Biodiversity outcomes of land management choices in Alberta's agricultural lands

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Abstract

Beneficial land management practices have been the center of conservation activities to mitigate biodiversity loss in agricultural lands. However, practical methods that account for the gains and losses in biodiversity from land management choices remain lacking. To help the Alberta Agriculture Sector in exploring opportunities to participate in biodiversity markets, we used species-specific habitat models for 232 native species from five different taxonomic groups to quantify current biodiversity intactness, and estimate the gains and losses in biodiversity from a set of relevant land management scenarios across an agricultural watershed in southwestern Alberta. Here we provide a summary of the modeling methods and results, with a focus on the biodiversity outcomes of (1) converting land areas under cultivation by annual crops to tame perennials or native perennials, and (2) changing grazing intensity management in non-footprint land areas that have been historically grazed by livestock.

The current biodiversity intactness varied among the analyzed species and taxonomic groups. Overall, the examined land management scenarios resulted in increased biodiversity across agricultural lands in the studied watershed. However, the magnitude of this increase varied among examined scenarios, species, and taxonomic groups. The examined management scenarios, therefore, can be considered beneficial management practices in Alberta's agricultural lands. However, to increase the success of markets for biodiversity, attention needs to be paid to the response of species or groups of species of interest to specific land management practices.

This assessment helps understand better market opportunities associated with biodiversity management in Alberta's agricultural lands. Serving as a proof of concept, the modeling framework developed here can be used as a step toward quantifying gains or losses in biodiversity from relevant land management scenarios. Furthermore, the information generated can be used by relevant industries to ensure biodiversity conservation through the procurement of biodiversity offsets. The data produced in this study will be integrated into a decision support tool that includes a wider range of ecosystem services and land management scenarios to help manage multiple ecosystem services and biodiversity in Alberta's agricultural landscapes.

Keywords: Agriculture Sector; biodiversity intactness; beneficial management practices; grazing management; land conversion; predictive habitat models; taxonomic groups.

1. Introduction

Agricultural landscapes provide many valuable ecosystem services, including biodiversity services (Power, 2010). Sustainable agricultural systems are needed to meet the food demands of a growing human population (Landis, 2016). However, agricultural systems are often managed for higher yields, and loss of biodiversity and critical ecosystem services due to agricultural intensification has received less attention (Dainese et al., 2019). In many geographic regions, landscape simplification and over-use due to agricultural intensification have resulted in the loss of biodiversity on which agriculture products depend (Adhikari et al., 2019).

Recently, substantial efforts have been initiated to mitigate biodiversity loss in agricultural lands, primarily via beneficial land management practices that promote biodiversity the farm to landscape scales (Power, 2010; Adhikari et al., 2019). Market-based mechanisms for biodiversity conservation have been proposed to support land management practices that protect and enhance biodiversity services on agricultural lands (Jack et al., 2008; Jellinek et al., 2019). Despite the growth of these market-based approaches, practical methods that account for biodiversity outcomes from land management practices under local environmental and management conditions remain unresolved (Salzman et al., 2018). A well-functioning biodiversity market would need to include agreed and practical approaches for measuring the biodiversity values on a given land area and the increase in certain biodiversity values in addition to business as usual land practices (Di Minin et al., 2017).

The biodiversity impact of beneficial land management practices has been examined in previous studies. However, the results of those studies are mostly specific to a species or group of species and limited to a particular geographic area. Hence, it is hard to use previous studies to quantify the impacts of suggested land management practices on larger groups of species and taxa. While expert opinion can provide useful guidance for identifying where beneficial land management practices have the most potential to improve biodiversity, it can lead to substantial variation among experts in their absolute predictions of biodiversity outcomes. Experts' knowledge of biodiversity is usually limited to specific species or taxonomic groups, for which they do not necessarily share similar opinions about the magnitude and direction of species responses to a specific management practice (Dorrough et al., 2019).

To help the Alberta Agriculture Sector in exploring opportunities to participate in biodiversity markets, we used the ABMI's biodiversity models and geospatial data to better understand the potential outcomes of biodiversity from relevant land management choices in an agricultural watershed in southwestern Alberta. Specifically, we used spatially-explicit information on multi-species biodiversity intactness to assess current biodiversity and examined biodiversity impacts from: (1) converting land areas under cultivation by annual crops to tame perennials or native perennials, and (2) changing grazing intensity management in non-footprint land areas that have been historically grazed by livestock.

2. Methods

2.1. Study area

We conducted this study in the Indian Farm Creek (IFC) watershed (141.45 km^2), located in the southwest corner of Alberta (Fig. 1). The IFC watershed lies mainly in the productive Black Soil Zone of the Foothills Fescue Natural Sub-region with annual precipitation of about 515 mm. The watershed upstream is a hilly and rocky landscape with short and complex slopes, while the watershed downstream is a flat landscape with much longer and simpler slopes. The dividing area between the watershed upstream and downstream is a high relief landscape with very steep slopes (Olson et al., 2011; Fig. 1). Agriculture is the primary land-use practice in the watershed (97%) with crop and livestock production dominating the landscape. 39% of the watershed area (mostly downstream) is covered by annual crops (primarily barley) and 56% by native or tame perennials (mostly upstream). Approximately 2500 grazing cattle were estimated to be in the watershed (Olson et al., 2011).

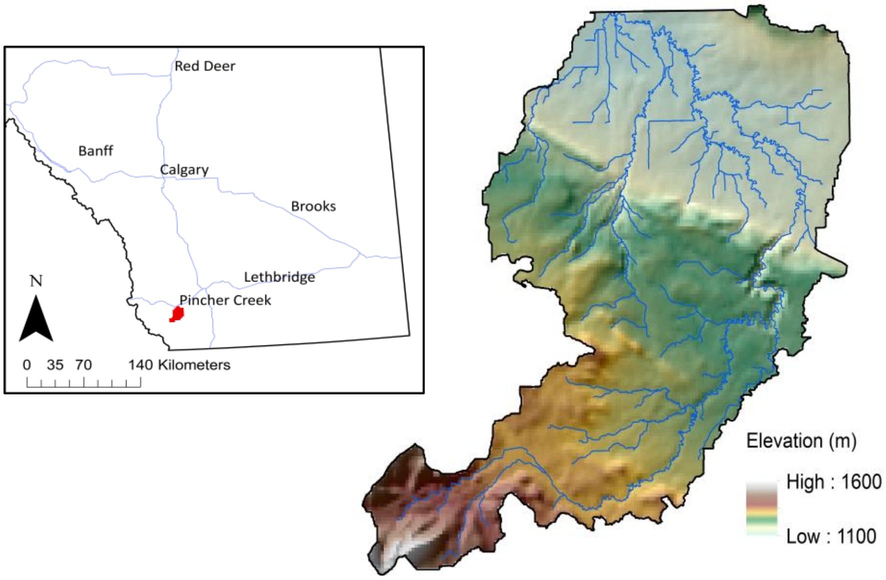

Fig. 1. Location of the IFC watershed (red area) in the province of Alberta (left) together with the relief map of the watershed (right).

2.2. Estimating current biodiversity intactness

We used biodiversity intactness (positive or negative deviation in biodiversity from a natural or reference condition; ranges from 0 to 100%; Biggs et al., 2006; Nielsen et al., 2007; Martin et al., 2019) to quantify biodiversity and its response to alternative land management scenarios across the watershed. We considered 232 native species from five taxonomic groups of vascular plants, lichens, mosses, mammals, and soil mites (152, 37, 15, 4, and 24 species, respectively) for spatially-explicit assessment of intactness across the watershed. For this study, we only considered native species that, based on the ABMI's simulated species occurrence data (ABMI, 2018c), showed a high probability of being present in the watershed area.

We delineated unique spatial units for quantification of intactness from the ABMI's Polygon Tool layer (Fig. A1). The Polygon Tool layer is intended to be used as a base layer for assessing the biodiversity value of all land in Alberta. It represents the spatial distribution of homogenous patches of natural habitat or native soil types, and human footprint types across Alberta as extracted from the ABMI's Human Footprint (ABMI, 2018a) and Native Vegetation (ABMI,2012; ABMI,2018b) layers.

For lichen, moss, mammal, and soil mite species, we used the existing species-specific habitat models developed by the ABMI (ABMI, 2018c) to spatially predict the relative abundance of individual species under two human footprint types of 'crop' and 'tame pasture' (ABMI, 2018a), as well as under a reference condition in which human footprint is back-filled by the natural habitat types that were most likely to occur before the creation of human footprint (ABMI, 2018b). We then employed these predicted relative abundances to calculate species-specific intactness under 'crop' and 'tame pasture' human footprint types across the watershed (Fig. A1). Further details of the methodology used to develop species-specific habitat models and calculate intactness for individual species are provided in Appendix 1.

For vascular plant species, we first incorporated the ABMI's field information on litter scores (range from 3 to 1; ABMI 2018d) as a proxy predictor for grazing intensity into the existing ABMI species-specific habitat models for vascular plants. We then spatially predicted the relative abundance of each analyzed species under different natural habitat or native soil types by employing grazing- intensity-modulated coefficients indicating the response of individual plant species to three proposed grazing intensity levels of 'healthy', 'healthy with problems' and 'unhealthy' that only reflected litter scores of 3, 2, and 1 (ABMI 2018d), respectively. For each species, we then calculated species-specific intactness under 'healthy with problems' and 'unhealthy' by comparing predicted species-specific abundances under these two proposed grazing intensity levels with the corresponding species-specific abundances under the 'healthy' grazing intensity level. Thus, any deviations (increases or decreases) from the proposed grazing intensity level of 'healthy', lower intactness. Further details on collection of the ABMI's field information on litter scores, as well as the methodology used to incorporate litter scores as a proxy predictor for grazing intensity into the ABMI's species-specific habitat models and calculate intactness under different grazing intensity levels, are provided in Appendix 2.

2.3. Estimating impacts of land management scenarios

Several land management scenarios have been suggested to protect biodiversity and ecosystem services in Alberta's agricultural lands. These include scenarios for the management of natural habitat and riparian ecosystems (e.g., fencing, buffer strips, grassed waterways), pastures (e.g., timing and intensity of grazing, pasture vegetation improvement), and marginal croplands (e.g., conversion to tame or native perennials). However, the nature of the ABMI's species-specific habitat models restricted our assessment to biodiversity outcomes from land conversion and grazing intensity management scenarios.

2.3.1. Land conversion scenarios

We examined biodiversity impacts of converting land areas under cultivation by annual crops to tame perennials ('crop to tame perennials' scenario) or native perennials ('crop to native perennials' scenario). For each spatial unit associated with annual crops (1077 units), we calculated multi-species intactness under the current land use or 'crop' human footprint type (ABMI, 2018a), as well as under the 'tame pasture' human footprint type (ABMI, 2018a) by averaging the mean intactness estimated for the analyzed species from five taxonomic groups. We then quantified the biodiversity outcome of the 'crop to tame perennials' scenario as the absolute difference between multi-species intactness under the 'tame pasture' and 'crop' human footprint types. In addition, we quantified biodiversity outcome of the 'crop to native perennials' scenario as the absolute deviation of multi-species intactness under the 'crop' human footprint type from a 100% intactness that was considered under the predicted reference or native soil types.

2.3.2. Grazing intensity management scenarios

We examined the biodiversity impacts of changing grazing intensity in non-footprint land areas that have been historically grazed by livestock by considering 129 native vascular plant species. In the IFC watershed, field-scale estimates on stocking density were obtained through aerial survey and producer interviews (Olson et al., 2011). However, converting stocking density information to grazing intensity is not straightforward and requires additional information, including site productivity, animal herd structure, and rate of forage offtake per animal (Hankerson et al., 2019). We therefore used ‘what if’ type scenarios to assess the impact of change in grazing intensity level on intactness of vascular plants in non-footprint land areas across the watershed.

To spatially quantify the biodiversity outcome of changes in grazing intensity level, we examined the impacts of the ‘healthy with problems to healthy’ and ‘unhealthy to healthy’ scenarios on multi-species intactness. For each spatial unit, we calculated the absolute deviation of multi-species intactness under ‘healthy with problems’ and ‘unhealthy’ from a 100% intactness that was considered under the ‘healthy’ grazing intensity level (‘healthy with problems to healthy’, and ‘unhealthy to healthy’ scenarios, respectively).

3. Results

3.1. Current biodiversity intactness

Current intactness for analyzed taxonomic groups varied between the ‘crop’ and ‘tame pasture’ human footprint types (Fig. A2). Overall, intactness for five taxonomic groups (except for mammals) were estimated to be slightly greater across spatial units associated with the ‘tame pasture’ compared to units associated with the ‘crop’ human footprint type (Fig. A1, Fig A2). However, assessment of individual species from analyzed taxonomic groups revealed a diverse range of species-specific intactness across the ‘crop’ and ‘tame pasture’ human footprint types in the watershed (Fig. A3).

The current multi-species intactness for vascular plants in non-footprint land areas varied among the proposed grazing intensity levels (Fig. A4). Across spatial units associated with natural habitat or native soil types (Fig. A1), vascular plant intactness was estimated to be greater when a ‘healthy with problems’ grazing intensity level, as opposed to an ‘unhealthy’ grazing intensity level, was assumed (Fig. A4). However, individual plant species showed varied species-specific intactness under these two proposed grazing intensity levels, specifically when an ‘unhealthy’ grazing intensity level was assumed across spatial units associated with natural habitat or native soil types in the watershed (Fig. A1, Fig. A5).

3.2. Biodiversity impacts of land conversion

Multi-species intactness for analyzed taxonomic groups varied among the examined land conversion scenarios (Fig. 2). Across spatial units associated with the ‘crop’ human footprint type (Fig. A1), both implemented land conversion scenarios resulted in an increase in multi-species intactness for different taxonomic groups. This increase, however, was relatively small under the ‘crop to tame perennials’ scenario. By contrast, the ‘crop to native perennials’ scenario resulted in a noticeably greater increase in multi-species intactness for different taxonomic groups, except for mammals, which showed the smallest increase in intactness under both land conversion scenarios (Fig. 2).

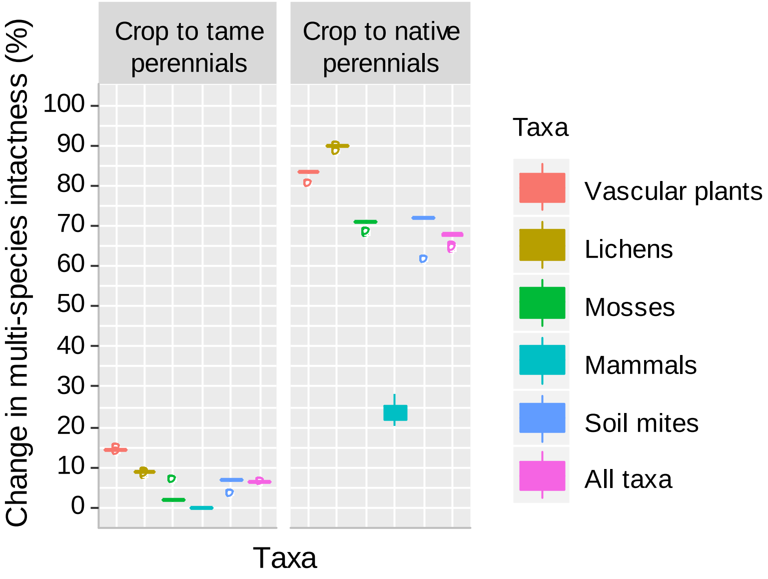

Fig. 2. Spatial variability in the impacts of implemented land conversion scenarios (vertical panels) on multi-species intactness for analyzed taxonomic groups (boxplots with different colors). Spatial change in multi-species intactness was calculated by considering the spatial units associated with crop human footprint type in the watershed (Fig. A1).

A diverse range of species responses to the implemented land conversion scenarios (Fig. 3). Although intactness decreased for a small group of species under the 'crop to tame perennials' scenario, this scenario resulted in an increase in species-specific intactness for the majority of species. The 'crop to native perennials' scenario, however, resulted in an increase in species-specific intactness for almost all species. This increase was noticeably greater for most species under the 'crop to native perennials' scenario than under the 'crop to tame perennials' scenario (Fig. 3).

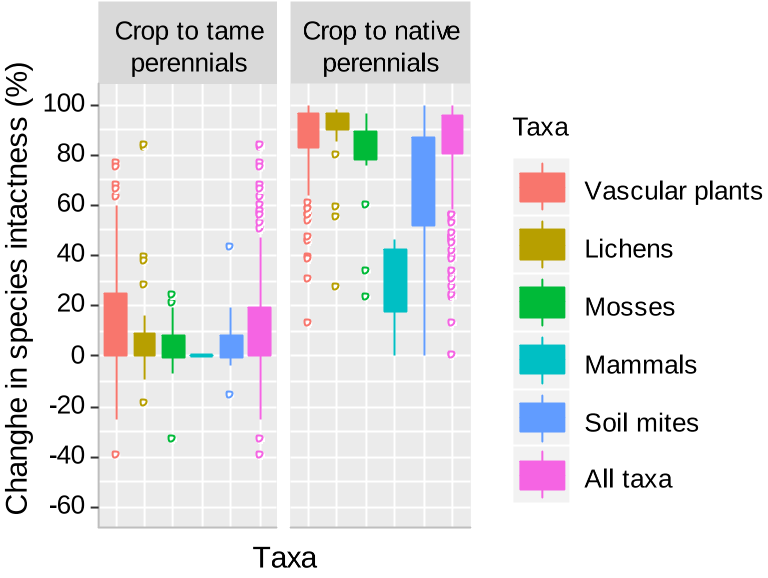

Fig. 3. Impacts of the implemented land conversion scenarios on mean intactness of individual species from analyzed taxonomic groups (boxplots with different colors). Change in species-specific intactness was calculated across spatial units associated with the 'crop' human footprint type in the watershed (Fig. A1).

3.3. Biodiversity impacts of grazing intensity management

The implemented grazing intensity management scenarios resulted in varied multi-species intactness for analyzed vascular plants (Fig. 4). Across spatial units associated with natural habitat or native soil types (Fig.

A1), both grazing intensity management scenarios increased multi-species intactness for vascular plants. This increase, however, was relatively smaller under the ‘healthy with problems to healthy’ scenario than under the ‘unhealthy to healthy’ scenario (Fig. 4).

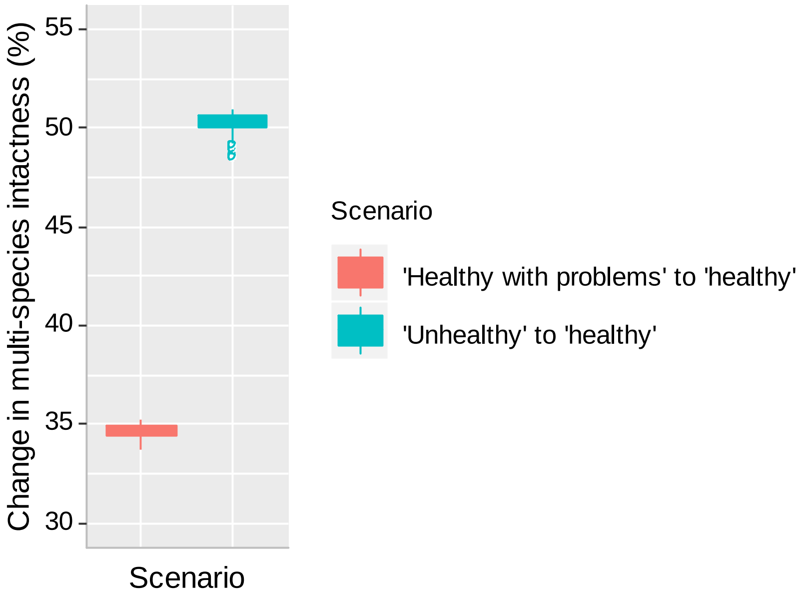

Fig. 4. Spatial variability in impacts of the implemented grazing intensity management scenarios (boxplots with different colors) on multi-species intactness for analyzed vascular plants. Spatial change in vascular plant intactness was calculated by considering the spatial units associated with the natural habitat or native soil types in the watershed (Fig. A1).

Individual vascular plant species responded differently to the implemented grazing intensity management scenarios (Fig. 4). Across natural habitat or native soil types (Fig. A1), species-specific intactness increased for almost all species under both grazing intensity management scenarios. This positive response of analyzed plant species, however, was noticeably greater for most species under the ‘unhealthy to healthy’ than under the ‘healthy with problems to unhealthy’ scenario (Fig. 5).

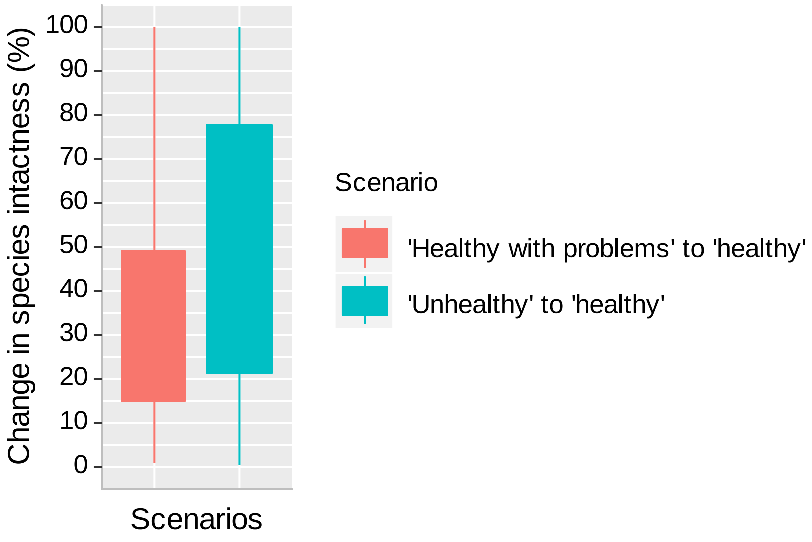

Fig. 5. Impacts of the implemented grazing intensity management scenarios (boxplots with different colors) on mean intactness of analyzed vascular plant species. Change in species-specific intactness was calculated across the spatial units associated with the natural habitat or native soil types in the watershed (Fig. A1).

4. Conclusion and implications

There has been a growing interest in biodiversity market programs as an innovative way to compensate for the biodiversity losses that occur from agricultural practices (Jellinek et al., 2019). Beneficial land management practices have been the center of conservation activities to mitigate biodiversity loss in agricultural lands at the farm to landscape scales (Power, 2010; Adhikari et al., 2019). However, measuring biodiversity is complex, and developing practical methods that account for gains and losses in biodiversity from alternative land management practices under local environmental and management conditions is technically challenging (Salzman et al., 2018).

To address this data gap for Alberta's agricultural lands and support Alberta Agriculture Sector in exploring opportunities to participate in biodiversity market programs, we explored the potential gains and losses in biodiversity from a set of relevant land management choices. By using species-specific habitat models for 232 native species from five taxonomic groups (vascular plants, lichens, mosses, mammals, and soil mites), we quantified current biodiversity intactness to better account for gains and losses in biodiversity from land management scenarios related to land conversion and grazing intensity management across an agricultural watershed.

We found pronounced variation in biodiversity intactness for analyzed species and taxonomic groups across the agricultural lands in the studied watershed. Overall, implementing land conversion scenarios resulted in biodiversity increases across the annual croplands in the watershed. However, the magnitude of this gain in biodiversity varied among analyzed taxonomic groups and was noticeably greater when the annual croplands were converted to native perennials than to tame perennials. Nevertheless, assessment of the response of individual species to the implemented land conversion scenarios revealed a diverse range of gains, or even losses, in biodiversity for the analyzed species.

We also found pronounced variation in biodiversity intactness for analyzed vascular plant species under the assumed grazing intensity levels for natural habitat or native soil types in the watershed. Overall, implementing grazing intensity management scenarios resulted in a gain in biodiversity for vascular plants across the watershed. However, the magnitude of this gain varied among analyzed plant species and was greater when the assumed 'unhealthy' grazing intensity level was substituted with the 'healthy' grazing intensity level.

Our findings collectively suggest that the implemented land management scenarios can enhance biodiversity and, therefore, can be proposed as beneficial management practices in Alberta's agricultural lands. However, the increase in biodiversity depends on the species or group of species (taxonomic group) of interest. Hence, to increase the success of markets for biodiversity, attention needs to be paid to the response of species or groups of species of interest to specific land management practices.

Our results are sensitive to the set of species and taxonomic groups analyzed. The implemented land management scenarios might affect a wider range of species and taxonomic groups than can currently be modeled due to the lack of necessary species-specific monitoring data. Furthermore, the nature of the ABMI's species-specific habitat models restricted our ability to assess temporal changes in biodiversity under the examined land management scenarios. It could take several years to reach the estimated level of biodiversity (close to pre-disturbance biodiversity levels) after implementation of the examined scenarios. Therefore, identifying and assessing the suitability of other available biodiversity data sources is a priority for advancing our knowledge of the biodiversity outcomes from relevant land management choices in Alberta's agricultural lands.

Our results provide a strong foundation for better understanding market opportunities associated with land management activities that encourage biodiversity services in Alberta's agricultural lands. Serving as a starting point and a proof of concept, the modeling framework developed here can be used as an important learning step to quantify gains or losses in biodiversity from alternative land management scenarios, and consequently identify beneficial management practices that encourage biodiversity in Alberta's agricultural lands. It is, therefore, essential to prioritize alternative land management practices that might improve the biodiversity of agricultural lands. Currently, information and knowledge developed through this project are being integrated into a decision support tool aimed at producing credible knowledge and information necessary for the development of market programs that improve multiple ecosystem services and biodiversity in Alberta's agricultural landscapes.

Biodiversity markets are experiencing rapid growth from the eco-labeling of consumer products such as crops and livestock meat. With further enhancement of the standards and metrics for biodiversity protection, companies are under increasing pressures to ensure biodiversity conservation through procurement of biodiversity offsets. Conservation markets for biodiversity have the potential to benefit agriculture producers, the environment, and society. Credible knowledge and information on the biodiversity outcomes of beneficial management practices can be used by industry in sustainability reporting. The relevant industries can use the information generated from this study to make informed decisions in their business to be more competitive, environmentally friendly, and socially responsible. Opportunities to integrate biodiversity metrics into sustainability reporting initiatives still need to be further explored and applied.

5. Acknowledgments

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Appendix 1: Developing predictive habitat models for estimating biodiversity intactness

We used biodiversity intactness to quantify biodiversity and its response to alternative land management scenarios across the watershed. Compared to more commonly used measures such as species richness, intactness better reflects the sensitivity of species to land use (Biggs et al., 2006; Nielsen et al., 2007; Martin et al., 2019). It integrates the responses of species that are both positively and negatively affected by disturbance relative to what would be expected in the absence of human intervention (Lamb et al., 2009). Therefore, intactness is a more robust measure for quantifying biodiversity impacts from alternative land management scenarios.

Intactness is calculated as a measure of deviance in the relative abundance of species from the natural condition, where 100% intactness represents reference or natural condition with no human intervention, and

0% intactness represents maximum human disturbance or completely degraded biodiversity (Nielsen et al., 2007; ABMI, 2018c). Consequently, intactness declines when species abundance deviates either positively or negatively from its expected abundance under natural or reference conditions. Because intactness for individual species decreases from 100% with either downwards or upwards differences from reference conditions, an 'increaser' species does not cancel out a 'decreaser' species; instead, both contribute to lowering the average intactness (ABMI, 2018c).

We employed the species-specific habitat models developed by the ABMI (ABMI, 2018c) to estimate intactness across the IFC watershed. Since 2007, the ABMI has generated rich biodiversity and habitat attribute data on a large number of species from a wide range of taxonomic groups, including birds, mammals, soil mites, vascular plants, lichens, and mosses (ABMI, 2018d). The ABMI's accumulated biodiversity and habitat databases support the creation of predictive species models that provide information on spatial distribution, habitat associations, responses to human footprint, and the predicted relative abundance of individual species for over 800 species (ABMI, 2018c).

The ABMI's predictive habitat models are developed using a set of statistical methods to associate the relative abundance of each species measured at the ABMI sites to various sets of variables. These variables include: (1) habitat types (e.g., forest stand types by broad age classes, and open vegetation including grass, shrub, open wetland, open water, and barren), (2) native soil types (e.g., productive, clay, saline and rapid-draining), (3) human footprint categories (e.g., cutblocks, cultivation, industrial and residential developments, roads and other linear and non-linear features), (4) geographic location (latitude and longitude), and (5) broad climate variables (e.g., monthly climate normals of temperature and precipitation; ABMI, 2018c).

The ABMI's predictive habitat models provide habitat coefficients separately for the northern or forested (mainly Boreal, and Foothills) and southern or prairie (mainly Parkland, and Grassland) regions of the province. These species-level habitat coefficients enable us to spatially predict the relative abundance of each analyzed species under current natural habitat or native soil types (ABMI, 2018b) and human footprint types (ABMI, 2018a), as well as under a reference condition in which human footprint is back-filled by the natural habitats that were most likely to occur before the creation of human footprint (ABMI, 2018b).

We carried out predictions of the relative abundance of each analyzed species under current and reference conditions by employing: (1) species-level habitat coefficients estimated for different soil types of natural habitats (i.e., productive, clay, saline, and rapid-draining), and human footprint types in the prairie region (south); (2) information on the current natural habitat or native soil types, and human footprint types across the watershed (Fig. A1); and (3) geographic location and broad climate variables (i.e., monthly climate normals of temperature and precipitation) for the watershed area. For each species, we then calculated intactness (%) as:

Current / Reference × 100, when current abundance is smaller than reference abundance, or

Reference / Current × 100, when reference abundance is smaller than current abundance (ABMI, 2018c)

Finally, we used species-specific intactness to assess variation in current intactness across the watershed (Fig. A2, Fig A3). Additional details on the methodology used to develop species-specific habitat models and calculate intactness for individual species are explained in ABMI, 2018c.

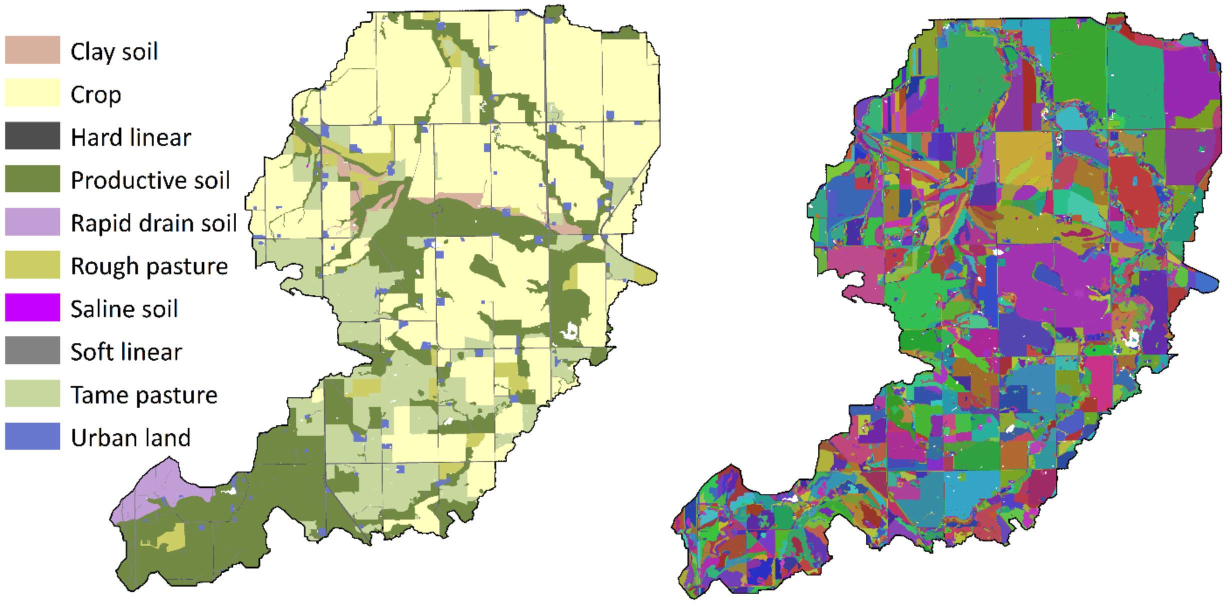

Fig. A1. Spatial distribution of upland natural habitat or native soil types, and human footprint types (left) together with the spatial modeling units considered for estimating biodiversity intactness across the IFC watershed (11073 units).

The ABMI's species-specific habitat models might have large errors for uncommon species. The spatial variation in the relative abundance of analyzed species might not be accurately captured by the use of estimated habitat coefficients for different native soil types of natural habitats (i.e., productive, clay, saline, and rapid-draining). In our analysis, the same habitat models were used to predict the relative abundances of analyzed species under both current and reference (i.e., no human footprint) conditions as we do not know the actual abundances of the analyzed species prior to the creation of human footprint or under natural habitats. Also, the reference habitat or vegetation types were predicted for large human footprint areas based on adjacent undisturbed habitat types and knowledge about the type of land areas in which different human footprint types might occur. Therefore, the reference natural habitat or vegetation type might not be accurately predicted for all the spatial modeling units considered in our analysis. Finally, in non-footprint land areas historically grazed by livestock, grazing impact was only considered for improving the predictions of vascular plant species. Updating habitat models with grazing impacts for species from other taxonomic groups is anticipated.

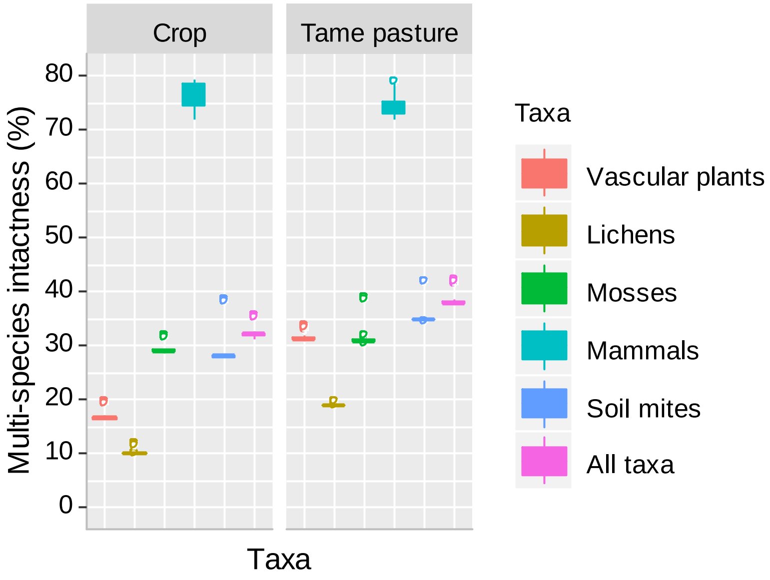

Fig. A2. Spatial variability in multi-species intactness for analyzed taxonomic groups (boxplots with different colors) across the modeling units associated with 'crop' (1077 units) and 'tame pasture' (582 units) human footprint types (vertical panels) in the IFC watershed (Fig. A1). Further description of these two human footprint types is provided in ABMI, 2018a.

Fig. A3. Variability in mean intactness of individual species from analyzed taxonomic groups (boxplots with different colors) across the 'crop' and 'tame pasture' human footprint types (vertical panels) in the IFC watershed (Fig. A1).

Appendix 2: Incorporating grazing intensity into predictive habitat models

In footprint land areas (e.g., cultivated areas with annual crops), the ABMI's intactness compares current abundances of species to their predicted abundances under reference conditions with natural habitat or soil types (ABMI, 2018b). However, in non-footprint land areas that have historically been grazed, selection of reference condition needs extra caution as grazing has been part of the history of these natural habitat areas (Herrero-Jáuregui and Oesterheld 2018) and a significant factor contributing to their biodiversity (Pulungan et al., 2019; Tonn et al., 2019).

The ABMI's species-specific habitat models predict the relative abundance of individual species as a function of niche-related predictors (vegetation type, soil type, bioclimatic variables, local human footprint), and spatial coordinates that limit a species' distribution (see Appendix 1 for further information). Yet, the ABMI's predictive models do not explicitly include grazing impacts. To improve the habitat models, we used the ABMI's field information on litter scores as a proxy measure for grazing intensity in non-footprint land areas covered with natural habitat types. Through its Range Status Assessment program, the ABMI has collected litter normals at more than 130 sites where biodiversity data has been obtained (ABMI, 2018d). The litter normals are assigned based on the amount, distribution, evenness, and patchiness of litter (i.e., standing dead and fallen dead plant material, and variably decomposed material on the soil surface) across the ABMI site.

In the field, one of the three litter scores of 1, 2, and 3 is given to the studied sites (ABMI, 2018d). The highest score (3) is given where litter is in the range of 65% to 100% of the expected level under proper grazing level, and litter amounts are more or less uniform across the site and include standing dead plant material, fallen dead plant material and variably decomposed material on the soil surface. The middle score or (2) is given where litter is in the range of 35% to 65% of the expected level under proper grazing level, and litter amounts are slightly or moderately reduced and are somewhat patchy across the site with fallen dead plant material and variably decomposed material on the soil surface being the dominant litter types. Finally, the lowest score (1) is given where litter is < 35% of the expected level under proper grazing level, and litter amounts are greatly reduced or absent with little or no standing or fallen litter and decomposing material on the soil surface as the main type of litter. Additional details on the methodology used to collect litter normals in the field are explained in ABMI, 2018d.

We incorporated the ABMI's field information on litter scores as a proxy predictor for grazing intensity into the ABMI's species-specific habitat models for vascular plants. Specifically, we assessed the fractions of additional variance explained by the litter score data after controlling for non-grazing predictors that already included in the ABMI's predictive habitat models, as explained in Appendix 1.

We then used the updated species-specific habitat models with a proxy predictor for grazing intensity to predict the relative abundance of each analyzed plant species under three proposed grazing intensity levels: 'healthy', 'healthy with problems', and 'unhealthy'. Although the ABMI's Range Status Assessment includes more questions for assessment of range health, these three proposed grazing intensity levels only reflected litter scores of 3 to 1, respectively (ABMI, 2018d).

By considering the 'healthy' level of grazing intensity as the reference condition, we then calculated species-specific intactness under two proposed grazing intensity levels: 'healthy with problems' and 'unhealthy'. Finally, we used species-level intactness to assess variation in current intactness under these two latter grazing intensity levels (Fig. A4, Fig. A5) across natural habitat or native soil types of the watershed (Fig. A1).

Fig. A4. Spatial variability in multi-species intactness for analyzed vascular plants under the proposed grazing intensity levels (boxplots with different colors). The values represent mean intactness of analyzed species across the modeling units associated with natural habitat or native soil types (3374 units) in the IFC watershed (Fig. A1).

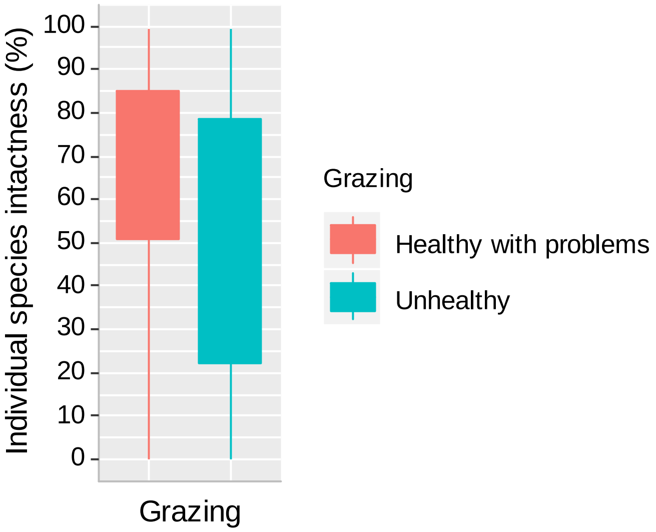

Fig. A5. Variability in mean intactness of individual plant species under the proposed grazing intensity levels (boxplots with different colors). The values represent species-specific intactness across the natural habitat or native soil types in the IFC watershed (Fig. A1).

The use of the ABMI's litter score data as a proxy predictor for grazing intensity might have caused additional uncertainty in the prediction of relative abundances for analyzed plant species. The ABMI's sampling scheme was not designed to statistically represent different grazing intensity levels. Also, the long-term impacts of grazing on analyzed plant species might not be accurately captured by the use of litter scores as a proxy predictor for grazing intensity. More precise surveys of grazing intensity or collection of more litter score data by targeting sites with a range of grazing intensity levels or litter scores would likely lead to a more accurate assessment of grazing intensity impacts on individual plant species.

6. References

ABMI (Alberta Biodiversity Monitoring Institute). 2012. ABMI Wall-to-Wall Land Cover Map circa 2010, Version 1.0. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at: www.abmi.ca.

ABMI (Alberta Biodiversity Monitoring Institute). 2018a. 2016 Human Footprint Map Layer Version 1.0 - Metadata. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at: abmi.ca.

ABMI (Alberta Biodiversity Monitoring Institute). 2018b. Alberta Backfilled Wall-to-Wall Vegetation Layer Version 6 - Metadata. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at: abmi.ca.

ABMI (Alberta Biodiversity Monitoring Institute). 2018c. Manual for Species Modeling and Intactness (20029), Version 2016-04-14. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at: abmi.ca.

ABMI (Alberta Biodiversity Monitoring Institute). 2018d. Terrestrial field data collection protocols (abridged version) 2017-03-27. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at: abmi.ca.

Adhikari, S., Adhikari, A., Weaver, D.K., Bekkerman, A., and Menalled, F.D. 2019. Impacts of agricultural management systems on biodiversity and ecosystem services in highly simplified dryland landscapes. Sustainability *11*, 3223.

Biggs, R., Reyers, B., Scholes, R.J. 2006. A biodiversity intactness score for South Africa. South African Journal of Science 102, 277-283.

Dainese, M., Martin, E.a., Aizen, M., Albrecht, M., Bartomeus, I., Bommarco, R. et al. 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. bioRxiv preprint first posted online Feb. 20, 2019.

Di Minin E, Soutullo A, Bartesaghi L, Rios M, Szephegyi MN, Moilanen A. Integrating biodiversity, ecosystem services and socio-economic data to identify priority areas and landowners for conservation actions at the national scale. Biological Conservation 206, 56–64.

Dorrough, J., Sinclair, S.J., and Oliver, I. 2019. Expert predictions of changes in vegetation condition reveal perceived risks in biodiversity offsetting. PLoS ONE 14: e0216703.

Hankerson, B.R., Schierhorn, F., Prishchepov, A.V., Dong, C., Eisfelder, C. and Müller, D. 2019 Modeling the spatial distribution of grazing intensity in Kazakhstan. PLoS One 14 e0210051.

Herrero-Jáuregui, and Oesterheld. 2018. Effects of grazing intensity on plant richness and diversity: a meta-analysis. Oikos 127, 757–766.

Jack, K., Kousky, C., and Sims, K. 2008. Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. Proceedings of the National Academy of Sciences 105, 9465-9470.

Jellinek, S., Wilson, K.A., Hagger, V., Mumaw, L., Cooke, B., Guerrero, A.M., Erickson, T.E., Zamin, T., Waryszak, P., and Standish, R.J. 2019. Integrating diverse social and ecological motivations to achieve landscape restoration. Journal of Applied Ecology 56, 246–252.

Lamb, E.G., Bayne, E., Holloway, G., Schieck, J., Boutin, S., Herbers, J., Haughland, D.L. 2009. Indices for monitoring biodiversity change: Are some more effective than others? Ecological Indicators 9, 432-444.

Landis, D.A. 2016. Designing agricultural landscapes for biodiversity-based ecosystem services. Basic and Applied Ecology 18, 1–12.

Martin, P. A., Green, R. E., Visconti, P. and Balmford, A. 2019. The biodiversity intactness index may underestimate losses. Nature Ecology & Evolution 3, 862–863.

Nielsen, S.E., Bayne, E.M., Schieck, J., Herbers, J., and Boutin, S. 2007. A new method to estimate species and biodiversity intactness using empirically derived reference conditions. Biological Conservation 137, 403-414.

Olson, B.M., Kalischuk, A.R., Casson, J.P., and Phelan, C.A. 2011. Evaluation of cattle bedding and grazing BMPs in an agricultural watershed in Alberta. Water Science & Technology 64, 326–333.

Power, A.G. 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B 365, 2959–2971.

Pulungan, M.A., Suzuki, S., Gavina, M.K.A., Tubay, J.M., Ito, H., Nii, M., Ichinose, G., Okabe, T.,Ishida, A., Shiyomi, M., Togashi, T., Yoshimura, J., and Morita, S. 2019. Grazing enhances species diversity in grassland communities. Scientific Reports 9,11201.

Salzman J., Bennett G., Carroll N., Goldstein A., Jenkins M. 2018. The global status and trends of payments for ecosystem services. Nature Sustainability 1, 136–144.

Tonn, B., Densing, E.M., Gabler, J., and Isselstein, J. 2019. Grazing-induced patchiness, not grazing intensity, drives plant diversity in European low-input pastures. Journal of Applied Ecology 56, 1624-1636.