabtree, King, and Newell-Price (2006) analysed the social values of total carbon sequestered (for society) and current values of soil organic carbon for different changes in land use or management.

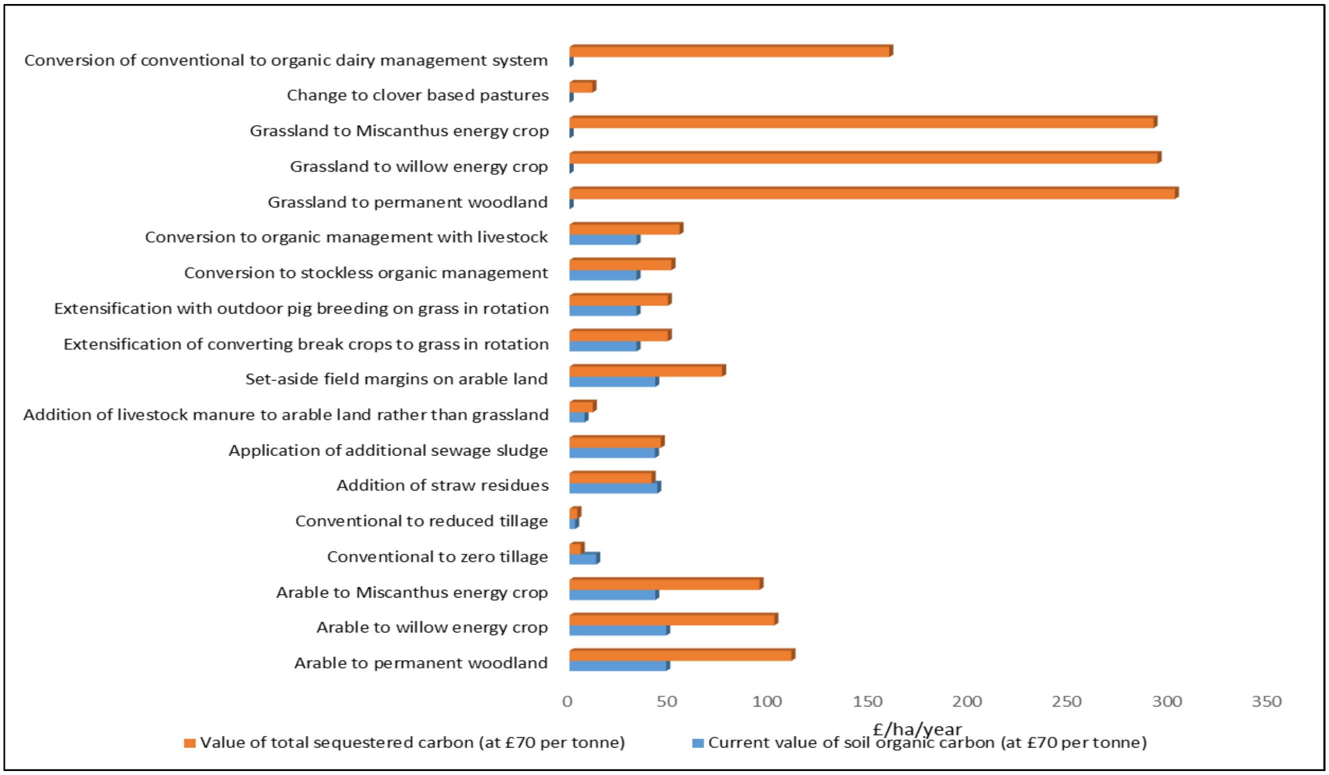


*Figure 9: Carbon sequestration values for different scenarios*
Data are from Harris et al. (2006)

Compared to other changes in land use, values for total sequestered carbon has been shown to be low for the scenario for changing from conventional to reduced tillage and the scenario for changing from conventional to zero tillage (Figure 9). Setting aside field margins on arable land is important in terms of value of total sequestered carbon. Values for change in land use of soil management range from £3.9 (change from conventional to reduced tillage) to £110.8 (change from arable to woodland).

Carbon sequestration can also be influenced by biodiversity on farms, in grasslands and forests. For example, Yang, Tilman, Furey and Lehman (2019) conducted experiments to show significantly higher rates of carbon sequestration in degraded and abandoned agricultural lands (in Minnesota) with higher levels of plant diversity. Theil, Smuckler, Krzic, Gergel, and Terpsma (2015) showed that “planting hedgerows designed for greater biodiversity, although resource intensive, does provide improved climate change mitigation through increased soil C storage on agricultural landscapes of the western Fraser Valley, British Columbia, relative to naturally regenerated hedgerows” (page 254). This connection between biodiversity and the rate of carbon sequestration, although needing further research in different conditions, is potentially important as the ability to sequester carbon becomes a sellable asset for farmers.

In Alberta, the carbon offset system is used to reduce greenhouse gas emissions and farmers can earn some extra income by creating carbon credits and selling them on the Alberta’s carbon market (Government of Alberta, 2019a). Conservation cropping is one of the protocols (major) that is used by farmers to produce carbon credits in Alberta (2019b). The Government of Alberta is still working on the Agricultural Nitrous Oxide Emissions Reduction Protocol and the protocol for wetlands was rejected due to differences in the science regarding wetlands being sources or sinks for carbon (Government of Alberta, 2019b). Quebec set up a cap-and -trade system in order to reduce greenhouse gas emissions and individuals and business entities can participate even when they have no obligations for doing so (Government du Québec, 2019).

Swinton et al. (2015) analysed the efficiency gains from changes in cropping systems (conventional to no-till, conventional to reduced input, reduced input to no-till and alfalfa to poplar) and the results are reported in Figure 10. Results show that changing from conventional tillage to no tillage has the highest impact on reducing global warming as compared to the other changes in cropping systems.

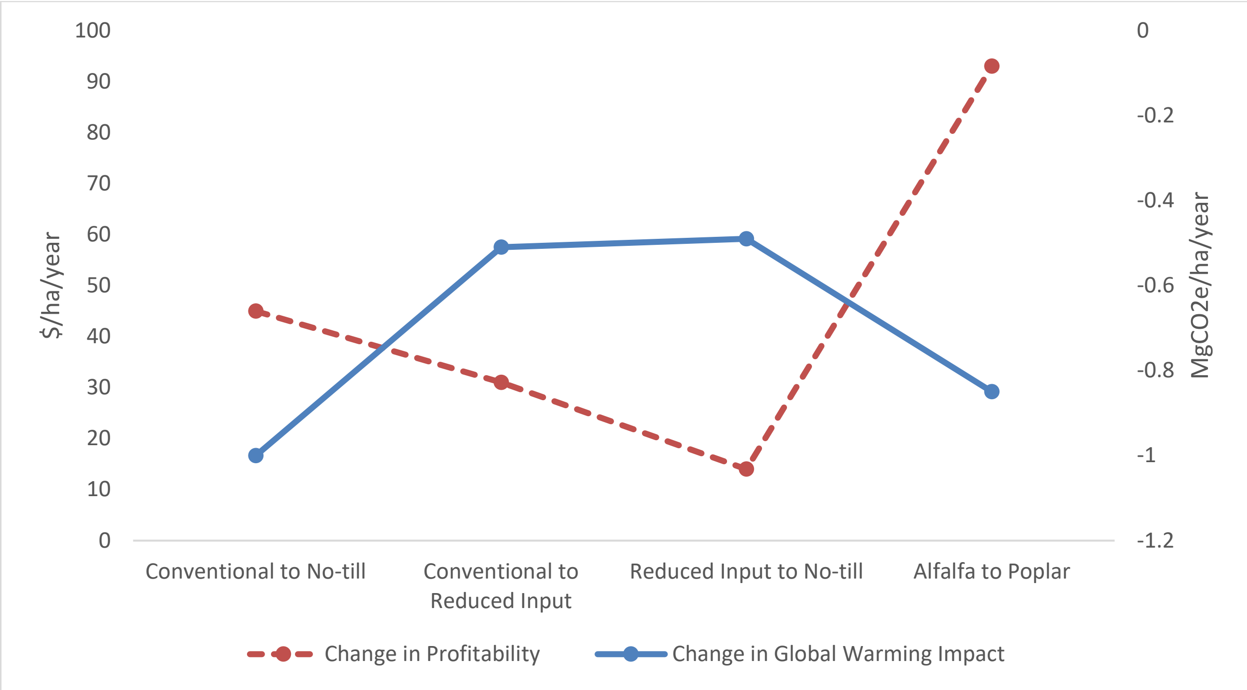


*Figure 10: Efficiency gains from changes in cropping systems*
Data are from Swinton et al. (2015)

It is worth noting though that there remains some controversy about rebuilding soil carbon for the benefits that can result or for rebuilding soil carbon as a means of mitigating climate change. Bradford et. al. (2019) argue that the benefits of rebuilding agricultural soil carbon are critical outcomes in and of themselves that should not be obscured by debate about whether or not rebuilding soil carbon should be viewed as a climate change mitigation strategy. Their paper provides an interesting assessment of policies which might be used to encourage the rebuilding of soil carbon.

*6.5 Grasslands*

Grasslands are important for crop production because they maintain the stability of the soils, prevent soil erosion and provide habitat for pollinators and insects that provide natural pest control services (Ducks Unlimited Canada, 2019). Most species at risk in Canada have grasslands as their habitat (Chris Nykoluk Consulting, 2012). Grasslands are also important for flood control, water quality and regulation, carbon sequestration and waste treatment (Chris Nykoluk Consulting, 2013).

The societal non-market ecosystem services of grasslands in the Ontario's Greenbelt were valued at $0.714 million per year ($1,618 per hectare) (Wilson, 2008) (Table A4). Wilson (2009) found that the non-market ecosystem services from grasslands for society in Pimachiowin Aki World Heritage Project Area and the Southern Ontario Greenbelt (per year) are worth a total of approximately $121 to $130 million and $2.6 billion respectively. Economic services products of grasslands in the Mackenzie Watershed for society (Alberta, British Columbia, Northwest Territories and Yukon) were valued at $12 million per year (Anielski and Wilson, 2009a). Ecosystem services from pastures and grasslands in the National Commission's Green Network were valued (for society) at approximately $7.74 million ($3,338 per hectare) per year (Dupras, L'Ecuyer-Sauvageau, Auclair, He, & Poder, 2016). The ecosystem service value for climate regulation for grasslands in the Lower Mainland in British Columbia to society was estimated to be $3.1 million ($594 per hectare) (Wilson, 2010). According to Chris Nykoluk Consulting (2013), converting native prairie to crop production has an annual opportunity cost that ranges from $21.58 to $1,836.80 per acre and the average annual indirect value of native grasslands to society is estimated to be $297.79 per acre.

*6.6 Forests*

Forest ecosystems provide benefits to crop farmers. The protection of native vegetation and planting of vegetative buffers such as shelterbelt benefit to agriculture in terms of productivity and biodiversity (Austin, 2014). According to Agriculture and Agri-Food Canada (2014b) agroforestry which involves intentionally designing and managing trees, crops and livestock has potential benefits for increasing crop production and economic gain, conserving the soil and improving soil quality, atmospheric carbon sequestration and increasing biodiversity. Previous studies have analysed the economic benefits of different forest ecosystems and the results are also summarized in Table A4. In the following section we specifically focus on the economic benefits of vegetative buffers to crop production.

*6.7 Vegetative buffers*

Vegetative buffers are important for crop management because they decrease the erosion of topsoil and stabilize riverbanks, they improve the quality of water by decreasing sediments, nutrient loads, for example and they increase biodiversity (wild species, plants and pollinators) (Hoekstra & Hannam, 2017). Permanent buffers are classified into two main types that are within-field buffers (grassed waterways, contour buffer strips, vegetative barriers and wind buffers that include shelterbelts) and edge-of-field buffers (field borders, filter strips, riparian forest buffers and ecological buffers) (Hoekstra & Hannam, 2017). Trautman, Jeffrey, and Unterschultz (2012) analysed the effect of establishing buffer strips (assuming that the area had been cropped) around wetlands and associated riparian areas for representative farms in Alberta. Results showed annualized reductions in net present values for farms that adopt buffer strips without hay of $95 to $339 per hectare lost and $20 to $277 per hectare lost for farms that adopt buffer strips with hay.

### *6.7.1 Shelterbelts*

Shelterbelts have been shown to increase crop yields in field that are adjacent to them as a result of improvements in microclimates, increased moisture retention (reduce evaporation and trap snow) and decreases in wind speeds (results in decreased wind erosion and crop damages) (Agriculture and Agri-Food Canada, 2014b). Shelterbelts are also important for increasing pest insect predators and can facilitate the resilience of crops to pests and diseases (Austin, 2014). In the study by Martens et al. (2013), shelterbelts were rated highly in terms of preventing soil erosion, providing natural pollination services and air quality protection. Kulshreshtha and Kort (2009) found that total external benefits of prairie shelterbelts to society were worth 140 million (39.1 million for non-public goods and 100.9 million for public goods (Table A4).

Mature shelterbelts were found to increase average yields by 3.5% for wheat and 6.5% for alfalfa in studies conducted in Saskatchewan, Manitoba and North and South Dakota (Agriculture and Agri-Food Canada, 2014). According to Austin (2014), shelterbelts can increase crop yields by 25%. Results in Table 7 from a literature review conducted by Kort (1988) show that spring wheat, oats and corn have lower levels of responsiveness to shelter while the opposite is true for alfalfa (Table 8).

Table 8: Responsiveness (relative) of crops to shelter

| Crop | No. of field-years | Weighted mean yield increase (%) |
|---|---|---|
| Spring wheat | 190 | 8 |
| Winter wheat | 131 | 23 |
| Barley | 30 | 25 |
| Oats | 48 | 6 |
| Rye | 39 | 19 |
| Millet | 18 | 44 |
| Corn | 209 | 12 |
| Alfalfa | 3 | 99 |
| Hay (mixed grasses and legumes | 14 | 20 |

Source: Kort (1988, p. 181)

Kort (1988) also reports results of the effect of shelterbelts on the yield of spring wheat from Canadian Prairies and Northern United States Great Plains (Figure 11) and the author concludes that careful selection of species for the shelterbelts, their design and timely management can optimize increases in crop yields. Nicholaichuk (1980) found a net economic return of $ 3.40 per hectare per year for shelterbelts. Marsh (1999) evaluated the economic value of shelterbelts to crop production in the northern Great Plains and results showed that the direct impact of shelterbelts on crop yields ranged from $118 to $357 million depending on climate change scenarios. Without climate change, direct benefits of shelterbelts ranged from $163 to $310 million (Marsh, 1999).

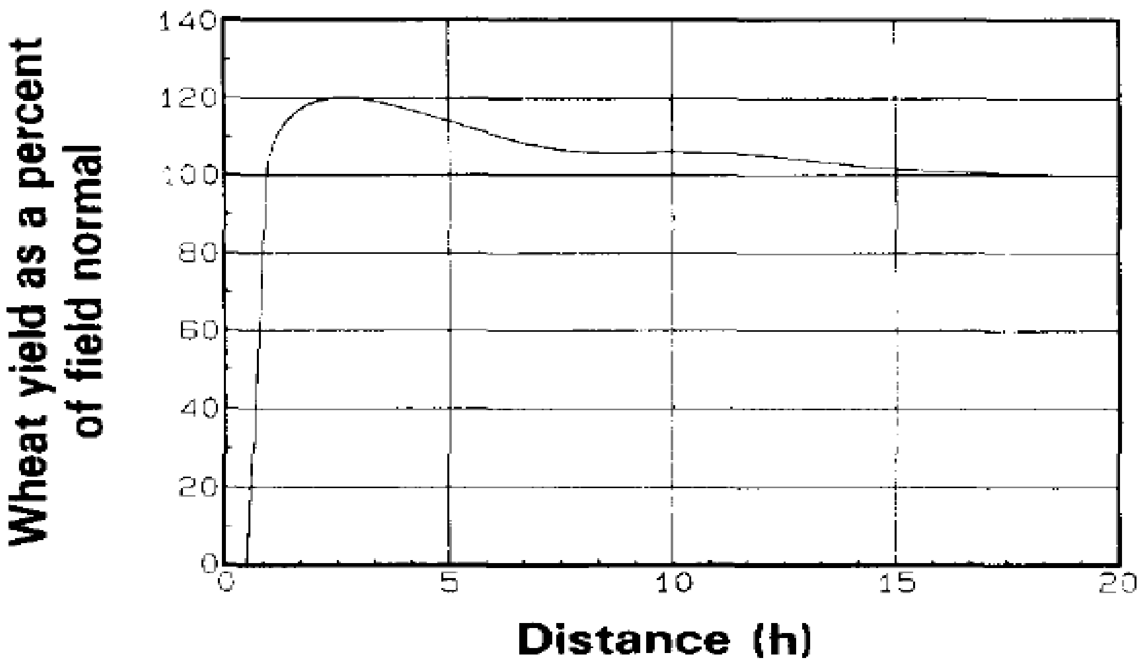


*Figure 11: Impact of shelterbelt on spring wheat yields (Canadian Prairies and Northern United States Great Plains)*
Source: Kort (1988, p. 185)

Although studies (e.g., Marsh, 1999; Nicholaichuk, 1980) show that shelterbelts have economic benefits to crop farmers, some studies have found the opposite to be true. McMartin, Frank, and Heintz (1974) analysed the economic impact of shelter belts on wheat yields in North Dakota and results showed a net economic return of -$6.00 per hectare per year. Trautman et al. (2012) found that converting cropland to shelter belts costs farmers $180 to $411 per hectare per year.

### *6.8 Wetlands*

Wetlands are important for the maintenance and enhancement of biodiversity, they provide habitat for wildlife and they reduce the impacts of climate change and regulate the quality and quantity of water, for example (Pattison-Williams et al., 2018). Therefore, the maintenance of permanent and temporary wetlands is important for protecting biodiversity. Vickruck, Best, Gavin, Devries, and Galpern (2019) sampled bees at 0m, 25m and 75m from the margin of wetlands into the surrounding cropland (for canola, cereals and perennial grass fields) and results showed that the abundance and diversity of native bees decreased further from the margin of wetlands in canola and cereal fields while the opposite was true for perennial grass.

It is estimated that the yearly economic benefit of remaining wetlands in Alberta for society declined from $6.3 billion in 1961 to $5.1 billion in 2003 (Pembina Institute, 2005). Lost wetland areas in Alberta had a cost of $7.7 billion in 2003 (1998 dollars) and the value of remaining wetlands was estimated to be $5 to $45 billion in Alberta in 2003 (Pembina Institute, 2005). Wilson (2008) estimated that the non-market value of economic services from wetlands in the Ontario's Greenbelt to society is $1,331 million per year ($14,153 per ha) (Table A4).

Pattison-Williams et al. (2018) evaluated the economic benefits of wetlands for flood control and nutrient removal to society for the Smith Creek Basin in Saskatchewan. Economic values were estimated for restoration (25%, 50% and 100%), retention of existing wetlands and wetland losses (25%, 50% and 100%) for society.

Table 9: Economic benefits of wetlands

| Ecosystem service | Proxy/crop | Country | State/Province | Valuation methods | Units | Value | Source |
|---|---|---|---|---|---|---|---|
| Flood regulation | Wetland % area in 1.5km radius of agriculture land parcels | United States | Michigan (Southwestern) | Hedonic analysis (land prices | % change in price per % change in wetland area | 3.1% increase in land value per 1% increase per wetland share | Ma & Swinton (2011) |
| Wetlands | | Canada | Alberta | | $ | 5-45 billion in 2003 | Pembina Institute (2005) |
| Flood control | Retention of existing wetlands | Canada | Saskatchewan, Smith Creek Basin | Hydrological model, transfer values, social return on investment | $/year | 1,832,800 | Pattison-Williams et al. (2018) |
| Removal of phosphorous | | | | | | 1,286,915 | |
| Removal of nitrogen | | | | | | 775,769 | |
| Additional services | | | | | | 2,618,337 | |
| Phosphorous removal | Retention of existing wetlands | Canada | Ontario, Black River watershed | Hydrological model, transfer values, social return on investment | $/year | 131,001 | Pattison-Williams, Yang, Liu, and Gabor (2017) |
| Removal of nitrogen | | | | | | 338,587 | |
| Biodiversity | | | | | | 569,250 | |
| Carbon storage | | | | | | 98,670 | |
| Tourism and recreation | | | | | | 9,343,290 | |
| Drainage of wetlands for crop farming | | Canada | Saskatchewan (Lost River and King George) | Agricultural benefits and costs of draining wetlands | $ /ha/year | Return per ha is -29 for Lost River and -70 for King George | Thompson and Young (1992) |

The results are summarized in Figure 12. For all the services, benefits are highest under full restoration of the wetlands. The authors calculated the social return on investment ratios for the retention and restoration scenarios and results show that retention of existing wetlands is more favorable (Pattison-Williams, 2018).

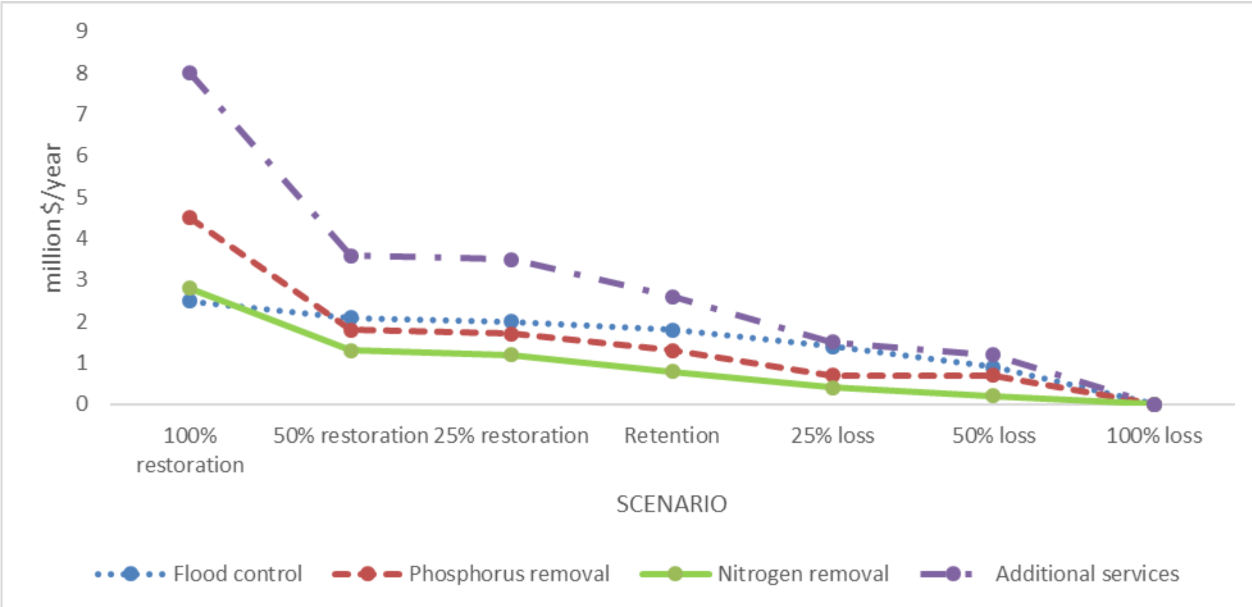


*Figure 12: Total benefit of Smith Creek wetlands, Saskatchewan for the different scenarios of loss or restoration*
Data are from Pattison-Williams et al. (2018)

Pattison-Williams et al. (2017) conducted a similar analysis for the Black River riparian wetlands in Ontario and results for the existing wetlands are in Table 9. In Figure 13, the results for the value of biodiversity under the different scenarios are reported. Benefits of biodiversity in the wetlands are highest when there is 100% restoration of the wetlands and lowest when there is a 25% loss of the wetlands.

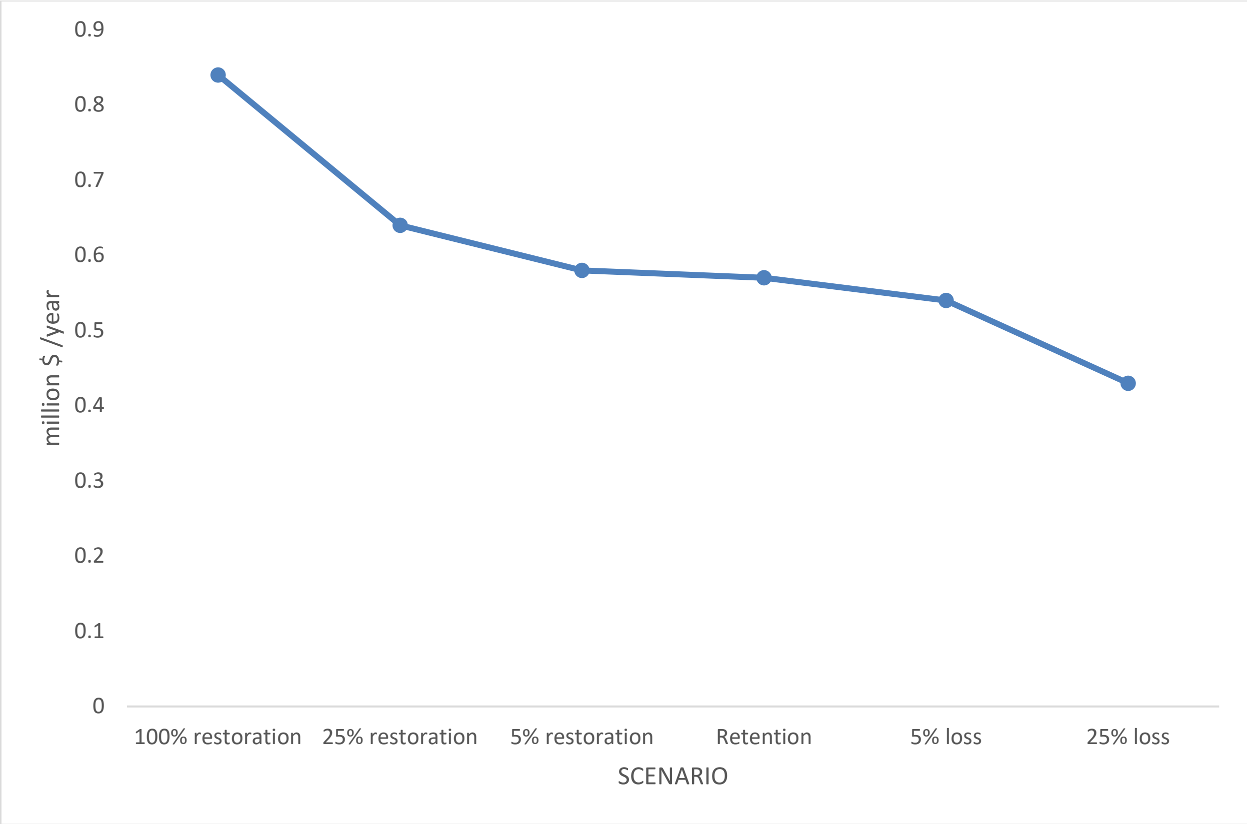


*Figure 13: Estimated benefits of biodiversity in the Black River riparian wetlands in Ontario under different scenarios of wetland loss and restoration*
Data are from Pattison-Williams et al. (2017).

Anderson and Rooney (2019) compared twenty-four restored wetlands and thirty-six natural wetlands in the Parkland region of Alberta and they found that there was overall lower beta diversity in restored wetlands as compared to natural wetlands. Thompson and Young (1992) analysed the benefits and costs of draining and cultivating prairie pothole wetlands to agriculture in Saskatchewan (King George and Lost River areas). Results showed that the annual return per hectare of draining and cultivating the wetlands was -$29 and -$70 for Lost River and King George for a 1.5-section farm. The results showed that further draining wetlands is not economically viable (Thompson & Young, 1992).

Yu and Belcher (2011) found that the magnitude of payment and factors such as the experience of the landowner, their planning horizon and beliefs about the values of wetlands influenced their decision to adopt wetland and riparian conservation management.

*6.9 Lakes and Rivers*

Lakes and rivers are an important habitat for wildlife and it provides other services such as irrigation to crop farmers. Therefore, protecting lakes and rivers is important for the conservation of biodiversity. In the previous literature, the economic value of services provided by lakes and rivers have been conducted. For example, the non-market ecosystem services of rivers in Ontario's Greenbelt were valued at $2.6 million per year for society ($335 per hectare per year) (Wilson, 2008) while natural capital of the Crane River, also in Ontario was valued at $19,400 per hectare per year (for society) (TD Economics & Nature Conservancy of Canada, 2017) (Table A4). In another study, streams in the Credit River-16 Mile Creek, Toronto area and Prince Edward Island were valued at $148.6 million, $176.5 million and $51.5 million per year respectively to society (Marbek, 2010). The ecosystem service product value of rivers and lakes to society in the Mackenzie watershed (Alberta, British Columbia, Saskatchewan, Northwest Territories and Yukon) was estimated to be $188.7 billion (Anielski and Wilson, 2009a).

*6.10 Wild Food Products and other benefits of protecting biodiversity*

In the literature, protection of biodiversity is important for providing wild food products. Pimentel et al. (1997) valued other wild foods at $0.50 billion per year in the United States and $180 billion per year for the world (for society). Hunting was valued at $12 billion per year in the United States and $25 billion per year to the world (Pimentel et al. (1997). Other benefits of biodiversity to society include wood products and ecotourism.

*6.11 Economic value of specific animal species*

The conservation of different species of wildlife is beneficial to society as a whole and to crop farmers. For example, the net economic value of the harvest of the Beverly and Qamanirjuag caribou herds was estimated to be $5.90 million in Saskatchewan, $3.80 million in Manitoba, $9.50 million in Nunavat and $0.80 million in Northwest Territories (Intergroup Consultants Ltd., 2013) (Table A5). The values were $15.1 million for the Qamanirjuag herd and $4.9 million for the Beverly herd (total value of $20 million). The value for harvests by local aboriginals was $14.8 million, 4.1 million is for outfitters and their clients, 0.6 million is for commercial harvesters and $0.5 million is for licensed harvesters.

Adamowicz et al. (1991) estimated the annual economic value of wildlife in Alberta and the values (to society) for hunting waterfowl, other birds, small mammals and large mammals were estimated to be 10.3, 11, 6.80 and 24.9 million dollars respectively. The annual non-consumptive value for the wildlife was estimated to be $64.5 million and preservation benefits were estimated to be $67.7 million (Adamowicz et al., 1991). The total economic value of wildlife in Alberta was estimated to be $185.2 million (annual) and $3,704 million in perpetuity. Kroeger and Casey (2006) estimated the economic value of the Canada lynx in the United States and they found that the estimated upper bound values were $557.7 million (lower bound is $211.3 million) in Montana and $69.6 million ($33.9 million) in Maine.

Martín-López, Montes, and Benayas (2008) conducted a meta-analysis of the economic value of biodiversity conservation. Most of the studies (65%) were from the United States, 6% were from Canada, 8% were from Australia and 6% were from Sri Lanka. Results for the economic values of the different species from different contingent valuation studies are summarized in Table 10.

Table 10: Economic values of different species

| Common name | Mean value (US$2005) | Species at Risk Act (SARA) status province |
|---|---|---|
| Eurasian red squirrel | 2.87 | |
| Water vole | 15.24 | |
| Bighorn sheep | 21.94 | |
| Elk (red deer) | 206.93 | |
| Moose | 145.49 | |
| Woodland caribou | 44.74 | |
| Coyote | 5.49 | |
| California sea otter | 36.76 | |
| European otter | 24.40 | |
| Giant panda | 13.81 | |
| Gray wolf | 19.26 | |
| Gray seals | 12.83 | |
| Grizzly bear | 38.89 | |
| Hawaiian monk seal | 93.87 | |
| Mediterranean monk seal | 17.54 | |
| Northern elephant seal | 31.53 | |
| Steller sea lion | 73.83 | |
| Beluga whale | 14.20 | Endangered (Quebec) |
| Blue whale | 44.57 | |
| Bottlenose dolphin | 23.17 | |
| Gray whale | 34.70 | Special concern (British Columbia and Yukon) |
| Humpback whale | 128.34 | |
| Brown hare | 0.00 | |
| Pentro horse | 33.89 | |
| Asian elephant | 1.94 | |
| Mahogany glider | 29.88 | |
| Tree kangaroos | 53.10 | |
| Leadbeater’s possum | 25.83 | |
| *Birds* | | |
| Harlequin duck | 11.15 | Special concern (Nova Scotia, New Brunswick and Quebec) |
| Wild goose | 11.91 | |
| Wild turkey | 11.59 | |
| Whooping crane | 53.42 | Endangered (Alberta, Manitoba and Saskatchewan) |
| Peregrine falcon | 29.89 | Special concern (Saskatchewan, Alberta, Manitoba, Ontario, Quebec, British Columbia, Nova Scotia, New Brunswick, Prince Edward Island and Yukon) |
| Bald eagle | 114.67 | |
| Northern spotted owl | 59.43 | |
| Mexican spotted owl | 74.38 | |
| Red-cockaded woodpecker | 12.10 | |
| White-backed woodpecker | 66.39 | |
| Loggerhead sea turtle | 16.98 | |
| *Fish* | | |
| Atlantic salmon | 9.45 | Endangered (Nova Scotia and New Brunswick) |
| Artic grayling | 22.69 | |
| Chinook salmon | 126.66 | Special concern (British Columbia) |
| Cutthroat trout | 17.02 | Threatened (Alberta) and special concern (British Columbia) |
| Steelhead | 64.47 | |
| Shortnose sturgeon | 30.86 | Special concern (New Brunswick and Nova Sotia) |
| Colorado squawfish | 10.91 | |
| Striped shiner | 6.83 | |
| Kelp bass | 43.35 | |
| White croaker | 43.35 | |
| *Crustacean* | | |
| Riverside fairy shrimp | 24.85 | |

Source: Economic values are from Martín-López et al. (2008) and SARA status is from Government of Canada (2019)

## 7. CONCLUSIONS

The objective of this report was to provide a literature review of the economic benefits of biodiversity to Canadian producers of cereals, oilseeds and special crops. The main focus of the literature review was on studies that assessed the economic benefits of biodiversity to crop farmers that are maintaining permanent and temporary wetlands, generating and renewing soils and natural vegetation, maintaining wildlife habitat and moderating extremes of temperature and force of winds. Publicly available research was included in the literature review. In summary, the results generally show that biodiversity provides economic benefits to crop farmers of cereals, oilseeds and special crops in terms of providing pollination services for crops, biocontrol of pests, soil formation, nitrogen fixation, improvements or maintenance of water quality, sequestration of carbon and the protection from the force of winds. Therefore, practices that conserve biodiversity on crop farms have economic benefits to farmers. The benefits can be variable across geographies and across crop types.

However, the regions that have the highest focus on biodiversity, such as the EU, do have agro-ecosystem payments to encourage farmers to adopt biodiversity friendly production practices. In Canada, there are programs such as the carbon offset program in Alberta which are providing economic benefits to farmers beyond the agronomic and environmental benefits from certain management decisions. There are also other specialized programs which exist. For example, the examination of the potential for hedgerows to sequester carbon in the lower Fraser Valley refers to an incentive program for farmers to maintain or plant hedgerows (Theil et al (2015)). ALUS Canada (https://alus.ca/) programs exist in 6 provinces in the country currently and across various different sustainable practices, participating farmers can receive payments per hectare for beneficial practices.

However there is the possibility, from some references, that in the short run adopting biodiversity friendly production could cost more than the benefits it provides farmers. In the long run, most estimates suggest the returns are highly positive particularly if risk mitigation is part of the calculation. It is clear that global supply chains, including those related to crops, are increasingly moving to the establishment of 'sustainable' supplies and requiring practices that can enhance environmental outcomes. By definition this includes aspects of biodiversity preservation and farmers may face demands for biodiversity protection as a 'ticket to enter' supply relationships with certain companies. Consumers may also be looking for more verification (certification possibly) of biodiversity friendly production practices.

The combination of demand pressures and longer run supply risk reduction may encourage the majority of farmers to adopt certain production practices. It is worth reiterating that farmers will each have unique approaches to the preservation of biodiversity, and in many cases know the most about how to conserve biodiversity on their own lands. Single approaches will not work everywhere in all geographies. Environmental attitudes are a major predictor of farmer adoption. It is also clear that although there is an increasing number of global reports highlighting the serious conditions of the world's biodiversity, many people (but not farmers who can define) are not even able to accurately define different types of biodiversity. To fully engage the public and to ensure public support for farmer initiatives, better global (ie by the public) understanding of biodiversity and how it works will be important. This is not a recommendation to 'educate' consumers on what they need to know (knowledge deficit approaches generally don't work), but more a realization that this is another area where our formal primary, secondary and even tertiary educational systems could benefit from increased focus. Common understanding of problem severity and how the problem can be approached in a win-win way for farmers and for society can generate significant support. Remember that when asked, the public does see biodiversity as something of significant value, mostly non-market value, to themselves and their country, so the good will is there.

## 8. REFERENCES


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# 9. APPENDIX

Table A1: Summary for biodiversity by province in Canada for areas with crop production

| Province | Background | Ecozone/ ecoprovince | Ecoregion | Soils | Natural vegetation include | Water bodies include | Crops include | Animals/reptiles/ amphibians include | Birds include | Fish include | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Saskatchewan | Ecozones are Taiga Shield (Selwyn lake Upland and Tazin Lake Upland), Boreal Shield (Athabasca Plain, and Churchill River Upland), Boreal Plain Ecozone (Mid-Boreal Upland, Mid-Boreal Lowland and Boreal Transition) and Prairie (Aspen Parkland, Moist Mixed Parkland, Mixed Grassland and Cypress Upland) | Boreal Plain ecozone | Mid-Boreal Upland | Gray Luvisolic soils, Gleysols and Mesisols | Trembling aspen, balsam poplar, while and black spruce, balsam fir, feathermoss, jack pine and tamarack | Rivers, small lakes, ponds and sloughs; Wetlands (bogs and fens) | Grains | Moose, woodland caribou, mule deer, white-tailed deer, elk, black bear, timber wolf, lynx, snowshoe hare, muskarat and beaver | Common loon, red-tailed hawk, white-throated sparrow, American redstart, ovenbird, hermit thrush and bufflehead | Northern pike, walleye, whitefish, perch and lake trout | Saskatchewan Conservation Data Centre (2019); University of Saskatchewan (n.d.); Virtual Saskatchewan (2019a, b, c, d, e, f, g) |
| | | Boreal Plain ecozone | Mid-Boreal Lowland | Eutric Brunisols, Mesisols and Grey Luvisols | Trembling aspen, balsam poplar, black and white spruce, balsam fir, tamarack, American elm, green ash and Manitoba maple | Rivers; Extensive wetlands (bogs and fens) on about 50% of the area) | Seed grains, oilseeds and forage crops | Moose, woodland caribou, black bear, wolf, lynx, snowshoe hare and muskrat | Common loon, Canada warbler, ruby-crowned kinglet, white-breasted nuthatch, ruffed grouse, duck, goose, pelican and sandhill crane. | Northern pike, walleye, lake trout, and perch | |
| | | Boreal Plain ecozone | Boreal Transition | Gray Luvisols, Dark Gray and Black Chernozemic, Peaty Greysolic and Mesisolic soils | Trembling aspen, balsam poplar, jack pine, white spruce, balsam fir, sedges, willow, black spruce and tamarack | Rivers, a large number of small lakes, ponds and sloughs | Mostly farmland (70% of the land); Spring wheat, other cereals, oilseeds and hay | White-tailed deer, black bear, elk, moose, beaver, coyote, snowshoe hare and cotton tail, northern flying squirrel and short tailed shrew | Gray jay, boreal chickadee, black and white warbler and great-crested flycatcher, ruffed grouse and waterfowl | Northern pike, walleye, perch, rainbow trout | |
| | | Prairie ecozone | Aspen Parkland | Black Chernozemic and Greysolic soils | Trembling aspen, oak groves, willow and fescue grasslands | Small lakes, ponds and sloughs | Mostly farmland; spring wheat, other cereals, oilseeds and forage crops | White-tailed deer, coyote, snowshoe hare, cottontail, red fox, northern pocket gopher, Franklin's ground squirrel and Richardson's ground squirrel | House wren, least flycatcher, western kingbird, yellow warbler, sharp-tailed grouse, black-billed magpie and waterfowl such as ducks | Northern pike, walleye and perch | |
| | | Prairie ecozone | Moist Mixed Grassland | Dark brown Chernoze | Wheatgrass, spear grasses deciduous shrubs (for | Lake; sloughs and ponds; | Spring wheat, other cereals, | White-tailed deer, mule deer, pronghorn | Western meadowlark, eastern kingbird, yellow- | Northern pike, walleye and perch | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mic and Solonetzic soils | example, snowberry, rose, buckbrush, chokecherry, wolf willow and saskatoon), scrubby aspen, willow, cottonwood, box-elder, meadow grasses, sedges, alkali grass, wild barley, red samphire and sea blite | Minor irrigation near Lake Diefenbaker | forage and oilseed crops | antelope, coyote, jack rabbit, red fox, badger and Richardson's ground squirrel | headed blackbird, piping plover, sharp-tailed grouse and Franklin's gull and waterfowl | | |
| | | Prairie ecozone | Mixed Grassland | Brown Chernozemic and Solonetzic soils | Wheatgrasses, speargrasses, blue grama grass, June grass, dryland sedge, sagebrush, yellow cactus, scrubby aspen, willow, cottonwood, box-elder, alkali grass, wild barley, greasewood, red samphire and sea blite | Rivers | Driest ecoregion; spring wheat, durum wheat and flaxseed | Pronghorn antelope, white-tailed and mule deer, sage grouse, short-horned lizard, prairie rattlesnake, western painted turtle, black-tailed prairie dog, coyote, jack rabbit and Richardson's ground squirrel | Ferruginous hawk, long-billed curlew, yellow-breasted chat, chestnut-collared longspur, burrowing owl, sage grouse and waterfowl | Northern pike, walleye, rainbow trout and perch | |
| | | Prairie ecozone | Cypress Upland | Chernozemic Black and Dark Brown, Luvisolic and Regosolic sils | Fescue grass, wheatgrass grasslands, forests, larkspur, lodgepole pine, death camas and wild lupine | River and creeks | Cereals (limited production) | Mule and white-tailed deer, elk, moose, pronghorn antelope, sage grouse, short-horned lizard, western rattlesnake, coyote, rabbit and ground squirrel | Trumpeter swan, golden eagle, yellow-rumped warbler, MacGillvary's warbler, Audonon's warbler, dusky flycatcher, Townsend's solitaire and Audubon's warbler | Brook, brown trout and rainbow trout | |
| Alberta | Ecozones are Rocky Mountain (Alpine, Subalpine, and Montane), Foothills (Upper Foothills and Lower Foothills), Grassland (Dry Mixedgrass, Northern Fescue and Foothills Fescue), Parkland | Foothills ecozone | Lower Foothills | Orthic Gray Luvisolic, Brunisolic Gray Luvisols, Dystric Brunisols, Eutric Brunisols, Regosols, | Aspen, balsam poplar, white birch, lodgepole pine, black spruce, white spruce, balsam fir, tamarack, bearberry, common juniper, hairy wild rye, green alder, low-bush cranberry, prickly rose, wild | Wetlands (20%) and lakes and streams (<1%); rivers; fens and bogs | Till cropping and forage crops; | Red squirrel, moose, flying squirrel, beaver black bear, elk, woodland caribou, wolverine, long-toed salamander, meadow vole, boreal toad and wood frog | Boreal chickadee, spruce grouse, rubycrowned kinglet, white-winged crossbill, ruffed grouse, black-capped chickadee and Tennessee warbler, warbling vireo, yellow-bellied sapsucker (northern race), rose-breasted | Rocky Mountain whitefish, bull trout, Arctic grayling, burbot and white sucker | Alberta Biodiversity Monitoring Institute (2019); Alberta Environmental Protection Natural Resources Service Recreation & |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Foothills Parkland, Central Parkland and Peace River Parkland), Boreal Forest (Dry Mixedwood, Central Mixedwood, Lower Boreal Highlands, Upper Boreal Highlands, Athabasca Plain, Peace-Athabasca Delta, Northern Mixedwood and Boreal Subarctic) and Canadian Shield (Kazan Upland) | | | Gleysolic, Mesisols, Orthic and Peaty Gleysols | sarsaparilla, dewberry, fireweed, bluejoint, feathermosses, Labrador tea, bog cranberry and common blueberry, bracted honeysuckle, ferns, bluejoint and cow parsnip, Devil's-club, horsetail and bog birch | | | | grosbeak, purple finch, Barrow's Goldeneye, trumpeter swan, lesser yellowlegs, common snipe and Lincoln's sparrow | | Protected Areas Division Natural Heritage Protection and Education Branch (1997); Alberta Parks (2015); Alberta Wilderness Association (2019 a, b); Government of Alberta (2007a, b); Natural Regions Committee (2006); Stelfox and Wynes (n.d.) |
| | | Grassland ecozone | Dry Mixedgrass | Solonetzic, Orthic Brown Chernozemic, Rego Chernozemic and Regosolic and Humic, Orthic and Luvisolic soils | Blue grama, needle-and- thread, June grass, western wheat grass, sand grass, silver sagebrush, silver berry, buckbrush, prickly rose, moss phlox, pasture sage, prairie selaginella, dotted blazingstar, willows, thorny buffaloberry, prickly-pear cactus, clammyweed, low milk vetch, annual skeletonweed and plains cottonwood | Wetlands (3%) and lakes and streams (2%); rivers; temporary waterbodies and marshes | 35% under dryland farming; Irrigation (nearly 10%); mainly wheat/fallow | Richardson's ground squirrel, pronghorn, Ord's kangaroo rat, western hognose snake, deer mouse, Nuttall's cotton tail, white tailed-deer, boreal chorus frog, northern leopard frog, plains spadefoot toad and garter snake | Brown thrasher, gray catbird, common yellowthroat, yellow-breasted chat and rufous-sided towhee, mourning dove, great-horned owl, northern flicker, least flycatcher, house wren and northern oriole, horned lark, McCown's longspur, chestnut-collared longspur, Baird's sparrow, Sprague's pipit, sharp-tailed grouse, upland sandpiper, sage grouse, lark bunting, Brewer's sparrow, golden eagle, rock wren ferruginous hawk, prairie falcon and mountain bluebird | Western silvery minnow and stonecat | |
| | | Grassland ecozone | Mixedgrass | Orthic Dark Brown Chernozems, Rego Chernozems, Regosols, Brown and Black Chernozemic and Solonetzic soils | Needle-and-thread, porcupine grass, northern and western wheatgrass, western porcupine grass, sand grass, June grass, buckbrush, blue grama grass, sedges, blue bunch fescue, plains rough fescue, silver sage brush, | Wetlands (5%), mostly marshes and lakes and streams (1%); few rivers | Mainly agricultural production (85% of land covered with crops); irrigation (5%); wheat, barley and canola | Similar to drymixed grass e.g., Richardson's ground squirrel | Similar to dry mixedgrass e.g., Baird's sparrow, Sprague's pipit, upland sandpiper and sharp-tailed grouse, horned lark, and chestnut-collared longspur | | |

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| | | | | | silverberry, prickly rose, willows, thorny buffaloberry, cottonwood and balsam poplar, sedges and spike-rushes | | | | | | |
| | | Grassland ecozone | Northern Fescue | Orthic Dark Brown and Black Chernozems, Solonetzics, Regosols, Rego Chernozems and Orthic, Humic and Luvic Gleysols | Plains rough fescue, aspen, balsam poplar, plains cottonwood, lue grama grass, northern wheat grass, sans grass, June grass, western porcupine grass, slender wheat grass, Hookers's oat grass, buckbrush,silverberry, prickly rose and saskatoon and herbs such as prairie crocus, prairie sagewort, wild blue flax, northern bedstraw and three-flowered avens | Wetlands (7%), mostly marshes and lakes and streams (3%); river; | Till-cropping; approximately 55% of the land is cultivated; wheat, barley and canola | Mule deer, white-tailed deer, moose and elk, thirteen-lined ground squirrel, Richardson's ground squirrel, prairie long-tailed weasel, white tailed jack rabbit, American badger, bison, pronghorn, coyote, tiger salamander, Canadian toad, boreal chorus frog, northern leopard frog, wandering garter snake, and western plains garter snake. | Baird's sparrow, Sprague's pipit, upland sandpiper, sharp-tailed grouse, horned lark, chestnut-collared longspur savannah sparrow, northern pintails, snow geese, loggerhead shrike, piping plover, ferruginous hawk, long-billed curlew, American white pelican, nesting geese. Harlequin ducks, Sabine's gull and Townsend's solitaires | | |
| | | Grassland ecozone | Foothills Fescue | Dark Brown and Orthic Black Chernozems, Solonetzics and Humic Gleysols | Mountain rough fescue, Parry oat grass, blue bunch fescue, creeping juniper, June grass, tufted hair grass, shrubby cinquefoil, sedges, western wheatgrass, buck brush, willow, sedge, silverberry, prickly rose and saskatoon. Herbs include silvery perennial lupine, sticky purple geranium, three-flowered avens, pasture sagewort and golden bean | Wetlands are uncommon (3%) and 1% lakes and streams (1%); rivers | Till cropping; 50% cultivated; barley and forage crops | Elk, pronghorn, white-tailed deer, mule deer, yellow bellied marmot and Northern leopard frog | Ferruginous hawks, golden eagles, prairie falcons, pintail duck, Baird's sparrow, Brewer's sparrow and sharp-tailed grouse | Shorthead (St. Mary) sculpin, Silvery minnow, stonecat, brassy minnow and sauger | |

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| | | Parkland ecozone | Foothills Parkland | Deep Orthic Black Chernozems, Orthic Dark Gray Chernozems and Orthic Gleysols | Aspen forests, willow, balsam poplar, white spruce, plains cottonwood, sedge, Douglas fir, mountain rough fescue, Parry's oatgrass, bluebunch fescue, needle-and-thread grass, tufted hair grass, lupines, oat grass, snowberry, silverberry, white meadowsweet, prickly rose, saskatoon, wild red raspberry, glacier lilies and wild white geranium | Wetlands (4%) and lakes and streams (<1%); river | Till cropping; hay or field crops (feed grains) | Moose and elk | Dusky flycatcher, MacGillivray's warbler, lazuli bunting, white-crowned sparrow, clay-colored sparrows, orange-crowned warblers, yellow warblers, alder flycatchers, white crowned sparrows, black-headed grosbeaks, blue grouse and trumpeter swan | Bull trout | |
| | | Parkland ecozone | Central Parkland | Orthic Black Chernozems, Orthic Dark Gray Chernozems, Dark Grey Luvisolic, Humic and Orthic Gleysols and Solonetzic soils. | Aspen, plains rough fescue, balsam poplar, jack pine, white spruce, common cattail, willow, beaked hazelnut, bunchberry, wild lily-of-the-valley and wild sarsaparilla,western porcupine grass, June grass, needle-and-thread grass, blue grama grass, dryland sedges, pasture sagewort, northern wheat grass, Hooker's oatgrass, herbs (prairie crocus, prairie sagewort, wild blue flax, northern bedstraw and three-flowered avens among others), buckbrush, silverberry, prickly rose, chokecherry, saskatoon, hay sedge, creeping juniper, common | Wetlands (10%) and lakes and streams (2%); Rivers; mainly marshes; seasonal ponds and fens | Land is extensively cultivated; Till cropping; Crops include wheat, barley canola, pulses and flax | Prairie vole, Franklin's ground squirrel, thirteen-lined ground squirrel, white-tailed deer, snowshoe hare, northern pocket gopher, red squirrel, least chipmunk, garter snake American porcupine, spadefoot toad, boreal chorus frog, wood frog, Canadian toad and northern leopard frog | Upland sandpiper, Sprague's pipit, Baird's sparrow woodchuck, broad-winged hawk, rose-breasted grosbeak, red-tailed hawk, least flycatcher, Baltimore oriole, red-eyed vireo, yellow warbler, hermit thrush, sharp-tailed grouse, American redstart, Tennessee warbler, mourning dove, great-horned owl, northern flicker, house wren, northern oriole, blue jay, white-throated sparrow, yellow-bellied, sapsucker and piping plover, diving ducks, grebes, American bittern, marsh wren, black tern and ducks, | Northern pike, yellow perch, white, brook stickleback and fathead minnow | |

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| | | | | | Labrador tea, feathermosses, bulrush marshes and treed fens | | | | | | |
| | | Parkland ecozone | Peace River Parkland | Solonetzic soils, Dark Gray and Black Chernozems, Dark Grey Luvisols, Orthic Gray Luvisols, Regosols, Brunisols, Rego Dark Brown Chernozems, Humic and Orthic Cumulic Regosols, Orthic and Humic Gleysols and Terric Mesisols | Aspen, jack pine, balsam poplar, white spruce, beaked willow, sedge, California oat grass, western porcupine grass, June grass, sedges, pasture sagewort, northern and slender wheat grass, brittle prickly pear, saskatoon, choke cherry, buckbrush, prickly rose, snowberry, bluejoint, red-osier dogwood, horsetail, common Labrador tea and peat moss fens | Wetlands (6%) and lakes and streams (2%); fens and ponds | Much of the land has been cultivated; Till cropping; Crops include canola, wheat and barley | Moose, elk, deer, black bear, grizzly bear, Wandering and red-sided gartersnakes | Trumpeter swan; golden eagle, bald eagle, osprey, western meadowlarks and savannah sparrows | Flathead chub, lake chub, longnose dace, longnose sucker, northern pike, trout-perch redside shiner, northern squawfish, largescale sucker, bull trout, goldeye, walleye, yellow perch, lake whitefish, mountain whitefish and burbot | |
| | | Boreal Forest ecozone | Dry Mixedwood | Orthic Gray and Dark Gray Luvisols; Solonetzic soils, Greysoils, Gleyed Gray Luvisons, and Organic soils (Terric Mesisols, Fibric Mesisols and Peaty | Aspen, treed and shrubby fens, jack pine, lichen, white spruce, balsam poplar, porcupine grass, June grass, sedges, pasture sagewort, northern and slender wheat grasses, saskatoon, buckbrush, bearberry, common blueberry, green alder, prickly rose, wild lily-of-the-valley, hairy wild rye, beaked hazelnut, wild sarsaparilla, cream | Wetlands (15%) and lakes and streams; rivers (3%); fens, bogs or mineral soils | Much of the land has been cultivated; Till cropping; oilseeds, wheat, barley and forages | Beaver, moose, snowshoe hare, black bear, wolf, lynx and ermine | Least flycatcher, house wren, ovenbird, red-eyed and warbling vireos, Baltimore oriole, rose-breasted grosbeak. Yellow-bellied sapsucker, Swainson's thrush, solitary vireo, magnolia warbler, white-throated sparrow, pileated woodpecker, northern goshawk, yellow rail, sedge wren, great-crested flycatcher, chestnut-sided warbler and | | |

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| | | | | and Orthic Gleysols | colored vetchling, purple peavine, bluejoint, low bush cranberry, Canada buffaloberry, bunchberry, red-osier dogwood, feathermosses, horsetails and bogs | | | | blackburnian warbler | | |
| | | Boreal Forest ecozone | Central Mixedwood | Gray Luvisols, Dystric, Eutric Brunisols, Solonetzic intergrades, Mesisols, Fibrisols, Cryosols and orthic and Peaty Gleysols | Aspen, white spruce, jack pine, lodgepole pine, balsam poplar, black spruce fens, bogs, conifer, balsam fir, northern rice grass, Rocky Mountain fescue, dryland sedges, plains wormwood, lichen, bearberry, common blueberry, green alder, prickly rose, wild lily-of-the-valley, hairy wild rye, low bush cranberry, Canada buffaloberry, bunchberry, wild sarsaparilla, and dewberry, feathermoss, red-osier dogwood, common Labrador tea, peat moss, feathermosses and willow, dwarf birch, sedges, bluejoint, tamarack, golden moss and rich-site forbs | Wetlands (40%) mainly peatlands; fens, bogs and marshes and lakes and streams (3%); rivers | Till cropping; hay crops, tame or native pasture | Red squirrel, beaver, moose, snowshoe hare, black bear, wolf, lynx, Southern red-backed vole, masked shrew, deer mouse, least chipmunk, moose and ermine, fisher, wolverine, river otter, and woodland caribou | Western wood pewee, gray jay, red-breasted nuthatch, golden and ruby-crowned kinglets, yellow-rumped warbler, pine siskin, red and white-winged crossbills, dark-eyed junco, boreal chickadee, bay-breasted, Cape May and black-throated green warblers, least flycatcher, house wren, ovenbird, red-eyed and warbling vireos, northern oriole and rose-breasted grosbeak, yellow-bellied sapsucker, Swainson's thrush, solitary vireo, magnolia warbler, white-throated sparrow, pileated woodpecker, northern goshawk, yellow and black-and-white warblers, American redstart, song sparrow, northern water thrush, fox sparrow, Philadelphia vireo and barred owl | | |
| Manitoba | Ecozones are Southern Arctic (Maguse River upland), Taiga Shield (Kazan River Upland and Selwyn Lake | Boreal Shield ecozone | Lac Seul Upland | Dystric Brunisolic soils, Organic Mesisols and Fibrisols, | Jack pine, trembling aspen, black spruce, white spruce, balsam fir, balsam poplar, feather mosses, ericaceous shrubs, | Lakes and rivers; wetlands (bogs and fens | Limited agriculture; native hay and alfalfa | Moose, black bear, wolf, woodland caribou, white-tailed deer, lynx, ermine, fisher, | Bald eagle, great horned owl and red-tailed hawk, spruce grouse, herring gull, double crested cormorant | Shortjaw cisco amd Carmine shiner | Government of Manitoba (2013); http://lakeofthewoods.ca/recreation/species-of-fish; Smith |

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| | Upland), Hudson Plain (Coastal Hudson Bay Lowland and Hudson Bay lowland), Boreal Shield (Churchill River Upland, Hayes River Upland, Lac Seul Upland and Lake of Woods), Boreal Plain (Mid-Boreal Uplands, Boreal Transition, Mid-Boreal Lowland and Interlake Plain) and Prairie (Lake Manitoba Plain, Southwest Manitoba. Uplands and Aspen parkland). | | | Gray Luvisols and Greysolic soils | mosses, lichens, dwarf birch, sedges and tamarack | | | mink, red squirrel, beaver, muskrat and snowshoe hare | and turkey vulture, ducks and geese | | et al. (2001); https://www.gov.mb.ca/sd/environment_and_biodiversity/cdc/ecoregions/index.html |
| | | Boreal Shield ecozone | Lake of the Woods | Organic Mesisols and Fibrisols, Eutric Brunisols, Dystric Brunisols, Gray Luvisols and Dark Gray Chernozemic soils and Greysolic soils | Jack pine, trembling aspen, paper birch, white spruce, eastern white cedar, black ash, white elm, red pine, eastern white pine, bur oak, red (green) ash, black spruce and tamarack | Rivers and lakes; wetlands (peatlands) | Limited arable agriculture; feed grains, oilseeds ad hay crops | Moose, black bear, wolf, lynx, snowshoe hare, white tailed deer and bobcat | Ruffed grouse, hooded merganser, pileated woodpecker, bald eagle, turkey vulture, herring gull and waterfowl | Walleye, small mouth bass, muskie, crappie and lake trout and northern pike, shortjaw cisco, banded killifish and carmine shiner | |
| | | Boreal Plains ecozone | Mid-boreal Lowland | Eutric Brunisols, Organic Mesisols and Fibrisols and Gray Luvisolic soils | Black spruce, trembling aspen, balsam polar, jack pine, white spruce, balsam fir, ericaceous shrubs, sedges, brown mosses, swamp birch and tamarack | Lakes and rivers; wetlands (include peatlands) | Limited arable agriculture; feed grains, oilseeds and hay | Moose, black bear, wolf, lynx, red fox, snowshoe hare, woodland caribou and deer | Raptors, sandhill crane, ruffed grouse, ducks, geese, white pelican and cormorant | Shortjaw cisco | |
| | | Boreal Plains ecozone | Boreal Transition | Dark Gray Chernozemic soil, Gray Luvisols, peaty Gleysols and Organic Mesisols | Trembling aspen, balsam poplar, white spruce, balsam fir, sedges, willow, black spruce, tamarack | Small lakes, ponds and sloughs; wetlands | Limited agricultural production; spring wheat, other cereals, oilseeds and hay crops | White-tailed deer, elk, black bear, moose, beaver, coyote and rabbit | Ruffed grouse and waterfowl | | |
| | | Boreal Plains ecozone | Mid-boreal Upland | Gray Luvisolic soils, Humic Gleysols, Organic Mesisols, Eutric Brunisols and Dark Gray | Trembling aspen, balsam poplar, white spruce, balsam fir, black spruce, jack pine, tamarack and feather moss | Small ponds, lakes and slough and rivers; wetlands (e.g., bog peatlands) | Land generally not used for agriculture | Elk, moose, black bear, wolf, lynx, , marten, snowshoe hare, red fox and beaver | Bald eagle, spruce grouse, duck and goose | | |

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| | | | | Chernozems | | | | | | | |
| | | Boreal plains ecozone | Interlake Plain | Chernozemic Dark Gray and Blay soils, Eutric Brunisols, Gray Luvisols, Organic Mesisols and Humic Gleysols | Trembling aspen, balsam poplar, white spruce, balsam fir, jack pine, sedges, willow, black spruce and tamarack | Lakes and rivers; peatlands | Spring wheat, other cereal grains, oilseeds and hay crops | White-tailed deer, black bear, moose, beaver, coyote, snowshoe hare and eastern cottontail | Ruffed grouse, cormorant, gull, tern, heron, American white pelican and grebe | Shortjaw cisco | |
| | | Prairie ecozone | Aspen Parkland | Chernozemic Black soils; Regosols; Gleysols | Trembling aspen, bur oak, fescues, wheat grasses, June grass, Kentucky bluegrass, slough grasses, marsh reed grass, sedges, cattails and shrubby willows | Small lakes, ponds, sloughs and rivers; wetlands | Spring wheat and other cereals, oilseeds and potatoes | Elk, pronghorn antelope, white-tailed deer, coyote, red fox, ground squirrel, cottontail rabbit, hare, striped skunk, redback vole deer mice, black bear, red-sided and western plains garter snakes | Raptors, ferriguous hawk, sparrow hawk and red-tailed hawk, mourning dove, black-billed magpie, red-winged blackbird, killdeer, meadowlark , ruffed grouse, and ducks | | |
| | | Prairie ecozone | Lake Manitoba Plain | Black Chernozemic soils, Humic Vertisolic and Gleysolic soils | Trembling aspen, bur oak, fescue grasses, wheat grasses, June grass and Kentucky bluegrass, slough grasses, marsh reed grass, sedges, cat-tails, sedge and shrubby willow | Lakes and rivers | Spring wheat, other cereal grains, oilseeds and hay | White-tailed deer, coyote, rabbit and ground squirrel | Waterfowl | | |
| | | Prairie ecozone | Southwest Manitoba Uplands | Dark Gray and Black Chernozemic, Gray Luvisols, Gleysoils and Organic Mesisols | White spruce, trembling aspen, balsam poplar, bur oak, sedges and willow. | Small lakes, ponds and sloughs; wetlands | Spring wheat, other cereals, oilseeds and hay crops are | White-tailed deer, black bear, beaver, coyote, rabbit and hare | Ruffed grouse, red-tailed hawk, common flicker and sparrows such as Le Conte's and the song sparrow, ducks and coots | | |
| Ontario | Ecozones are Hudson Bay Lowlands (Hudson | Ontario Shield ecozone | Lake Temagami (4E) | Podzols, Brunisols, Greysols, | Eastern white pine, red pine, sugar maple, red maple, | Various lakes and rivers | Agriculture is important | Moose, beaver, American marten, | American black duck, broad-winged hawk, barred owl, | Lake trout, brook trout, lake | Crins, Gray, Uhlig, and Wester (2009) |

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| | Bay Coast, Northern Taiga and James Bay), Ontario Shield (Big Trout Lake, Lake Abitibi, Lake St. Joseph, Lake Nipigon, Lake Temagami, Lake Wabigoon, Pigeon River, Georgian Bay and Agassiz Clay Plain) and Mixedwood Plains (Lake Simcoe-Rideau and Lake Erie-Lake Ontario) | | | Mesisols and Dystric Brunisols | yellow birch, jack pine, black spruce, sugar maple and red maple | | in the Little Clay belt | American black bear, snapping turtle, eastern garter snake, Northern ring-necked snake, eastern red-backed salamander, mink frog, northern leopard frog and spring peeper | winter wren, hermit thrush, black-throated green warbler and white-throated sparrow | whitefish, northern pike, emerald shiner, longnose sucker, creek chub, rock bass and pumpkinseed | |
| | | Ontario Shield ecozone | Lake Wabigoon (4S) | Dystric Brunisols and Mesisols | Jack pine, black spruce, balsam fir, trembling aspen, white birch, white spruce, tamarack, black ash and balsam poplar, American elm, ironwood, bur oak, large-tooth aspen, eastern white pine, and red pine, red maple, sugar maple, and American basswood, bur oak, nodding onion and big bluestem | Various lakes and rivers; wetland | Agriculture is found in the Dryden and Fort Frances areas | Gray wolf, ermine, fisher, American mink, moose, snowshoe hare, blue-spotted salamander, boreal chorus frog, green frog western painted turtle and red-sided gartersnake. | Bald eagle, merlin, ruffed grouse, gray jay, common raven, hermit thrush and yellow-rumped warbler | Lake trout, northern pike, northern redbelly dace, goldeye, muskellunge, pumpkinseed and river darter | |
| | | Ontario Shield ecozone | Pigeon River (4W) | Dystric Brunisols, Gray Luvisols, Mesisols and Gleysols | Eastern white pine, white spruce, Jack pine, red pine, Jack pine, trembling aspen, large-tooth aspen, white birch, balsam fir, white spruce, black spruce, sugar maple, yellow birch, American basswood, ironwood, box elder, bur oak, tamarack, eastern white cedar, black ash, American elm and red maple | Various lakes and few major rivers | Agriculture is predominant | Moose, American black bear, snowshoe hare, spotted salamander, gray treefrog, western painted turtle, northern red-bellied snake and central newt | Ruffed grouse, pileated, woodpecker, hermit thrush, magnolia warbler, white-throated sparrow and hooded merganser | Lake trout, lake chub, northern pike, burbot, golden shiner, bluntnose minnow, and rock bass | |
| | | Ontario Shield ecozone | Agassiz Clay plain ecoregion (5S) | Gleysols, Gray Luvisols, hernozemi | Black spruce, tamarack, eastern white cedar, willow, speckled alder, sugar maple, | Lakes, rivers, extensive wetlands; | Agriculture is predominant | White-tailed jack rabbit, Franklin's ground squirrel blue-spotted salamander, | Sharp-tailed grouse, black-billed magpie, western meadowlark, golden-winged | Lake trout, lake whitefish, northern pike, muskellunge, | |

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| | | | | c soils and Mesisols | red maple, wild black cherry, American basswood, green ash, white spruce, balsam fir, trembling aspen, and white birch, bur oak, northern pin oak and American elm | peatlands and swamps | | northern red-bellied snake, American black bear, snowshoe hare boreal chorus frog and American toad | warbler, scarlet tanager, Connecticut warbler, boreal chickadee and gray jay | rock bass, pumpkinseed, black crappie, bluntnose minnow and blacknose dace | |
| | | Mixedwood Plains ecozone | Lake Simcoe-Rideau (6E) | Gray Brown Luvisols, Melanic Brunisols, Gleysols and Humoferric Podzols | Sugar maple, American beech, white ash, eastern hemlock, green ash, silver maple, red maple, eastern white cedar, yellow birch, balsam fir, black ash, fens, bogs, black spruce and tamarack and American alvar | Lakes and rivers; wetlands (peatlands) | Most of the land is cropland | White-tailed deer, Northern raccoon, striped skunk, and woodchuck, snapping turtle, eastern gartersnake common watersnake, red-spotted newt, American bullfrog, northern leopard frog and spring peeper | Field sparrow, grasshopper sparrow, eastern meadowlark, hairy woodpecker, wood thrush, scarlet tanager, rose-breasted grosbeak, Wood duck, great blue heron and Wilson's snipe | White sucker, smallmouth bass, walleye, northern pike, yellow perch, rainbow darter, emerald shiner and pearl dace | |
| | | Mixedwood Plains ecozone | Lake Erie-Lake Ontario (7E) | Gray Brown Luvisols and Gleysols | Tulip-tree, black gum, sycamore, Kentucky coffee-tree, pawpaw, oaks, hickories, common hackberry, sugar maple, American beech, white ash, eastern hemlock, eastern white pine and tall-grass prairie | Watershed; various rivers and a few small lakes; most wetlands have been eliminated; some coastal marshes, swamps and open fens | 78% of the land has been converted to agriculture | White-tailed deer, northern raccoon, striped skunk, Virginia opossum, spiny softshell turtle, eastern red-backed salamander, eastern gartersnake, Midland painted turtle, spiny softshell turtle, blue racer, small-mouthed salamander and American toad | Green heron, Virginia rail, Cooper's hawk, eastern kingbird, willow flycatcher, brown thrasher, yellow warbler, common yellowthroat, northern cardinal, savannah sparrow, wild turkey, Acadian flycatcher, king rail, prothonotary warbler and hooded warbler | Longnose gar, channel catfish, smallmouth bass, yellow perch, walleye, northern hogsucker, banded killifish and spottail shiner | |
| Quebec | Ecozones are Arctic Cordillera (Torngat Chain), Northern Arctic (Northern Ungava Peninsula), Southern Arctic (Central Ungava Peninsula), Taiga | Boreal Shield ecozone | Southern Laurentians | Humo-Ferric Podzols, Ferro-Humic Podzols, Dystric Brunisols | White spruce, balsam fir, paper birch, aspen, trembling aspen, black spruce, balsam fir and tamarack | Rivers and lakes; wetlands | Limited farming | Moose, black bear lynx, snowshoe hare, wolf, coyote, white-tailed deer and chipmunk | American black duck, wood duck, hooded merganser, pileated woodpecker and cardinal | | http://ecozones.ca/english/zone/index.html; http://www.corridorappalachien.ca/en/biodiversity/; https://mreac.o |

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| | Shield (La Grande Hills, Southern Ungava Peninsula, New Quebec Central Plateau, Ungava Bay Basin, George Plateau, Kingurutik-Fraser River, Smallwood Reservoir-Michikamau and Mecatina River), Boreal shield (Abitibi Plains, Lake Temiskaming Lowland, Southern Laurentians, Riviere Rupert Plateau, Central Laurentians, Anticosti Island and Mecatina Plateau), Atlantic Maritime (Appalachians, Northern new Brunswick Highlands and Iiles-de-la-Madedeleine), Mixedwood plains (St-Lawrence Lownlands) and Hudson plains (James Bay Lowlands). | | | and Mesisols | | | | | | | rg/watershed/; DePratto and Kraus (n.d.); Wiken, Nava, and Griffith (2011) |
| | | Boreal Shield ecozone | Central Laurentians | Dystric Brunisolic , Luvisolic and Organic soils | Black spruce, balsam fir white spruce, paper birch lichens, feathermosses, sugar maple, beech, and yellow birch, eastern hemlock, eastern white pine, white, red and jack pine and white cedar | Wetlands; rivers | Limited agriculture | Caribou, black bear, wolf, moose, lynx, snowshoe hare, white tailed deer fox and lynx | Canada goose, ruffed grouse, and American black duck, shorebirds and seabirds | | |
| | | Atlantic Maritime ecozone | Appalachian s | Dystric Brunisols and Gleysols | Black spruce, balsam fir, paper sugar maple, beech, yellow birch, eastern hemlock, eastern white pine, white spruce, red maple, black ash and tamarack | Rivers; wetlands | Agriculture is one of the main land uses | Moose, black bear, white-tailed deer, beaver, porcupine, bobcat, red fox, lynx, marten and rabbit | Pileated woodpecker, American redstart, Eurasian wren, barred owl, seabirds and shorebirds | | |
| | | Atlantic Maritime ecozone | Northern New Brunswick Highlands | Loamy Humo-Ferric and Ferro-Humic Podzols and Gray Luvisols | Sugar maple, beech, yellow birch, eastern hemlock, balsam fir, eastern white pine, white, white, red and jack pine. | Rivers | Some agriculture | Moose, black bear, white-tailed deer, red fox, snowshoe hare, porcupine, fisher, coyote, beaver, bobcat, and marten | Ruffed grouse, seabirds and shorebirds | atlantic salmon, brook trout, sea lamprey, 84arbor8484 eel, alewife, blueback herring, 84arbor8484 shad, rainbow smelt, atlantic tomcod, striped bass, dace, chubs sticklebacks, flounder and capelin | |
| | | Mixedwood Plains ecozone | St-Lawrence lowlands | Gleysolic soils, Humo-Ferric Podzols and Dystric Brunisols | Sugar maple, yellow birch, eastern hemlock, eastern white pine, beech, red pine, eastern white cedar, red oak, red maple, black ash, white spruce, tamarack and eastern white cedar | Rivers | Mixed farming with corn as one of the dominant crops | Deer, black bear, moose, wolf, hare and chipmunk | Waterfowl, and other birds | | |

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| British Columbia | Ecoprovinces of British Columbia are Boreal Plains, Central Interior, Coast and Mountains, Georgian Depression, Northeast Pacific, Northern Boreal Mountains, Southern Alaska Mountains, Southern Interior, Southern Interior Mountains, Sub-boreal Interior and Taiga Plains. | Georgian Depression ecoprovince | | Fine silt, clay, coarse sand, gravel and glacial deposits | Douglas-fir, mountain hemlock, alpine, tufted hairgrass, fescues, rushes, seaside arrow-grass, silverweed, sedges, black cottonwoods, red alder, bigleaf maple, grand fir, western redcedar, flowering dogwood, salal, dull Oregon-grape, sword fern, starflower, mosses, arbutus, camas, sea blush, shootingstar, blue-eyed Mary, oceanspray, common snowberry, eastern red cedar salal, dull Oregon-grape, red alder, salmonberry, bracken, fireweed, amabalis fir, western hemlock, yellow-cedar, white-flowered rhododendron, false azalea, blueberries, queen's cup, bunchberry, twayblades, and five-leaved bramble, mountain-heathers, crowberry, partridgefoot. Sitka valerian, Indian hellebore, white marsh-marigold, leatherleaf saxifrage, black alpine sedge, Mountain-heathers, saxifrages, and lichens | Wetlands; rivers and streams | Food crops, berries and cereals | Columbian black-tailed deer, American black bear, cougar, Roosevelt elk, coyote, mink, raccoons, Vancouver Island Marmot, Olympic Marmot, marsh shrew, Trowbridge's shrew, shrew-mole, Townsend's and coast mole, Douglas' squirrel, creeping vole, eastern cottontail, sharptail snake, Pacific treefrog, Pacific giant salamander and ensatina | Snow geese, northern harrier, red-tailed hawk, short-eared owl, dulin, Pacific loon, western grebe, Brandt's cormorant, common and Barrow's goldeneyes, surf, white-winged and black scoter, greater and lesser scaup, Thayer's and glaucous-winged gulls, common Murre, and marbled and ancient murrelets, black turnstone and surfbird, barn owl, Anna's hummingbird, double-crested cormorants, glaucous-winged Gulls, purple martin, bushtit, and Hutton's vireo, and crested myna | Rockfish, flounder, spiny dogfish, Pacific herring, ling cod, Pacific salmon, steelhead, coastal cutthroat trout, and eulachon, native peamouth chum and threespine stickleback, green sturgeon, Dolly Varden char, bull trout and Coast Range sculpin | Demarchi (2011) |
| | | Sub-boreal interior ecoprovince | | Soils are strongly acidicand often has | White spruce, subalpine fir, lodgepole pine, trembling aspen, paper birch, | Wetlands, rivers | Few cereal crops are produced | Moose, woodland caribou, mountain goats, Stone's Sheep, | Boreal owl, herring gull and black tern, rusty blackbird and magnolia warbler | Chinook and sockeye salmon, rainbow trout, lake trout, | |

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| | | | | turfy topsoils | prickly rose, soopolallie, willows, black twinberry, thimbleberry, devil's club, bunchberry, arnicas, twinflower, fireweed, trailing raspberry, oak fern, creamy peavine, asters, sedge fens, scrub birch, willows, sedges, black spruce, Labrador tea, black cottonwood, red-osier dogwood, highbush cranberry, black gooseberry, horsetails, bluejoint, whiteflowered rhododendron, black huckleberry, mountain-ash, black gooseberry, bunchberry, arnica, twisted stalks, Sitka alder, valerian, Indian hellebore, ragwort, hellebore, Indian paintbrush, mountain heathers and lichens | | | mule deer and white-Tailed deer, American black bears, wolves, grizzly bears lynx, fisher, muskrat, common garter snake, western toad, wood frog, spotted frog and long-toed salamander | | bull trout, lake and mountain whitefish, Arctic grayling, longnose sucker, slimy sculpin and torrent sculpin | |
| | | Southern Interior Mountains | | Soils are moderately weathered, have clay layers or strongly weathered and acidic | Douglas-fir, ponderosa pine, western larch, lodgepole pine, saskatoon, antelope-brush, redstem ceanothus, rough fescue, bluebunch wheatgrass, junegrass, Kentucky Bluegrass, Canada bluegrass, needlegrasses, and cheatgrasses, rose, kinnikinnick, soopolallie, birch-leaved spirea, | Rivers; | Cereal crops produced in lowlands and flood plains | Mountain goats, mule and white-tailed deer, Rocky Mountain elk mountain caribou, bighorn sheep, grizzly and black bears, coyotes, cougars, grey wolves, Canada lynx, wolverine, martin, bobcats, fisher, American badger, long-eared myotis, pika, hoary marmot, Columbian | Forster's Tern, ospreys western grebe, long-billed curlew, black-billed cuckoo, American coots, tundra swans, Canada geese, redhead, white-breasted nuthatch and Clark's nutcracker | Chinook salmon, sturgeon, rainbow trout, bull trout, mountain whitefish, mottled sculpin and Yellowstone cutthroat trout | |

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| | | | | | pinegrass, black cottonwood, spruce, red-osier dogwood, false Solomon's-seal, horsetails, Engelmann spruce, subalpine fir, honeysuckle, saskatoon, birch-leaved spirea, false azalea, pinegrass, bunchberry, mosses white-flowered rhododendron, grouseberry, false azalea, thimbleberry, queen's cup, bunchberry, pinegrass, mosses, Sitka alder, rough fescue whitebark pine and alpine larch, western hemlock, western redcedar, grand fir, western white pine, paper birch, or trembling aspen, blueberries, false box, devil's club, Utah honeysuckle, twinflower, queen's cup, oak fern, mountain hemlock, rhododendron, black gooseberry, false azalea, twisted stalk, Sitka valerian, bunchberry | | | ground squirrel, golden mantled ground squirrel, water vole, the painted turtle, common and western terrestrial garter snakes, long-toed salamander, western toad, and spotted and northern leopard frogs | | | |
| | | Boreal Plains ecoprovince | | Clay and silt or coarser textured soils | White spruce, black spruce, trembling aspen, balsam poplar, lodgepole pine, paper birches, high bush cranberry, prickly rose, soopolallie, willows, fireweed, bunchberry, asters, creamy peavine, mosses, red-osier | | Some cereal production | Moose, mule deer and white-tailed deer, woodland caribou, plains bison and rocky mountain elk, elk grey wolves, coyotes, lynx and American black bears, Arctic shrew, common | Eared grebe, Hudsonian godwit, white-rumped sandpiper, stilt sandpiper, broad-winged hawk, sharp-tailed grouse, upland sandpiper, Franklin's gull, common grackle, eastern phoebe, Philadelphia vireo, | Arctic grayling, northern pike, walleye, bull trout, slimy sculpin, flathead chub, lake trout, lake whitefish and pearl dace. | |

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| | | | | | dogwood, horsetails, tamarack, Labrador tea, horsetails, sphagnum, saskatoon, trembling aspen, roses, wheatgrass, and needlegrass, scrub birch, Engelmann spruce and subalpine fir, white-flowered rhododendron, black huckleberry, and scrub-birch. | | | garter snake, salamander, the long-toed salamander andnorthern chorus frog | chestnut-sided warbler, black-throated green warbler, Connecticut warbler and Lapland longspur. | | |
| Nova Scotia | Atlantic Maritime ecozone (Northern Plateau, Cape Breton Highlands, Nova Scotia Uplands, Eastern, Northumberland/Bras D'or, Valley and Central Lowlands, Western, Atlantic Coastal and Fundy Shore) | Atlantic Maritime ecozone | Cape Breton Highlands | Orthic Humo-Ferric and Ferro-Humic Podzols and Gleyed and Cemented (Ortstein) subgroups | Balsam fir, white spruce, heart-leaf birch and white birch | Wetlands, lakes and streams | Agriculture is very minimal | Moose, snowshoe hare, black bear, Canada lynx and American marten | Bicknell's thrush | | Government of Nova Scotia (2015); Government of Nova Scotia (2019); Neily, Basquill, Quigley, and Keys (2017); Webb and Marshall (1999) |
| | | Atlantic Maritime ecozone | Nova Scotia Uplands | Orthic Humo-Ferric, Ferro-Humic Podzols, Gleyed Luvisons, and Sombric and/or Dystric Brunisols | Sugar maple, beech, yellow birch, hemlock, red spruce and white spruce | Many rivers and a few lakes | Farming is carried out | White-tailed deer, moose, black bear, snowshoe hare, fisher, coyote, and porcupine | | | |
| | | Atlantic Maritime ecozone | Eastern | Orthic Humo-Ferric, Ferro-Humic Podzols, Gleyed Luvisols, Gleysols, Luvic Gleysols, Folisols, | Red spruce, hemlock yellow birch, red maple, sugar maple and black spruce | Wetlands; lakes, streams and stillwaters | Some agriculture | | | | |

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| | | | | Mesisols and Humisols | | | | | | | |
| | | Atlantic Maritime ecozone | Northumberland/ Bras d'Or | Gleyed Luvisols, Luvic Gleysols, Gleyed Humo-Ferric and Ferro-Humic Podzols Gleysols, Humic Gleysols and Orthic Humo-Ferric soils | Black source, jack pine, red pine, yellow birch, hemlock, red spruce, elm, sugar maple, white ash, white spruce, tamarack and aspen | Wetlands; lakes, rivers and streams | Some agriculture | Moose, black bear, skunk, eastern coyote, lynx, woodchuck, porcupine, raccoon, snowshoe hare, bobcat, American marten, white-tailed deer and bat hibernacula, wood turtle, snapping turtle and four-toed salamander | Eagle, osprey, goshawk, owls, hawk, waterfowl, shorebirds, tern, heron, gull, and seabirds | Atlantic salmon, brook trout, shad, Atlantic sturgeon, lake whitefish smelt, gaspereau, striped bass, American eel, northern cod and mussels | |
| | | Atlantic Maritime ecozone | Valley and Central lowlands | Orthic Humo-Ferric and Ferro-Humic Podzols, Gleyed Luvisols, Luvic Gleysols and Orthic, Gleyed Humic Regosols and Cemented (Ortstein) subgroups | Red spruce, hemlock, white pine, yellow birch, red maple, black spruce, red and white pine, red oak, aspen and grey and white birch | Rivers and streams | Most of salt marsh dyked and turned to farmland. Flood plains extensively used for agriculture | White tailed deer, wood turtles | American golden plover, semipalmated plover, killdeer, greater yellowlegs, willet, spotted sandpiper, red knot, semipalmated sandpiper, least sandpiper, bald eagle and black ducks | Striped bass, sturgeon and Atlantic salmon, gaspereau, shad, and eels, tomcod and sea trout | |
| | | Atlantic Maritime ecozone | Western | Orthic Humo-Ferric1 and Ferro-Humic Podzols, Gleyed subgroups , Cemented (Ortstein) subgroups | White pine, hemlock, red pine, red oak, sugar maple, beech, yellow birch, red spruce, hemlock, black spruce, white spruce balsam fir, ericaceous plants (kill, huckleberry, rhodora, blueberry, bearberry and broom crowberry) | Extensive wetlands; rivers and lakes | Field crops, orchards and forage | | | | |

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| | | | | , Sombric Podzols | | | | | | | |
| | | Atlantic Maritime ecozone | Atlantic Coastal | Orthic, Gleyed, Ortstein and Gleyed Ortstein Humo-Ferric and Ferro-Humic Podzols, Fibrisols, Mesisols, Humisols, Folisols and Gleysols. | White and black spruce, balsam fir, red spruce, red maple, yellow birch, raised and flat bogs, fens and salt marshes, white birch, heart-leaf birch, mountain-ash, downy alder, bayberry, foxberry, hemlock, sugar maple and beech | Wetlands; rivers and lakes | Some agriculture | White- tailed deer | Shorebirds and seabirds | | |
| | | Atlantic Maritime ecozone | Fundy shore | Orthic and Sombric Ferro-Humic and Humo-Ferric Podzols, Gleyed subgroups, Humic Gleysols, Mesisols and Humisols) | Yellow birch, red spruce, hemlock, sugar maple and beech | Wetlands; lakes, rivers and streams | Some agriculture | | | | |
| New Brunswick | Atlantic Maritime ecozone (Highlands, Northern Uplands, Central Uplands, Fundy Coast, Valley Lowlands, Eastern Lowlands and Grand Lake Lowlands | Atlantic Maritime ecozone | Northern Uplands | | Sugar maple, yellow birch, beech, cedar, red spruce, beech, hemlock, black ash, balsam poplar, balsam fir, black spruce, white spruce, white pine, red pine, jack pine, white pine, wood-sorrel, wood fern, and wild lily-of-the-valley | Wetlands; streams and rivers | Forage, grain and pasture | Pine marten and Canadian lynx | Osprey and great blue heron | | Government of New Brunswick (2007); http://ecozones.ca/english/region/123.html |
| | | Atlantic Maritime ecozone | Central uplands | | Balsam fir, red, white, and black spruce, yellow birch, sugar maple, | Wetlands (peatlands, streamside alder | Forage, grain and pasture | | American black duck, blue-winged teal, common merganser bald | | |

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| | | | | | beech, cedar, red oak, ironwood, basswood, butternut, white ash, green ash, hemlock, mountain maple, striped maple, and hobblebush, mountain fern moss, wood sorrel, wood fern, shining clubmoss | swamps, marshes and shallow open waters) | | | eagle, osprey and great blue heron | | |
| | | Atlantic Maritime ecozone | Fundy Coast | Humo-Ferric Podzols, Mesisols, Regosols and Gleysols | Red spruce, balsam fir, black spruce, white spruce, tamarack, cedar, white birch, mountain ash, red maple, yellow birch, red maple, jack pine and white pine | Wetland types are diverse; rivers and lakes | Mixed farming | Moose, black bear, white-tailed deer, red fox, snowshoe hare, porcupine, fisher, coyote, beaver, bobcat, raccoon, four-toed salamander, little brown bat, long-eared bat, and eastern pipistrelle | Ruffed grouse, ducks, seabirds, cormorants, gulls, arctic tern, Atlantic puffin, razorbill and puffin | | |
| | | Atlantic Maritime ecozone | Valley Lowlands | | Red spruce, balsam fir, white spruce, basswood, butternut, ironwood, silver maple, green ash, white ash, cedar, sugar maple, yellow birch, hemlock, beech, aspen, red maple, red and white pine, red oak dogtooth violet, hay-scented fern, sensitive fern, tamarack, Christmas fern and riverbank grape | Wetland types are diverse; rivers and lakes | Mixed farming; potatoes and grain | | Nesting loons, bald eagle, osprey, scarlet tanager, wood duck, pied-billed grebe, scarlet tanager, warbling vireo and wood thrush | Searun brook trout, Miramichi salmon, crayfish, American black duck, goldeneye, eiders, scoters, and bufflehead | |
| | | Atlantic Maritime ecozone | Eastern Lowlands | | Trembling aspen, jack pine, red pine, white pine and black spruce | Highest percentage of wetlands in New Brunswick; rivers and lakes | Mixed farming; grains (e.g., alfalfa and oats), forage, pasture and horticultural crops | | Piping plover, terns, ducks, great blue heron, belted kingfisher, ruffed grouse, willet, rail and American bittern, fork-tailed flycatcher and the scissor-tailed | | |

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| | | | | | | | | | flycatcher, lack-crowned night heron | | |
| | | Atlantic Maritime ecozone | Grand Lake Lowlands | | Ironwood, basswood, white ash, green ash, northern red oak, and silver maple, bur oak, butternut, American elm, red maple, green and black ash, beech, sugar maple, yellow birch, red spruce, hemlock, white pine, black spruce, red pine and jack pine | Diverse wetlands; rivers and lakes | Fruits and vegetables | Salamanders, toads and frogs (e.g., eastern gray tree frog) | Waterfowl, shorebirds, gulls, osprey and black tern | | |
| Prince Edward Island | | Atlantic Maritime ecozone | | Podzols and Luvisols | Stunted balsam fir, red spruce, eastern hemlock, white pine, balsam fir, yellow birch,beech and sugar maple | WetlandsRivers and lakes | Crops produced | White-tailed deer, moose, black bear, raccoon, striped skunk, bobcat, and eastern chipmunk, northern flying squirrel, coyote, snowshoe hare, mink, wolves and lynx; | Whip-poor-will, blue jay, eastern bluebird, rose-breasted grosbeak, loons, Canada geese and blue-winged teal, ring-neck ducks and ospreys | Atlantic salmon, striped bass, Atlantic whitefish and American eel, Brook Trout, Gaspereau, Halibut, scallop, mackerel, groundfish, and herring | https://www.thecanadianencyclopedia.ca/en/article/natural-regions; http://ecozones.ca/english/zone/AtlanticMaritime/land.html |
| Newfoundland and Labrador | Ecozones in Newfoundland and Labrador are Arctic Cordillera, Taiga Shield and Boreal Sheild | Boreal Shield ecozone | | | Balsam fir, white spruce, black spruce, tamarack, white birch, trembling aspen, balsam poplar white, red and jack pine, lichens and shrubs | Peatlands and lakes | Agriculture is in suitable climates and soils | Black bear, lynx, marten, woodland caribou, moose, raccoon, eastern chipmunk, white-tailed deer, fisher, striped skunk, and bobcat | Blue jay, warbler, owl and loon | | https://www.heritage.nf.ca/articles/environment/boreal-shield.php |
| Yukon | Ecozones in Yukon are the Southern Arctic (Yukon Coastal Plain), Taiga plain (Peel River Plateau, Fort McPherson, Muskwa Plateau), Taiga Cordillera (British-Richardson Mountains, Old Crow Basin, Old Crow Flats, North | Boreal Cordillera ecozone | Klondike Plateau | Cryosols, Eutric Brunisols, Mesic Organic Cryosols, Dystric Brunisols, Regosols and Turbic Cryosols | Forests and grasslands | Wetlands; rivers | Some localized agriculture in valley bottoms | Barren-ground caribou herd, Dall's sheep, moose, snowshoe hare, lynx, marten, wolverines, wolves, coyote, mule-deer, wood chuck, grizzly and black bear, muskarats, house | Northern goshawk, red-tailed hawk, great horned owl, northern hawk owl, bald eagles, ospreys, spruce grouse, three-toed woodpecker, gray jay, common raven, black-capped chickadee, boreal chickadee, pine grosbeak, northern goshawk, common | | Smith, Meikle, and Roots (2004)) |

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| | Ogilvie Mountains, Eagle Plains, Mackenzie Mountains and Selwyn Mountains), Boreal Cordillera (Klondike Plateau, St. Elias Mountains, Ruby Ranges, Yukon Plateau-Central, Yukon Plateau North, Yukon Southern Lakes, Pelly Mountains, Yukon Stikine Highlands, Boreal Mountains and Plateaus, Liard Basin and Hyland Highland) and Pacific Maritime (Mount Logan). There is some forage crop based agriculture in the Yukon Southern Lakes and Boreal Mountains and Plateaus | | | | | | | mouse, beaver, fox | redpoll, northern flicker, western wood-pewee, ruby-crowned kinglet, varied thrush, yellowrumped warbler, dark-eyed junco, white winged crossbill, Townsend's warbler, ruffed grouse, yellow-bellied sapsucker, orange-crowned warbler, blue grouse, sharp-tailed grouse, northern shrike, Townsend's solitaire, common nighthawk, savannah sparrow, western wood-pewee, alder flycatcher, say's phoebe, mountain bluebird, hermit thrush, American robin, dark-eyed junco, American kestrels, rock ptarmigan, horned lark, American pipit, possibly long-tailed jaeger, willow ptarmigan, American tree sparrow, white-crowned sparrow and common redpoll | | |

Table A2: Wildlife at risk in Canada by province and status

| | Species at Risk Act status (Schedule 1) | | | |
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| | Endangered | Threatened | Special concern | Extirpated |
| Saskatchewan | *Mosses*<br>Rusty cord-moss<br>*Vascular plants*<br>Small-flowered sand-verbena<br>*Arthropods*<br>Dakota skipper, dusky dune moth, gold-edged gem and gypsy cuckoo bumble bee<br>*Reptiles*<br>Greater short-horned lizard<br>*Birds*<br>Burrowing owl, eskimo curlew, greater sage-grouse urophasianus subspecies, mountain plover, piping plover circumcinctus subspecies, red knot rufa subspecies, sage thrasher and whooping crane<br>*Mammals*<br>Little brown myotis, northern myotis and Ord's kangaroo rat | *Mosses*<br>Alkaline wing-nerved moss<br>*Vascular plants*<br>Slender mouse-ear-cress, smooth goosefoot, soapweed, tiny cryptantha and western spiderwort<br>*Arthropods*<br>Gibson's big sand tiger beetle and Verna's flower moth<br>*Fishes*<br>Mountain sucker and plains minnow<br>*Reptiles*<br>Eastern yellow-bellied racer<br>*Birds*<br>Bank swallow, barn swallow, bobolink, Canada warbler, chestnut-collared longspur, chimney swift, common nighthawk, eastern whip-poor-will, ferruginous hawk, lark bunting, loggerhead shrike prairie subspecies, McCown's longspur, olive-sided flycatcher, red-headed woodpecker and Sprague's pipit<br>*Mammals*<br>Black-tailed prairie dog, caribou and swift fox | *Vascular plants*<br>Athabasca thrift, blanket-leaved willow, buffalograss, dwarf woolly-heads, floccose tansy, hairy prairie-clover, large-headed woolly yarrow, Mackenzie hairgrass, sand-dune short capsuled willow and Turnor's willow<br>*Arthropods*<br>Greenish-white grasshopper, monarch, mormon metalmark, pale yellow dune moth and yellow-banded bumble bee<br>*Fishes*<br>Bigmouth buffalo<br>*Amphibians*<br>Great plains toad, northern leopard frog and western tiger salamander<br>*Reptiles*<br>Prairie rattlesnake and snapping turtle<br>*Birds*<br>Baird's sparrow, buff-breasted sandpiper, eastern-wood pewee, evening grosbeak, horned grebe, long-billed curlew, peregrine falcon anatum/tundrius, red necked phalarope, rusty blackbird, short-eared owl, western grebe and yellow rail<br>*Mammals*<br>American badger taxus subspecies, grizzly bear and wolverine | *Birds*<br>Greater prairie chicken<br>*Mammals*<br>Black footed ferret |
| Alberta | *Vascular plants*<br>Small flower sand-verbena and whitebark pine<br>*Molluscs*<br>Banff Springs snail<br>*Arthropods*<br>Bert's predaceous diving beetle, dusky dune moth, five-spotted bogus yucca moth, gold-edged gem, gypsy cuckoo bumble bee, half-moon hair streak, non-pollinating yucca moth and yucca moth<br>*Fishes*<br>Rainbow trout<br>*Reptiles*<br>Greater short-horned lizard<br>*Birds*<br>Black swift, burrowing owl, eskimo curlew, greater sage-grouse urophasianus species, mountain plover, piping plover circumcinctus | *Mosses*<br>Haller's apple moss and Porsild's bryum<br>*Vascular plants*<br>Bolander's quillwort, hair-footed locoweed, slender-mouse-ear cress, smooth goosefoot, soapweed, tiny cryptantha and western spiderwort<br>*Arthropods*<br>Gibson's bid sand tiger beetle and Verna's flower moth<br>*Fishes*<br>Bull trout, mountain sucker, rocky mountain sculpin, western silvery minnow and westslope cutthroat trout<br>*Reptiles*<br>Eastern yellow-bellied racer<br>*Birds*<br>Bank swallow, barn swallow, bobolink, Canada warbler, chestnut-collared longspur, common nighthawk, ferruginous hawk, lark bunting, | *Vascular plants*<br>Dwarf woolly-heads, floccose tansy and western blue flag<br>*Arthropods*<br>Greenish-white grasshopper, monarch, pale yellow dune moth, vivid dancer, Weidemeyer's admiral and yellow-banded bumble bee<br>*Fishes*<br>Bull trout<br>*Amphibians*<br>Great plains toad, northern leopard frog, western tiger salamander and western toad<br>*Reptiles*<br>Prairie rattlesnake<br>*Birds*<br>Baird's sparrow, buff-breasted sandpiper, evening grosbeak, horned grebe, long-billed curlew, peregrine falcon anutum/tundrius, red- | *Birds*<br>Greater prairie-chicken<br>*Mammals*<br>Black-footed ferret |

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| | subspecies, red knot rufa subspecies, sage thrasher and whooping crane<br>*Mammals*<br>Little brown myotis, northern myotis, Ord's kangaroo rat and western harvest mouse dychei subspecies | loggerhead shrike prairie species, McCown's longspur, olive-sided flycatcher and Sprague's pipit<br>*Mammals*<br>Caribou, swift fox and wood bison | necked phalarope, rusty blackbird, short-eared owl, western grebe and yellow rail<br>*Mammals*<br>American badger taxus subspecies, grizzly bear and wolverine | |
| Manitoba | *Vascular plants*<br>Fascicled ironweed, Gattinger's agalinis, rough agalinis and western prairie fringed orchid<br>*Arthropods*<br>Dakota skipper, dusky dune moth, gold-edged gem, gypsy cuckoo bumble bee, ottoe skipper, poweshiek skipperling and white flower moth<br>*Amphibians*<br>Eastern tiger salamander<br>*Reptiles*<br>Prairie skink<br>*Birds*<br>Burrowing owl, eskimo curlew, loggerhead shrike migrans subspecies, piping plover circumcinctus subspecies, red knot rufa subspecies and whooping crane<br>*Mammals*<br>Little brown myotis and northern myotis | *Vascular plants*<br>Small white lady's-slipper, smooth goosefoot, western silvery aster and western spiderwort<br>*Molluscs*<br>Mapleleaf<br>*Arthropods*<br>Verna's flower moth<br>*Fishes*<br>Carmine shiner<br>*Birds*<br>Bank swallow, barn swallow, bobolink, Canada warbler, chestnut-collared longspur, chimney swift, common nighthawk, eastern whip-poor-will, ferruginous hawk, golden-winged warbler, lark bunting, least bittern, loggerhead shrike prairie subspecies, olive-sided flycatcher, red-headed woodpecker, Ross's gull and Sprague's pipit<br>*Mammals*<br>Caribou and wood bison | *Lichens*<br>Flooded jellyskin<br>*Vascular plants*<br>Buffalograss, hairy prairie-clover and Riddell's goldenrod<br>*Arthropods*<br>Greenish-white grasshopper, monarch, pale yellow dune moth and yellow-banded bumble bee<br>*Fishes*<br>Bigmouth buffalo and lake sturgeon<br>*Amphibians*<br>Great plains toad, northern leopard frog and western tiger salamander<br>*Reptiles*<br>Snapping turtle<br>*Birds*<br>Baird's sparrow, buff-breasted sandpiper, eastern wood-pewee, evening grosbeak, horned grebe, peregrine falcon anatum/tundrius, red-necked phalarope, rusty blackbird, short-eared owl, western grebe and yellow rail<br>*Mammals*<br>American badger taxus subspecies, grizzly bear, polar bear and wolverine | *Birds*<br>Greater prairie-chicken |
| Ontario | *Lichens*<br>Pale-bellied frost lichen<br>*Mosses*<br>Spoon-leaved moss<br>*Vascular Plants*<br>American chestnut, American columbo, American ginseng, bashful bulrush, bent spike-rush, bird's-foot violet, bluehearts, butternut, cherry birch, colicroot, cucumber tree, drooping trillium, eastern flowering dogwood, eastern prairie fringed-orchid, eastern prickly pear cactus, Engelmann's quillwort, false hop sedge, forked three-awned grass, Gattinger's agalinis, heart-leaved plantain, hoary mountain-mint, horsetail spike-rush, juniper sedge, large whorled pogonia, nodding pogonia, Ogden's pondweed, pink milkwort, red mulberry, scarlet ammannia, showy goldenrod, Skinner's agalinis, slender bush-clover, small whorled pogonia, small-flowered | *Lichens*<br>Black-foam lichen<br>*Vascular plants*<br>American water-willow, blunt-lobed woodsia, branched bartonia, deerberry, dense blazing star, dwarf hackberry, false rue-anemone, goldenseal, Hill's thistle, Kentucky coffee-tree, lakeside daisy, purple twayblade, round-leaved greenbrier, showy goldenrod, small white lady's-slipper, toothcup, western silvery aster, white wood aster, wild hyacinth and willowleaf aster<br>*Molluscs*<br>Threehorn wartyback<br>*Fishes*<br>Black redhorse, eastern sand darter, pugnose minnow, pugnose shiner and silver shiner<br>*Amphibians*<br>Western chorus frog<br>*Reptiles* | *Lichens*<br>Flooded jellyskin<br>*Vascular plants*<br>American Hart's tongue fern, blue ash, climbing prairie rose, common hoptree, crooked-stem aster, dwarf lake iris, Hill's pondweed, Houghton's golden rod, Pitcher's thistle, Riddell's goldenrod, swamp rose-mallow and tuberous Indian-plantain<br>*Molluscs*<br>Eastern pondmussel, mapleleaf, rainbow and wavy-rayed lampmussel<br>*Anthropods*<br>Monarch, pygmy snaketail and yellow-banded bumble bee<br>*Fishes*<br>Blackstripe topminnow, bridle shiner, channel darter, cutlip minnow, deepwater sculpin, grass pickerel, lake sturgeon, northern brook lamprey, | *Mosses*<br>Incurved grizzled moss<br>*Vascular plants*<br>Illinois tick-trefoil and spring blue-eyed Mary<br>*Anthropods*<br>American burying beetle, frosted elfin and karner blue<br>*Fishes*<br>Gravel chub and paddlefish<br>*Amphibians*<br>Eastern tiger salamander<br>*Reptiles*<br>Eastern box turtle and timber rattlesnake |

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| | lipocarpha, spotted wintergreen, Virginia goat's-rue, Virginia mallow, white prairie gentian and wood-poppy<br>*Molluscs*<br>Broad-banded forestsnail, fawnsfoot, hickorynut, kidneyshell, lilliput, northern riffleshell, proud globelet, rayed bean, round hickorynut, round pigtoe, salamander mussel and snuffbox<br>*Anthropods*<br>Aweme borer moth, bogbean buckmoth, eastern persius duskywing, gypsy cuckoo bumble bee, Hine's emerald, hoptree borer, Hungerford's crawling water beetle, northern barrens tiger beetle, rapids clubtail, riverine clubtail and rusty-patched bumble bee<br>*Fishes*<br>Channel darter, lake chubsucker, northern madtom, redside dace, shortnose cisco, silver chub and spotted gar<br>*Amphibians*<br>Allegheny mountain dusky salamander, Blanchard's cricket frog, Fowler's toad, Jefferson salamander, northern dusky salamander and small-mouthed salamander<br>*Reptiles*<br>Blue racer, Butler's gartersnake, eastern foxsnake, five-lined skink, gray ratsnake , massasauga , queensnake, spiny softshell and spotted turtle<br>*Birds*<br>Acadian flycatcher, barn owl, cerulean warbler, eskimo curlew, Henslow's sparrow, king rail, Kirtland's warbler, loggerhead shrike migrans species, northern bobwhite, piping plover, circumcinctus subspecies, prothonotary warbler, red knot rufa subspecies and yellow-breasted chat virens supspecies<br>*Mammals*<br>American badger jacksoni subspecies, little brown myotis, northern myotis and tri-colored bat | Blanding's turtle, eastern hog-nosed snake, gray ratsnake, massasauga and wood turtle<br>*Birds*<br>Bank swallow, barn swallow, bobolink, Canada warbler, chimney swift, common nighthawk, eastern meadowlark, eastern whip-poor-will, golden-winged warbler, least bittern, Louisiana waterthrush, olive-sided flycatcher, red-headed woodpecker and wood thrush<br>*Mammals*<br>Caribou and gray fox | northern sunfish, river redhorse, silver lamprey, spotted sucker, Upper Great Lakes kiyi and warmouth<br>*Reptiles*<br>Eastern milksnake, eastern musk turtle, eastern ribbonsnake, five-lined skink, Lake Erie watersnake, northern map turtle and snapping turtle<br>*Birds*<br>Buss-breasted sandpiper, eastern wood-pewee, evening grosbeak, grasshopper sparrow pratensis subspecies, horned grebe, peregrine falcon anatum/tundrius, red-necked phalarope, rusty blackbird, short-eared owl and yellow rail<br>*Mammals*<br>American badger taxus subspecies, eastern mole, eastern wolf, polar bear, wolverine and woodland vole | *Birds*<br>Greater Prairie-chicken |
| Quebec | *Lichens*<br>Pale-bellied frost lichen<br>*Vascular plants*<br>American ginseng, butternut, false hop sedge, forked three-awned grass and spotted wintergreen<br>*Molluscs*<br>Hickorynut<br>*Anthropods* | *Lichens*<br>Black-foam lichen and eastern waterfan<br>*Vascular plants*<br>American water willow, anticosti aster, blunt-loped woodsia, green-scaled willow, Griscom's arnica, Gulf of St. Lawrence aster, mountain holly fern, purple twayblade, Van Brunt's Jacob's ladder, Victorin's gentian and white wood aster<br>*Fishes*<br>Eastern sand darter | *Lichens*<br>Flooded jellyskin,<br>*Vascular plants*<br>Fernald's milk-vetch and Victorin's water-hemlock<br>*Arthropods*<br>Monarch and yellow-banded bumble bee<br>*Fishes*<br>Bridle shiner, channel darter, cutlip minnow, deepwater sculpin, grass pickerel, lake sturgeon, | *Anthropods*<br>American burying beetle<br>*Mammals*<br>Atlantic walrus |

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| | Gypsy cuckoo bumble bee, Maritime ringlet, northern barrens tiger beetle and rusty patched bumble bee<br>*Fishes*<br>Copper redhorse, spring cisco and striped bass<br>*Reptiles*<br>Spiny softshell and spotted turtle<br>*Birds*<br>Cerulean warbler, eskimo curlew, Henslow's sparrow, horned grebe, loggerhead shrike migrans subspecies, piping plover melodus subspecies, red knot rufa and roseate tern<br>*Mammals*<br>Beluga whale, harbour seal lacs loups marins species, caribou, little brown myotis, northern myotis and tri-colored bat | *Amphibians*<br>Allegheny mountain dusky salamander, spring salamander and western chorus frog<br>*Reptiles*<br>Blanding's turtle and wood turtle<br>*Birds*<br>Bank swallow, barn swallow, Bicknell's thrush, bobolink, Canada warbler, chimney swift, common night hawk, eastern meadowlark, eastern whip-poor-will, golden winged warbler, least bittern, Louisiana waterthrush, olive-sided flycatcher, red crossbill percna subspecies, red-headed woodpecker and wood thrush<br>*Mammals*<br>Caribou | northern brook lamprey, northern sunfish, river redhorse and silver lamprey<br>*Reptiles*<br>Eastern milksnake, eastern musk turtle, eastern ribbonsnake, northern map turtle and snapping turtle<br>*Birds*<br>Barrow's goldeneye, buff-breasted sandpiper, eastern wood-pewee, evening grosbeak, grasshopper sparrow pratensis subspecies, harlequin duck, peregrine falcon anutum/tundrius, red-necked phalarope, rusty blackbird, short-eared owl and yellow rail<br>*Mammals*<br>Eastern wolf, polar bear, wolverine and woodland vole | |
| British Columbia | *Lichens*<br>Batwing vinyl lichen and seaside centipede lichen<br>*Mosses*<br>Margined streamside moss, nugget moss, poor pocket moss, rigid apple moss, Roell's brotherella moss, rusty cord-moss and silver hair moss<br>*Vascular plants*<br>Bearded owl-clover, bent spike-rush, bog bird's foot trefoil, branched phacelia, brook spike-primrose, California buttercup, coast microseris, coastal Scouler's catchfly, contorted-pod evening-primrose, deltoid balsamroot, dense spike-primrose, dense-flowered lupine, dwarf sandwort, dwarf woolly-heads, foothill sedge, fragrant popcornflower, golden paintbrush, grand coulee owl-clover, Howell's triteleia, Kellogg's rush, Lindley's false silverpuffs, Muhlenberg's centaury, phantom orchid, pink sand-verbena, prairie lupine, rayless goldfields, rosy owl-clover, scarlet ammannia, seaside birds-foot lotus, short-rayed alkali aster, slender collomia, small-flowered lipocarpha, small-flowered tonella, southern maidenhair fern, Spalding's campion, stoloniferous pussytoes, streambank lupine, tall bugbane, tall woolly-heads, toothcup, Tweedy's lewisia, Victoria's owl clover, water-plantain buttercup, white meconella, whitebark pine and yellow montane violet praemorsa subspecies<br>*Molluscs*<br>Hotwater physa, northern abalone and Oregon forestsnail<br>*Arthropods* | *Lichens*<br>Crumpled tarpaper lichen and seaside bone lichen<br>*Mosses*<br>Alkaline wing-nerved moss, Haller's apple and Porsild's bryum<br>*Vascular plants*<br>Bear's foot sanicle, cliff paintbrush, Gray's desert-parsley, Lemmon's holy fern, Macoun's meadowfoam, Mexican mosquito fern, mountain holy fern, purple sanicle, showy phlox and slender popcornflower<br>*Molluscs*<br>Blue-grey taildropper and dromedary jumping-slug<br>*Anthropods*<br>Audouin's night stalking tiger beetle and dun skipper vestris subspecies<br>*Fishes*<br>Coastrange sculpin, salish sucker and Vancouver lamprey<br>*Amphibians*<br>Coastal giant salamander, great basin spadefoot and rocky mountain tailed frog<br>*Reptiles*<br>Great basin gophersnake and western rattlesnake<br>*Birds*<br>Bank swallow, barn owl, barn swallow, bobolink, Canada warbler, common nighthawk, Lewis's woodpecker, marbled murrelet, northern goshawk laingi subspecies, Northern saw-whet owl brooksi subspecies, olive-sided flycatcher, red knot roselaari type, short tailed albatross, Western screech-owl kennicottii subspecies and Western screech-owl macfarlanei subspecies<br>*Mammals* | *Lichens*<br>Cryptic paw lichen, mountain crab-eye, oldgrowth specklebelly lichen, peacock vinyl lichen and western waterfan<br>*Mosses*<br>Banded cord-moss, Columbia carpet moss, tiny tassel and twisted oakmoss<br>*Vascular plants*<br>Coastal wood fern, Lyall's mariposa lily, Vancouver Island beggarticks and white-top aster<br>*Molluscs*<br>Haida gwaii slug, magnum mantleslug, olympia oyster, pygmy slug, rocky mountain ridged mussel, sheathed slug, threaded vertigo and warty jumping slug<br>*Arthropods*<br>Georgia basin bog spider, monarch, sonora skipper, vivid dancer and yellow-banded bumble bee<br>*Fishes*<br>Bull trout, Columbia sculpin, giant threespine stickleback, green sturgeon, mountain sucker, rocky mountain sculpin, shorthead sculpin, unarmoured threespine stickleback and westslope cutthroat trout<br>*Amphibians*<br>Coastal tailed frog, Coeur d'Alene salamander, northern red-legged frog, wandering salamander and western toad<br>*Reptiles*<br>Northern rubber boa, western painted turtle, western skink and western yellow-bellied racer<br>*Birds* | *Vuscular plants*<br>Oregon lupine<br>*Molluscs*<br>Puget oreginian<br>*Arthropods*<br>Island marble<br>*Reptiles*<br>Pacific gophersnake, pacific pond turtle and pygmy short-horned lizard<br>*Birds*<br>Greater sage-grouse phaois subspecies |

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| | Behr's hairstreak, Edward's beach moth, gypsy cuckoo bumble bee, half-moon hairstreak, island blue, mormon metalmark, Okanagan efferia, olive clubtail, sand-verbena moth, Taylor's checkerspot and Wallis' dark saltflat tiger beetle<br>*Fishes*<br>Basking shark, Enos Lake benthic threespine stickleback, Enos Lake limnetic threespine stickleback, Misty Lake lentic threespine stickleback, Misty Lake lotic threeespine stickleback, nooksack dace, Paxton Lake benthic threespine stickleback, Paxton Lake limnetic threespine stickleback, speckled dace, Vananda Creek benthic threespine stickleback,Vananda Creek limnetic threespine stickleback, Western Brook lamprey and white sturgeon<br>*Amphibians*<br>Northern leopard frog, Oregon spotted frog and western tiger salamander<br>*Reptiles*<br>Desert nightsnake, sharp-tailed snake and western painted turtle<br>*Birds*<br>Black swift, burrowing owl, coastal vesper sparrow, pink-footed shearwater, red knot rufa subspecies, sage thrasher, spotted owl caurina subspecies, streaked horned lark, white-headed woodpecker, Williamson's sapsucker and yellow-breasted chat auricollis subspecies<br>*Mammals*<br>American badger jeffersonii subspecies and little brown myotis | Caribou, ermine haidarum subspecies, pallid bat, wood bison and woodland caribou | Ancient murrelet, band-tailed pigeon, buff-breasted sandpipe, Cassin's auklet, evening grosbeak, flammulated owl, great blue heron fannini subspecies, horned grebe, long-billed curlew, peregrine falcon anatum/tundrius, peregrine falcon pealei subspecies, red-necked phalarope, rusty blackbird, short-eared owl, western grebe and yellow rail<br>*Mammals*<br>Grey whale, Harbour porpoise, sea otter and steller sea lion, collared pika, grizzly bear, mountain beaver, Nuttall's cottontail nuttallii subspecies, spotted bat, western harvest mouse megalotis subspecies, wolverine and woodland caribou | |
| Nova Scotia | *Lichens*<br>Boreal felt lichen and vole ears<br>*Vascular plants*<br>Eastern mountain avens, pink coreopsis, plymouth gentian, tall beakrush and three-leaved sundew<br>*Arthropods*<br>Gypsy cuckoo bumble bee and macropis cuckoo bee<br>*Fishes*<br>Atlantic salmon and Atlantic whitefish<br>*Reptiles*<br>Blanding's turtle<br>*Birds*<br>Eskimo curlew, piping plover melodus subspecies, red knot rufa subspecies and roseate tern<br>*Mammals*<br>Little brown myotis, northern myotis and tri-colored bat | *Lichens*<br>Black foam lichen, eastern water fan and wrinkled shingle lichen<br>*Vascular plants*<br>Eastern baccharis and sweet pepperbrush<br>*Arthropods*<br>Sable island sweet bee<br>*Reptiles*<br>Eastern ribbonsnake and wood turtle<br>*Birds*<br>Bank swallow, barn swallow, Bicknell's thrush, bobolink, Canada warbler, chimney swift, common nighthawk, eastern meadowlark, eastern whip-poor-will, least bittern, olive-sided flycatcher and wood thrush | *Lichens*<br>Blue felt lichen and frosted glass-whiskers<br>*Vascular plants*<br>Eastern lilaeopsis, goldencrest, New Jersey rush, prototype quillwort, redroot, tubercled spike-rush and water pennywort<br>*Molluscs*<br>Brook floater and yellow lampmussel<br>*Arthropods*<br>Monarch and yellow-banded bumble bee<br>*Fishes*<br>Shortnose sturgeon<br>*Reptiles*<br>Snapping turtle<br>*Birds*<br>Barrow's goldeneye, eastern wood-pewee, evening grosbeak, harlequin duck, peregrine falcon anatum/tundrius, red-necked phalarope, | *Mammals*<br>Atlantic walrus |

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| | | | rusty blackbird, savannah sparrow princeps subspecies and short-eared owl | |
| New Brunswick | *Lichens*<br>Boreal felt lichen and vole ears lichen<br>*Vascular plants*<br>Butternut and Furbish's lousewort<br>*Arthropods*<br>Cobblestone tiger beetle, gypsy cuckoo bumble bee, Maritime ringlet and skillet clubtail<br>*Fishes*<br>Atlantic salmon<br>*Birds*<br>Eskimo curlew, piping plover melodus subspecies, red knot rufa species and roseate tern<br>*Mammals*<br>Little brown myotis, northern myotis, tri-colored bat | *Lichens*<br>Black-foam lichen, eastern waterfan and wrinkled shingle lichen<br>*Vascular plants*<br>Anticosti aster and Gulf of St. Lawrence aster<br>*Fishes*<br>Rainbow smelt<br>*Reptiles*<br>Wood turtle<br>*Birds*<br>Bank swallow, barn swallow, Bicknell's thrush, bobolink, Canada warbler, chimney swift, common nighthawk, eastern meadowlark, eastern whip-poor-will, least bittern, olive-sided flycatcher and wood thrush | *Lichens*<br>Blue felt lichen<br>*Arthropods*<br>*Vascular plants*<br>Beach pinweed and prototype quillwort<br>*Molluscs*<br>Brook floater and yellow lampmussel<br>*Arthropods*<br>Monarch, pygmy snaketail and yellow-banded bumble bee<br>*Fishes*<br>Shortnose sturgeon<br>*Reptiles*<br>Snapping turtle<br>*Birds*<br>Barrow's goldeneye, eastern wood-pewee, evening grosbeak, harlequin duck, peregrine falcon anatum/tundrius, red-necked phalarope, rusty blackbird, short-eared owl and yellow rail | *Molluscs*<br>Dwarf wedgemussel<br>*Mammals*<br>Atlantic walrus |
| Prince Edward Island | *Athropods*<br>Gypsy cuckoo bumble bee<br>*Birds*<br>Eskimo curlew, piping plover melodus subspecies and red knot rufa<br>*Mammals*<br>Little brown myotis and northern myotis | *Lichens*<br>Wrinkled shingle lichen<br>*Vuscular plants*<br>Gulf of St. Lawrence aster<br>*Birds*<br>Bank swallow, barn swallow, bobo link, Canada warbler, common night hawk and olive sided flycatcher | *Vascular plants*<br>Beach pinweed<br>*Arthropods*<br>Monarch and yellow-banded bumble bee<br>*Birds*<br>Barrow's goldeneye, eastern wood-pewee, evening grosbeak, red-necked phalarope, rusty blackbird and short-eared owl | *Mammals*<br>Atlantic walrus |
| Newfoundland and Labrador | *Lichens*<br>Vole ears lichen<br>*Vascular plants*<br>Barrens willow, Fernald's braya and Long's Braya<br>*Arthropods*<br>Gypsy cuckoo bumble bee<br>*Birds*<br>Eskimo curlew, ivory gull, piping plover melodus subspecies and red knot rufa subspecies<br>*Mammals*<br>Little brown myotis and northern myotis | *Lichens*<br>Wrinkled shingle lichen<br>*Mosses*<br>Porsild's bryum<br>*Vascular plants*<br>Griscom's arnica and mountain holly fern<br>*Birds*<br>Bank swallow, barn swallow, bobolink, common nighthawk, olive-sided flycatcher and red crossbill percna subspecies<br>*Mammals*<br>American marten and caribou | *Lichens*<br>Blue felt lichen and boreal felt lichen<br>*Vascular plants*<br>Fernald's milk vetch<br>*Arthropods*<br>Yellow-banded bumble bee<br>*Fishes*<br>Banded killifish<br>*Birds*<br>Barrow's goldeneye, evening grosbeak, harlequin duck, peregrine falcon anatum/tundrius, red-necked phalarope, rusty blackbird and short-eared owl<br>*Mammals*<br>Polar bear and wolverine | *Mammals*<br>Atlantic walrus |
| Yukon | *Arthropods*<br>Gypsy cuckoo bumble bee<br>*Birds*<br>Eskimo curlew<br>*Mammals*<br>Little brown myotis and northern myotis | *Birds*<br>Bank swallow, barn swallow, Canada warbler, common nighthawk, olive-sided flycatcher and red knot roselaari<br>*Mammals*<br>Caribou and wood bison | *Vuscular plants*<br>Baikal sedge, spiked saxifrage and Yukon podistera<br>*Arthropods*<br>Dune tachinid fly and yellow-banded bumble bee<br>*Fishes* | |

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| | | | Bull trout and dolly varden<br>*Amphibians*<br>Western toad<br>*Birds*<br>Buff-breasted sandpiper, evening grosbeak, horned grebe, peregrine falcon anatum/tundrius, red-necked phalarope, rusty blackbird and short-eared owl<br>*Mammals*<br>Grey whale, collared pika, grizzly bear, polar bear, wolverine and woodland caribou | |

Source: Government of Canada (2019)

Table A3: Ecosystems at risk in Canada

| Biome | Background | Reference |
|---|---|---|
| Grasslands | Estimated losses in grasslands before the 1990's are 97% of tall grass/savannah in Southern Ontario, 70% of prairie grasslands and 19% of bunchgrass/sagebrush in British Columbia. Losses still occur in small amounts. The health of grasslands is influenced by natural disturbances such as fires, grazing of cattle, non-native invasive species, encroachment of forests, fragmentation, intensification of agriculture, contamination from pesticides and insecticides, irrigation and urbanization among others. | Federal, Provincial and Territorial Governments of Canada (2010); Kraus (2018); Roch and Jaeger (2014); |
| Wetlands | Roughly16% of the area of land in Canada is covered by wetlands. Southern Canada experienced high losses of wetlands and It is estimated that 200,00km$^2$ of wetlands were lost before 1990. Although efforts are being taken to reduce losses of wetlands, they still occur especially near urban areas. Wetlands are threatened by conversion to other land uses, pollution, water regulation and invasive non-native species. | Federal, Provincial and Territorial Governments of Canada (2010) |
| Forest | Sixty percent of the land in Canada is covered by forests and 70% of the forests are of the boreal type. Although losses of forests are little at the national level, there are some regions that have significant losses. Approximately 0.01-0.02% of forests in Canada are lost per year. Forests are converted to other land uses such as cropland, resource roads, transmission lines, oil and gas development, urban areas and flooding of new hydro reservoirs. | Federal, Provincial and Territorial Governments of Canada (2010) |
| Lakes and rivers | Changes in the flow of rivers and lakes affect aquatic life and the changes include seasonal changes in the magnitude of the flows of the streams, rising temperatures in rivers and lakes and reductions in the levels of the lakes, habitat loss and fragmentation. | Federal, Provincial and Territorial Governments of Canada (2010) |

Note: Coastal, marine and ice across biomes are also at risk (see Federal, Provincial and Territorial Governments of Canada (2010) for more information)

## Table A4: Economic valuation of ecosystems

| | Canada | Place | Province | Ecozone | Ecoregion/Region | | Value ($/year unless stated otherwise) | | Methods | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Biodiversity ecosystem services | | | | | | | *United States* | *World* | | Pimentel et al. (1992) |
| | | | | | | Nitrogen fixation | 7 billion | 50 billion | | |
| | | | | | | Cross-pollination | 30 billion | | | |
| | | | | | | Pest control | | 20 billion | | |
| | | | | | | Fish, other wildlife and plant materials harvested from the wild | 2 billion | | | |
| Biodiversity | United states | | | | | | *United States* | *World* | | Pimentel et al. (1997) |
| | | | | | | Total | 319 billion | 2,928 billion | | |
| | | | | | | Waste disposal | 62 billion | 760 billion | | |
| | | | | | | Soil formation | 5 billion | 25 billion | | |
| | | | | | | Nitrogen fixation | 8 billion | 90 billion | | |
| | | | | | | Bioremediation of chemicals | 22.5 billion | 121 billion | | |
| | | | | | | Crop breeding (genetics) | 20 billion | 115 billion | | |
| | | | | | | Livestock breeding (genetics) | 20 billion | 40 billion | | |
| | | | | | | Biotechnology | 2.50 billion | 6 billion | | |
| | | | | | | Biocontrol of pests (crops) | 12 billion | 100 billion | | |
| | | | | | | Biocontrol of pests (forests) | 5 billion | 60 billion | | |
| | | | | | | Host plant resistance (crops) | 8 billion | 80 billion | | |
| | | | | | | Host plant resistance (forests) | 0.80 billion | 11 billion | | |
| | | | | | | Perennial grains (potential) | 17 billion | 170 billion | | |
| | | | | | | Pollination | 40 billion | 200 billion | | |
| | | | | | | Fishing | 29 billion | 60 billion | | |
| | | | | | | Hunting | 12 billion | 25 billion | | |
| | | | | | | Seafood | 2.50 billion | 82 billion | | |
| | | | | | | Other wild foods | 0.50 billion | 180 billion | | |
| | | | | | | Wood products | 8 billion | 84 billion | | |
| | | | | | | Ecotourism | 18 billion | 500 billion | | |
| | | | | | | Pharmaceuticals from plants | 20 billion | 84 billion | | |
| | | | | | | Forests sequestering of carbon | 6 billion | 135 billion | | |
| Biodiversity | Ireland (€ per year) | | | | | Nutrient assimilation and recycling | 1 billion | | Production function and replacement cists | Bullock, Kretsch, and Candon (2008) |
| | | | | | | Pollination | 220 million or even 500 million | | | |
| | | | | | | Baseline pest control | 20 million | | | |
| | | | | | | Forest ecosystem services | 55 million | | | |
| Ecosystem services, forests | Canada | Ontario's Greenbelt | Ontario | | | Total | 2,651,707,951 | 3,487 per ha | Avoided cost, replacement cost and | Wilson (2008) |
| | | | | | | Air quality | 68,868,821 | | | |
| | | | | | | Carbon stored | 366,451,342 | | | |
| | | | | | | Carbon uptake | 10,982,151 | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Flood control (wetlands) | 379,676,010 | | contingent valuation (both direct analysis and value transfer) | |
| | | | | | | Control of runoff (forests) | 278,103,520 | | | |
| | | | | | | Water filtration | 131,107,489 | | | |
| | | | | | | Erosion control and sediment retention | 532,417 | | | |
| | | | | | | Soil formation | 6,005,164 | | | |
| | | | | | | Nutrient cycling | 2,141,547 | | | |
| | | | | | | Waste treatment | 294,360,279 | | | |
| | | | | | | Pollination (agriculture) | 298,235,257 | | | |
| | | | | | | Natural regeneration | 98,001,705 | | | |
| | | | | | | Biological control | 8,175,746 | | | |
| | | | | | | Habitat (refugia) | 548,184,172 | | | |
| | | | | | | Recreation and aesthetics | 95,207,535 | | | |
| | | | | | | Cultural/spiritual (agriculture) | 65,674,796 | | | |
| | | | | | | *Nonmarket ecosystem services* | | | | |
| | | | | | | Wetlands | 1,331 million | 14,153/ha | | |
| | | | | | | Forests | 989 million | 5,414/ha | | |
| | | | | | | Grasslands | 0.714 million | 1,618/ha | | |
| | | | | | | Rivers | 2.6 million | 335/ha | | |
| | | | | | | Cropland | 183 million | 477/ha | | |
| | | | | | | Orchards | 2.6 million | 494/ha | | |
| | | | | | | Hedgerows | 11.8 million | 1,678/ha | | |
| | | | | | | Idle land | 132 million | 1,667/ha | | |
| Ecosystem services | Canada | Pimachiowin Aki World Heritage Project Area | Manitoba and Ontario | | | Grasslands | 121-130 million | | Values based on literature | Wilson (2009) |
| | | Southern Ontario Greenbelt | Ontario | | | | 2.6 billion | | | |
| | South Africa (Rands) | | | | | | 9.7 billion | | | |
| Ecosystem services, forests | Canada | Long Tusket Lake | Nova Scotia | | Acadian Forest | Forests | | 26,250/ha | Abatement costs; values based on literature | TD Economics & Nature Conservancy of Canada (2017) |
| | | Maymont Property | Saskatchewan | | Boreal Forest | | | 5,800/ ha | | |
| | | Kurian property | Manitoba | | Boreal Forest | | | 26,800/ha | | |
| | | Salmonier Conservation Project | Newfoundland & Labrador | | Boreal Forest | | | 26,300/ha | | |
| | | Backus Woods | Ontario | | Carolinian Forest | | | 19,353/ha | | |
| | | Crane River | Ontario | | Great Lakes-St. Lawrence Forest | | | 19,400/ha | | |
| | | Gullchucks Estuary | British Columbia | | Coastal Forest | | | 33,700/ha | | |
| | | Midgeley | British Columbia | | Columbia Forest | | | 46,000/ha | | |
| | | Enchantment Property | British Columbia | | Subalpine Forest | | | 24,600/ha | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| | | Kenauk | Quebec | | Great Lakes-St. Lawrence Forest | | | 20,000/ha | | |
| | | Lusicich | Alberta | | Montane Forest | | | 42,000/ha | | |
| Ecosystem services | Canada | Lake Simcoe Watershed | Ontario | | | Total | 922.7 million | | Values from literature (eg., expenditure) | Green Analytics (2017) |
| | | | | | | Recreation | 487.4 million | | | |
| | | | | | | Water supply | 157 million | | | |
| | | | | | | Pollination | 45.4 million | | | |
| | | | | | | Clear air | 5 million | | | |
| | | | | | | Food regulation | 169.3 million | | | |
| | | | | | | Carbon sequestration | 35.9 million | | | |
| | | | | | | Habitat and refugia | 22.7 million | | | |
| Ecosystem Services | Canada | Yamasca River Watershed | Quebec | | | Wetlands | | 5,277 or 9,080/ha | Metanalysis; second values based on a more detailed sub-watershed scale | He et al. (2015) |
| | | Bécancour River Watershed | Quebec | | | Wetlands | | 3,979 or 4,702/ha | | |
| Ecosystem services, Great Lakes | Canada | Credit River-16 Mile Creek | Ontario | | Great Lakes | Wetlands, | 10,191,324 | | Value transfer and metanalysis | Marbek (2010) |
| | | Toronto Area | | | | | 6,521,303 | | | |
| | | Prince Edward Bay | | | | | 23,565,905 | | | |
| | | Credit River-16 Mile Creek | | | | Streams | 148,643,615 | | | |
| | | Toronto Area | | | | | 176,534,484 | | | |
| | | Prince Edward Bay | | | | | 51,473,336 | | | |
| Ecosystem services | Canada | Mackenzie Watershed | Alberta, British Columbia, Saskatchewan, Northwest Territories and Yukon | Boreal Cordillera, Boreal Plains, Boreal Shield, Montane Cordillera, Prairies, Southern Artic, Taiga Cordillera, Taiga Plains and Taiga Shield | | Total | 570,648 million | | Market value and values from literature | Anielski and Wilson 2009a |
| | | | | | | Cropland | 297 million | | | |
| | | | | | | Deciduous Broadleaf | 366 million | | | |
| | | | | | | Evergreen needleleaf | 54,714 million | | | |
| | | | | | | Grassland | 12 million | | | |
| | | | | | | Mixedwood | 20,710 million | | | |
| | | | | | | Mosaic land (cropland and native vegetation) | 604 million | | | |
| | | | | | | Transition treed and shrubland | 6,620 million | | | |
| | | | | | | Urban and Built-up | 0.7 million | | | |
| | | | | | | Water bodies (rivers and lakes) | 188,675 million | | | |
| | | | | | | Wetland/shrubland | 181,869 million | | | |
| Natural capital/ecosystem services of peatlands | Canada | Eastern and Interlake regions | Manitoba | | | Total | 128 million | | | Voora, Swystun, Dohan, and Thrift (2013) |
| | | | | | | Water supply | 3 million | | | |
| | | | | | | Subsistence | 1 million | | | |
| | | | | | | Carbon sequestration | 15 million | | | |
| | | | | | | Flood protection | 2 million | | | |
| | | | | | | Water treatment | 74 million | | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Erosion control | 3.32 million | | | |
| | | | | | | Habitat and refugia services | 24 million | | | |
| | | | | | | *Natural capital* | | | | |
| | | | | | | Peat (extracted good) | 1.914 billion | | | |
| | | | | | | Carbon | 34 billion | | | |
| | | | | | | Water | 4 billion | | | |
| Prairie shelterbelts ecosystem services | Canada | | Prairie provinces | | | Total of external benefits (public and non-public goods (1981-2001) | 140 million | | Benefit transer used in some cases | Kulshreshtha and Kort (2009) |
| | | | | | | Total benefits (public goods) | 100.9 million (1981-2001) | | | |
| | | | | | | Total benefits from non-public goods | 39.1 million (1981-2001) | | | |
| | | | | | | Reduced soil erosion | 15-97 million | | | |
| | | | | | | Air quality (non-odor) | 3.71 million per year | | | |
| | | | | | | Reduced net emissions for carbon | 72.8 (for 1981-2001) | | | |
| | | | | | | Water quality benefits | 1.21 million | | | |
| | | | | | | Protected or enhanced biodiversity | 4.72 million (1981-2001) | | | |
| | | | | | | Consumptive wildlife | 39 million | | | |
| | | | | | | Non-consumptive wildlife | 3.70 million | | | |
| Aquatic ecosystem service benefits | Canada | Blue Network of Greater Montreal | Quebec | Upper St. Lawrence Plain | | Biodiversity (one species improvement) | 1.2 million | | Contingent choice study using real projects | Poder, Duoras, Fetue Ndefo, and He (2016) |
| | | | | | | Water Quality | 13.5 million | | | |
| | | | | | | Carbon sequestration | 0.1 million | | | |
| Forest | Canada | Midgeley property | British Columbia | | Columbia Forest Region/Columbia Mountains Highlands | Total | 3,162,401 | 46,476/ha | Values based on literature | DePratto and Kraus (n.d.) |
| | | Lusicich property | Alberta | | Montane Forest Region/Northern Continental | | 4,685,827 | 42,136/ha | | |
| | | Kenauk property | Quebec | | Great Lakes-St. Lawrence Forest Region/Southern Laurentians | | 78,925,706 | 19,405/ha | | |
| Prairie native grasslands | Canada | | Saskatchewan | | | Direct economic value | 412 million | 32.19 per acre | Values from literature | Chris Nykoluk Consulting (2013) |
| | | | | | | Indirect value | | 297.79/acre | | |
| Grasslands | Canada | | Manitoba | | | Total | 936.2 million | | | The National Centre for Livestock and the Environment, University of |
| | | | | | | Forage production | 524.6 million | | | |
| | | | | | | Carbon storage | 9.4 – 637 million | | | |
| | | | | | | Nutrient cycling | 127 million | | | |
| | | | | | | Water regulation | 12.2 million | | | |
| | | | | | | Soil erosion control | 31.9 million | | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Soil formation | 25.5 million | | | Manitoba (2019) |
| | | | | | | Waste treatment | 153.9 million | | | |
| | | | | | | Recreation and aesthetics | 40.7 million | | | |
| | | | | | | Refugium function | 11.0 million | | | |
| Wetland program social benefits | Canada | Credit River Watershed | Ontario | | | Total | 220.9-250.4 million (total willingness to pay in the next 5 years) | | | Lantz, Boxall, Kennedy, and Wilson (2010) |
| Wetlands and biodiversity | Canada | Laurentian Great Lakes Basin | | | | | 70 million | | Market values, and maintenance and restoration costs | Krantzberg and De Boer (2008) |
| Wetland ecosystem services | | | | | | Wildlife habitat | | 3,000/ha | Values from literature | Hotte, Kennedy, and Lantz (2009) |
| | | | | | | Recreational hunting | | 2,500/ha | | |
| | | | | | | Amenity | | 8,500/ha | | |
| | | | | | | Recreational fishing | | 3,500/ha | | |
| | | | | | | Raw materials | | 450/ha | | |
| | | | | | | Water quality | | 8,500/ha | | |
| | | | | | | Flood protection | | 5,500/ha | | |
| | | | | | | Water supply | | 2,000/ha | | |
| | | | | | | Fuelwood | | 80/ha | | |
| | | | | | | Biodiversity | | 11,500/ha | | |
| Boreal ecosystem services | Canada | | | Taiga Plains, Taiga Shield, Boreal Shield, Boreal Plains, Taiga Cordillera, Boreal Cordillera and Hudson Plains | | Total net market value | 50.9 billion | | Market values, costs and non-market values such as replacement costs | Anielski & Wilson (2009b) |
| | | | | | | Total non-market value | 703.2 billion | 1,204/ha | | |
| | | | | | | Pest control by birds | 5.4 billion | | | |
| | | | | | | Nature related activities | 4.5 billion | | | |
| | | | | | | Carbon sequestration | 582 billion | | | |
| | | | | | | Subsistence for Aboriginal peoples | 575 million | | | |
| | | | | | | Non-timber forest products | 79 million | | | |
| | | | | | | Municipal water use | 18.3 million | | | |
| | | | | | | Passive conservation value | 1.1.7 million | | | |
| | | | | | | Wetlands and peatlands (non-market) | 512.6 billion | 4,809/ha | | |
| | | | | | | Water resources | 19.5 billion | | | |
| Ecosystem services | Canada | National Commission's Green Network (Gatineau Park, Greenbelt and urban lands) | Ontario and Quebec | Canadian Shield and St. Lawrence Lowlands | | Total | 332,172,600 | | Market values, transfer values and replacement costs | Dupras et al. (2016) |
| | | | | | | Urban forests | 14,514,300 | 9,352/ha | | |
| | | | | | | Rural forests | 159,489,400 | 4,183/ha | | |
| | | | | | | Wetlands | 145,693,500 | 59,394/ha | | |
| | | | | | | Croplands | 4,506,100 | 1,363/ha | | |
| | | | | | | Prairies, grasslands | 7,744,200 | 3,338/ha | | |
| | | | | | | Freshwater systems | 225,100 | 137/ha | | |
| Ecosystem services | Canada | Peace River Watershed | British Columbia | | | Total value (10 years) | 204.6 billion | | Market values, transfer | Wilson (2014) |
| | | | | | | Water supply | 2,502,441 | 32.60/ha | | |
| | | | | | | Air filtration by trees | 12,684,230 | 3.51/ha | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Forest ecosystem carbon storage | 1.56-8.5 billion | 1,175.69/ha (central value) | values, avoided, replacement and travel costs, meta-analysis and willingness to pay | |
| | | | | | | Wetland soil carbon storage | 401 million-1.89 billion | 715.24-2,453.85/ha | | |
| | | | | | | *Other soil carbon storage* | 413.5 million-1.95 billion | | | |
| | | | | | | Grassland | | 921.32/ha | | |
| | | | | | | Pasture | | 1,073.77/ha | | |
| | | | | | | Shrubland | | 1,552.03/ha | | |
| | | | | | | Cropland | | 1,181.55/ha | | |
| | | | | | | *Carbon sequestration* | 285.5 million-1.15 billion | | | |
| | | | | | | Forest | | 138.08/ha | | |
| | | | | | | Wetland | | 33.42/ha | | |
| | | | | | | Shrubland/grassland/perennial cover | | 56.20/ha | | |
| | | | | | | Wetland flood control, water supply, nutrient recycling | 133,157,316 | 256.67/ha (wetland) | | |
| | | | | | | Water filtration | 22,529,524 | 6.23/ha (forest, treed wetland) | | |
| | | | | | | Erosion control/sediment retention | 4,467,440 | 6.60/ha (grassland/perennial cover) | | |
| | | | | | | Waste treatment | 46,970,791 | 27.92/ha (perennial cover/grassland) and 54.10/ha (wetland) | | |
| | | | | | | Pollination | 39,895,056 | 43.63/ha (shrubland/grassland/perennial cover/pasture | | |
| | | | | | | Habitat | 206,744,044 | 379.43/ha (wetlands) and 41/ha (perennial cover/pasture) | | |
| | | | | | | Recreation | 119,738,498 | 21.47/ha (forest, wetland, shrubland and grassland and 214.97/ha (water) | | |
| | | | | | | Cultural values | 5,258,881 | 9.38/ha (farmlands) and 0.39/ha (protection of forests and wetlands | | |
| Ecosystem services | Canada | Northern Alberta | Alberta | | | Forest (regional)-total | 232.4 million | Values are for 1996 | Net national product and value transfer | Haener and Adamowicz (2000) |
| | | | | | | Biodiversity maintenance | 58.4 million | | | |
| | | | | | | Carbon sequestration | 9.5 million | | | |
| Ecosystem services, Prairie wetlands | Canada | | Saskatchewan | | | Riparian area | 26.5 million | One-time payment | Choice experiment | Dias and Belcher (2015) |
| | | | | | | Wildlife population | 23.6 million | | | |
| | | | | | | Water quality | 42.9 million | | | |
| Ecosystem services, wetlands | United States | | | | | Fish and shellfish support | 1992 values | 6,132/acre | Based on literature | Heimlich et al. (1998) |
| | | | | | | Fur-bearing animals | | 137/acre | | |
| | | | | | | Ecological functions | | 32,149/acre | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Amenity and cultural | | 2,722/acre | | |
| Natural capital | Canada | Lower mainland | British Columbia | Pacific Maritime | | *Climate regulation* | | | Avoided cost, replacement cost, production function method and travel cost | Wilson (2010) |
| | | | | | | Forests (primary study area) | 246 million | 1,709/ha | | |
| | | | | | | Forests (secondary study area) | 1,280 million | 1,898/ha | | |
| | | | | | | Wetlands | 44 million | 1,432/ha | | |
| | | | | | | Grasslands | 3.1 million | 594/ha | | |
| | | | | | | Shrublands | 61 million | 1,000/ha | | |
| | | | | | | Croplands | 41 million | 698/ha | | |
| | | | | | | Clean air-forests | 409 million | 495/ha | | |
| | | | | | | Flood protection/water regulation-forests | 1,241 million | 1,502/ha | | |
| | | | | | | Waste treatment-wetlands | 41 million | 1,283/ha | | |
| | | | | | | *Water supply* | | | | |
| | | | | | | Forests | 1,561 million | 1,890/ha | | |
| | | | | | | Wetlands | 61 million | 1,890/ha | | |
| | | | | | | *Pollination (primary study areas)* | | | | |
| | | | | | | Forests | 234 million | 1,669/ha | | |
| | | | | | | Shrublands | 14 million | 1,669/ha | | |
| | | | | | | Grasslands | 0.1 million | 1,669/ha | | |
| | | | | | | Salmon habitat-Integral forests | 1.6 million | 3/ha | | |
| | | | | | | *Recreation/tourism* | | | | |
| | | | | | | Forests | 105 million | 127/ha | | |
| | | | | | | Wetlands | 4.1 million | 127/ha | | |
| | | | | | | Farm-based | 13 million | 422/ha | | |
| | | | | | | Local food production-croplands | 24 million | 382/ha | | |
| | | | | | | *Total* | *5,384 million* | | | |

Table A5: Economic benefits of different species

| Species | Country | Place | Province | Ecozone | Ecoregion | Total value ($/year) | | Methods | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Bats (importance to agriculture) | United States | | | | | 22.9 billion | | Reduced costs of pesticides | Boyles et al. (2011) |
| Caribou | Canada (based on 2005-2006 harvest) | | Nunavat | | | 9.50 million | | | Intergroup Consultants Ltd. (2013) |
| | | | Saskatchewan | | | 5.90 million | | | |
| | | | Manitoba | | | 3.80 million | | | |
| | | | Northwest territories | | | 0.80 million | | | |
| Economic value of wildlife (annual values | Canada | | Alberta | | | | | Contingent valuation and market values | Adamowicz et al. (1991) |
| *Total* | | | | | | 185.2 million | | | |
| *Preservation benefits* | | | | | | 67.7 million | | | |
| *Hunting* | | | | | | | | | |
| Waterfowl | | | | | | 10.3 million | | | |
| Other birds | | | | | | 11.0 million | | | |
| Small mammals | | | | | | 6.8 million | | | |
| Large mammals | | | | | | 24.9 million | | | |
| *Non-consumptive use* | | | | | | 64.5 million | | | |
| Canada Lynx (upper bound values) | United States | Montana<br>Maine | | | | 557.,30,084<br>69,611,046 | | Market value, willingness to pay and avoided and replacement costs | Kroeger and Casey (2006) |