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Review

Beef production and ecosystem services in Canada's prairie provinces: A review

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ABSTRACT

Globally, consumption of bovine meat is projected to increase by 1.2% per annum until 2050, a demand likely met in part by increased Canadian beef production. With this greater production on a finite agricultural land base, there is a need to weigh the contribution of this industry to the Canadian economy against the full range of positive and negative ecological and social impacts of beef production. This review, focussing on the prairie provinces of Alberta, Saskatchewan and Manitoba, which collectively support just over 80% of the Canadian beef herd, examines the social and ecological footprint of the cow-calf, backgrounding, finishing and forage/feed production stages of beef production within an ecosystem services framework. We summarise the literature on how beef production and management practices affect a range of services, including livestock; water supply; water, air and soil quality; climate regulation; zoonotic diseases; cultural services; and biodiversity. Based on 742 peer-reviewed publications, spanning all agricultural stages of beef production, we established a framework for identifying management practices yielding the greatest overall socio-ecological benefits in terms of positive impacts on ecosystem service supply. Further, we identified research gaps and crucial research questions related to the sustainability of beef production systems.

1. Introduction

1.1. Sustainable food production and Canadian beef

In 2015, 37% of the global land area was used for agriculture (World Bank, 2018a). Agricultural systems play a dominant role in feeding the human population and provided 26.5% of global employment in 2017 (World Bank, 2018b). However, agricultural management and deforestation to provide land for farming accounted for 24% of total global greenhouse gas (GHG) emissions in 2014 (FAO, 2017), 70% of freshwater withdrawals worldwide (FAO, 2016), and widespread nitrogen pollution of aquifers (Mateo-Sagasta et al., 2017). A projected rise in the human population to 9.8 billion by 2050 (UN, 2017), coupled with rising per capita food consumption and income, may increase annual global food production by *c*. 60% by 2050 (FAO, 2017).

Global meat production is projected to increase *c*. 200 million tonnes (Mt) by 2050, due to population growth and shifting dietary preferences in developing countries (Alexandratos and Bruinsma, 2012; Hunter et al., 2017). In terms of increased consumption in developing countries, bovine meat is second only to poultry meat, with a projected per annum growth rate of 1.9% from 2005/07 to 2050 (Alexandratos and Bruinsma, 2012). This growing demand will be partially met by an expanded Canadian beef industry, the 11th largest producer and 5th largest exporter of beef globally (CanFax, 2016).

With minimal potential for expanding agricultural land even under climate change scenarios, increases in production will be realized mostly through intensified production and reduced losses throughout the supply chain. In Canada, agricultural land declined from 7.7% to

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6.9% of total land area between 1961 and 2015 (World Bank, 2018a), despite the continual conversion of native grasslands to cropland in the prairie provinces (0.44 million hectares in 2014 - WWF, 2016). Of particular concern is the permanent loss of agricultural land to residential, commercial and industrial development. For example, the province of Alberta lost 5.6% of its agricultural land and converted 23% of pastureland to cropland between 2000 and 2012 (Haarsma et al., 2014).

Global warming may increase food production in Canada due to a northward expansion of suitable growing conditions and a longer grazing season, although weed, pest and disease expansion, combined with increased drought frequency and storm intensity, may limit such gains (Campbell et al., 2014). Moreover, any gains would have to compensate for land lost to development. Therefore, intensified production through increases in carcass weight and enhanced reproductive efficiency appears the most likely way forward (FCC, 2015).

Expected intensification on a shrinking agricultural land base, together with potentially adverse future climatic conditions, warrants an investigation of the full ecological and social impacts of beef production, as recognized globally by the formation of the Global Roundtable on Sustainable Beef (GRSB), and nationally by the Canadian Roundtables on Sustainable Beef (CRSB) and Sustainable Crops (CRSC). Reviews of ecosystem service research exist for pasture-based cattle in Europe (Dumont et al., 2017; Rodríguez-Ortega et al., 2014), and beef cattle on native grasslands in South America (Modernel et al., 2016). Although the environmental footprint of Canadian beef has been widely studied, a holistic investigation of the full range of positive and negative impacts encompassing all stages of beef production (grazing, confined feeding, and forage and feed production) has not yet been conducted (Janzen, 2011).

1.2. An ecosystem services approach to assessing sustainability

A sustainable agricultural system is “one where food is nutritious and accessible for everyone and one where natural resources are managed in a way that maintains ecosystem functions to support current as well as future human needs” (FAO, 2017). This sustainability can be assessed using an ecosystem services framework. Ecosystem services are the outcomes from ecosystems that can lead to benefits valued by people and are produced by the interacting ecological and social structures and processes of the system. Ecosystem services include provisioning services such as water, crop and livestock products; regulating services such as soil, air and water quality regulation; and cultural services such as recreation and tourism. The benefits that flow from these services contribute in varying degrees to the economic, health and social well-being of human beneficiaries (Yahdjian et al., 2015), as they consume, make use of or enjoy these benefits. Changes in human well-being due to changes in the supply of services from the landscape can influence system governance and management, which in turn affect the social and ecological structures and processes that underpin service provision (Reyers et al., 2013) (Fig. 1). For instance, the capacity of the beef system to regulate water quality influences human well-being through effects on the suitability of water for drinking, recreational and other purposes, which motivates the formulation, legislation, and adoption of on-farm best management practices. This framework provides the basis for linking management practices to changes in the total bundle of ecosystem services from beef production, using western Canadian systems as a case-study.

Villamagna et al. (2013) point out that many ecosystem service studies measure environmental quality rather than actual service supply, and recommend instead measuring ecological work, equal to ecological pressures minus environmental quality. For example, sediment filtration performed by a system is equal to cumulative sediment loading in the watershed (ecological pressure) minus ambient sediment concentration (environmental indicator). In this review, direct measurements of regulating service supply were reported where available, e.g., carbon sequestration. However, in many cases, available data related to environmental quality rather than service supply. Nonetheless, environmental quality indicators serve as an effective proxy for regulating services, are readily measured and available, convey meaningful information to decision-makers, and are discussed in this review in the context of their relationships to the services themselves.

The main goal of this review was to investigate: how production practices implemented during the agricultural stages of beef production in the Canadian prairie provinces influence the provision of ecosystem services from this system. More specifically, the objectives of this review were to: (1) synthesize the current knowledge on the provision of ecosystem services from prairie beef production systems, and trade-offs and synergies between different services in response to management practices; and (2) highlight information gaps and priority areas for future research.

2. Methodology

2.1. Beef production system boundaries

Canadian beef production typically consists of a cow-calf stage in which calves remain with the cows on pasture until weaning, and a finishing stage during which weaned calves are fed to slaughter weight in confinement. A backgrounding or growing stage of varying length on pasture and/or in confinement may be included in between the other two stages (Figure 2). In this ‘cradle-to-farm gate’ review, we consider all three stages, with accompanying production of forage and feed crops, and associated social and ecological structures and processes, an approach used in assessments of GHG emissions from Canadian beef production (Beauchemin et al., 2010; Legesse et al., 2016).

Approximately one third (21.1 million hectares, Mha) of agricultural land in Canada supports beef production, including 12.9 Mha of native grassland and 5 Mha of tame/seeded grassland consisting of commercial grass-legume mixtures (CRSB, 2016) (Figure 3). A further 1.8 Mha is used to produce hay (CRSB, 2016) for winter feeding. Annual crops (barley - *Hordeum vulgare*, oats - *Avena sativa,* and corn - *Zea mays*) provide forage, silage and grain, while alfalfa is the most common forage legume grown in western Canada (Sheppard et al., 2015). Across Canada, 1.4 Mha are used to grow feed crops, with the majority (1.1 Mha) used for barley (CRSB, 2016).

In response to rising demand for beef, the total cattle inventory (dairy and beef) rose by 57% nationally and by 160% in the prairie provinces between 1950 and 2015 (Statistics Canada, 2017a). The proportion of the national herd raised in these provinces has also increased over time, from 43% in 1950 to 71% in 2015 (Statistics Canada, 2017a). Canada’s beef cattle are particularly unevenly distributed: more than 80% of the national beef herd is raised in Alberta (AB; 46%), Saskatchewan (SK; 23.8%) and Manitoba (MB; 10.1%) (Statistics Canada, 2017a). Feedlots are also concentrated in southern Alberta (capacity of 1.24 million cattle - CanFax, 2015), co-located with the major barley growing areas.

Climatic conditions and soil type vary across the prairies, with the driest areas in the Mixed grassland ecoregions of the south-west prairies receiving 201-400 mm of precipitation per year (Natural Resources Canada, 2009) and dominated by Brown and Dark Brown Chernozemic soils. Precipitation increases from southwest to northeast, with the Black and Dark Grey soil zones of the Aspen parkland, Peace lowland, Boreal transition and Lake Manitoba plain ecoregions receiving 401-600 mm per year (Natural Resources Canada, 2009). From 1980-2010, mean annual temperatures ranged from -14 to -4 °C in winter (Dec-Jan-Feb; Environment Canada, 2016a) and from 14 to 20 °C in summer (Jun-Jul-Aug; Environment Canada, 2016b).

We considered nine ecosystem services: livestock[1], water supply,

[1] Information on livestock production derives from additional non-peer-reviewed sources