ECONOMIC BENEFITS OF BIODIVERSITY TO CROP PRODUCERS IN CANADA: A LITERATURE REVIEW

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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, Musßhoff, 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.

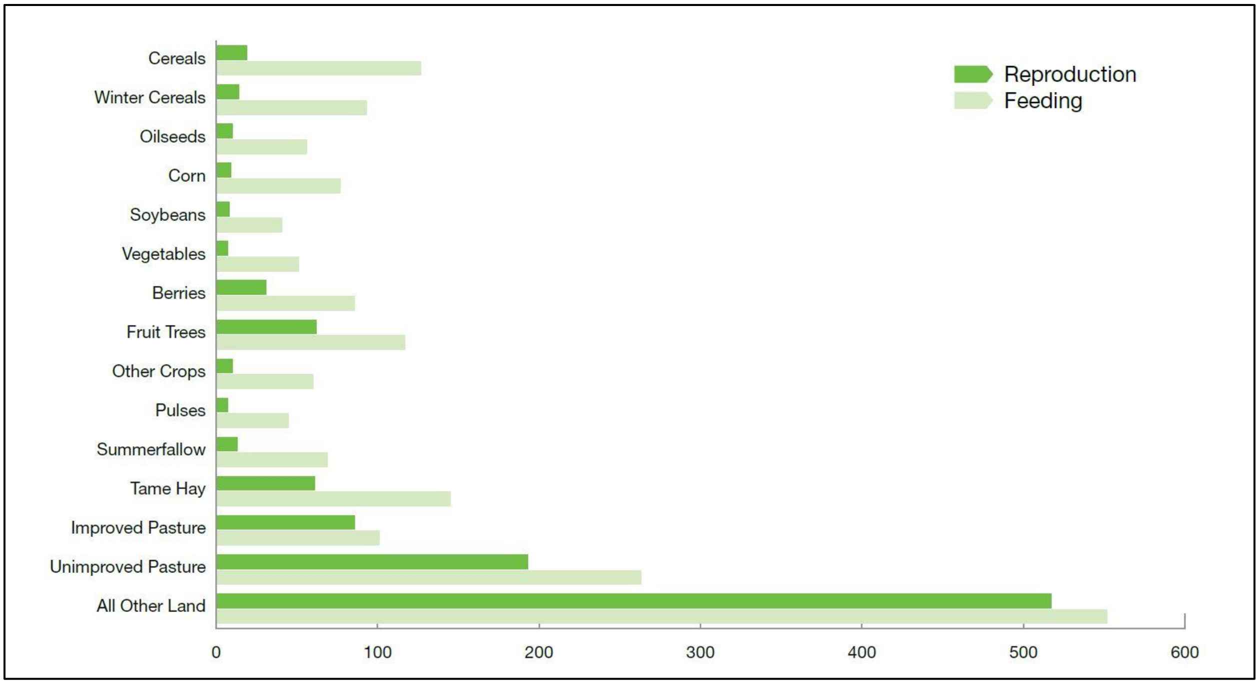

Figure 1: Cover type and number of wildlife species on agricultural land in Canada
Adapted from Agriculture and Agri-Food Canada (2016)

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.

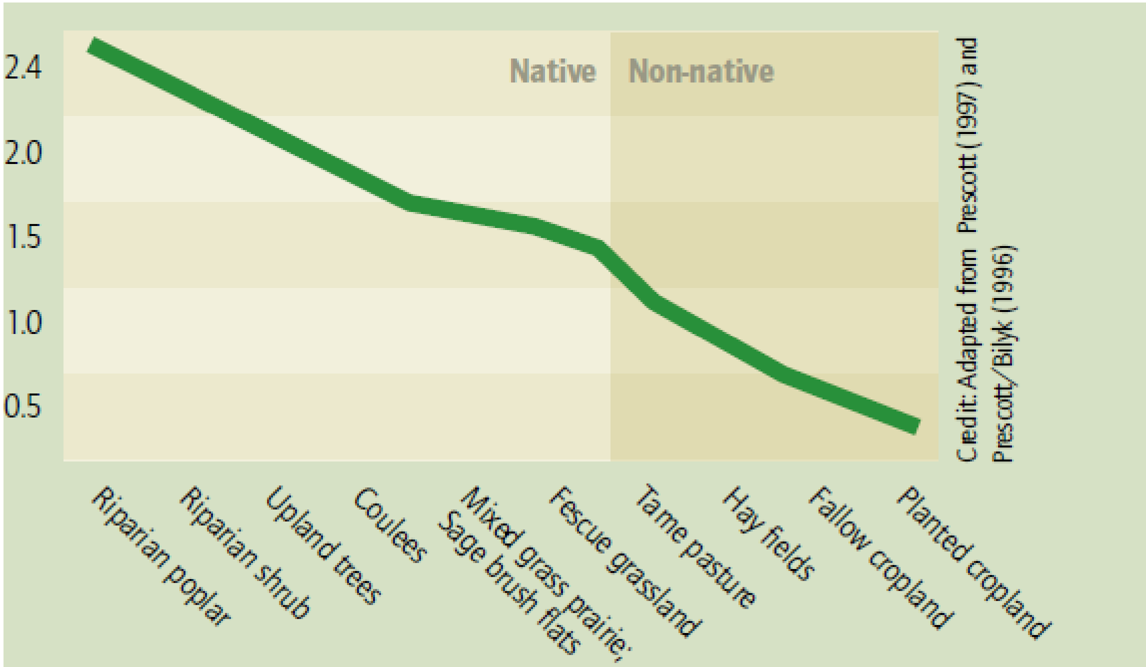

Figure 2: Biodiversity values for birds
Adapted from Alberta Agriculture and Food (2007)

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 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 student 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.

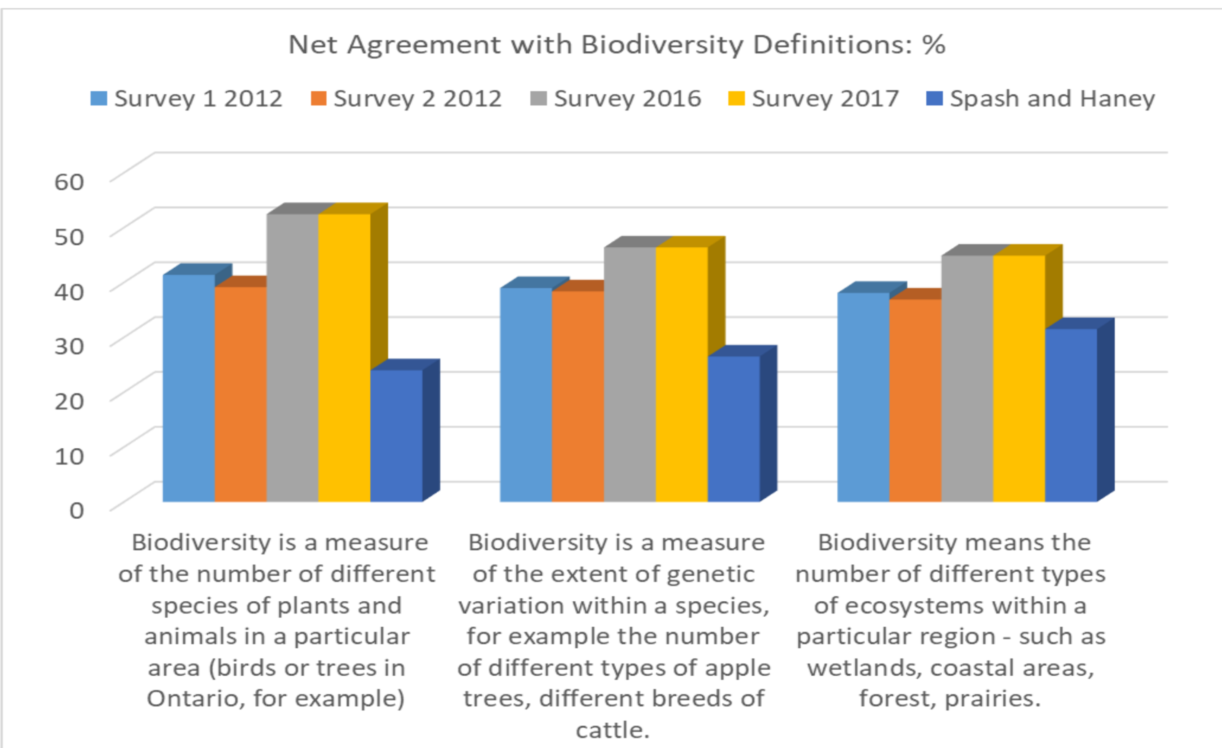

Figure 3: Data on biodiversity definitions from various Canadian surveys (>1800 Canadian respondents) and original survey data by Spash and Hanley (1995)

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.

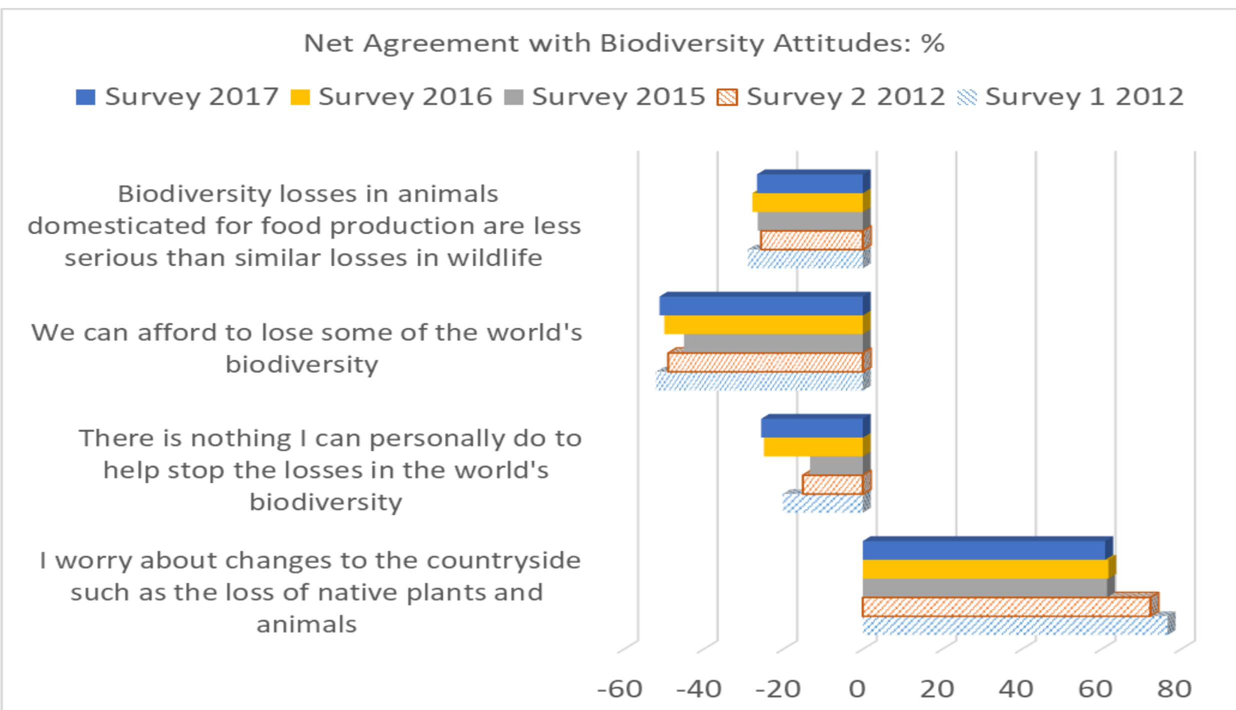

Figure 4: Data on biodiversity attitudes from various Canadian surveys (>1800 Canadian respondents)

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, buck wheat 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.

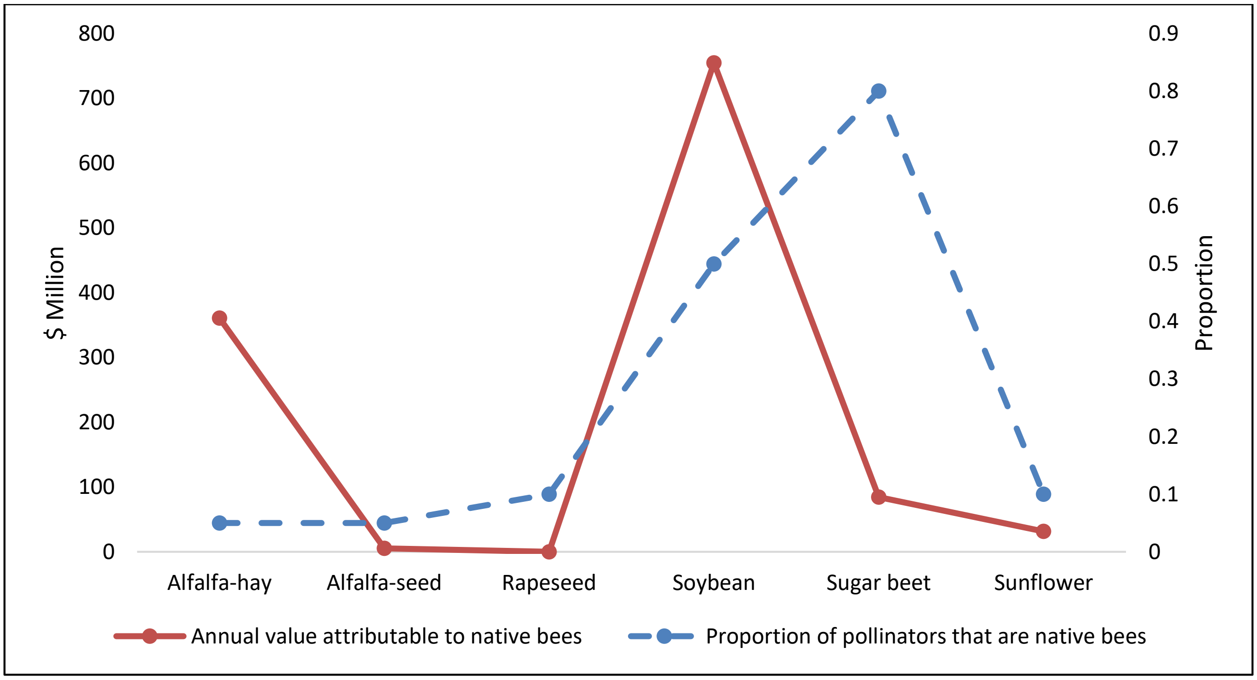

Figure 5: Value of crops (per year) attributable to native bees in the United States
Data are from Losey and Vaughan (2006)

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).

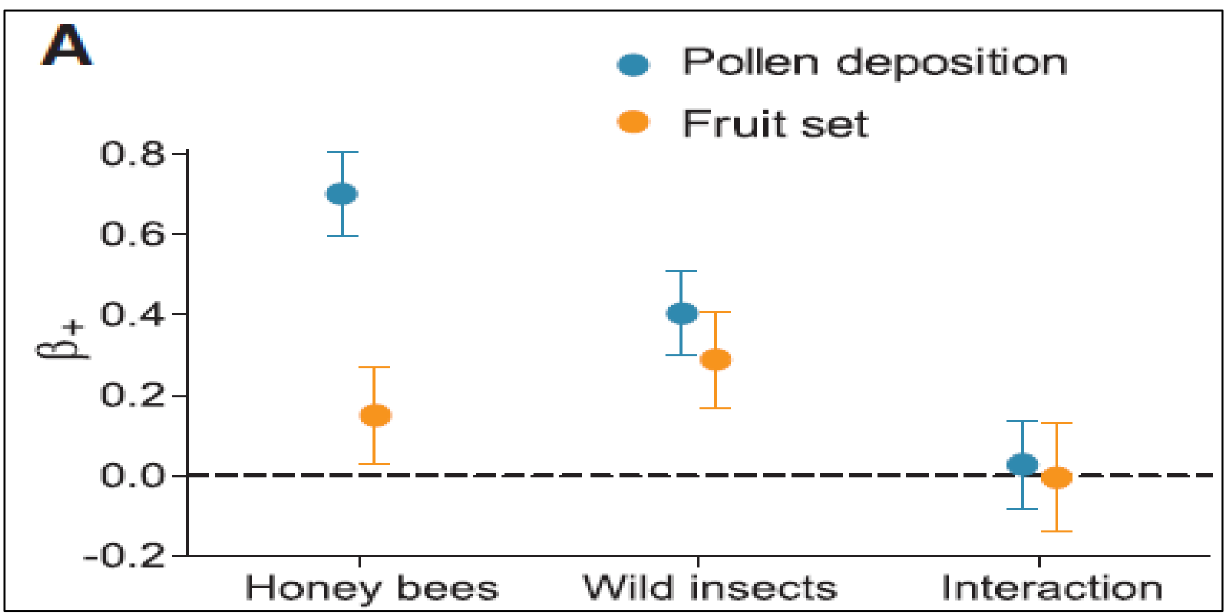

Figure 6: Effects (direct and interaction) of visitation of flowers by honey bees and wild insects on fruit set and pollen deposition
Source: Adapted from Garibaldi et al. (2013, p. 1610)

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)	Landis et al. (2008)
						1,407 million for biocontrol alone	
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.

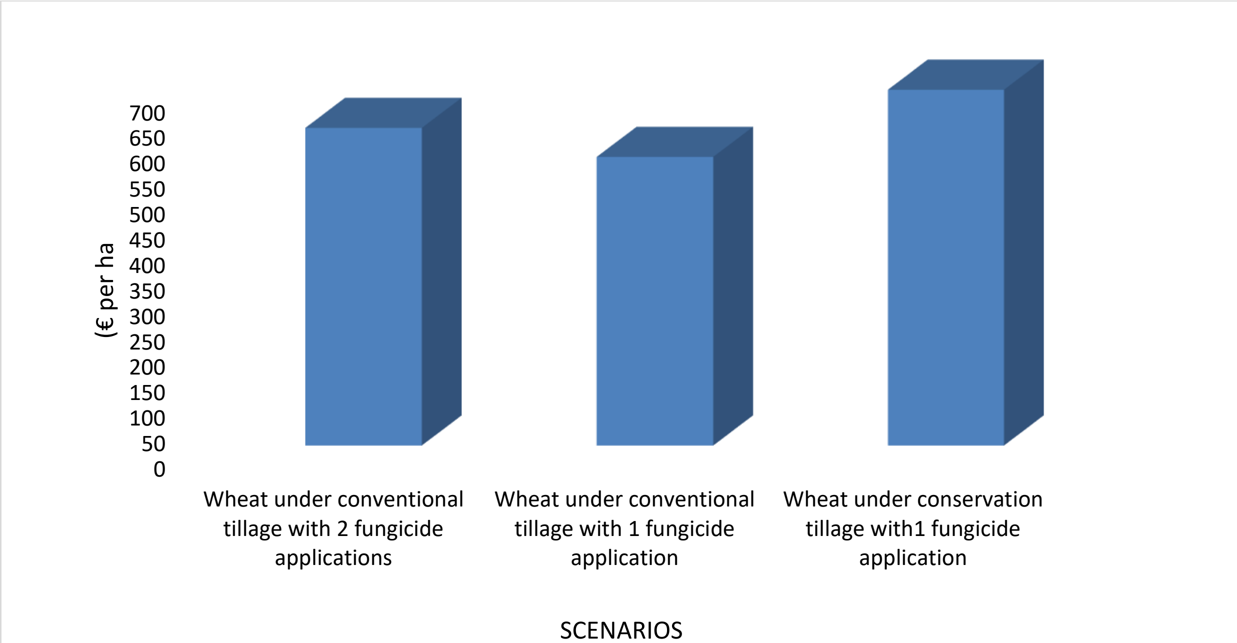

Figure 7: Standard gross margins for different scenarios for tillage and fungicide application
Data are from Plaas et al. (2019)

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).

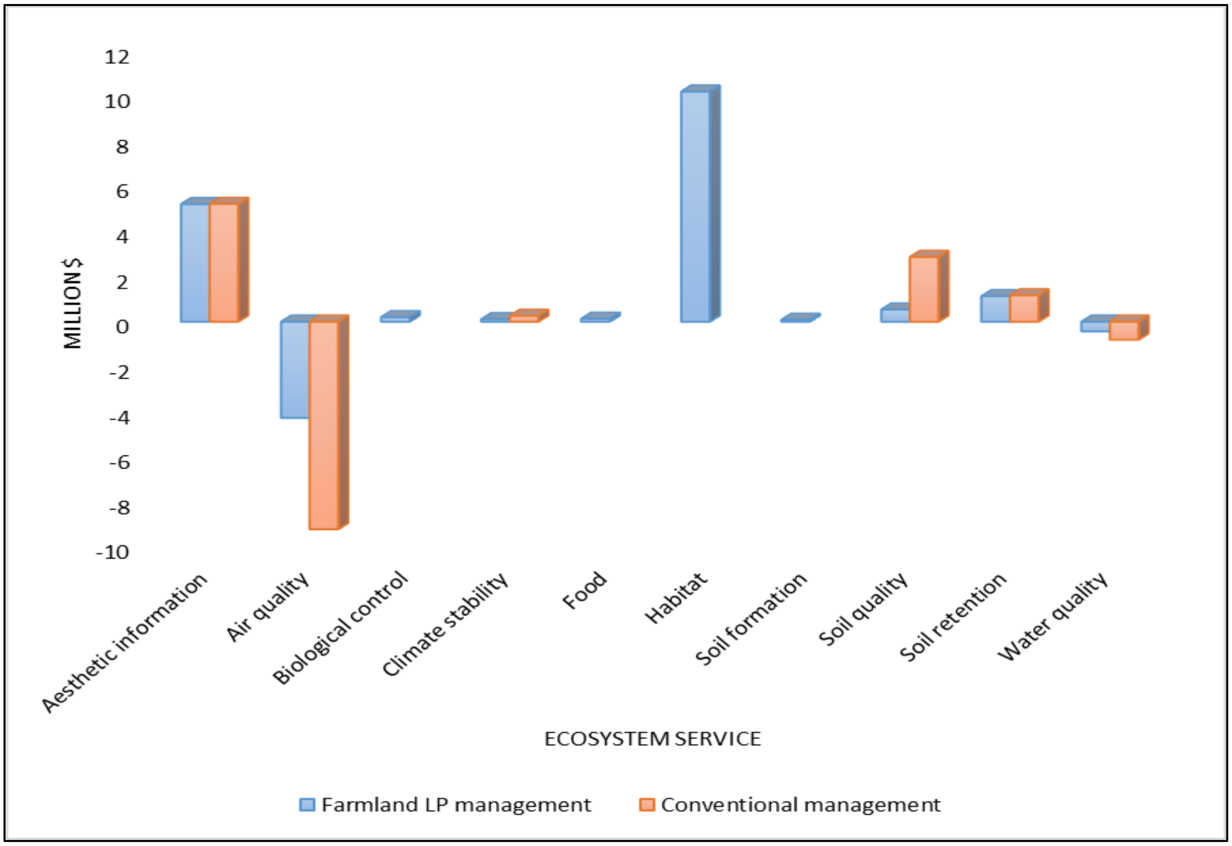

Figure 8: Ecosystem service values for Farmland LP and conventional management
Data are from Farmland LP (2017)

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.

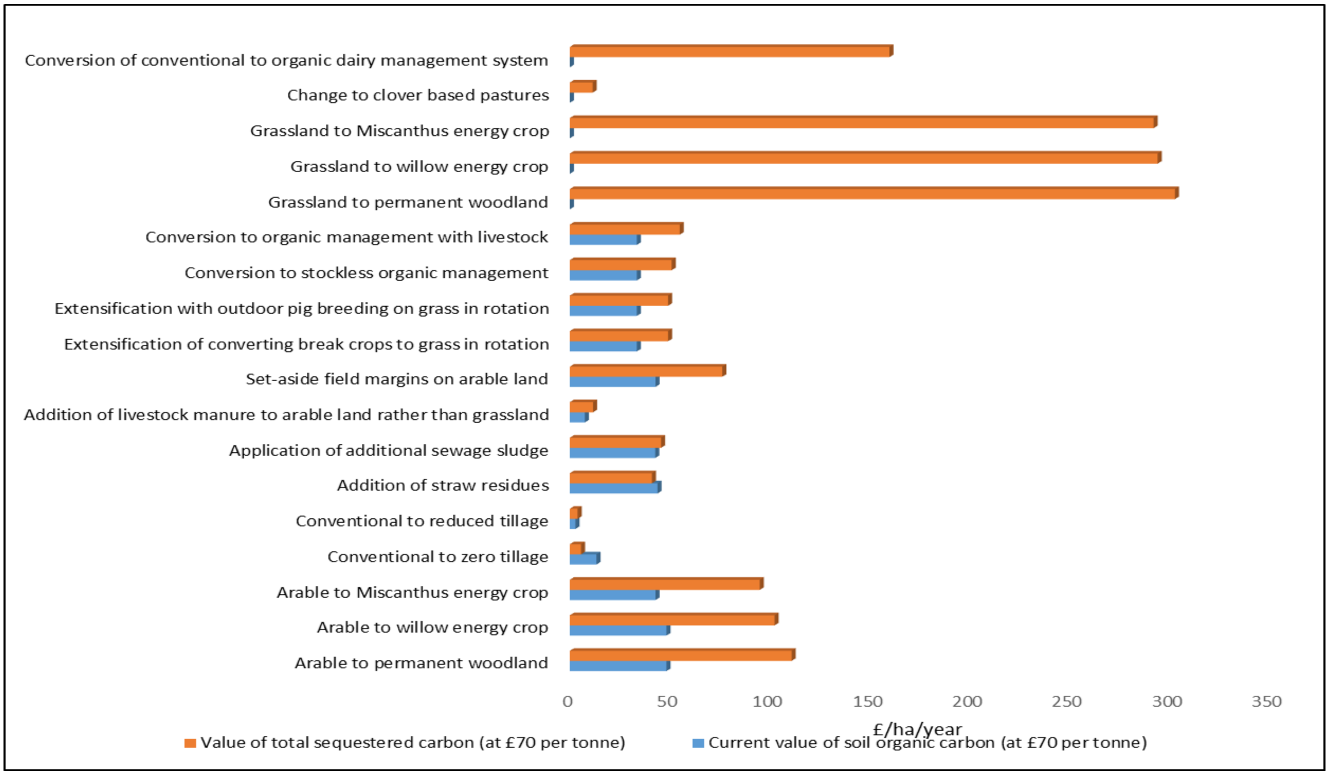

Figure 9: Carbon sequestration values for different scenarios
Data are from Harris et al. (2006)

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.

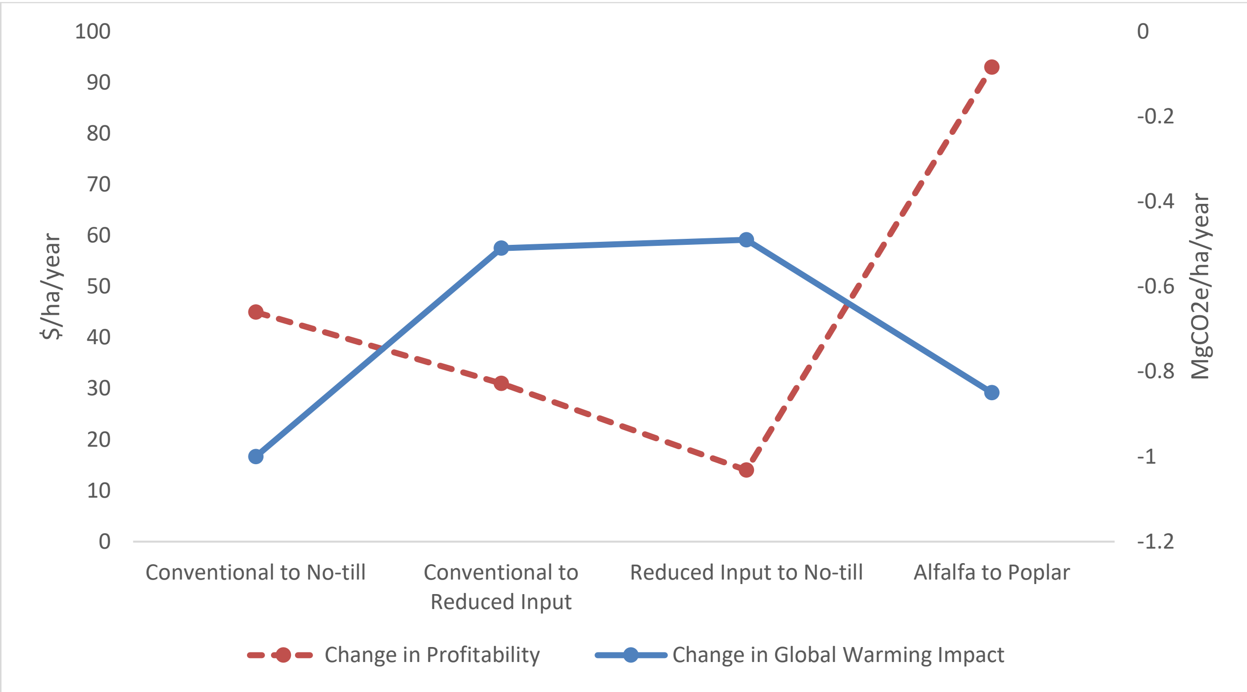

Figure 10: Efficiency gains from changes in cropping systems
Data are from Swinton et al. (2015)

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. This 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).

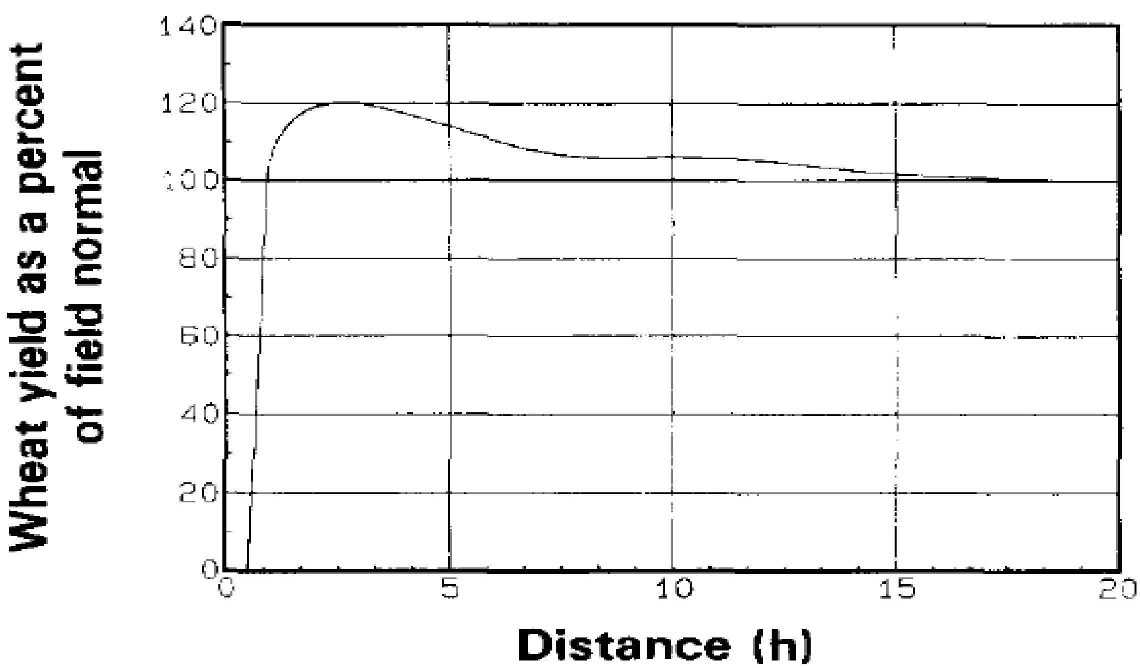

Figure 11: Impact of shelterbelt on spring wheat yields (Canadian Prairies and Northern United States Great Plains)
Source: Kort (1988, p. 185)

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 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).

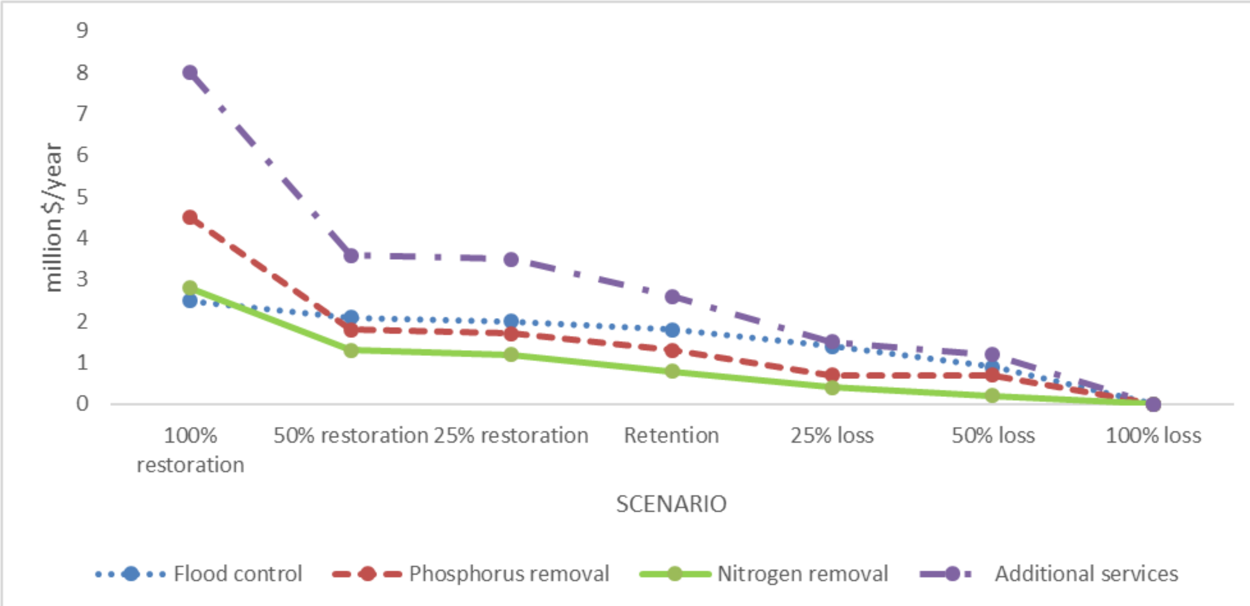

Figure 12: Total benefit of Smith Creek wetlands, Saskatchewan for the different scenarios of loss or restoration

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.

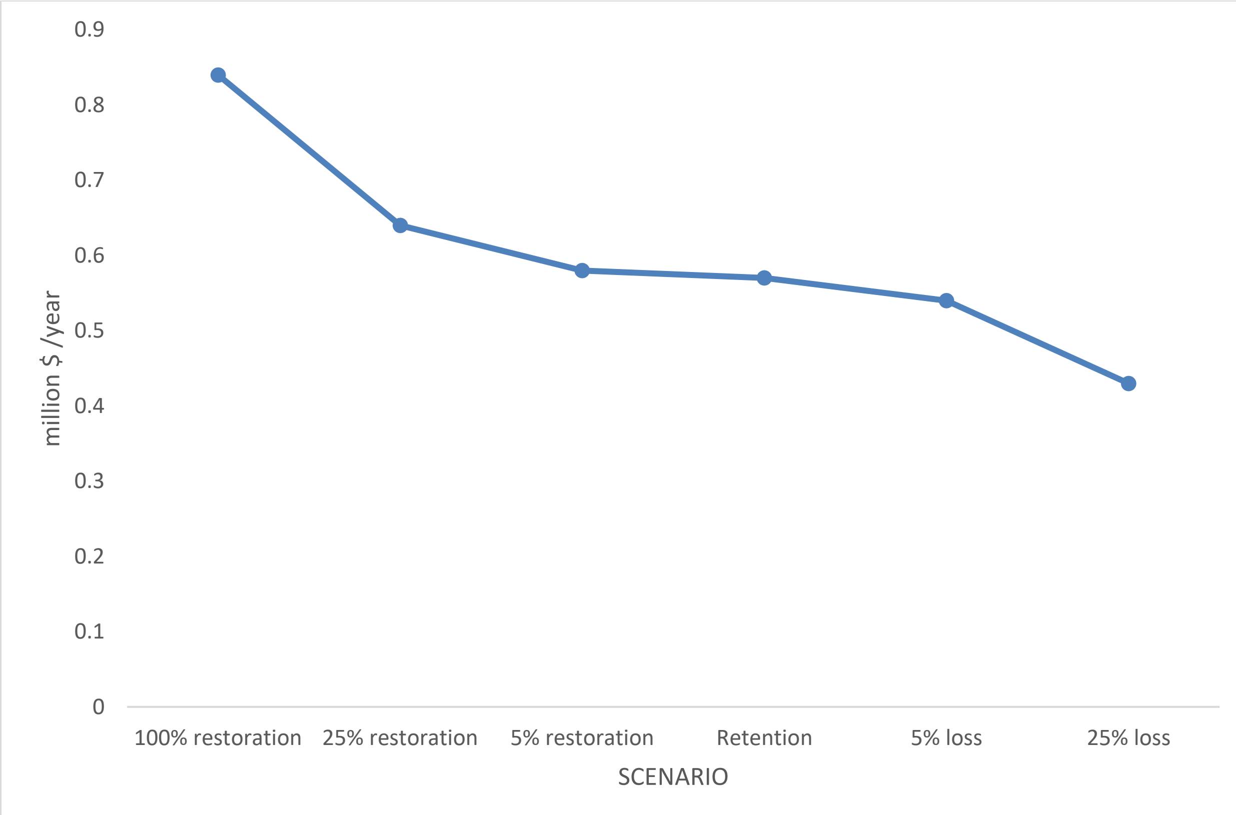

Figure 13: Estimated benefits of biodiversity in the Black River riparian wetlands in Ontario under different scenarios of wetland loss and restoration
Data are from Pattison-Williams et al. (2017).

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.

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