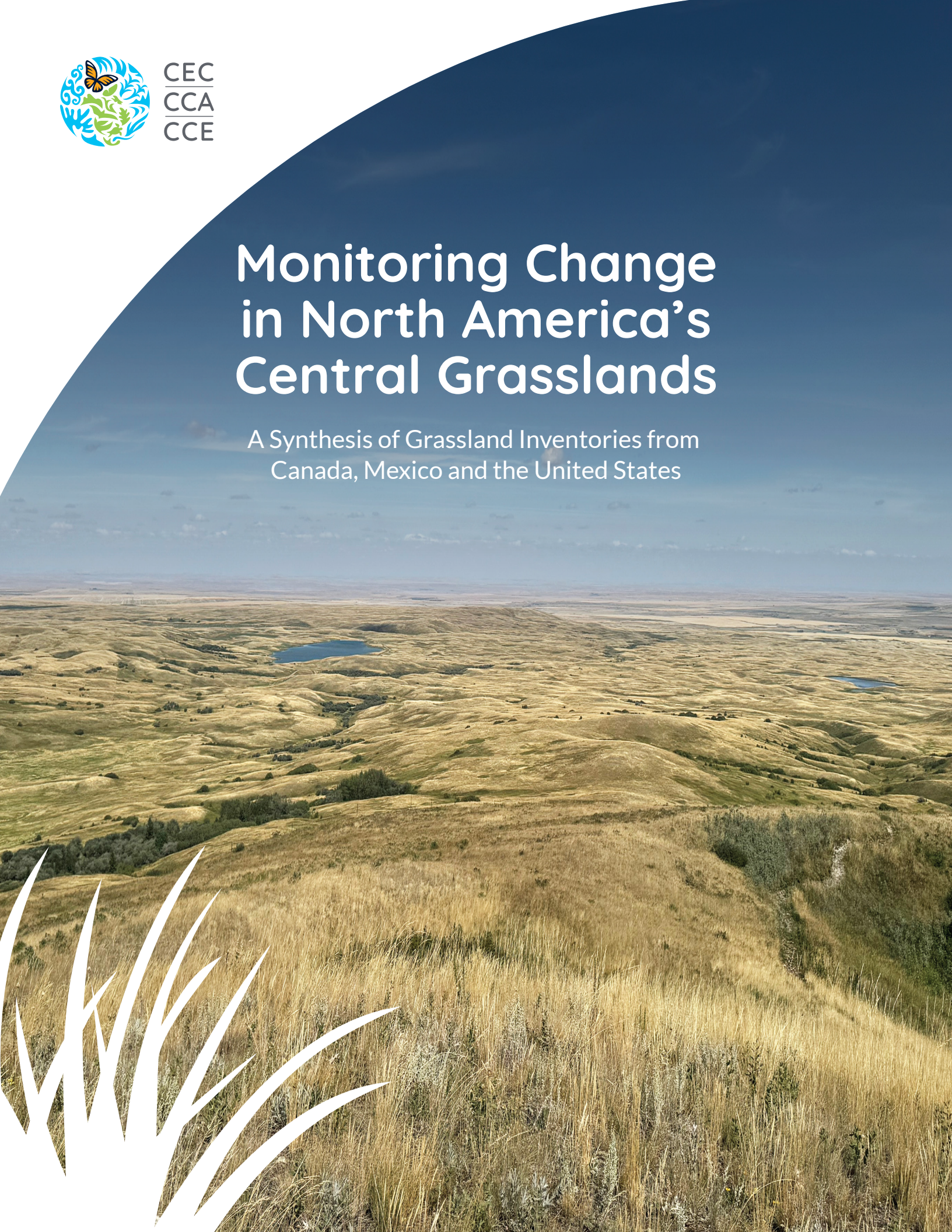




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Monitoring Change in North America's Central Grasslands

A Synthesis of Grassland Inventories from
Canada, Mexico and the United States



Please cite as:

CEC. 2025. *Monitoring Change in North America's Central Grasslands: A Synthesis of Grassland Inventories from Canada, Mexico and the United States*. Montreal, Canada: Commission for Environmental Cooperation. 40 pp.

This publication was prepared by Pattison Resource Consulting, Ltd., for the Secretariat of the Commission for Environmental Cooperation. The information contained herein is the responsibility of the author and does not necessarily reflect the views of the governments of Canada, Mexico or the United States of America.

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ISBN: 978-2-89700-384-5

Disponible en français—ISBN: 978-2-89700-385-2

Disponible en español—ISBN: 978-2-89700-383-8

Legal deposit—Bibliothèque et Archives nationales du Québec, 2025

Legal deposit—Library and Archives Canada, 2025

Cover photo: Cypress Hills, Alberta; John K. Pattison-Williams

Publication Details

Document category: Project publication

Publication date: November 2025

Original language: English

Review and quality assurance procedures:

Final Party review: September 2025

QA 390

Project: Operational Plan 2021 / Grasslands Conservation and Migratory Birds

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List of Abbreviations and Acronyms

AAFC	Agriculture and Agri-Food Canada
CEC	Commission for Environmental Cooperation
CLI	Canada Land Inventory
Conabio	National Commission for the Knowledge and Use of Biodiversity (Mexico) / <i>Comisión Nacional para el Conocimiento y Uso de la Biodiversidad</i>
Conafor	National Forestry Commission (Mexico) / <i>Comisión Nacional Forestal</i>
CS	Community/Citizen Science
ECCC	Environment and Climate Change Canada
EO	Earth Observation
GRS	Grassland Remote Sensing
GT	Ground Truthing
GVI	Grassland Vegetation Inventory
Inegi	National Institute of Statistics and Geography (Mexico) / <i>Instituto Nacional de Estadística y Geografía</i>
IUCN	International Union for the Conservation of Nature
MODIS	Moderate Resolution Imaging Spectroradiometer
NALCMS	North American Land Change Monitoring System
NRCS	Natural Resources Conservation Service
PLVI	Primary Land and Vegetation Inventory
PHJV	Prairie Habitat Joint Venture
Snib	National Information System on Biodiversity (Mexico) / <i>Sistema Nacional de Información sobre Biodiversidad</i>
SRC	Saskatchewan Research Council
TEK	Traditional Ecological Knowledge
UAV	Unmanned Aerial Vehicle
USGS	United States Geological Survey

Abstract

Grassland loss across North America has prompted significant conservation efforts, underscoring the need to accurately understand the extent of this loss over time. To address this need, various grassland inventory initiatives have been established across Canada, Mexico and the United States. These diverse inventories employ different methodologies, which can yield varying results, potentially compromising the effectiveness of conservation messages and impeding decision-making for grassland conservation. As such, the Commission for Environmental Cooperation (CEC) supported the development of this report to list the inventories, compare their approaches, and gather input of grassland remote sensing (GRS) and monitoring experts through virtual workshops conducted from 2023 to 2024. A literature review and information drawn from the workshops identified 33 central grassland inventories across North America. These inventories have leveraged advancements in remote sensing technology to conduct more efficient and comprehensive assessments at larger scales. However, efforts to assess ground-truthing accuracy require significant time and human effort, causing delay between when data is collected and when it is verified and published. Additionally, there is limited collaboration among inventories to enhance methodologies, standardize practices, or share data. Recommendations for improving standardization include supporting a community of practice, committing to data sharing, and conducting a technical analysis of methods. Such initiatives would advance the field of GRS and grasslands monitoring, provide a consistent message to stakeholders, and assist in mitigating the loss of the central grassland biome in North America.

Executive Summary

Approximately 60% of the native grassland ecosystems in North America have been converted to other land uses or degraded in the last century (Central Grasslands Roadmap 2022; FWS 2024) and 32 million acres have been converted to cropped agriculture since 2012 alone (WWF 2023). Causes of this degradation are mostly from conversion to cultivated agriculture or overgrazing leading to other non-grassland vegetation cover (mostly woody encroachment) resulting in a loss of biodiversity and ecosystem services. As such, grassland loss has been identified as an issue of pressing concern by a wide range of stakeholders, including governments, nongovernmental organizations, local communities, conservation groups, and academics across the continent. When faced with the urgent issue of grassland loss, it is integral to understand the current inventory of existing grasslands as a foundation for considering conservation incentives, promoting government funding and regulation, and implementing landscape-level strategies. Multiple conservation efforts have arisen to address this issue in different local contexts, with different visions and engagement approaches.

Foundational to these efforts is a clear, consistent, and coherent understanding of the extent of grassland loss. However, this coherence is complicated by the diverse political, economic, social, and environmental contexts across the North American grassland biome. Over 30 different grassland inventories currently exist across the continent, each using different methodologies. To address these challenges, the Commission for Environmental Cooperation (CEC) supported the development of this report to list these inventories, compare their approaches, and incorporate insights from grassland remote sensing (GRS) and monitoring experts through virtual workshops conducted from 2023 to 2024. The varying narratives from the identified inventories present a challenge for end-users and the public, who may receive conflicting messages about the rate of grassland loss and the urgency of the issue. Highlights from the inventory review include:

- **Diverse Methodologies:** Multiple grassland inventories across North America use a mix of satellite and mapping techniques to create their final products.
- **Limited Coordination:** Interaction among provincial/state and federal agencies is often minimal, as stated by lead and collaborating organizations represented at the expert workshops.
- **Varied Definitions:** Definitions of grasslands vary among inventories, ranging from binary classifications (native versus tame) to broader categories such as “disturbed” by human activities or invasive species, complicating standardization efforts.
- **Inconsistent Accuracy Assessments:** Accuracy assessments vary widely among inventories, lacking a standardized approach, and error rates are not well defined or equitable across different methodologies.
- **Diverse and Limited Ground Truthing Methods:** Ground-truthing methods are not standardized and often opportunistic, though some inventories use roadside surveys and other physical checks.
- **Technological Advances:** Advances in satellite technology and access have enabled faster development of inventories and new techniques.
- **Data Accessibility:** While visualization maps are commonly available online, accessing raw data can be challenging.
- **Collaborative Efforts:** Many inventories involve collaborative partnerships with other agencies, though not all collaborations are fully documented.

To address limitations and challenges, the best practices identified in the workshops and supported by the literature review include:

- **Establish a Community of Practice:** Develop a collaborative network across multiple inventories.
- **Leverage New Technologies:** Use advanced satellite technologies to improve existing inventories.

- **Involve End-Users and Practitioners Early:** Include end-users and practitioners in the design stage to ensure practicality and support for ground-truthing and implementation.
- **Implement Data Sharing Plans from the Start:** Establish data sharing protocols from inception of inventories development.
- **Enhance Engagement with Indigenous Communities:** Actively involve Traditional Ecological Knowledge (TEK) and Indigenous communities in the process.
- **Incorporate Human Dimensions and Policy Insights:** Engage with experts in human dimension and policy to address broader impacts and integration.

This report summarizes the current state of grasslands monitoring in North America through a review of inventories, a description of limitations and challenges, best practices, and reflections on next steps for standardization. Results from this analysis indicated that over 30 inventories exist across Canada, Mexico and the United States, each with their own strengths and limitations. However, by supporting a community of practice, these limitations can be addressed and allow for a standardized approach where information and methodologies can be shared to allow for common messaging around grassland loss.

Supported by the CEC's unique role in trilateral environmental cooperation, the integration of published literature with perspectives from workshop participants makes this report unique and valuable, with results providing a foundation to inform discussion on future grassland research and policy efforts. The intent is for the information to serve as a starting point to enhance existing grassland conservation efforts, promote new cooperation, and address the ongoing loss of North America's Central Grasslands.

Acknowledgments

Pattison Resource Consulting Ltd. acknowledges the administrative support of Antoine Asselin-Nguyen, Nicole Goñi and Lucie Robidoux from the CEC; conceptual guidance from the CEC steering committee members Christian Artuso, Natalie Savoie, Vicente Rodriguez Contreras, Jose Manuel Galindo Jaramillo, Sigrid Gutierrez Aquino, Samantha Brooke, John Carlson, and Orien Richmond; and reviewers of this report: Sarah Olimb (United States), Thuy Doan and Bill Houston (Canada), Rurik List and Jose Armando Alanis de la Rosa (Mexico), and Arvind Panjabi (United States and Mexico).

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*Disclaimer: The affiliations of workshop participants mentioned in this report are included for reference purposes only. Note that participants' contributions were made in their personal and professional capacity as experts. The views and opinions expressed in the report are solely those of the participants and do not necessarily represent the positions of their affiliated organizations.

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1 Introduction

Grasslands cover between 30–50% of the earth's surface and these landscapes are integral to the functioning ecological systems and for human welfare (Remote Sensing 2022; Encabo et al., 2023; Stevens, 2018). In 2008, the International Union for the Conservation of Nature (IUCN) asserted that temperate grasslands were the most endangered ecosystem on the planet (IUCN 2010). Defining grasslands as *an ecosystem in which grass is the dominant vegetation* (FAO 2005)¹ this ecosystem is the second largest terrestrial landscape on earth (Yan et al. 2023). Yet as human populations grow, increasing consumptive demand on natural resources, these historic grassland landscapes are now transected and overlaid with vast tracts of cultivated crops, human transportation corridors and urban areas, and suffering from desertification and shrub encroachment enhanced by climate change (Yan et al. 2023).

In the North American central grassland biome, the trend of conversion has been observed for decades (Pieper 2005). Although estimates vary, roughly 60% of historic grasslands have been lost (Central Grasslands Roadmap 2022; FWS 2024) the Central Grasslands Roadmap estimates that approximately 435 million acres of grassland has been lost (Central Grasslands Roadmap 2022; Gage, Olimb, and Nelson 2016) and 32 million acres since 2012 (WWF 2023). Due to the vast size of the North American central grasslands—extending from southern Canada through the Central United States to northern Mexico—the economic, social, and environmental factors driving the conversion differ. Published and technical literature on grassland conversion identifies primary drivers as cultivated crop conversion (Olimb and Robinson 2019) and forest transition expansion or woody encroachment (Robinson, Hopkinson, and Vanderwel 2021); common secondary drivers include desertification (Reynolds et al. 2007), urban expansion (Augustine et al. 2021; Rabbetts et al. 2023) and climate change (Harrison, Gornish, and Copeland 2015). Demand for alternative renewable energy sources is also exacerbating this loss (Ott et al. 2021), as suggested in recent examples of investments in renewable energy and the associated demand for annual crops as feedstock (Western Producer 2022). Combined, these losses are substantial.

A foundational component of conserving this threatened ecosystem is a precise understanding of the current extent of grasslands and the rate of loss over time (Li et al., 2021; Reinermann Asam, and Kuenzer

¹ A common definition of grasslands was identified as a challenge and discussed at the CEC expert workshops in 2023 and 2024. As no common definition was agreed upon, the general definition from *Grasslands of the World* (FAO 2005) is used in this context.

2020; Remote Sensing 2022; Wang et al. 2022). Grassland inventories are an essential tool that economists, social scientists and policymakers use to guide land management decisions. However, due to diverse political and geographical contexts, there are multiple approaches, definitions and challenges that exist. For example, in Canada, central grassland change is mapped by three different federal government agencies and three provincial government agencies, and to date there has been limited² success in integration. The United States and Mexico have a similar issue with integration, and while initiatives like the Central Grasslands Roadmap is seeking to track change at a biome level, tracking grassland change at the biome level is even more challenging.

In response to the urgent need for integration of the various grassland inventories and methodologies, the Commission for Environmental Cooperation (CEC)³ organized a series of workshops, and ultimately developed this report, to understand the trends and synthesise the current state of knowledge of grassland monitoring in North America. Informed by both a comprehensive online search of grassland remote sensing inventories and facilitated discussions with representatives of inventories across Canada, Mexico, and the United States, this report seeks to synthesize the state of knowledge, identify approaches to integration and build capacity for future collaboration between disparate initiatives.

Section 2 contains relevant background information, including the study area and a brief literature review on grassland remote sensing (GRS); Section 3 presents a scan of existing inventories, including the methodological approach taken and identified strengths and limitations; Section 4 summarizes identified best practices; Section 5 summarizes the data and information needs required for integration; Section 6 explores the opportunities and challenges required for standardization of inventories; Section 7 explores future directions and capacity building for integration; and Section 8 contains conclusions and limitations of the report.

² The Canadian Forage and Grassland Association (CFGa) has been funded by Environment and Climate Change Canada (ECCC) to establish a National Grasslands Inventory; that process was completed in 2024 with finalized results pending at the time of this report.

³ The CEC is supported by the governments of Canada, Mexico and the United States, and seeks to enhance environmental cooperation in North America.

2. Background and Approach

2.1 Purpose and Study Area

The Commission for Environmental Cooperation (CEC), established in 1994 by the governments of Canada, Mexico, and the United States, brings together a wide range of stakeholders, including the public, Indigenous people, youth, nongovernmental organizations, academia, and the business sector, to seek solutions to protect North America's shared environment while supporting sustainable development for the benefit of present and future generations (CEC, 2024). The [Grasslands Conservation and Migratory Birds](#) project of the CEC has an objective to produce knowledge to inform decision-making and actions to stop and prevent the loss of the Central Grasslands of North America, and support sustainable grasslands, wildlife, and human communities. The study area for this report is the Central Grasslands biome, shown in Figure 1 below.

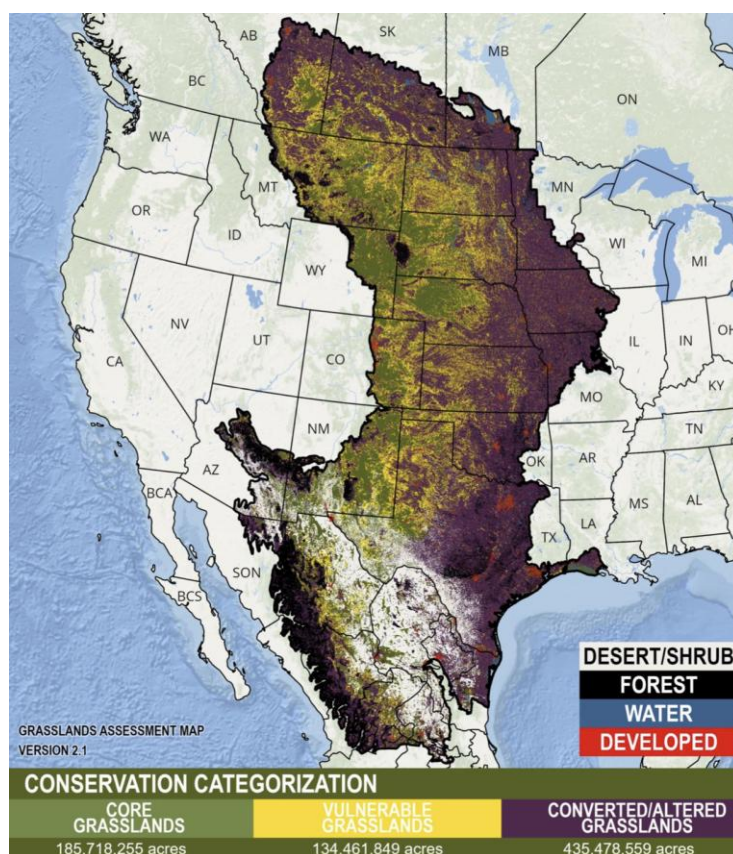


Figure 1. Central Grasslands Roadmap Grasslands Assessment Map, Version 2.1 (2024)

Enhancing collaboration between experts on the current state of grasslands monitoring in Canada, Mexico, and the United States is necessary to identify and evaluate different approaches to monitoring change, identify best practices and provide opportunities for collaboration. This collaboration was conducted at four levels: i) a preliminary scoping workshop held in May 2023 with representatives from all three countries, designed to understand initial perspectives and needs; ii) a second detailed workshop held in September 2023 containing presentations from various inventories and also focused on issues arising from the first session; iii) a third workshop with sessions focusing on national Mexican collaboration held in April 2024 and on trilateral areas of collaboration held in May 2024; and iv) this final technical report on the state of grassland monitoring in North America that summarizes information from those workshops, augmented by published literature and a review of existing grassland inventories.

2.2 Review of Practices in Grasslands Monitoring

While the summaries provided below do not provide an exhaustive exploration of the literature on grassland remote sensing, conclusions from these published systematic reviews elevates and enforces the learnings from the CEC workshops in 2023 and 2024, with application to grassland ecosystems and beyond. The studies explored below can be seen as a starting point for further scientific reading on the subject, that will provide information to enhance the theory and application of central grassland inventories in North America.

2.2.1 Grassland Remote Sensing (GRS)

Grassland remote sensing (GRS) refers to the use of various remote sensing technologies to monitor and analyze grassland ecosystems. It has evolved from early methods like aerial photography to the highly advanced satellite sensing techniques used today (Wang et al. 2022). With recent advances in satellite imagery and computing capacity in the last decade, the field of remote sensing has advanced significantly. One metric of this change is the number of papers published—a systematic review of GRS indicates that the annual number of documents published has increased exponentially, with more than 100 papers published each year since 2010 (Li et al. 2021). Some general trends and lessons can be drawn from several recent systematic reviews (Reinermann, Asam, and Kuenzer 2020) and are highlighted below.

Ali et al. (2016) explores the issue of grassland change from a forage management perspective for agricultural production purposes. Specifically aligning with this report, the authors present current GRS methods, technological advancements, and challenges and trends for future development. A challenge

they identified was the current low spatial resolution of hypertemporal satellite data, which limits use for field-scale application in many countries. However, they suggest this challenge may be mitigated with the recent launching of satellite constellations, such as RapidEye, Sentinel-2 and various microsatellites (Ali et al. 2016). The authors also suggest several future advancements that be used in grassland application, such as i) microwave imagery, ii) backscatter behavior from different phenological stages for reliability in cloudy regions, and iii) hyperspectral satellite instrumentation and analytical methods. The detailed differentiation of habitat types would help in analysis and have practical implications for end-users (Ali et al. 2016).

A quantitative analysis of the research trends in GRS between 1980–2020 is presented by Li et al. (2021). The authors suggest that *emerging or underutilized methodologies and technologies, such as unmanned aerial systems, cloud computing, and deep learning will continue to further enhance GRS research in the process of achieving sustainable development goals*. Lyu et al. (2022) supports this assertion as it pertains to unmanned aerial vehicle (UAV) and suggest *systematically and comprehensively summarizing the application of UAV remote sensing in grassland ecosystem monitoring* would be important to understand the value and challenges that currently exist for the field of GRS.

Summarizing findings across the literature, Wang et al. (2022) capture a more general overview of GRS application in grassland monitoring, with the authors draw several conclusions that can enhance the ability to track change in grasslands over time: i) *applications should adopt the advanced estimation methods rather than simple statistical regression models*; ii) *the potential of deep learning in processing high-dimensional data and fitting non-linear relationships should be further explored*; iii) *explore the potential of some new vegetation indices based on the spectral characteristics of the specific grassland under study*; and iv) *the fusion of multi-source images should also be considered to address the deficiencies in information and resolution of remote sensing images acquired by a single sensor or satellite* (Wang et al. 2022).

2.2.2 Ground Truthing and Accuracy Assessment

Ground truthing (GT) refers to the process of verifying remote sensing data by comparing it with actual observations and measurements taken on the ground. This verification is crucial to train the classification models for GRS, thereby ensuring the accuracy and reliability of data obtained. Despite the significant advancements in GRS technology, ground truthing remains a major challenge. Zhou and Pilesjo (1996) raise concern over *the inconsistent and unreliable results* provided by visual estimation methods in

rangeland remote sensing nearly three decades ago, and while immense technological advances have occurred since that time, their caution remains valid. The immense value in ground truthing the remote sensing approaches remains integral even with today's advances— though it is costly and time consuming. Several articles are summarized below that explore best practices and limitations of the current approaches to GT.

Historical remote sensing data now spans decades and has global coverage (Purdy et al. 2023). In contrast, ground observations of phenology vary widely in methodological approaches, observation protocols, duration, and spatial coverage. Badreldin et al. (2021) present a methodological approach for mapping grasslands using a ground-truthing technique in the province of Saskatchewan, Canada. The evaluation of the classification accuracy of this research used a confusion matrix to compare classified classes against the reference ground-truthing. Within the mixed grassland ecoregion of Saskatchewan, an assessment of the current grassland spatial distribution was done using remote sensing data from MODIS, Sentinel 1, and Sentinel 2. Authors found the overall accuracy of the classification was 90.2%, which is considered very high when compared with producer's accuracy, which represents how well reference pixels of the ground cover type are classified by the machine learning algorithm in this study. The authors determined that *native grassland had 98.20% of user's accuracy and 88.40% producer's accuracy, tame grassland had 81.4% user's accuracy and 93.8% producer's accuracy, whereas mixed grassland class had very low user's accuracy (45.8%) and producer's accuracy 82.83%*. The discrepancies between accuracies for the mixed grassland are caused by the comparison to other landcover maps of the same region that did not include a mixed grassland class.

Tran et al. (2023) systematically reviewed 601 research papers published from 2011 to 2021 that assessed the uncertainty or accuracy of remote sensing estimates. The authors categorized and classified them based on (i) the methods used to assess uncertainties, (ii) the context where uncertainties were evaluated, and (iii) the metrics used to report uncertainties. *Most studies evaluated remote sensing uncertainties at spatial supports of 500 m to 5 km (244 out of 601) and 100m to 475m (164 out of 601)*. This can be attributed to the availability of remote sensing datasets that are widely used to estimate evapotranspiration, *such as MODIS (250 m to 1 km) and Landsat (30 m to 100 m)*. In the case of validation, the spatial support of uncertainty assessment was determined by the spatial support of the ground truth reference. *All methods have common sources of error and uncertainty, such as sensor response (detection limit), calibration error (sensor drift over time), noise (spurious random spikes in the signal from the*

sensor), and *poor installation and maintenance*. Additionally, each method has specific sources of error and uncertainty due to its theoretical assumptions (Tran et al. 2023).

Improving accuracy and extending results beyond traditional ground-truth periods in remote sensing classification of a complex landscape involves several methods. By using available remote sensing derived from Landsat, Moderate Resolution Imaging Spectroradiometer (MODIS) 16-day composites, and the National Agriculture Imagery Program, ((Mueller-Warrant et al. (2015) conducted a study across 25,303 km² area of the Willamette River basin and nearby drainages in western Oregon and south-western Washington. Synthetic ground-truth data for the 2004 harvest year based on the most common land *use classes over the following 7 years classified 49 of 57 categories at an overall accuracy of 96% in a final version* (Mueller-Warrant et al. 2015)

Hansen and Loveland 2012) suggest *Improved data availability, advanced processing methods, and pressing need for information on environmental change* will dictate a commensurate increase in our quantification of global land change. The authors highlight how each of these three aspects is necessary for realizing this improved monitoring capability, although *none is more critical than data availability*. The expansion of land monitoring methods and systems to other regions of the world and to other themes of interest will be maximized best *via a free and easy access data policy for global monitoring systems* (Hansen and Loveland 2012). 2012).

2.2.3 Community/Citizen Science (CS)

Community/citizen Science (CS) involves the participation of non-professional scientists or community members in scientific research, often to collect, analyze or disseminate data (Purdy et al. 2023). This approach has become increasingly integral to GT efforts, enhancing remote sensing methodologies across different biomes. Hecker et al. (2019) examine citizen science as a strategy to address challenges and apply solutions across science, practice and policy. They highlight how evolving technologies facilitate effective collaboration between the public and scientific community, noting that citizen science has a long history of application in fields such as astronomy, biology, biodiversity monitoring, environmental monitoring, and public health (Hecker et al. 2019). Their work underscores the role of citizen science in improving research quality and integrating with scientific practices, including the use of supporting technology like satellite imagery and ground-truthing.

Domingo-Marimon et al. (2022) suggest that monitoring observations of seasonal plant and animal life cycle events *have been traditionally linked to CS practices and limited to common species closely located to an observer's residence*. While this approach has provided valuable local insights, it falls short in capturing the extensive variability in vegetation phenology across different biomes. This limitation restricts our understanding of how climate change affects vegetation on a broader scale. However, recent advancements in remote sensing, particularly with high spatial and temporal resolution satellites such as Sentinel-2A and 2B, offer a promising solution (Domingo-Marimon et al. 2022). These satellites provide detailed imagery that can enhance citizen science efforts by guiding volunteers and extending the spatial and temporal coverage of phenology monitoring.

To tackle issues related to deploying citizen science and the potential challenges of an uninformed or undertrained citizen base, Boyd et al. (2022) conducted a survey to assess the use of citizen science in the United Kingdom (i.e. filling data gaps; contributing to EO outputs; ground-truthing; providing local knowledge). The survey found that the majority (65%) of respondents were using citizen science data in these ways, but with limited training. The authors suggest that progress could be enhanced by addressing the awareness deficit within the EO community regarding the existing quality of citizen science infrastructure, methodologies, and approaches. Additionally, they recommend *improving the availability and adaptability (flexibility) of current and future citizen science infrastructure*.

Basile et al. (2023) introduce the concept of data perspectivism, which emphasizes integrating the perspectives and opinions of human subjects involved in the knowledge representation phase of machine learning processes. They argue that this approach addresses the limitations of traditional aggregated gold standards, which often oversimplify complex phenomena (Basile et al. 2021). Data perspectivism advocates for greater representativeness and reliability in ground truthing by incorporating diverse human inputs. This is particularly relevant to CS, where volunteers provide crucial ground-truthing data and diverse observations. By acknowledging the complexity and variability captured by citizen science participants, this approach highlights the importance of incorporating multiple perspectives to enhance the accuracy and robustness of data in both machine learning and citizen science contexts.

3. Synthesis of Current State of Central Grasslands Monitoring in North America

3.1 Methodology

A scan for central grassland inventories was conducted following a systematic search process online; this process is described in Table 1. Stage 1 was a comprehensive scan using defined search terms; Stage 2 was a title and summary review; Stage 3 was a scan of the document or website to determine components of the inventory.; and in Stage 4, the inventory list was reviewed by expert members from the CEC workshops that had a connection to the inventory (where possible) in order to glean addition detail and ensure no inventories were excluded.

Table 1. Search methodology for North American central grassland inventories

Stage	Description	Action
1	Google Scholar Google Science Direct	Grassland / rangeland / prairie + conversion + remote sensing + inventory + monitoring + North America Grassland / rangeland / prairie + conversion + remote sensing + inventory + monitoring + Canada Grassland / rangeland / prairie + conversion + remote sensing + inventory + monitoring + United States Grassland / rangeland / prairie + conversion + remote sensing + inventory + monitoring + Mexico
2	Title and Summary Review	Inventory and summary material (website, maps, reports, etc.) were reviewed for retention / exclusion. Criteria: defined inventory and discussion of approach
3	Inventory Review	Documents were read to explore key themes and relevance.
4	Expert Review	Inventories identified were reviewed by experts in respective countries for inclusion or exclusion.

3.2 Inventories

The results of the inventory scan are provided in Table 3.⁴ In general terms, a total of 33 grassland inventories were identified. These inventories include 6 major North American initiatives, 13 Canadian Prairie Inventories, 7 US Inventories and 7 Mexican inventories. Each inventory has 9 descriptive variables attached (Table 2), which were developed in consultation with the CEC Project Steering Committee.

Table 2. Description of variables captured in the scan of North American central grassland inventories

Variable	Description
Inventory	Name of the inventory.
Geographical Scope	Spatial extent or geographic area covered by the inventory.
Description	Summary of the purpose of the inventory
Grassland Definition ⁵	Definition or criteria used to categorize grasslands, such as native, tame, or other classifications.
Duration	Timeframe over which the inventory was conducted.
Reported Accuracy Assessment	Level of accuracy reported by the inventory.
Field-based Methods	Description of any field-based methods used to verify or validate the inventory data.
Visualization, Data Source, and Access	Link to visualization map if available; types of data source utilized (e.g. aerial photography, satellite imagery); and availability of the data to the public and accessibility details, including links if available
Lead and Collaborative Agencies	Organizations responsible for leading (in bold) and collaborating on the inventory.

⁴ Table 3 includes inventories identified through online research and consultations with GRS experts from Canada, Mexico, and the United States. However, there may be locally specific inventories that are not listed.

⁵ The diversity of grassland definitions used by the different inventories is an ongoing challenge. Mapping the various grassland definitions employed to identify commonalities and differences would be a useful next step; however, this is beyond the scope of this report.

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Table 3. Overview of North American Central Grassland Inventories and Key Variables

Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
North America	Central Grasslands Assessment Initiative (incorporates RAP and Plowprint)	Canada, Mexico, and United States	Provides a map to guide voluntary conservation investments, helping local partners prioritize conservation programs. Maps core grasslands, vulnerable grasslands, and converted/alterd grasslands.	Areas not developed or converted to row-crop agriculture or woody encroachment/ Categorized as “core, threatened, and encroached areas”	Ongoing; Updated 2023	Row-crop conversion data based on Cropland Data Layer with reported annual accuracy of 85 to 95% and Annual Crop Inventory (ACI) with estimated 85% to 90% accuracy Accuracy is derived from the base data layers: Plowprint (WWF), Olimb and Robinson (2019), and RAP/Rangeland Informatics (UNL)	Row-crop conversion data and encroachment data are both based on satellite imagery. Row-crop conversion data has classification points and accuracy assessment points; the number and location are variable across the ecoregion.	<i>Visualization:</i> link to map <i>Data Source:</i> derived from the base data layers of the Plowprint (WWF), Olimb and Robinson (2019), and Rangeland Analysis Platform (RAP) <i>Public Access:</i> raw data available upon request (not online)	Central Grasslands Roadmap Initiative (Central Grasslands Roadmap, 2022)
North America	Plowprint Report	Canada, Mexico, and United States	Analyzes grassland plow-up rates across the Great Plains using USDA's Cropland Data Layer, Agriculture and Agri-Food Canada's Annual Crop Inventory, and Sentinel-2 satellite data for Mexico from two years prior to the release date.	Areas not developed or converted to row-crop agriculture or woody encroachment/ Categorized as “core, threatened, and encroached areas”	Ongoing; Updated 2023	Row-crop conversion data based on Cropland Data Layer with reported annual accuracy of 85 to 95%	Row-crop conversion data and encroachment data are both based on satellite imagery. Row-crop conversion data has classification points and accuracy assessment points; the number and location are variable across the ecoregion.	<i>Visualization:</i> link to map <i>Data Source:</i> analysis is based on the USDA's annual Cropland Data Layer and the Agriculture and Agri-Food Canada's Annual Crop Inventory which looks at grasslands plow-up that has occurred two years prior to the release date. <i>Public Access:</i> raw data available upon request (not online)	World Wildlife Fund (WWF, 2023)
North America	Grassland Assessment of North American Great Plains	Canada, Mexico, and United States	Uses time-series landcover data to identify potentially undisturbed lands (PUDL), with supervised classification of	Grassland complex with no history of agricultural cultivation or development	2019 - 2020	Accuracy rates of potentially undisturbed grass and disturbed grass classes varied by Migratory Bird Joint	Not explicitly stated in available online literature. Row-crop conversion data and encroachment data	<i>Visualization:</i> link to map and report <i>Data Source:</i> RADARSAT-2 (2011-2017), and optical data came from Landsat-5 (2011–	Migratory Bird Joint Ventures / Prairie Pothole Joint Venture (PPJV, 2019)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
			Sentinel-2 satellite data to refine vegetation composition in the PUDL layer.			Venture regions, ranging from 54 to 77%	are both based on satellite imagery.	2012), Landsat-8 (2013–2017), Sentinel-2 (2016–2017), and Gaofen-1 (2016–2017). <i>Public Access:</i> raw data available upon request (not online)	
North America	Grassland Strategic Habitat Conservation	Canada, Mexico, and United States	Interactive web program highlighting priority grassland areas for Strategic Habitat Conservation (linked with the Central Grasslands Roadmap).	Areas not developed or converted to row-crop agriculture or woody encroachment	2021–Present; Updated 2023	Not explicitly stated	Not explicitly stated in available online literature. Row-crop conversion data and encroachment data are both based on satellite imagery.	<i>Visualization:</i> link to map <i>Data Source:</i> based upon RAP/Rangeland Informatics (UNL) <i>Public Access:</i> raw data available upon request (not online)	US Fish & Wildlife Service (FWS, 2024)
North America	North American Land Change Monitoring System (NALCMS)	Canada, Mexico, and United States	Produces land cover maps for 2005, 2010, 2015, and 2020, using MODIS, Landsat 7–8, and RapidEye satellite imagery. Includes nineteen land cover classes based on the Food and Agriculture Organization (FAO) of the United Nations Land Cover Classification System (LCCS).	Three categories of grassland based on the FAO's Land Cover Classification System: subtropical (dominated by graminoid or herbaceous vegetation generally accounting for greater than 80% of total vegetation cover), temperate (dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover) and subpolar (grassland with lichen and moss typically accounting for at least 20% of total vegetation cover)	2005–Present; Updated 2023	An accuracy assessment at the North American level is not done since we are not redoing the classification but harmonizing the data when there are discrepancies at the borders. From the metadata file of the 2020 North American Land Cover (see attached), we have the following information: Accuracy Assessments: Canada (86.9%), United States (77.5%) and Mexico (no accuracy assessment performed)/	Completed at the national level: Canada , United States , and Mexico .	<i>Visualization:</i> link to map <i>Data Source:</i> land cover maps at 250m spatial resolution based on Moderate Spatial Resolution Imaging Spectroradiometer (MODIS) imagery; and at 30m spatial resolution based on Landsat-7 imagery for Canada and the United States, and RapidEye imagery for Mexico. <i>Public Access:</i> metadata available here	Commission for Environmental Cooperation (CEC) <i>Natural Resources Canada</i> <i>Conafor</i> <i>Conabio</i> <i>United States Geological Survey (USGS)</i> <i>INEGI</i> (NALCMS, 2024)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
North America	Land Use & Land Cover in the Crown of Continent Ecosystem c2000	Canada and United States	Represents land cover and land use for the Crown of the Continent Ecosystem, with land cover classes including water, barren, ice/snow, developed, scrub/shrub, wetland, grassland, agriculture, coniferous forest, deciduous forest, and mixed forest.	Not explicitly stated in available online literature.	2000; 2015–Present	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> link to map <i>Data Source:</i> data are a compilation from multiple sources [Multi-Resolution Land Characteristics (MRLC) Consortium, Agriculture and Agri-Food Canada (AAFC), and the Canadian Forest Service (CFS)] <i>Public Access:</i> metadata available here.	Great Northern Landscape Conservation Cooperative <i>Agriculture and Agri-Food Canada (AAFC)</i> <i>Canadian Forest Service</i> <i>Canadian Centre of Remote Sensing</i> <i>United States Geological Survey (CCE, 2016)</i>
Canada	National Grassland Inventory (NGI)	National	Aims to identify and harmonize existing grassland inventories across Canada to create a cohesive national grassland inventory, updating policies and risk assessments, improving carbon store assessments in grassland soils, and predicting real or expected loss of grasslands over time.	Native—at least 75 % cover by native species Tame—at least 75 % cover by tame species Altered/degraded—less than 75 % cover by tame species and less than 75% cover by native species	2022–2024	Manitoba, Saskatchewan and Alberta (range of 74–77%) Overall assessment for three provinces is 75%	Roadside surveys using Environmental Systems Research Institute's Survey123	<i>Visualization:</i> no public link to map currently available. <i>Data Source:</i> Sentinel 1, Sentinel 2, Resampled Shuttle Radar Topography Mission for Digital Elevation Models <i>Public Access:</i> no public link to dataset currently available.	Canadian Grassland and Forage Association <i>Manitoba Habitat Conservancy</i> <i>Nature Conservancy Canada</i> <i>Manitoba Ministry of Agriculture</i> <i>Department of National Defense (Canadian Forces Base Shilo)</i> (CFG, 2024)
Canada	Land Cover of Canada	National	Shows distribution of land cover types across Canada from 1965 to 2006 using AVHRR data, with 31 land cover classes including forests, shrubland, barren land, grassland, developed land, and	Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover.	1965–present; Updated 2020	Accuracy assessment based on 832 randomly distributed samples shows that land cover data produced with this new approach has achieved 86.9% accuracy with no	Not explicitly stated in available online literature.	<i>Visualization:</i> link to map <i>Data Source:</i> Operational Land Imager (OLI) Landsat sensor, based upon Canadian 30m resolution component of NACLMS.	Natural Resources Canada (Government of Canada, 2020)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
			non-vegetative cover types.			marked spatial disparities		<i>Public Access:</i> metadata available here	
Canada	Canada Land Inventory (CLI)	National	A comprehensive land inventory covering over 2.5 million square kilometers of rural Canada, mapping land capability for agriculture, forestry, wildlife, and recreation.	Not explicitly stated in available online literature.	1963–1995	Target accuracy of at least 85% at a final spatial resolution of 30m	Not explicitly stated in available online literature.	<i>Visualization:</i> link to maps <i>Data Source:</i> Produced using observation from Operational Land Imager Landsat sensor. The most recent edition uses Landsat-8 imagery. <i>Public Access:</i> no public link to metadata available.	Agriculture and Agri-Food Canada (Government of Canada, 1995)
Canada	Annual Crop Inventory (ACI)	National	Provides interactive data for the Agriculture and Agri-Food Canada Annual Crop Inventory from 2009 to the present, allowing landowners, decision-makers, and the general public to examine crop inventory across Canada, including grassland categories.	Predominantly native grasses and other herbaceous vegetation, may include some shrubland cover.	2009 - Present	Accuracy ~70%, though different year to year and only reported by province, and not by individual land cover classes Consistently deliver a crop inventory that meets the overall target accuracy of at least 85% at a final spatial resolution of 30 m (56 m in 2009 and 2010)	Groundtruth information was provided by provincial crop insurance companies, point observations, and data collection supported by regional AAFC offices	<i>Visualization:</i> link to map <i>Data Source:</i> Decision Tree based methodology was applied using optical (Landsat-5) and radar (Radarsat-2) based satellite images. <i>Public Access:</i> metadata available here	Agriculture and Agri-Food Canada (AAFC, 2023)
Canada	Wetland Trends and Upland Land Use	Prairie Provinces (Alberta, Saskatchewan Manitoba)	Represents Alberta's biophysical, anthropogenic, and land-use inventory for the White Area, commenced in 2006 and using digital color-infrared stereo photography, updated from the Native Prairie Vegetation Inventory	Tame pasture/hay/forage - Improved grass such as tame pasture, forage crops, roadside ditch planted grass cover, disturbed site cover, lawns, farmyard grass cover, and grass cover with evidence of recent (less than 5	2001–2011	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> link to map <i>Data Source:</i> combination of detailed sample-based datasets, agricultural lands inventory and agricultural census products (Canadian Wildlife Service Prairie Habitat Monitoring Program, Statistics Canada Census of Agriculture,	Prairie Habitat Joint Venture (PHJV, 2017)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
			(NPVI) completed circa 1993.	years) seeding or plowing. Natural grassland - Primarily natural grasslands, remnant grass cover, wetland margins, uncultivated perennials, low density shrub, forb, and grass complexes. Natural grasslands do not show evidence of cultivation (in past 5 years), seeding, and/or plowing. Includes seeded pastures and forage plantings estimated to be older than 5 years.				and AAFC Annual Crop Inventory) <i>Public Access:</i> links to multiple datasets provided, but not complete dataset available online.	
Canada	Grassland Vegetation Inventory (GVI)	Alberta (Grassland Natural Region, excluding Parklands)	Focuses on wetland and upland habitat conservation in the Prairie Pothole Region through the North American Waterfowl Management Plan (NAWMP), monitoring status and trends of wetland and grassland habitats.	Grasslands areas undisturbed by industrial activities	2006–2018	Accuracy assessment for vegetation types estimated at >90% (Smith 2018)	Ground-truthing quality control determined by road-side surveys conducted by contractors	<i>Visualization:</i> link to map <i>Data Source:</i> Aerial photography / Softcopy Photogrammetry; color infrared digital airborne imagery 0.4 m Polygon-based <i>Public Access:</i> dataset available here	Government of Alberta <i>Ministry of Sustainable Resource Development</i> <i>Alberta Prairie Conservation Forum</i> (GVI, 2019)
Canada	Primary Land and Vegetation Inventory (PLVI)	Alberta (excluding the GVI area of the south, but including parklands and forested areas)	Photo-based digital inventory identifying vegetation types, extent, and conditions in Alberta's forested and parkland areas, including ecological site phases for classification.	Grassland areas undisturbed by industrial activities	2020–Present	Not explicitly stated in available online literature.	Ground survey conducted to ensure correct assessments	<i>Visualization:</i> no map currently available online. <i>Data Source:</i> photo-based digital inventory (Lidar) developed to identify the type, extent and conditions of vegetation in the forested and parkland areas of the province of Alberta	Government of Alberta <i>Ministry of Environment and Parks</i> (Government of Alberta, 2020)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
								Public Access: dataset can be requested here	
Canada	Grassland Vegetation Classification Using TimeScan Data	Alberta (southern area)	Maps native grasslands in southern Alberta over three-year periods from 1984 to 2016, using TimeScan data.	Grassland areas undisturbed by industrial activities	1984–2016	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here. <i>Data Source:</i> LandSat <i>Public Access:</i> data available here upon request.	Government of Alberta Agriculture and Forestry Open Data Areas Alberta Hyperspectral Intelligence Maapera Inc.
Canada	Native Prairie Vegetation Inventory (NPVI)	Alberta (southern area)	A quarter section-based vegetation inventory covering southern Alberta, including areas of unbroken grassland or parkland and reverted areas. Includes data for adjacent regions and multiple Natural Subregions.	An area of unbroken grassland or parkland dominated by non-introduced species, and an area of previously broken grassland that has reverted to native vegetation (30 to 60 years)	1991–1993 (was not updated, leading to the creation of GVI)	Approx. 80% Resolution at ¼ section scale	No formal ground field method used, but limited amount of field-checking of the final inventory was conducted by the research team	<i>Visualization:</i> no formal map, though approximation available here. <i>Data Source:</i> Black and white Aerial photography at 1:30,000 scale. Stereoscopes <i>Public Access:</i> dataset available here.	Government of Alberta <i>Prairie Conservation Forum</i> (Government of Alberta, 2012; PCF, 2010)
Canada	Saskatchewan Digital Landcover (Southern Digital Landcover)	Saskatchewan	Provides seamless provincial coverage of Saskatchewan, combining the Saskatchewan Research Council's Northern Digital Land Cover with Southern Digital Land Cover.	Native dominant grasslands that may contain tame grasses and herbs. Seeded grasslands dominated by tame grass species.	1994–Present	The accuracy of this classification was to be demonstrated by the Saskatchewan Research Council to be at least 90% correct.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here. <i>Data Source:</i> Landcover dataset created for the northern part of Saskatchewan based on a combination of Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper (ETM+) data representing circa 2000 conditions. <i>Public Access:</i> dataset available here.	Saskatchewan Research Council <i>University of Regina</i> <i>Government of Saskatchewan</i> (Government of Saskatchewan, 2023)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
Canada	Prairie Landscape Inventory (PLI)	Provincial (Saskatchewan) <i>Prairie and Boreal Transition</i>	Land cover imagery for Saskatchewan's mixed grassland ecoregion with a 10 m resolution, classifying native and tame grasslands using Sentinel-1 and Sentinel-2 imagery, an aiming to distinguish native from tame grasslands.	Native grassland: composed of at least 75% native grass and forb species; unbroken grassland that is invaded by species like Kentucky bluegrass, crested wheatgrass or smooth brome, such that native cover is < 75%, is not considered native Tame grassland: composed of at least 75% seeded or planted species with introduced grasses and forb species Mixed grassland: a heterogenic grassland with a mix of less than 75% native grass species or less than 75% tame species.	2019–Mixed Grassland 2022–Moist Mixed Grassland 2023–Aspen Parkland (draft) 2024–Boreal transition and Cypress Upland (models in progress)	Overall accuracy of 90.2% (Mixed Grassland) and 70.3% (Moist Mixed Grassland)	Roadside surveys using Environmental Systems Research Institute's Survey123	<i>Visualization:</i> map available here . <i>Data Source:</i> resolution of 10m and was based on machine learning analysis and remote sensing data of Sentinel-1 and Sentinel-2 imagery. <i>Public Access:</i> dataset available here .	Government of Saskatchewan <i>Environment and Climate Change Canada</i> <i>Saskatchewan Ministry of Environment</i>
Canada	Mixed Grassland Prairie Inventory Project	Manitoba	Identifies and ranks remaining mixed grass prairie in Manitoba from 1989 to 2016, assessing quality and threats like cultivation, woody plant encroachment, exotic species invasion and inappropriate grazing management.	Grassland is graded from "A" to "D." A grade of "C" or higher indicates a good quality community with the potential to improve over time. A grade of "D" indicates poor quality sites that require extensive management to improve.	1989–2016	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here . <i>Data Source:</i> Not explicitly stated in available online literature. <i>Public Access:</i> not currently available online.	Government of Manitoba <i>Critical Wildlife Habitat Program</i> <i>Environment and Climate Change Canada (ECCC)</i> (Badreldin, Prieto, and Fisher, 2021)
Canada	Manitoba Grassland	Manitoba	Land cover imagery for Manitoba's mixed	Native—at least 75 % cover by native species	2019 and 2020	87% accuracy	Roadside surveys using Environmental	<i>Visualization:</i> map available here .	University of Manitoba

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
	Inventory (MGI) 2.0		grassland ecoregion with a 10m resolution, classifying native and tame grasslands using Sentinel-1 and Sentinel-2 imagery, and aiming to distinguish native from tame grasslands.	Tame—at least 75 % cover by tame species Altered/degraded—less than 75 % cover by tame species and less than 75% cover by native species			Systems Research Institute's Survey123	<i>Data Source:</i> Sentinel 1, Sentinel 2; Resampled Shuttle Radar Topography Mission for Digital Elevation Models (to add topography) <i>Public Access:</i> dataset available upon request from Coordinator (raster, report and different materials available).	(Government of Manitoba, 2021)
United States	Cropland Data Layer (CDL)	National	Allows statistical analysis of planted United States commodities. Known as CroplandCROS, the app allows users to geolocate farms and map areas of interest. It includes a Grassland/Pasture category and has been in use since 1971.	Range, pasture, hay, alfalfa, and other grasslands	1971–Present; Updated 2023	86.9% accuracy for grasslands (Reitsma et al. 2016) Accuracy assessments published since 2008.	No USDA led field-based ground truthing identified in literature; accuracy evaluations for each crop at the state level use ground truth validation data from other agencies (e.g., the USDA Farm Service Agency (FSA))	<i>Visualization:</i> map available here . <i>Data Source:</i> Landsat-8 OLI/TIRS sensor, the Disaster Monitoring Constellation (DMC) Deimos-1 and UK2, the ISRO ResourceSat-2 LISS-3, and the ESA Sentinel-2 <i>Public Access:</i> metadata available here .	United States Department of Agriculture (USDA) (USDA, 2024)
United States	GAP/LANDFIRE National Terrestrial Ecosystems	National	Combines GAP land cover data with LANDFIRE data for vegetation, wildland fuel, and fire regimes across the United States, including Alaska, Hawaii, and Puerto Rico.	Range, pasture, hay, alfalfa, and other grasslands	2001–Present; Updated 2020	Overall target accuracy of at least 85% at a final spatial resolution of 30m (56m in 2009 and 2010).	No identified field-based ground-truthing identified; reliant on remote sensing evaluations	<i>Visualization:</i> map available here . <i>Data Source:</i> spatial layer satellite Imagery; Landsat products since its inception. <i>Public Access:</i> metadata available here .	United States Geological Survey (USGS) (USGS, 2019)
United States	National Land Cover Database (NLCD)	National	The 2019 iteration includes 28 products characterizing land cover, urban imperviousness, tree	<i>Native grassland:</i> areas dominated by graminoid or herbaceous vegetation, generally	2001–Present; last updated 2021	>70% for 2011–2016 grassland loss and grassland gain (Wickham et al. 2021)	No identified field-based ground-truthing identified; reliant on remote sensing evaluations	<i>Visualization:</i> map available here .	United States Geological Survey Multi-Resolution Land

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
			canopy data, and shrub and grassland areas, with coverage from 2001–2019.	greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing. <i>Tame grassland:</i> areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.				<i>Data Source:</i> Defense meteorological satellite LANDSAT <i>Public Access:</i> metadata available here .	<i>Characteristics Consortium</i> (USGS 2024)
United States	Natural Resources Inventory (NRI)	National	Provides data on land, soil, water, and related resources on non-federal lands in the United States, using a longitudinal dataset with sampling from 1982 to 2017.	Are that is composed principally of native grasses, grasslike plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland.	1982–Present	Not explicitly stated in available online literature.	No identified field-based ground-truthing identified; reliant on remote sensing evaluations	<i>Visualization:</i> map available here . <i>Data Source:</i> Landsat imagery <i>Public Access:</i> metadata available here .	United States Department of Agriculture (USDA) <i>Natural Resources Conservation Service</i> (USDA, 2023)
United States	Rangeland Assessment Project (RAP)	National	Combines satellite imagery with on-the-ground vegetation measurements for rangeland monitoring collected by BLM, NPS and NRCS, using cloud computing and machine learning to map vegetation across the United States.	Components mapped include annual herbaceous, perennial herbaceous, total herbaceous, sagebrush, non-sagebrush shrub, total shrub, litter, bare ground, and tree canopy cover.	1985–2021; updated annually	Maps are rigorously validated using field data not included as training (that is, independent validation) and by assessing model fit to training data. Accuracy assessments vary by land cover.	Independent field data consist of 1,880 points, each specifically designed to represent a single Landsat pixel	<i>Visualization:</i> map available here . <i>Data Source:</i> Landsat and Continuous Change Detection and Classification (CCDC) synthetic imagery <i>Public Access:</i> metadata available here .	United States Geological Survey (USGS) (USGS, 2023)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
				Grasslands are areas not developed or converted to row-crop agriculture or woody encroachment/ Categorized as “core, threatened, and encroached areas”					
United States	Rangeland Condition Monitoring Assessment and Projection (RCMAP)	National (Western United States)	Quantifies percent cover of rangeland components across the western United States using Landsat imagery from 1985–2021, with nine fractional components (annual herbaceous, bare ground, herbaceous, litter, non-sagebrush shrub, perennial herbaceous, sagebrush, shrub, and tree) and associated temporal trends.	An area that has at least 50% aerial coverage of grasses, grass-like plants and or forbs. The total area coverage of shrubs and trees must be less than 50 %. The minimum area for classification of grassland is 1 acre, and the area must be at least 100 feet wide.	1985–2021; Every 5 years Last Updated 2021	Percentage for grasslands not provided; land use accuracy described in (Shi et al. 2022)	No identified field-based ground-truthing identified, reliant on remote sensing evaluations Landsat 9 Data is expected to enhance observation frequency and reduce biases of model inputs, therefore improving	<i>Visualization:</i> map available here . <i>Data Source:</i> Landsat imagery time series of rangeland fractional components across the Western United States from 1985 to the present year released. <i>Public Access:</i> metadata available here .	United States Geological Survey (USGS) (MRLC, 2024)
United States	Parent material, landform, and soil maps of the Jornada Basin	Jordana Basin, United States and Mexico	Research focuses on vegetation change, climate and land use impacts on ecosystem function, and the role of dryland processes in structuring communities and landscapes in the Mexican and United portions of the Jornada Basin.	Desert grass species	1982–Present; 2024	Not explicitly stated in available online literature.	Not a dedicated grassland inventory, so varies by project.	<i>Visualization:</i> maps available here . <i>Data Source:</i> Satellite imagery. <i>Public Access:</i> metadata in development.	Jornada Basin Long Term Ecological Research (Jornada Basin LTER, 2024)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
Mexico	Use of Soil and Vegetation Inventory (INEGI)	National	Provides extensive data on soil and vegetation across Mexico, including grasslands. This inventory offers detailed maps and datasets that aid in land management and conservation planning.	Not explicitly stated in available online literature.	1983–Present	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> maps available here. <i>Data Source:</i> RapidEYE 2012 and Landsat <i>Public Access:</i> metadata available here.	National Institute of Statistics and Geography (<i>Instituto Nacional de Estadística y Geografía</i>)
Mexico	Geoinformation Portal (Conabio)	National	Offers thematic cartography of different scales and grassland inventories across all of Mexico through a geographic information portal.	Not explicitly stated in available online literature.	1992; 2015–Present	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here. <i>Data Source:</i> Advanced Very High-Resolution Radiometer (AVHRR) of the NOAA satellites (National Oceanic and Atmospheric Administration) and from the MODIS sensor (Moderate Resolution Imaging Spectroradiometer) of the TERRA-1 satellite. <i>Public Access:</i> metadata available here upon request.	National Information System on Biodiversity (SNIB) Government of Mexico (Conabio, 2024)
Mexico	National Forestry Monitoring System (<i>Sistema Nacional de Monitoreo Forestal - INFyS</i>)	National	Provides comprehensive, updated information on forest resources and associated data in Mexico, with field data collected in five-year cycles, for which 20% of the annual sample is systematically distributed, in such a way that representative information is available for all ecosystems.	Not explicitly stated in available online literature.	2004–Present; Last updated 2022	Accuracy is determined only for forest indicators such as volume, biomass and basal area for major forest formations and vegetation types. It does not consider accuracy assessment of area / extent of such forest formations or vegetation type.	INFyS uses systematic-stratified sampling design in which 26,220 sampling plots or Primary Sample Units (UMP) are in three sampling strata and intensities as follows: 5x5 km for temperate, sub-humid, and humid forests; 10x10 km for semi-arid forest-vegetation types;	<i>Visualization:</i> map available here. <i>Data Source:</i> Landsat imagery. <i>Public Access:</i> metadata available here upon request.	Instituto Nacional de Estadística y Geografía National Institute of Statistics and Geography (INEGI)

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
							and 20x20 km for arid forest-vegetation types.		
Mexico	Janos Biosphere Reserve Janos Grassland Priority Conservation Area	Chihuahua	Uses remote sensing to classify grasslands and shrub components in the Janos Grassland Priority Conservation Area, identifying best techniques for large-scale remote sensing application in the desert grasslands and shrublands.	Not explicitly stated in available online literature.	2013–2017; Last Updated 2017	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here . <i>Data Source:</i> Landsat 8 Satellite imagery <i>Public Access:</i> metadata available here .	Bird Conservancy of the Rockies (Bird Conservancy of the Rockies, 2017)
Mexico	Google Earth Engine Mexico GPCAs	12 Mexican Grassland Priority Conservation Areas	Provides yearly estimates of change of irrigated and dryland cropland, as well as grassland, in the Mexican GPCAs since 1990.	Not explicitly stated in available online literature, though follows INEGI Uso de Suelos (several iterations through series VI)	Ongoing, Updated 2020	Generally, 70-90% accuracy of cropland cover classification, depending on Dryland (lower) versus Irrigated (higher) and Year. Lower accuracy in earlier years in some GPCAs. Grassland classification based on INEGI grassland classification (accuracy unknown, but probably the best grassland classification available for Mexico).	A supervised classification program was developed to gather imagery and vector spatial data, perform agricultural classification, analyze grassland loss, and execute summation and output functions on the Google Earth Engine (GEE) platform. It initially collected independent and derived variables from Landsat imagery, built a classification algorithm, and applied this classifier to generate maps of agriculture and grasslands across	Visualization available upon request Data Sources: <i>Google Earth Engine, Landsat, NDVI, INEGI</i> <i>Public Access</i> available upon request	Bird Conservancy of the Rockies

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Region	Inventory	Geo-graphical Scope	Description	Grassland Definition Used	Duration	Reported Accuracy Assessment (%)	Field-based Methods	Visualization, Data Source and Access	Lead Agency and Source
							GPCAs in Mexico from 1990 to the present.		
Mexico	Land Suitability for Grasslands Conservation (LSGC)	Chihuahua	Defines areas for grassland conservation using GIS-based multicriteria evaluation, incorporating qualitative considerations into the evaluation process.	Not explicitly stated in available online literature.	2020	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here. <i>Data Source:</i> Geographic Information Systems (GIS)-based multicriteria evaluation techniques with weighted overlay <i>Public Access:</i> metadata not publicly available online.	Autonomous University of Chihuahua (Universidad Autónoma de Chihuahua) <i>Nature-Based Solutions in Conservation Management</i> (Vázquez-Quintero et al., 2019)
Mexico	Pastizales de El Tokio	El Tokio, Chihuahua	Determine and quantify the current and historical coverage and extent of GPCA grasslands el Tokio through remote sensing	Grasslands are communities of grasses that develop in soils containing large proportions of gypsum, often at the bottom of closed basins in arid and semi-arid areas. Some of the main species that make it up are the gypsum razor (<i>Bouteloua chasei</i>), gypsum grass (<i>Sporobolus nealleyi</i>), liendrilla (<i>Muhlenbergia purpusii</i>), etc.	1986–2016	Not explicitly stated in available online literature.	Not explicitly stated in available online literature.	<i>Visualization:</i> map available here. <i>Data Source:</i> For the present work, 6 scenes of images from the LANDSAT 5 TM satellite from 1986 and 6 scenes from LANDSAT 8 OLI images from 2016 were used, between the months of August and November of each year. <i>Public Access:</i> metadata not publicly available online.	Especies, Sociedad Y Habitat, A.C. (ESHAC) Universidad Autónoma de Nuevo León (UANL)

3.3 Common Themes Arising

Several of the common themes arising from this scan are captured below and relate to the various thematic variables captured above.

- Multiple inventories exist across North America, often integrating a combination of satellite and mapping techniques to create a final product.
- Limited provincial/state interaction and federal counterparts' interaction is implied from the lead and collaborating agencies.
- The definition of grasslands used in inventories often vary between binary native and tame, to using other classifications such as "disturbed" by anthropogenic sources or invasive species. This situation will prove challenging to standardization efforts.
- Accuracy assessments vary widely among inventories, lacking a standardized approach, and error rates are not well defined or equitable across different methodologies.
- Ground-truthing methods are not standardized and often opportunistic, though some inventories use roadside surveys and other physical checks.
- Substantial technological advances in satellite technology and access have allowed for faster development of inventories and new techniques.
- Access to data is common in the form of visualization maps online; however raw data access is often difficult to discern.
- Most of these inventories have collaborative partnerships with other agencies that may not be fully captured, although the primary ones are identified.

4. Strengths, Limitations, and Best Practices

The existence of multiple and diverse grassland inventories across North America highlights the need for a clear, standardized approach to tracking grassland change over time, supported by a dedicated community of practice. Professionals in remote sensing techniques and modeling are supported by ground truthing approaches that engage local citizen stakeholders, are at times conducted by the professionals themselves, or a combination of both. The funding invested in such initiatives indicates that grassland loss is a recognized issue across North America, and these efforts should be acknowledged and celebrated for their success.

While diverse approaches to grassland monitoring offer numerous advantages, they also present limitations. Variations in approaches, definitions, methodologies, and objectives arise as different inventories align with funding priorities, local stakeholder interests, and often context-specific political and economic realities. For example, different states or provinces may have different levels of legal jurisdiction over their grasslands; ranching cultures may push up against crop row agricultural communities; drivers of conversion may vary from woody encroachment to urban expansion. Therefore, inventory efforts may evolve to address local needs, national initiatives may focus on national priorities, and international efforts tackle broader global concerns. As a result, various stakeholders might view the goal of a coherent, international, and standardized approach to grassland remote sensing as either unattainable or potentially counterproductive.

However, the absence of common approaches or explicit methodologies can be a major limitation that leads to inconsistent messaging about grassland loss, potentially resulting in apathy or suspicion towards the shared results. Clearly identifying both the strengths and limitations of various inventories is essential for highlighting best practices in the field. This approach can lead to effective grassland change modeling as well as consistent communication across the community of practice. Based on the literature review, the inventory scan, and the participants input at the CEC workshops, Table 4 outlines current challenges facing the GRS community and recommends best practices for addressing these issues, considering both current limitations and strengths.

This section provides a comprehensive, though not exhaustive, list of best practices derived from the literature and insights from workshops with GRS experts across North America. It is also important to

acknowledge that professionals involved in developing grassland inventories bring unique experiences and qualifications, which can greatly influence the effectiveness of their process.

Table 4. Review of challenges and best practices in grassland monitoring

Challenges	Best Practice	Current Limitations	Current Strengths
Indigenous Engagement	Engage with Indigenous communities and incorporate Traditional Ecological Knowledge (TEK)	Very few inventories incorporate TEK	The Central Grasslands Roadmap and Indigenous Kinship Circle are actively engaging in grasslands conservation
Multiple Inventories	Support a community of practice	Many inventories operate in isolation	Efforts are underway for larger inventories that reflect local differences
New Technologies	Engage with emerging technology, such as new satellites, freely cloud-computing (i.e., Google Earth Engine), and machine learning algorithms	Integration of new technology is challenging for ongoing inventories	Significant opportunities to leverage new and emerging technologies
	Plan to integrate older technology when relevant	Significant datasets are not integrated due to outdated practices	Extensive history of remote sensing and aerial photography can complement new satellite approaches
Condition versus Extent	Integrate and support both condition and extent in mapping	Condition and extent are typically assessed separately; mapping condition is currently lagging relative to mapping extent	Rigorous application of both condition and extent approaches.
Accuracy Assessment	Develop an initial ground truthing plan leading into a field monitoring program	Methods for accuracy assessment vary and may not be comparable	Most inventories have identified methods for accuracy assessment
	Implement a field monitoring program	Implementation is costly and time-consuming	Many inventories have recognized the need for field monitoring

	Foster positive relationships with local landowners	Time-consuming and require specialized communication skills	Successful examples of engagement could serve as case studies
Scale	Balance local and large-scale efforts	Often focused on either small local context or very large scale	Some efforts exist to integrate local and large-scale approaches
Data Sharing	Develop a data sharing plan from inception	Ensure equity in data sharing can be challenging	Data sharing is acknowledged as important and some efforts to improve exist
	Foster willingness to engage with others	Strong personalities and competitive nature of some institutions	Efforts such as CEC engagement and the Central Grassland Roadmap provide templates
	Common definitions agreed upon	There is a lack of common definitions/vegetation types associations	Efforts to align definitions and communicate definitions are occurring through international engagement and building community of practice
Data Management	Clarify data storage and ownership	Costly, requires long-term maintenance, property rights, stigma associated with being the data holder, and supercomputing power	Some universities offer to serve as hubs; large data repositories are available for payment
Funding	Be explicit about funders	High funding needs can be challenging to meet	Grassland conservation is a crucial issue in combating climate change, creating opportunities for funding
End Users	Identify and align with end-user priorities	End-users often have different priorities; inventories need to be "marketed" to show alignment	Many stakeholders are interested in grassland conservation
	Establish positive partnerships	Time-consuming; requires finding connection points and adapting communication styles	Many positive examples of partnerships exist
	Ensure ease of use and adaptability	Adapting inventories to diverse end-user needs is challenging	Many stakeholders are willing to share approaches and recommendations for ease of use

Policy Engagement	Align approaches with policy considerations	Limited engagement with policymakers evident in the literature	Some inventories are considering policy as an end-user
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5. Data and Information Needs for Effective Grasslands Monitoring

High quality grassland inventories are reliant upon high quality, maintainable and accessible datasets. These datasets range from quantitative remote sensing datasets from satellites to ground-truthing efforts that engage with local consultants or citizen stakeholders. Relationships and contracts must be established to obtain the data, and then strategies for housing and maintaining the data over time must be established in advance and maintained over time. Data accessibility in a format that has utility for GRS experts or practitioners can also be a part of the success or failure of an inventory.

A clear limitation identified in the GRS literature and the CEC workshops was the challenge of data sharing, integration, and standardized protocols (Long et al. 2019). When supporting a community of practice of GRS specialists across North America, each with experience with a specific grassland inventory effort, this becomes a very important challenge to address. As such, the CEC grasslands project aimed to *identify the data and information needs for monitoring grassland change, and the potential sources of data available*. Response from participants of CEC workshops on grasslands monitoring are identified in Table 6.

Table 5. Data and information needs identified during CEC workshops on grasslands monitoring

Data and Information Need	Description
<i>Willingness to Share</i>	Need a willingness to share large datasets with researchers, government employees, Indigenous communities, etc., and have sharing agreements in place. Specific issues and comments include: ○ AAFC's crop inventory dataset uses insurance data, which cannot be directly shared, but derived products and field data can be. AAFC advocates for recognizing the value of shared data for mutual benefit. ○ Common Land Unit data in the United States is restricted to federal employees and academic institutions. ○ Mexican data faces similar access challenges.

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	○ Academic sharing is often hindered by intellectual property concerns. ○ A directory of data producers would be useful.
<i>Ability to Share / Data Hub</i>	Requires a platform that is accessible, secure, and cost-effective for sharing data across Canada, Mexico and the United States.
<i>Traditional Ecological Knowledge</i>	GRS professionals primarily use Western science and may lack familiarity with TEK. Engagement and training in TEK would be beneficial to enhance data.
<i>Unified Definitions of Tame and Native Grassland</i>	A unified definition of native, mixed, and tame grasslands is needed based on current technology. Possible sources of guidance include: ○ The Carbon A List Project, working on defining grasslands and achieving consensus. ○ The World Resources Institute Land Carbon Lab, which is using remote sensing and ground truthing to classify grasslands in the United States.
<i>Maps of Vegetation Types</i>	Consistent maps of vegetation types across Canada, Mexico and the United States are needed. Current mapping efforts often lack seamless data and species information.
<i>Community/citizen Science</i>	Citizen science is important for engaging stakeholders and aiding in ground-truthing efforts. CS has been useful in Mexico for species data but has been more limited for habitat monitoring. In Canada and the United States, incorporating CS into inventory work has proven challenging. There is a need for a strategy to effectively engage with quality CS.
<i>Socioeconomic Data</i>	Human dimensions data (social, economic, etc.) about land ownership and perspectives is essential for understanding threats to grasslands (e.g., conversion) and identifying habitat needs for specific species or corridors.

The results from this section reveal several data challenges affecting both individual GRS inventories and standardization efforts. These challenges encompass the lack of a unified North American community or practice, technical issues related to data sharing, security and ownership, funding constraints for data collection and maintenance, and limited integration of diverse data sources such as TEK and socioeconomic data. Additionally, while engaging stakeholders for citizen science and ground-truthing efforts is particularly difficult in Canada and the United States, there may be valuable insights and positive experiences from other regions that could inform and improve practices elsewhere.

6. Standardizing Grassland Monitoring: Opportunities and Challenges

Standardization of diverse and multiple inventories for any issue is challenging. Integrating multiple initiatives at a biome level, across provincial, state, national and international jurisdictions is an even more daunting task. As such, the collective insights gleaned from the CEC workshops on grassland monitoring were essential in identifying existing challenges and considering future opportunities to address them. Specifically, a facilitated discussion was dedicated to what a standardized framework to achieve data-based, comparable, collaborative monitoring of grassland change in North America would look like. Specifically, workshop participants were asked to reflect on i) what is needed to achieve that approach? ii) is there a single existing initiative we could all agree to support? and iii) how do we move forward building a community of practice? The discussion was supported by a comprehensive literature review to inform the participants' answers. Table 7 identifies goals that would lead to that success, linked with opportunities and challenges.

Table 6. Opportunities and challenges related to standardization goals for grassland monitoring, as discussed in the CEC workshops and supported by GRS literature

Goal	Opportunity	Challenge
<i>Purpose</i>	Define a clear purpose that all partners can align with and set specific goals, which will guide standardization, scalability, and collaboration, etc.	Identifying a common purpose can be challenging due to different jurisdictions and land use pressures.
<i>Awareness</i>	Distinguish this standardization effort from others by identifying what gaps are being filled that other efforts do not.	Ensure that work is not duplicated.
<i>Scale</i>	Defining the best scale for trinational relevance that will provide useful information and explore what is being done across spatiotemporal scales and for what purpose.	Requires cooperation, coordination, and detailed background research.
<i>Integration Approaches</i>	(1) Standardize existing efforts in each country to build something useful in the short term while leveraging existing programs and allowing continued monitoring.	Requires significant funding, effective communication, and a trusted community of practice to harmonize efforts nationally and internationally.

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	(2) Harmonize efforts using the same data and methods.	
<i>Expand Boundaries</i>	Expanding boundaries of existing approaches may be simpler than creating new ones.	Involves different stakeholders, language barriers, and cultural differences.
<i>Promote Comparability</i>	Allow jurisdictions to measure according to their own policy goals while distilling comparable metrics.	Identifying methods and variables to ensure comparability.
<i>Enhanced Training</i>	Engage professionals who can provide training in techniques not widely applied across all three countries.	Challenges include travel, language barriers, and availability of trainers.
<i>UAV Technology</i>	UAVs are valuable for linking with ground-truthing efforts.	Time-consuming and costly, and weather dependent.

The goals described above would support standardization efforts. At a more technical level, workshop participants emphasized the need to review all methods used in grassland monitoring. This includes assessing the technical details, approaches, nature and parameters of outputs, and limitations of each method. Once this comprehensive evaluation would be completed, an informed strategic discussion about standardization could take place. This discussion should consider the local context and the specific objectives each inventory addresses, allowing for a focused conversation on which inventory is best suited for questions and scenarios.

7. Future Direction, Integration and Capacity Building

The CEC-facilitated workshops aimed to foster collaboration among grasslands monitoring experts from Canada, Mexico and the United States. These discussions provided valuable insights into future direction, integration and capacity building that are not found in published literature or summaries of grassland inventories. Table 7 outlines some of the next steps informed by the workshop discussions.

Table 7. Suggested next steps for future direction in grassland monitoring as determined by CEC workshops participants

<i>Theme</i>	<i>Suggested Next Steps</i>
<i>North American Community of Practice</i>	Develop a collaborative network to improve integration and knowledge sharing across the three countries. Enhance understanding of ongoing work in other countries to better integrate efforts and practices.
<i>Agreed Commonality</i>	Identify and integrate commonalities in existing efforts to develop a more harmonious and standardized framework.
<i>Data Repository and Exchange</i>	Establish a centralized platform for data uploads and include detailed classifications and definitions of existing datasets.
<i>International Overlap in Mapping</i>	Implement additional mapping into adjacent countries (e.g., 20 km overlap) to create a cohesive and uniform view across borders.
<i>Enhanced Indigenous Engagement and Understanding</i>	Initiate long-term engagement strategies to integrate TEK and build trust with Indigenous communities.
<i>Workshop Continuity</i>	Ensure continuity, foster technical collaboration and standardization of data between countries, and include broader stakeholder engagement (e.g., other agencies in Mexico). Establish regular meetings for workshop participants to foster ongoing collaboration and standardization.
<i>Technical Review</i>	Conduct a comprehensive review and evaluation of methods to assess technical details, advantages, and limitations, and strategize their application based on identified needs.

The future direction for capacity building in GRS, as identified by the participants in the CEC workshops, aligns with themes such as data sharing, continuity in building a community of practice, and ensuring that missing voices, particularly from Indigenous communities, are included in the conversation. A technical evaluation conducted by an unbiased GRS expert on methods would also be an excellent next step to inform future discussions. Each of these points would benefit from a strategic discussion on how to operationalize these actions and could serve as topics for facilitated discussions at future meetings.

8. Conclusion

Approximately 60% of North America's native grassland ecosystems have been converted to other land uses over the past century (Central Grasslands Roadmap 2022; FWS 2024) and 32 million acres have been converted since 2012 alone (WWF 2023), leading to significant loss of biodiversity and ecosystem services. This has been recognized as a pressing issue by provincial, state, and national governments across the continent. Addressing the loss of grasslands requires a thorough understanding of current grassland inventories, which can support conservation incentives, encourage government funding and regulation, and foster personal action at the landscape level. Various conservation efforts have emerged in response to this issue, each tailored to local contexts and employing different engagement strategies.

A foundational element to these efforts is a clear, consistent understanding of grassland loss. However, achieving this coherence is complicated by the diverse political, economic, social, and environmental contexts across North America's grassland biome, as well as different grassland inventories, each differing in their approaches. This diversity presents a challenge to end-users and the public, who may receive conflicting messages about the rate of loss and its urgency.

This report addresses these challenges by summarizing the current state of grassland monitoring in North America, including a scan of inventories, an exploration of limitations and challenges, best practices, and reflections on the next steps for standardization. The analysis revealed that while over 30 inventories exist across the continent, each with their own strengths and limitations, there is potential to address these limitations by integrating efforts and building a community of practice. Such an approach could facilitate standardized messaging and shared methodologies, enhancing overall coherence in addressing grassland loss.

Limitations of this report include: i) reliance on online information and partial direct communication with inventory representatives, as not all were contacted; ii) the authors' language barriers that may have impacted the capture of the unique language and cultural context of Mexico; and iii) qualitative insights from workshops were constrained due to time. Further research involving direct engagement with inventory representatives and workshop participants would enhance the quality of future reports.

Supported by the CEC's trilateral cooperation framework for environmental management, this report combines published literature with workshop perspectives to provide a unique and valuable resource. It

is expected that the findings will serve as a foundation for future grassland research and policy efforts, enhancing existing conservation initiatives, promoting new collaborations, and mitigating the loss of grasslands across Canada, Mexico and the United States.

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