Environ Monit Assess
DOI 10.1007/s10661-013-3557-9

Monitoring an ecosystem at risk: What is the degree of grassland fragmentation in the Canadian Prairies?

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Received: 18 June 2013 / Accepted: 19 November 2013

Abstract Increasing fragmentation of grassland habitats by human activities is a major threat to biodiversity and landscape quality. Monitoring their degree of fragmentation has been identified as an urgent need. This study quantifies for the first time the current degree of grassland fragmentation in the Canadian Prairies using four fragmentation geometries (FGs) of increasing specificity (i.e. more restrictive grassland classification) and five types of reporting units (7 ecoregions, 50 census divisions, 1,166 municipalities, 17 sub-basins, and 108 watersheds). We evaluated the suitability of 11 datasets based on 8 suitability criteria and applied the effective mesh size (m_{eff}) method to quantify fragmentation. We recommend the combination of the Crop Inventory Mapping of the Prairies and the CanVec datasets as the most suitable for monitoring grassland fragmentation. The grassland area remaining amounts to 87,570.45 km^2 in FG4 (strict grassland definition) and 183,242.042 km^2 in FG1 (broad grassland definition), out of 461,503.97 km^2 (entire Prairie Ecozone area). The very low values of m_{eff} of 14.23 km^2 in FG4 and 25.44 km^2 in FG1 indicate an extremely high level of grassland fragmentation. The m_{eff} method is supported in this study as highly suitable and recommended for long-term monitoring of grasslands in the Canadian Prairies; it can help set measurable targets and/or limits for regions to guide management efforts and as a tool for performance review of protection efforts, for increasing awareness, and for guiding efforts to minimize grassland fragmentation. This approach can also be applied in other parts of the world and to other ecosystems.

Keywords Effective mesh size · Ecological indicators · Grassland conservation · Landscape fragmentation · Fragmentation *per se* · Protected areas · Prairie ecozone · Roads · Urban sprawl

Abbreviations used

CBI	City Biodiversity Index
FG	Fragmentation geometry
CESI	Canadian Environmental Sustainability Indicators
FSDS	Federal Sustainable Development Strategy
m_{eff}	Effective mesh size
s_{eff}	Effective mesh density
AAFC	Agriculture and Agri-Food Canada
SpATS	Spatial and Temporal Variation in Nesting Success of Prairie Ducks Study
CUT procedure	Cutting-out procedure
CBC procedure	Cross-boundary connections procedure
CD	Census division
WS	Watershed

Electronic supplementary material The online version of this article (doi:10.1007/s10661-013-3557-9) contains supplementary material, which is available to authorized users.

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Published online: 04 January 2014

CARTS	Conservation Areas Reporting and Tracking System
CCEA	Canadian Council on Ecological Areas
RAN	Representative Areas Network
ESM	Electronic supplementary material

Urgent need for monitoring grassland fragmentation

Increasing threats to grassland habitats

Native grasslands have one of the richest biological diversity of all the Earth's ecosystems, including many species at risk (White et al. 2000; Henwood 2010; Federal and Provincial and Territorial Governments of Canada 2010; Samson and Knopf 1994). The shrinkage and increased isolation of remnant grassland habitat patches lead to reductions in species richness and biodiversity, the disruption of possibilities of movement, e.g. dispersal and (re-)colonization, the disruption of metapopulation dynamics, and a greater vulnerability and risk of extinction. Native grasslands support many important ecosystem services. They "provide soils and water conservation, nutrient recycling, pollination, habitat for livestock grazing, genetic material for crops, recreation, climate regulation and storage for about 34 % of the terrestrial global carbon stock" (Federal and Provincial and Territorial Governments of Canada 2010, p. 15) and represent a major carbon sink (White et al. 2000; Henwood 2010), superior to that of forests (Samson and Knopf 1994). When native grasslands are converted to other land use types, carbon is released contributing significantly to greenhouse gas emissions (White et al. 2000; Henwood 2010). Grasslands are an important source of food and genetic material, which is used for augmenting crops and pharmaceuticals (White et al. 2000). They are also used for recreational activities such as hunting and tourism, and have significant aesthetic and spiritual properties (White et al. 2000).

Even though temperate grasslands constitute one of the most endangered ecosystem types on Earth and have the highest risk of biome-wide biodiversity loss, they are one of the least protected biomes; with only 4 % under protection (Henwood 2010; Federal and Provincial and Territorial Governments of Canada 2010; White et al. 2000). The Prairies of North America have declined by 79 % since the early 1800s (White et al. 2000). By 2003, over 97 % of tall-grass prairie, 71 % of mixed prairie, and 48 % of short-grass prairie had been lost in North America (Federal, Provincial and Territorial Governments of Canada 2010); making grasslands the most endangered ecosystem in North America (CEC and TNC 2005). Few grassland landscapes, that are sufficient in size to properly sustain biodiversity and ecological processes which are native to the landscape, remain (Samson et al. 2004); therefore, the need is great to preserve the few grasslands that are left. However, the estimates of the amount of grassland lost vary considerably between different sources as different methods, data sources, and definitions of grassland types (Table 1) can influence such estimates. These variations can also affect the estimates of the degree of grassland fragmentation.

Increasing fragmentation due to human activities is a major threat to the conservation value of grasslands, but their degree of fragmentation and rate of change are currently not known. The focus of this study is on the grasslands in the three Prairie provinces (Manitoba, Saskatchewan, and Alberta), which make up the Prairie Ecozone of Canada. The Northern Great Plains cover 5 % of Canada's land area, taking up 16 % of the area of the three Prairie provinces (Gauthier and Wiken 2003) and have "been identified as a global priority for conservation" (Henwood 2010, p. 129). Of the portion located in Canada (Prairie Ecozone), approximately 3.5 % are under some form of conservation (Gauthier and Wiken 2003).

Canada has lost 44 % of grassland species populations since the 1970s (Federal and Provincial and Territorial Governments of Canada 2010). Edge effects from fragmented habitat patches play an important role to this decline, as grassland birds avoid nesting close to these edges (Merola-Zwartjes 2004; A1 in Electronic supplementary material (ESM)). The majority of the decline in native grasslands happened before the 1930s due to conversion to agricultural land (Riley et al. 2007; Gauthier and Wiken 2003). However, further alteration and degradation is still continuing, with small patches being affected the most (Federal and Provincial and Territorial Governments of Canada 2010; Samson and Knopf 1996). As a consequence, grasslands are under serious threat of further degradation and fragmentation (Table 2).

Table 1 Commonly used grassland terms and definitions in the literature

Term used	Definition	Source
Grasslands	"…as terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures. This definition includes vegetation covers with an abundance of non-woody plants and thus lumps together some savannas, woodlands, shrublands, and tundra, as well as more conventional grasslands".	White et al. (2000, p. 1)
Grasslands	"Less than 10% tree cover".	White et al. (2000, p. 11)
Grasslands	"Grasslands generally include land that is in perennial grasses and herbaceous species for grazing or other uses including native range, seeded tame pasture, abandoned farm areas and other non-cultivated uses (e.g. ditches, riparian areas etc.). Grasslands represent an environment historically or currently dominated by graminoids, occurring primarily over light to dark brown chernozemic soils, under semi-arid to arid conditions with dry, warm summers".	Gauthier and Wiken (2003, p. 362)
Grasslands	"Grasslands are open ecosystems dominated by herbaceous (non-woody) vegetation".	Federal and Provincial and Territorial Governments of Canada (2010, p. 15)
Native grass	"Predominantly native grasses and other herbaceous vegetation may include some shrubland cover. Land used for range or native unimproved pasture may appear in this class. Comments: Alpine meadows fall into this class".	Centre for Topographic Information and Earth Sciences Sector and Natural Resources Canada (2009, p. 4–5)
Native grassland	"Areas vegetated with various mixtures of native grasses, forbs, and short (<2 m tall) woody plants. Native grasslands have usually never been broken and are often found in large contiguous blocks, but small remnant native grasslands may remain. May contain some invasive species".	IWWR, DUC (2011)
Planted grassland	"Areas planted to introduced grasses to provide pasture. Use this coding when the grasses show evidence of being mechanically seeded (e.g. grasses are in rows, limited species diversity reflects original seed mix)".	IWWR, DUC (2011)
Other grassland	"Areas vegetated with various mixtures of introduced and native grasses, forbs, and short (<2 m tall) woody plants. Usually found in smaller blocks but previously ploughed areas that have reverted (not planted) to introduced species are considered Other Grassland. Use for most wetland margins and all rights-of-way and fenceline strip".	IWWR, DUC (2011)
Native prairie	"An area of unbroken grassland or aspen parkland dominated by non-introduced species".	PCF (2011, p. 24)
Prairie	"An area of flat or rolling topographic relief that principally supports grasses and forbs, with few trees, and is generally of a mesic (moderate or temperate) climate. The French explorers called these areas *prairie* from the French word for 'meadow'".	Riley et al. (2007, p. 104)
Pasture land	"min size, 10 ha, Includes native and seeded grazing land but not riparian areas. Some shrubland may be included because of the small size of shrubby patches".	Digital Environmental (2008)
Hay land	"min size, 10 ha, Land used for cut forage (alfalfa, clover, grass, mix)".	Digital Environmental (2008)

Monitoring is an important prerequisite for grassland conservation (Gauthier and Wiken 2003). It is difficult to allocate resources unless we know where we stand in terms of past and ongoing trends in grassland fragmentation. Numerical data will be more useful and provide greater accuracy than qualitative information and anecdotal observations when assessing long-term trends, when identifying areas of rapid change or high risk of degradation, or evaluating whether conservation activities are having their desired effects.

Table 2 Overview of current threats to grasslands in the Canadian Prairies

Threat	Description	Sources
Agriculture	Conversion of native grasslands to croplands and intensification of agricultural practices. In addition, contamination from the use of pesticides, insecticides, herbicides and irrigation systems reduces grassland habitat quality.	Federal and Provincial and Territorial Governments of Canada (2010); CEC and TNC (2005); White et al. (2000); Forrest et al. (2004); Samson and Knopf (1994); PCF (2011)
Urbanization	Increasing population growth and increasing land uptake (built-up area) per person lead to the development and expansion of urban areas and residential subdivision.	Federal and Provincial and Territorial Governments of Canada (2010); CEC and TNC (2005); Merola-Zwartjes (2004); White et al. (2000); PCF (2011)
Invasive species (non-native)	Invasive species often contribute to a loss in native species as invasive species take over resources (space, nutrients, light, etc.).	Federal and Provincial and Territorial Governments of Canada (2010); CEC and TNC (2005); Merola-Zwartjes (2004); White et al. (2000); Forrest et al. (2004); PCF (2011)
Oil, gas, and coal extraction	Canada is the eighth largest oil and gas producer and exporter in the world. In 2006, there were more than 20,000 oil and gas wells drilled in Alberta and more than 5,000 in Saskatchewan; almost all of which were developed in the prairie and parkland region. Nasen et al. (2011) found disturbance impacts on native grasslands from well sites were evident for more than 50 years after their construction. In addition to the well sites themselves, there are many impacts from the associated pipeline and road infrastructure, seismic lines for exploration as well as vehicle activity.	CEC and TNC (2005); Riley et al. (2007); Nasen et al. (2011); Forrest et al. (2004); PCF (2011)
Energy production	Wind power and solar power development.	CEC and TNC (2005); PCF (2011)
Overgrazing	Overgrazing may degrade habitat quality, increase soil loss, decrease infiltration rates and change the composition and extent of plant species. As intensity of grazing increases, so does their effect on the surrounding environment. The construction of fences, which are thought to be a solution to overgrazing, contribute to further fragmentation of the grasslands.	Federal and Provincial and Territorial Governments of Canada (2010); CEC and TNC (2005); Samson et al. (2004); Merola-Zwartjes (2004); White et al. (2000); Forrest et al. (2004)
Water diversions/alterations	The construction of dams, reservoirs, irrigation and drainage causes changes in the landscape and decreases groundwater levels.	Merola-Zwartjes (2004); Forrest et al. (2004); Samson and Knopf (1994)
Shrub/forest encroachment	Shrub and forest encroachment is a common result from overgrazing and can lead to the degradation and fragmentation of habitat which may increase edge effects and push out native species.	Merola-Zwartjes (2004); Federal and Provincial and Territorial Governments of Canada (2010)
Disruption of natural fire cycles	Fire is an important process in the maintenance of grasslands, as fire prevents the encroachment of shrubs, removes dead material and recycles nutrients.	Merola-Zwartjes (2004); White et al. (2000); Federal and Provincial and Territorial Governments of Canada (2010)
Climate change	Desertification and drought resulting from increased aridity.	Gauthier and Wiken (2003); Forrest et al. (2004); PCF (2011); White et al. (2000)
Fragmentation	Fragmenting barriers include: roads, railroads, expansion of built-up areas, intensification of agriculture, construction of fences and pipelines, as well as natural elements such as rivers, shore-lines and lakes.	White et al. (2000); Federal and Provincial and Territorial Governments of Canada (2010); Forrest et al. (2004); Jaeger et al. (2008)

Accordingly, the Canadian Environmental Sustainability Indicators Initiative has a mandate to report indicators for tracking progress on the new Federal Sustainable Development Strategy (FSDS). Goal 6 of the FSDS covers Ecosystem/Habitat Conservation and Protection. Its objective is to "maintain productive and resilient ecosystems with the capacity to recover and adapt; and protect in ways that leave them unimpaired for present and future generations" (Sustainable Development Office and Environment Canada 2010).

Relationship between landscape fragmentation and connectivity

Fragmentation is defined as "the breaking up of a habitat, ecosystem, or land use type into smaller parcels" (Forman 1995, p. 39; Schumacher and Walz 2000) and implies a reduction in landscape connectivity, which is defined as "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al. 1993, p. 571). Landscape connectivity depends on landscape composition and configuration, and on a species' movement ability and risk of mortality when moving through the landscape (Tischendorf and Fahrig 2000).

Research questions

This study addresses two research questions:

1. What data are available for long-term monitoring of grassland fragmentation in the Canadian Prairies and how suitable are they?
2. What is the current degree of fragmentation of the Canadian prairie grasslands?

In addition, we explore the feasibility of determining fragmentation for historic points in time and of continuing monitoring grassland fragmentation in the future. We also examine the applicability and utility of the effective mesh size metric for monitoring grasslands.

How to measure fragmentation?

Data availability and suitability

We found 11 candidate datasets that provide at least some information about the spatial distribution of grasslands in the Canadian Prairies between 1993 and 2011. We used eight suitability criteria, each of them mandatory or desirable: (1) regular time step updates (e.g. every 5 years)—mandatory; (2) complete coverage of the Canadian grasslands—mandatory; (3) classes and definitions clear and consistent over time—mandatory; (4) classes and definitions consistent between provinces—desirable; (5) resolution consistent over time, for the future—mandatory, and for the past—desirable; (6) historical data available—desirable; (7) contains a grassland class—mandatory; and (8) distinguishes between native and non-native grassland—desirable. We then assigned scores for total overall suitability, total mandatory suitability, and total desirable suitability.

Fragmentation geometries and reporting units

A fragmentation geometry (FG) specifies all the elements of fragmentation that will be considered (Jaeger et al. 2008). We used four FGs (full list given in Table 3 and further details in A8, A9, and A10 in ESM) that cover a range in land covers, with increasing restrictiveness of the definition of grassland from FG1 to FG4 in order to gauge the uncertainty of our findings about grassland fragmentation, as there are some variations in the definitions of the land cover types that are considered "grassland" (Table 1). For example, the definition of grasslands by Gauthier and Wiken (2003) includes seeded tame pasture and abandoned farm areas as grassland areas. Therefore, we created this array of FGs, which provide different combinations of land covers that could possibly include some type of grasslands. Another benefit of using several FGs is they are applicable to a range of species, e.g. from habitat specialists which can only live in grassland habitat in a strict sense (FG4) to habitat generalists which can live in a wider range of habitats (FG1). An example of a habitat specialist is the Sprague's Pipet who requires specifically native grasslands, whereas the Loggerhead Strike is a habitat generalist who uses a wide variety of habitats: grasslands, pastures, shrubland, and even some agricultural areas (Parks Canada 2009; SARA 2010; COSEWIC 2010).

We report the degree of fragmentation for the 7 ecoregions, 17 sub-basins, 108 watersheds, 1,166 municipalities, and 50 census divisions located within the Prairie Ecozone, which we call "reporting units".

Table 3 GIS layers included in the four fragmentation geometries used in this study. For a full list and description of the CanVec and AAFC barriers included in the four FGs see A8, A9, and A10. The numbers in brackets indicate the grid code of the classes in the AAFC dataset

Number and name of the fragmentation geometry	Definition and relevance	Two-dimensional features			One-dimensional features
		AAFC's crop type mapping of the prairies		CanVec	CanVec
		Not considered as barriers	Barriers considered	Barriers considered in all four FGs	Barriers considered in all four FGs
FG1: Broad grassland fragmentation	Includes several other land cover types in addition to the grasslands class; in order to incorporate all possible land covers which may be related to grasslands based on the various definitions of land cover types which may or may not include grasslands. This FG would demonstrate a minimum level of fragmentation because it provides a conservative estimation of the real fragmentation as the real fragmentation is probably higher due to barriers that are not represented in the available datasets and due to the inclusion of other land cover types not specifically defined as grassland. The real degree of grassland fragmentation is at least as high as this estimate.	Grassland (110) Wetland (80) Shrubland (50) Hay/pasture (122) Fallow (131)	All other land cover types	*Building structures:* Buildings, tanks, residential areas, transformer stations and gas and oil facilities *Hydrology:* Permanent snow and ice *Industrial and commercial areas:* Mines, extraction areas, industrial and commercial areas, industrial solid depots, domestic waste, peat cutting, quarries, auto wreckers, pits and lumber yards. *Places of Interest:* Picnic sites, campgrounds, cemeteries, drive-in-theatres, lookouts, ruins, sports track/race tracks, golf driving ranges, park/sports fields, amusement parks, forts, stadiums, zoos, golf courses, exhibition grounds *Transportation:* Runways *Water body:* All water bodies (except ditches): canals, lakes, reservoirs, watercourses, tidal rivers, ponds, liquid waste and side channels.	Walls/fences Manmade hydrographic entities Sports tracks/race tracks Railways Cutlines Canals All road segments (except winter roads): freeways, expressways/highways, arterial, collectors, local, alleyways/lanes, ramps, resource/recreation and rapid transit service lanes
FG2: Fragmentation of grassland, wetland, shrubland and hay/pasture	This FG is similar to FG1, in that it includes other land cover types that are closely related to grasslands or could also be classified as grasslands (pasture in some datasets are grouped into their defined grassland class). The only difference between FG1 and FG2 is that "fallow" is considered a barrier for FG2.	Grassland (110) Wetland (80) Shrubland (50) Hay/pasture (122)	Fallow (131) All other land cover types		
FG3: Fragmentation of grassland, wetland and shrubland	This FG provides an intermediate level of grassland fragmentation as it incorporates not only grasslands but other land cover types which are closely related to grasslands and are less likely to be a barrier for most	Grassland (110) Wetland (80) Shrubland (50)	Fallow (131) Hay/pasture (122) All other land cover types		

Table 3 (continued)

Number and name of the fragmentation geometry	Definition and relevance	Two-dimensional features			One-dimensional features
		AAFC's crop type mapping of the prairies		CanVec	CanVec
		Not considered as barriers	Barriers considered	Barriers considered in all four FGs	Barriers considered in all four FGs
	grassland species as these land cover types are still quite natural. Unlike FG1, this FG does not include any agricultural land (e.g. fallow or pasture). The values of this FG would fall between the fragmentation levels of FG1 and FG4, thereby providing a medium degree of fragmentation.				
FG4: Strict grassland fragmentation	Describes grassland fragmentation in a narrow sense, as the grassland class is the only AAFC land use class that was not considered as a barrier. All other land cover types were assumed to be a barrier. This FG represents the maximum degree of fragmentation (relative to the particular datasets used and the year being analyzed). The real degree of grassland fragmentation may be less than this estimate, since there may be some grassland included in other land cover types other than in the "grassland" class.	Grassland (110)	Fallow (131) Hay/pasture (122) Wetland (80) Shrubland (50) All other land cover types		

Effective mesh size and effective mesh density

Various landscape metrics have been suggested in the literature for quantifying fragmentation (e.g. Gustafson 1998; Leitão et al. 2006). Their behaviour needs to be carefully studied before they are applied (Jaeger 2000, 2002; Li and Wu 2004). We illustrate this by comparing four metrics with the effective mesh size (m_{eff}) based on their behaviour in the phases of shrinkage and attrition of habitat patches which contribute to landscape fragmentation (Forman 1995; Fig. 1). This example shows that the average patch size, the number of remaining patches, the number of large undissected low-traffic areas >100 km^2, and the density of transportation lines do not behave in a suitable manner in the phases of shrinkage and attrition (Fig. 1). Therefore, their suitability is limited, whereas the m_{eff} behaves as desired.

The m_{eff} metric is based on the probability that any two points chosen randomly in a region are connected, i.e. are located in the same patch (Jaeger 2000). This can be interpreted as the probability that two animals, placed in different locations somewhere in a region, can find each other within the region without having to cross a barrier such as a road or urban area. By multiplying this probability by the total area of the reporting unit, it is converted into the size of an area, which is called the *effective mesh size*. The smaller the m_{eff}, the more fragmented the landscape. The largest possible value of m_{eff} is the size of the landscape studied when the landscape is unfragmented. The smallest value of 0 km^2 indicates complete fragmentation, i.e. no suitable area left. This leads to the formula:

$$m_{\mathrm{eff}} = \left(\left(\frac{A_1}{A_{\mathrm{total}}} \right)^2 + \left(\frac{A_2}{A_{\mathrm{total}}} \right)^2 + \left(\frac{A_3}{A_{\mathrm{total}}} \right)^2 + \ldots + \left(\frac{A_n}{A_{\mathrm{total}}} \right)^2 \right) \cdot A_{\mathrm{total}} = \frac{1}{A_{\mathrm{total}}} \sum_{i=1}^{n} A_i^2, \tag{1}$$

where n is the number of patches, A_1 to A_n represent the sizes of patches 1 to n, and A_{total} is the area of the reporting unit.

The m_{eff} has highly advantageous properties, e.g. m_{eff} is relatively unaffected by the inclusion or exclusion of small or very small patches, and is suitable for comparing the fragmentation of regions of differing total areas and with different proportions occupied by the barriers. Its reliability has been confirmed through a systematic comparison with other quantitative measures based on nine suitability criteria (Jaeger 2000, 2002; Girvetz et al. 2007). The suitability of other metrics was limited as they only partially met the criteria.

An important strength of m_{eff} is that it describes the spatial structure of a network of barriers in an ecologically meaningful way that is easy to understand (Girvetz et al. 2007). Landscape-level ecological processes associated with species movements, such as foraging, dispersal, genetic connectivity, and meta-population dynamics, all depend on the ability to move through the landscape. The m_{eff} is a direct quantitative expression of landscape connectivity, as m_{eff} corresponds with the proposed measurement of landscape connectivity by Taylor et al. (1993): 'landscape connectivity can be measured for a given organism using the probability of movement between all points or resource patches in a landscape'. As a consequence, m_{eff} has substantial advantages, e.g. it meets all scientific, functional, and pragmatic requirements of environmental indicators (see Jaeger et al. 2008 for a systematic assessment of m_{eff} based on 17 selection criteria for indicators for monitoring systems of sustainable development). Alternatively, the degree of fragmentation can be expressed as the *effective mesh density* $s_{\mathrm{eff}}=1/m_{\mathrm{eff}}$, i.e. the effective number of patches per 1,000 km^2 (Jaeger et al. 2007, 2008; Fig. 2).

We used the cross-boundary connections (CBC) procedure to remove any bias due to the boundaries of the reporting units by accounting for the connections within patches that extend beyond the boundaries of the

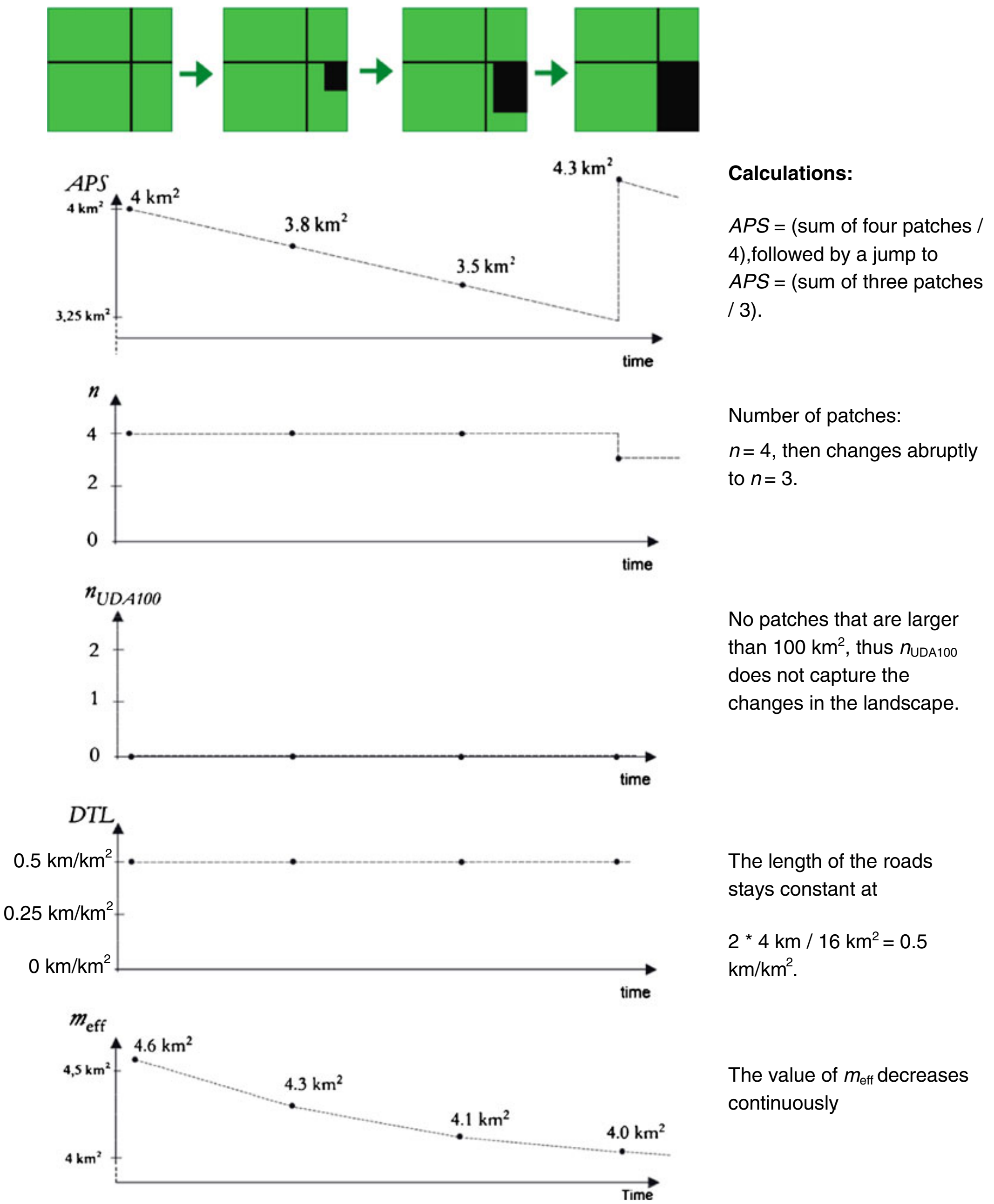

Fig. 1 Illustration of the behaviour of four landscape metrics in the phases of shrinkage and attrition of the remaining parcels of grassland due to the growth of an urban area. *First row* change of the landscape over time (*black lines* highways, *black area* residential or commercial area; size of the landscape= 4 km×4 km= 16 km^2). Only the effective mesh size behaves in a suitable way (*bottom diagram*). *APS* and *n* both exhibit a jump in their values (even though the process in the landscape is continuous); *DTL* and n_{UDA100} do not respond to the increase in fragmentation (m_{eff} effective mesh size, *n* number of patches, *APS* average patch size, n_{UDA100} number of large undissected low-traffic areas >100 km^2, *DTL* density of transportation lines)

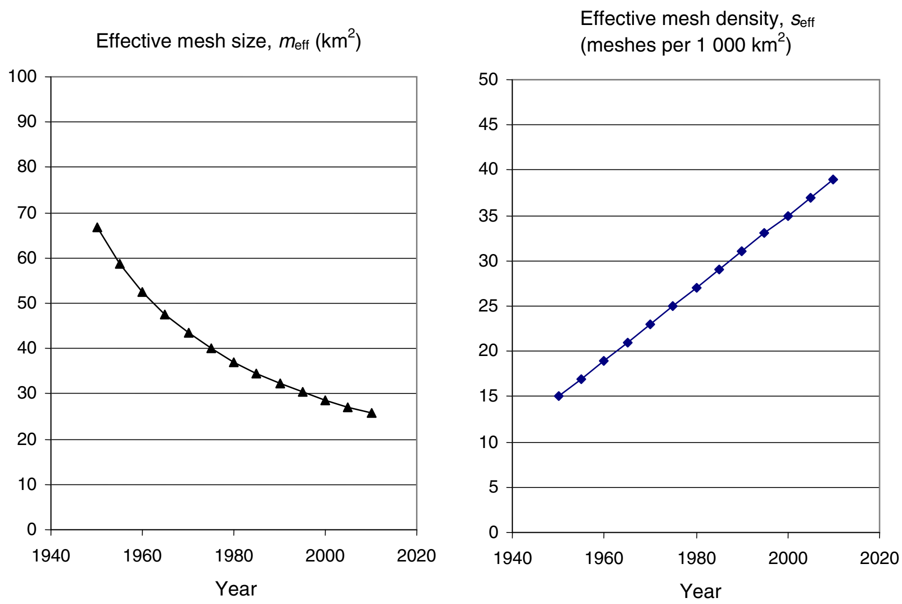

Fig. 2 Example illustrating the relationship between effective mesh size and effective mesh density (effective number of meshes per 1,000 km^2). In this hypothetical example, the trend remains constant. A linear rise in effective mesh density (*right*) corresponds to a $^1/_x$ curve in the graph of the effective mesh size (*left*). A slower increase in fragmentation results in a flatter curve for effective mesh size, and a more rapid increase produces a steeper curve. It is therefore easier to read trends off the graph of effective mesh density (*right*)

reporting units (Moser et al. 2007). However, we applied the cutting out (CUT) procedure along the outer boundaries of the Prairie Ecozone, i.e. only patches inside this border were considered.

The m_{eff} can be split into two components: (a) proportion of habitat and (b) habitat fragmentation *per se*, where "habitat" refers to grassland or suitable area ($A_{\text{total\_suitable}} = \sum_{i=1}^{n} A_i$). Their multiplication results in m_{eff}:

$$m_{\text{eff}} = \frac{1}{A_{\text{total\_landscape}}} \sum_{i=1}^{n} A_i^2 = \frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}} \cdot \frac{1}{A_{\text{total\_suitable}}} \sum_{i=1}^{n} A_i^2 = \frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}} \cdot m_{\text{eff\_per\_se}},$$

with

$$m_{\text{eff\_per\_se}} = \frac{1}{A_{\text{total\_suitable}}} \sum_{i=1}^{n} A_i^2, \qquad (2)$$

where $\frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}}$ is the proportion of suitable area in the reporting unit, and $m_{\text{eff\_per\_se}}$ is the degree of grassland fragmentation *per se*, i.e. it measures the probability that two points chosen randomly *within grassland patches* are connected (not including locations outside of grassland patches) and thus is conceptually independent of habitat amount. We used ArcGIS 9.3 (ESRI 2008) and two tools (one for creating the FGs and one for calculating m_{eff}).

Results

Data suitability

With a score of 33 out of 40 (mandatory 24/25 and desirable 9/15), the Crop Inventory Mapping of the Prairies provided by Agriculture and Agri-Food Canada (AAFC) is the best dataset to use for monitoring (Table 4; full rating scores in A2 of ESM). It is expected to be updated annually and has the long-term objective of expanding agricultural mapping to the entire extent of Canada (making it highly suitable for future monitoring), it has consistent classes and resolution over time and space; distinguishes grasslands from other land cover types such as fallow, shrubland, and hay/pasture; and includes

Table 4 Result of the ranking of the 11 candidate grassland datasets according to eight suitability criteria: 1 regular time step updates, 2 complete coverage of the Canadian grasslands, *3* classes and definitions clear and consistent over time, 4 classes and definitions consistent between provinces, 5 resolution consistent over time (for the past and future), 6 historical data available, 7 contains a grassland class, and 8 distinguishes between native and non-native grassland. The scores are explained in more detail in A2 in ESM

Dataset	Source(s)	Total suitability (40)	Mandatory suitability (25)	Desirable suitability (15)	Rank
Crop Inventory Mapping of the Prairies	AAFC (2009)	33	24	9	**1**
Land Cover Circa 2000	Centre for Topographic Information, Earth Sciences Sector and Natural Resources Canada (2009)	30	21	9	**2a**
Crop Condition Assessment Program	National Land and Water Information Service (2010)	30	21	9	**2b**
2006 Agricultural Land Cover Classification	Digital Environmental (2008)	30	18	12	**3**
WGTPP Generalized Land Cover	Data Basin (2010b)	29	21	8	**4**
2005 North America Land Cover	Commission for Environmental Cooperation CEC (2010)	27	22	5	**5**
Conservation Blueprint	Riley et al. (2007)	23	16	7	**6**
SpATS study data	DUC (2011); IWWR, DUC (2011)	28	17	11	**7**
GlobCover	Bontemps et al. (2009); Bicheron et al. (2008)	22	21	1	**8**
Grassland Vegetation Inventory	Alberta ESRD (2011); ASRD (2010)	19	15	4	**9**
Native Prairie Vegetation Inventory	Alberta ESRD (2011); ASRD (2001); ASRD (2004); PCF (2000)	17	16	1	**10**

various barrier features such as urban areas and cropland. With a pixel resolution of 56 m and an accuracy of 80 %, it can identify rather small changes in grassland distribution, allowing for a more precise calculation of grassland fragmentation than other datasets (AAFC 2009). Downsides are that it does not yet cover other areas in Canada which have grasslands, for example in Southern Ontario, and there are no historical data available. As its grassland class does not break down into native and non-native grasslands, estimates of the degree of natural grassland fragmentation will always be lower than the actual level of fragmentation of natural grasslands. However, these downsides do not impact its suitability for its application for future monitoring of grassland fragmentation within the Prairie Ecozone.

This dataset needs to be combined with an additional dataset to account for linear barriers such as roads and railways, and other barrier features which are not captured (e.g. oil and gas facilities and mines). The most suitable dataset to account for all these additional barriers is the CanVec dataset from Natural Resources Canada. CanVec was created from the best available data sources, is scheduled to be updated twice every year, has complete Canadian coverage, and it contains all the necessary barrier files (e.g. oil and gas facilities, roads, and railways) (Natural Resources Canada 2011). It does not provide any information about grasslands.

The more detailed SpATS dataset is even more reliable and has higher resolution (2.5 m) than the AAFC dataset, but only covers approximately 1.09 % of the Prairie Ecozone. It is unsuitable for monitoring the entire study area, but it may be useful to gauge the classification of grasslands of other datasets because it provides well-defined grassland classes and is the most detailed among all datasets (see "Comparison with grassland classification in the SpATS data" section).

Current degree of fragmentation of the Canadian Prairies

Overview

The following maps depict FG1=the broadest definition of grasslands (Fig. 3a) and FG4=the most specific definition of grasslands (Fig. 3b) for the entire Prairie Ecozone (FG2 and FG3 are found in A3 and A4 in ESM). The size of the largest patch is 1,114.25 km^2 in FG1. The rather low median patch size (around 0.62 ha)

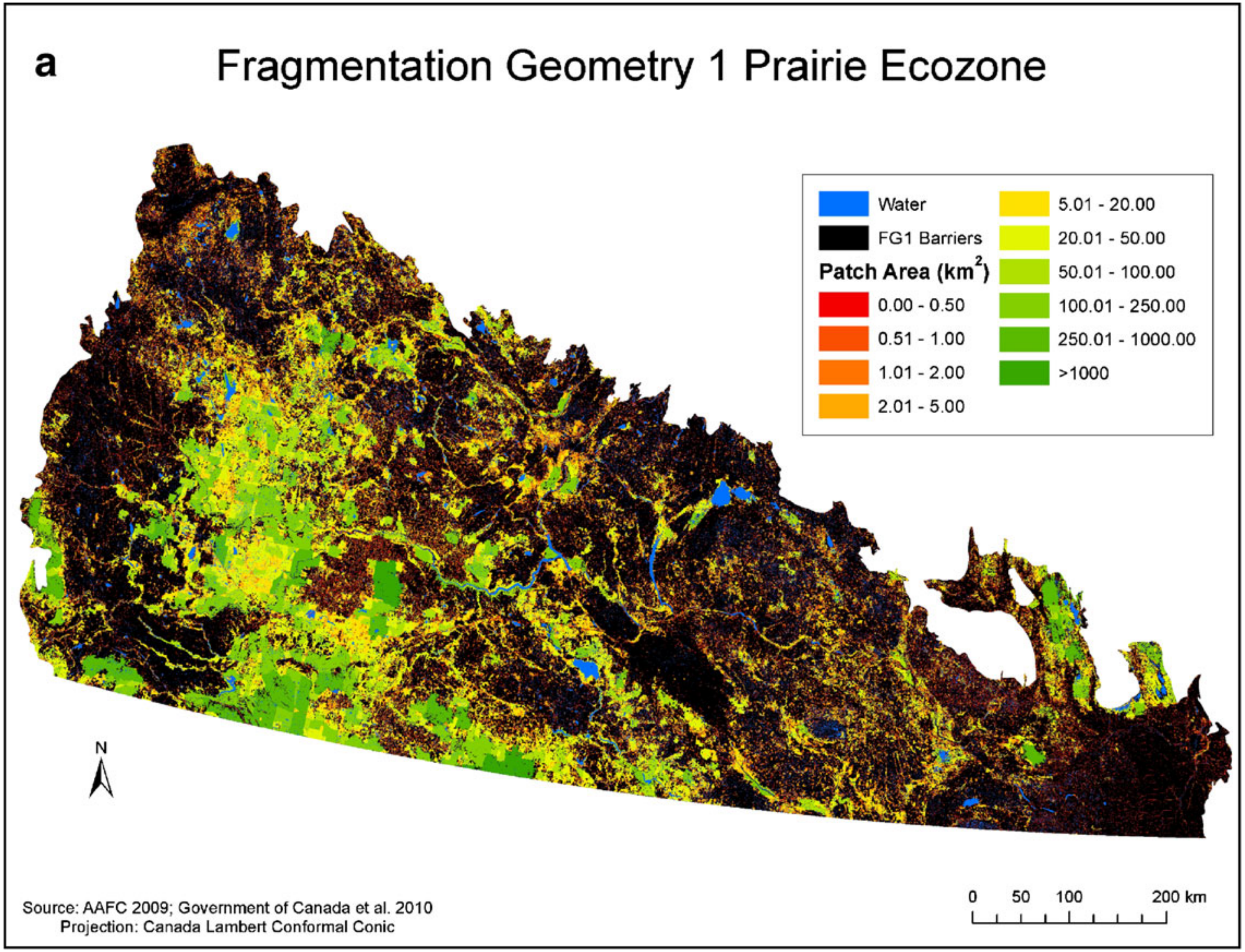

Fig. 3 **a** Fragmentation geometry 1 of the prairie ecozone. The *black patches* represent various types of barriers and the *other colours* indicate the sizes of remaining grassland patches ranging from *red* (very small) to *green* (larger). **b** Fragmentation geometry 4 of the prairie ecozone. The *black patches* represent various types of barriers and the *other colours* indicate the sizes of remaining grassland patches ranging from *red* (very small) to *green* (larger)

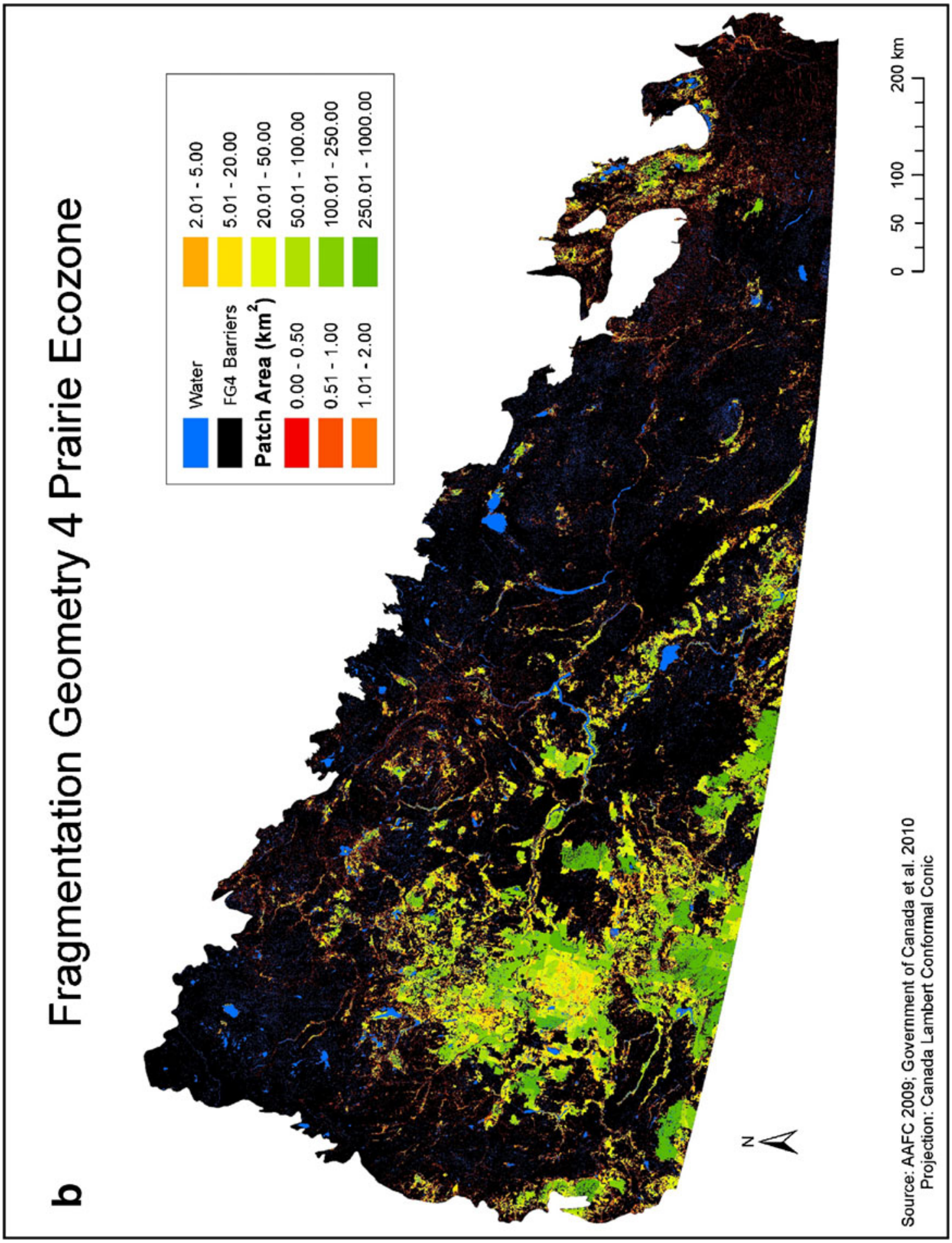

Fig. 3 (continued)

indicates that there are many small patches and few large patches of suitable area left. The sizes of these remaining patches strongly relate to the total land cover areas that are considered as potentially suitable areas (Table 5). The differences between FG1 and FG4 demonstrate how including the land cover types of hay/pasture, shrubland, wetland, and fallow (FG1) in addition to only “grasslands” (FG4) affects grassland fragmentation. As FG1 includes the most land cover types as suitable, it seems natural to expect that it would exhibit the lowest level of fragmentation and the largest remaining patch sizes, whereas FG4 would be expected to exhibit the highest level of fragmentation.

FG1 and FG2 are quite similar to each other in terms of the spatial distribution and sizes of the remaining patches (as are FG4 and FG3). These similarities indicate that the addition or removal of fallow land as a barrier has rather little impact on the level of fragmentation, whereas the addition of hay/pasture as a barrier plays a much greater role (Table 4). Overall, many smaller patches are located along the outer boundary of the Prairie Ecozone in all FGs. Large patches are concentrated in the lower sections of Saskatchewan and Alberta; most of them are found in the ecoregions of Moist Mixed Grassland, Mixed Grassland, or Cypress Upland. There are very few large patches in Manitoba, with most patches located in the northern section of the Prairie Ecozone.

In Alberta, a major difference between FG1 and FG4 is the higher number of small patches in the northern section of the Prairie Ecozone in FG4. In fact, there are almost no patches of grassland remaining here in FG4. In addition, the areas exhibiting a heavy concentration of smaller patches in FG1 are further fragmented in FG4, and where there are larger areas (near the Saskatchewan border in the centre and lower sections), the reduction in patch size is less pronounced. In Saskatchewan, a similar relation exists between FG1 and FG4: the northern section of the province is much more fragmented in FG4, also near the Manitoba border. The largest patches, located in the south-west of the province, next to the Alberta border, remain rather similar in both FGs. In Manitoba, the large patches in both of the northern peninsulas in FG1 are almost completely fragmented in FG4. In addition, the western side of Manitoba is much more fragmented in FG4. The

Table 5 Total land cover areas related to grassland for the Prairie Ecozone, Alberta, Saskatchewan and Manitoba. In addition, the median, minimum, and maximum values of the remaining patch sizes of potentially suitable areas (i.e. grassland or related) considered in the four FGs are listed

	Total land-cover amount (km^2)			
Land cover type	Prairie Ecozone	Alberta	Saskatchewan	Manitoba
Fallow	13,847.558	1,172.163	12,216.203	459.193
Grassland	89,881.299	44,410.608	36,952.295	8,518.396
Hay/pasture	62,678.213	19,568.146	36,492.404	6,617.663
Shrubland	13,852.565	4,636.424	7,044.421	2,171.720
Wetland	9,947.429	3,432.846	4,233.499	2,281.084
FGs	Prairie Ecozone	Alberta	Saskatchewan	Manitoba
FG1	183,241.176	73,220.187	96,938.822	20,048.056
FG2	169,572.693	72,048.024	84,722.619	19,588.863
FG3	108,372.420	52,479.878	48,230.215	12,971.200
FG4	87,568.590	44,410.608	36,952.295	8,518.396
	Amount of suitable area in the Prairie Ecozone (km^2)			
	FG1	FG2	FG3	FG4
Sum	183,241.176	169,572.693	108,372.420	87,568.590
Median patch size	6.21E-03	6.18E-03	6.04E-03	6.26E-03
Min patch size	9.6E-12	9.6E-12	4.5E-12	2.9E-12
Max patch size	1,114.247	1,111.193	981.641	856.933

areas that experience little change are those on the eastern side of Manitoba; in FG1, there were already hardly any patches left and those that remain are very small, and therefore, FG4 exhibits little change. These comparisons reveal the distribution and sizes of the remaining patches and show how the consideration of different land cover types influences this configuration.

The value of m_{eff} for the Prairie Ecozone in FG1 is 25.44 km^2. Considering the five classes: grassland, hay/pasture, fallow, shrubland, and wetland, there is 183,241.176 km^2 of suitable area left out of 461,503.970 km^2 (total area of the Prairie Ecozone). With the omission of fallow land in FG2, m_{eff} results in 24.67 km^2, a 3.0 % decrease from FG1. When only considering the AAFC's true grassland class, only 87,568.590 km^2 of grassland area remain, and FG4 results in a much lower m_{eff} value of 14.23 km^2, a 44.1 % decrease from FG1. When shrubland and wetlands are added, FG3 results in a considerably higher value of m_{eff}=18.91 km^2 (32.9 % higher; Table 7).

The m_{eff} are also measured for seven ecoregions (Table 7 and Fig. 5), 50 census divisions (Fig. 4 and 5; A5 in ESM), 1,166 municipalities (Fig. 5 and A12 in ESM), 17 sub basins (Fig. 5 and A6 in ESM), and 108 watersheds (Fig. 5 and A7 in ESM). The values (median, min, and max values) for all four FGs are summarized in Table 6.

Ecoregions

The Southwest Manitoba Uplands region has the highest level of grassland fragmentation, indicated by the lowest values of m_{eff}, with m_{eff}=0.170 km^2 in FG1 and m_{eff}=0.018 km^2 in FG4. This ecoregion is primarily composed of forests and includes many lakes and ponds, but a rather low proportion of grasslands (337.19 km^2 in FG1 and 176.71 km^2 in FG4 out of a total area of 2,183.44 km^2).

The lowest levels of grassland fragmentation are observed in the Cypress Upland, Mixed Grassland, and Fescue Grassland ecoregions, with the Cypress Upland region exhibiting the highest values of m_{eff} of

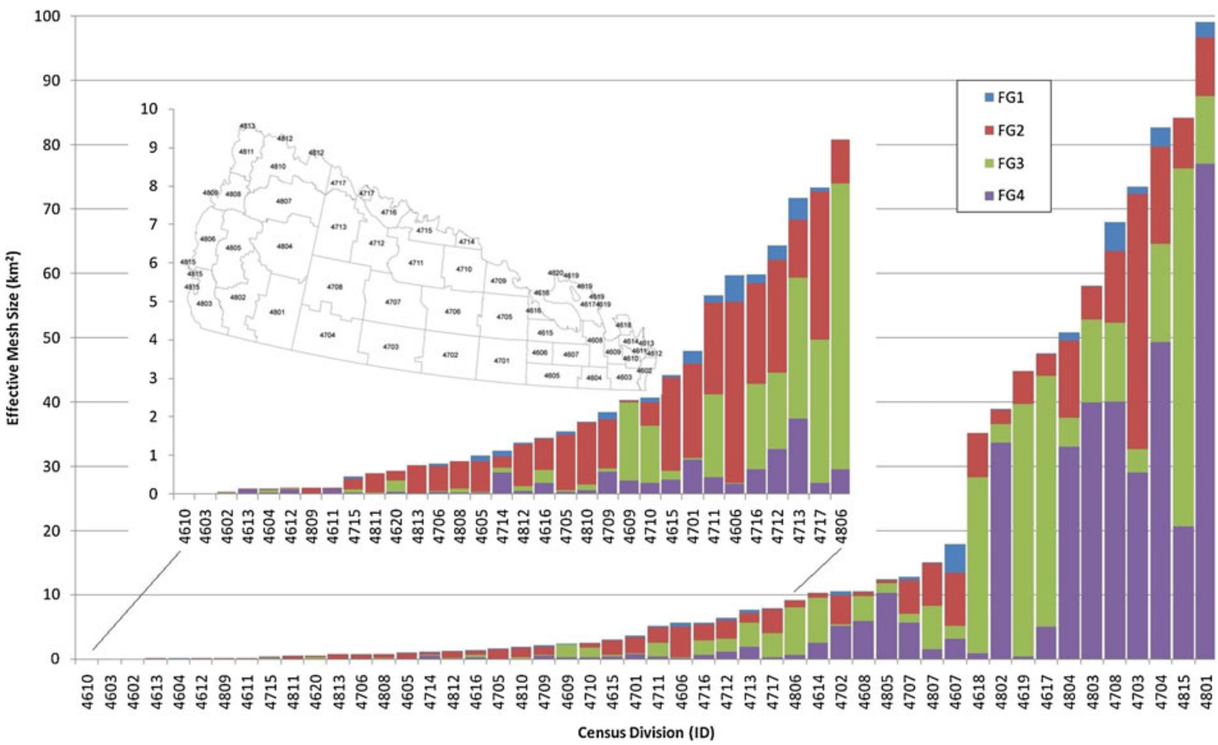

Fig. 4 Distribution of the values of effective mesh size (in square kilometers) for each of the four fragmentation geometries in the 50 census divisions in the prairie ecozone. Since the fragmentation geometries are building on each other, the values of m_{eff} are ordered: m_{eff} (FG1)≥m_{eff} (FG2)≥m_{eff} (FG3)≥m_{eff} (FG4). The *inset* shows the 32 census divisions whose m_{eff} values are lower than 10 km^2 in FG1

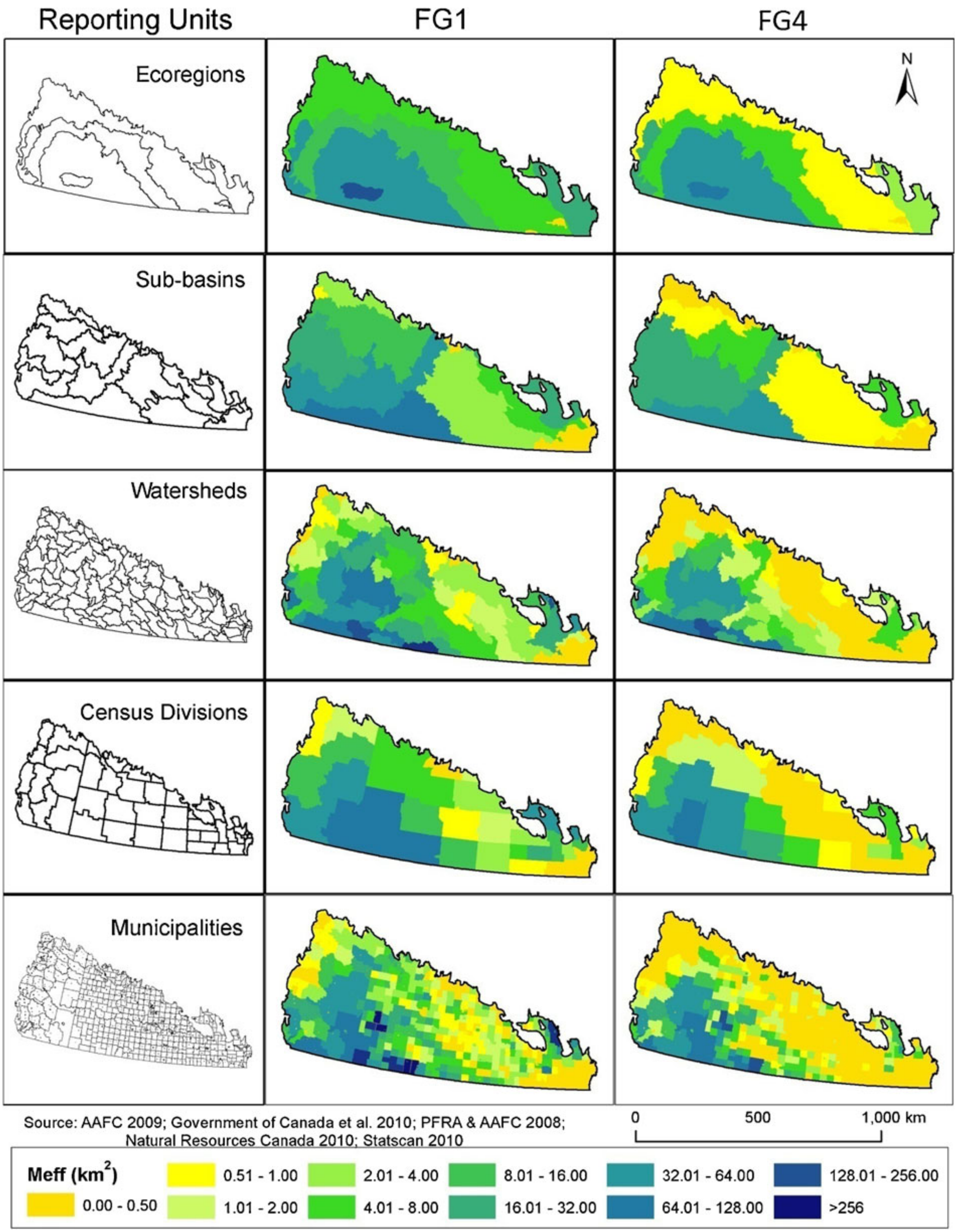

Fig. 5 Comparing effective mesh sizes (in square kilometers) between FG1 (minimum level of fragmentation) and FG4 (maximum level of fragmentation) for the following reporting units: ecoregions, sub-basins, watersheds, census divisions, and municipalities. The colours indicate the m_{eff} values from *yellow* (very small) to *blue* (larger)

Table 6 Reporting unit area and effective mesh size summary statistics for the five types of reporting units: census divisions, municipalities, ecoregions, sub-basins, and watersheds. For each type of reporting unit, the median, minimum, and maximum effective mesh size values are given for each of the four fragmentation geometries. The reporting unit area for the whole Prairie Ecozone is 461,503.97 km^2 and the effective mesh size of the Prairie Ecozone is 25.443 km^2 for FG1, 24.669 km^2 for FG2, 18.912 km^2 for FG3, and 14.233 km^2 for FG4

		Ecoregions	Sub-basins	Census divisions	Watersheds	Municipalities
Number of units		7	17	50	108	1,166
Reporting unit area (km^2)	Median	29,529.875	28,538.559	7,413.911	4,085.551	4.998
	Min	2,183.440	11.444	1.330	0.206	0.109
	Max	174,122.274	58,577.122	22,787.467	15,376.294	13,488.740
FG1 m_{eff} (km^2)	Median	20.411	5.250	4.425	3.610	0.250
	Min	0.170	0.100	0.011	0.006	0.000
	Max	129.267	82.269	99.085	264.411	380.227
FG2 m_{eff} (km^2)	Median	20.408	4.284	4.171	3.330	0.227
	Min	0.166	0.082	0.011	0.006	0.000
	Max	128.174	80.295	96.760	262.794	378.045
FG3 m_{eff} (km^2)	Median	18.646	1.367	2.065	1.520	0.017
	Min	0.032	0.000	0.000	0.000	0.000
	Max	116.476	60.111	87.630	197.729	294.748
FG4 m_{eff} (km^2)	Median	5.802	0.877	0.447	0.765	0.005
	Min	0.018	0.000	0.000	0.000	0.000
	Max	85.603	51.350	77.034	131.094	226.240

129.267 km^2 in FG1 and 85.603 km^2 in FG4 (the same is observed for FG2 with m_{eff}=128.174 km^2 and FG3 with m_{eff}=116.476 km^2). A major reason is that this is where most grasslands are located (6,574.48 km^2 in FG1 and 5,305.28 km^2 in FG4 out of 8,286.48 km^2). However, the comparison of the m_{eff} values with the total area of grassland demonstrates that the grasslands are highly fragmented even in these ecoregions.

Census divisions

Among the census divisions, the highest values of m_{eff} are 99.085 km^2 in FG1 and 77.034 km^2 in FG4 (Figs. 4 and 5). Both are observed in the census division (CD) 4801, which is located to 15.4 % in the Cypress Upland ecoregion and to 84.6 % in the Mixed Grassland ecoregion. The second highest value is 84.174 km^2 in FG1 for the CD 4815 and 49.307 km^2 in FG4 for the CD 4704 located east of CD 4801. CD 4704 is located to 23.1 % in the Cypress Upland ecoregion and to 76.9 % in the Mixed Grassland ecoregion.

The lowest value of m_{eff} is 0.011 km^2 in FG1 for the CD 4610 (located in the south-east of the Prairie Ecozone) and 0 km^2 in FG4 for both the CDs 4809 and 4813 (however, these CDs are located on the west border of the Prairie Ecozone, the CUT procedure was applied along the Prairie Ecozone's border, which could influence these results). The next most heavily fragmented grassland area for FG1 is found in CD 4603 with a m_{eff} of 0.019 km^2, and for FG4 in CD 4811 with a m_{eff} of 0.001 km^2. Interestingly, 26 CDs out of 50 fall into the 0–0.5 km^2 m_{eff} category for FG4, whereas only 10 CDs fall into this category for FG1. This indicates that a large number of CDs are excessively fragmented. In addition, all CDs exhibit a significant reduction in m_{eff} when comparing FG4 to FG1.

Municipalities

Among the 1,166 municipalities, one can observe grassland fragmentation at a finer scale, giving the most detailed picture (Fig. 5). Three municipalities exhibit either the highest or second highest m_{eff} values among all four FGs: Mankota no. 45 (ID: 4703018) which is located in the centre of Saskatchewan at the southern border of the Prairie Ecozone with a m_{eff} of 380.227 km^2 in FG1, Pitville no. 169 (ID: 4708028) which is located in central Saskatchewan, near the Alberta border with a m_{eff} of 226.240 km^2 in FG4, and Clinworth no. 230 (ID:

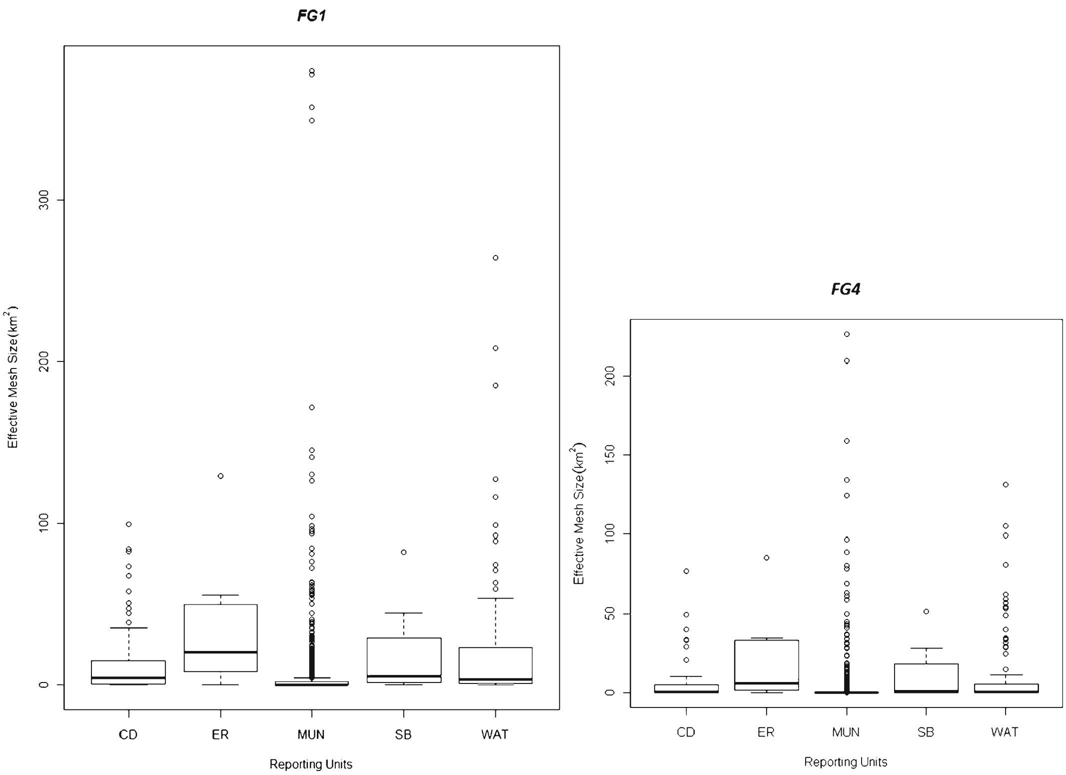

Fig. 6 *Box and whisker plots* showing the distribution of the values of the effective mesh size (in square kilometers) according to the fragmentation geometries FG1 and FG4, for the reporting units of census divisions (*CD*), ecoregions (*ER*), municipalities (*MUN*), sub-basins (*SB*), and watersheds (*WAT*). FG1 depicts the broadest definition of grasslands (minimum degree of fragmentation) and FG4 the most specific definition of grasslands, i.e. for the "grasslands" class only (maximum degree of fragmentation). Therefore, the m_{eff} values in FG4 are always smaller than in FG1. The *dark lines* in the middle of the boxes represents the median, the *bottom edge of the boxes* represents the 25 % quantile, the *top edge of the boxes* represent the 75 % quantile, the *whiskers* represent the 5 and 95 % quantiles, and the *circles* represents outliers beyond the 5 and 95 % quantiles

4708053) located in Saskatchewan above Pitville no. 169 with a m_{eff} of 209.453 km^2 in FG2.

In terms of the highest fragmentation level, all four geometries exhibit at least some m_{eff} values of zero. FG1 displays 41 municipalities, FG2 displays 51 municipalities, FG3 displays 192 municipalities, and FG4 393 municipalities that have a m_{eff} value of 0 km^2.

There are striking similarities between FG1 and FG4 in terms of the minimum and maximum levels of fragmentation observed. The municipalities where fragmentation is the lowest are generally the same for both geometries, and are located within the Mixed Grassland ecoregion. The regions further away from this ecoregion have a greater number of municipalities with higher fragmentation levels. For FG4 in particular, most municipalities along the outer border of the Prairie Ecozone exhibit low m_{eff} values in the range of 0.0–0.5 km^2. Both geometries also indicate a high degree of fragmentation in the south-east of Manitoba, with very little suitable area remaining.

The northern section of Manitoba is significantly more fragmented in FG4 than in all other FGs. This is especially evident at the municipality scale in the smaller of the two peninsulas. However, the whole province is extremely fragmented in FG4, with many m_{eff} values in the range of 0.0–0.5 km^2. There are almost no grasslands remaining in Manitoba.

Sub-basins

The m_{eff} values of the 17 sub-basins provide a broad-scale picture of fragmentation. For both FGs, sub-basin 11A is the least fragmented, with a m_{eff} of 82.269 km^2 for FG1 and a m_{eff} of 28.463 km^2 for FG4. The highest level of fragmentation is observed in two different regions with m_{eff}=0.10 km^2 in 05S for FG1 and m_{eff}=0 km^2 in 07B for FG4. There are remarkable differences between FG1 and FG4 (Fig. 5) for the sub-basins of 05J (m_{eff}= 3.069 km^2 for FG1 and m_{eff}=0.677 km^2 for FG4), 05N

Table 7 Total amount of suitable area (i.e. grassland or related), effective mesh size, effective mesh density (in meshes per 1,000 km^2), and fragmentation *per se* for all four fragmentation geometries for the Prairie Ecozone and its seven ecoregions in alphabetical order. The FGs are ordered in order of decreasing value of m_{eff} (i.e. from FG1 to FG4)

		Total amount of suitable area (km^2)				Effective mesh size: m_{eff} (km^2)				Effective mesh density: s_{eff} (meshes per 1,000 km^2)				Fragmentation *per se*: $m_{eff\_per\_se}$ (km^2)			
Name	Area (km^2)	FG1	FG2	FG3	FG4	FG1	FG2	FG3	FG4	FG1	FG2	FG3	FG4	FG1	FG2	FG3	FG4
Prairie ecozone																	
Prairie ecozone	461,503.972	183,242.042	169,574.738	108,374.280	87,570.450	25.443	24.669	18.912	14.233	39.30	40.54	52.88	70.26	64.079	67.138	80.535	75.009
Ecoregions																	
Aspen Parkland	174,122.274	53,165.343	50,925.264	21,503.921	11,244.814	5.185	4.923	2.722	0.611	192.86	203.13	367.38	1,636.66	16.981	16.833	22.041	9.461
Southwest Manitoba Uplands	2,183.440	337.186	334.198	233.245	176.714	0.17	0.166	0.032	0.018	5,882.35	6,024.10	3,1250.00	55,555.56	1.101	1.085	0.300	0.222
Cypress Upland	8,286.484	6,574.485	6,497.981	5,755.681	5,305.281	129.27	128.17	116.48	85.603	7.74	7.80	8.59	11.68	162.928	163.453	167.691	133.706
Fescue Grassland	14,899.793	4,913.175	4,913.175	3,991.522	3,423.755	43.812	43.812	40.245	31.9	22.82	22.82	24.85	31.35	132.865	132.865	150.229	138.825
Lake Manitoba Plain	29,529.875	8,837.685	8,825.185	7,859.587	5,223.430	20.411	20.408	18.646	3.058	48.99	49.00	53.63	327.01	68.200	68.287	70.056	17.288
Mixed Grassland	133,567.000	75,460.930	66,989.835	50,296.922	47,525.454	55.611	53.546	40.209	34.541	17.98	18.68	24.87	28.95	98.432	106.762	106.778	97.075
Moist Mixed Grassland	98,915.107	33,952.373	31,087.056	18,731.543	14,669.142	10.964	10.693	7.764	5.802	91.21	93.52	128.80	172.35	31.942	34.024	40.999	39.123

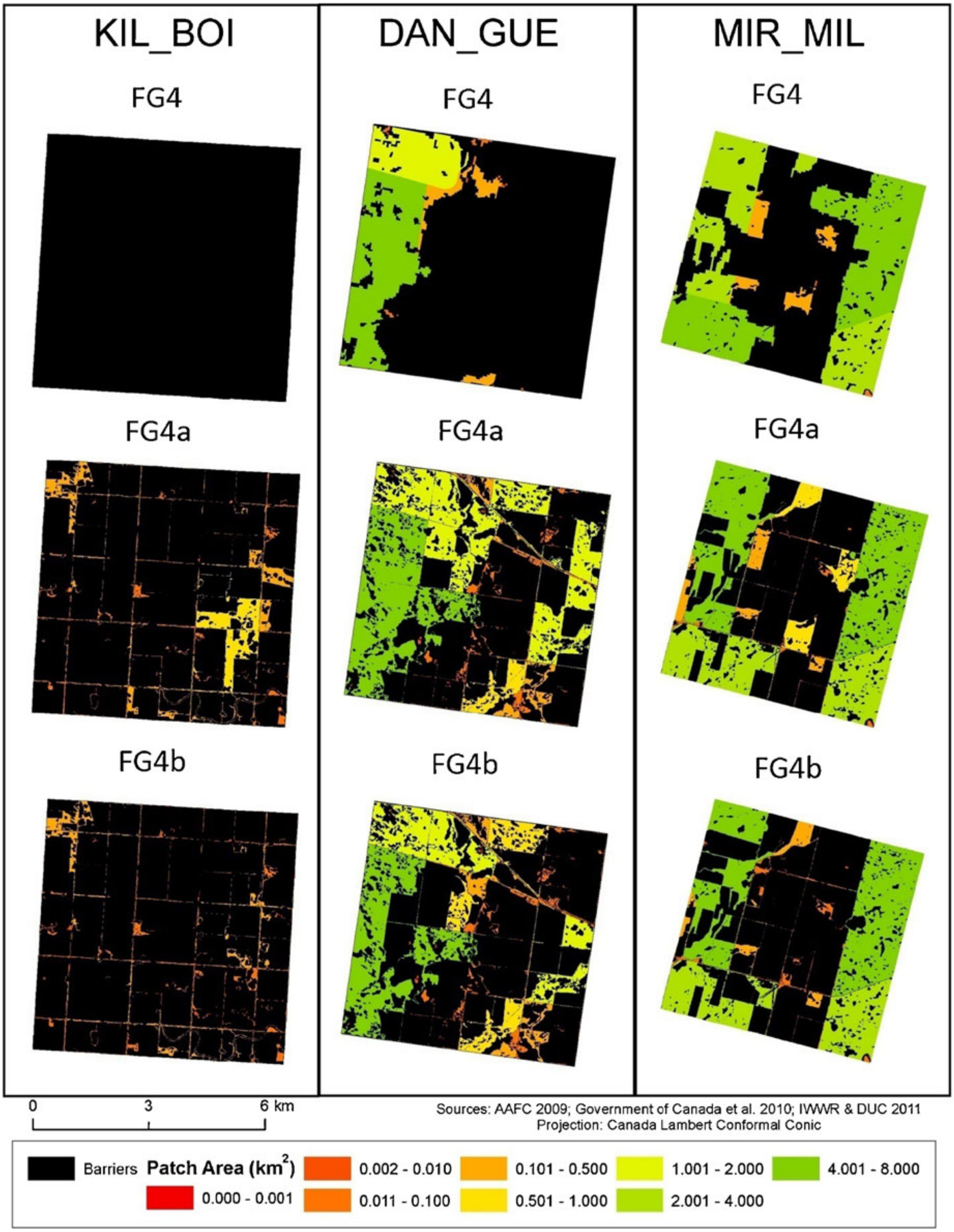

Fig. 7 Comparison of three SpATS study sites (KIL_BOI, DAN_GUE, and MIR_MIL) of differing fragmentation levels and differing fragmentation geometries (FG4, FG4a, and FG4b) with the AAFC data. The colours range from *red*, indicating very small patches, to *dark green* for larger patches, and *black* represents the barrier areas

Table 8 Comparing effective mesh size and effective mesh density of FG4 with FG4a and FG4b for three SpATS study sites (using the CUT method). The suitable areas in FG4 are from the class "grasslands" in the AAFC dataset. The suitable areas for FG4a are all grasslands classified in the SpATS data. For FG4b, the only suitable areas are from the "natural grassland" class in the SpATS data. CanVec barriers have been included in all FGs (*NSAL* no suitable area left, i.e. m_{eff}=0 km^2, which would correspond to an infinite value of s_{eff})

SpATS comparisons

			Total amount of suitable area (km^2)			Effective mesh size: m_{eff} (km^2)			Effective mesh density: s_{eff} (meshes per 1,000 km^2)		
Study site	Province	Area (km^2)	FG4	FG4a	FG4b	FG4	FG4a	FG4b	FG4	FG4a	FG4b
DAN_GUE_2008	AB	41.746	10.257	18.027	14.262	1.080	1.557	0.987	925.983	642.065	1,013.597
KIL_BOI_2008	MB	43.266	0.000	4.012	2.536	0.000	0.033	0.006	NSAL	29,855.178	154,800.091
MIR_MIL_2008	SK	42.276	22.303	21.641	18.326	2.483	2.222	1.837	402.811	450.139	544.399

(m_{eff}=3.340 km^2 for FG1 and m_{eff}=0.877 km^2 for FG4) and 05M (m_{eff}=5.250 km^2 for FG1 and m_{eff}=0.851 km^2 for FG4). These are situated in the eastern side of Saskatchewan near Manitoba. Another region exhibiting large decreases includes the sub-basins 05F (m_{eff}= 10.518 km^2 for FG1 and m_{eff}=0.925 km^2 for FG4) and 05E (m_{eff}=2.891 km^2 for FG1 and m_{eff}=0.053 km^2 for FG4) located at the northern peak of Alberta.

Watersheds

Watersheds provide a more detailed portrayal as they subdivide the larger sub-basins. Comparing the highest and lowest m_{eff} values between FG1 and FG4 (Fig. 5) shows how considering different land cover types influences the location of high and low fragmentation levels. The lowest fragmentation is found in the watershed (WS) 11AE for FG1, where m_{eff}=264.411 km^2, and the second lowest in WS 11AB for FG4, where m_{eff}= 131.094 km^2. The WS exhibiting the highest fragmentation in FG1 is WS WAT with m_{eff}=0.006 km^2, followed by a m_{eff}=0.007 km^2 in WS 05OD. In FG4, the lowest m_{eff} observed is 0 km^2 (i.e. complete fragmentation) in five watersheds: 07BC, 05GF, 07BB, 05DE, and WAT. The box and whisker plots illustrate how the distributions of m_{eff} values differ among the reporting units (Fig. 6).

Partitioning fragmentation into proportion of suitable area and fragmentation *per se*

The two components of m_{eff} are proportion of grassland (or suitable area) and grassland fragmentation *per se* ("Effective mesh size and effective mesh density" section; Eq. 2). For example, the m_{eff} value of the Prairie Ecozone of 14.233 km^2 in FG4 can be partitioned into the two components:

$$\frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}} = \frac{87,570.45\ \text{km}^2}{461,503.972\ \text{km}^2} = 18.97\%$$

$$\text{and } m_{\text{eff\_per\_se}} = \frac{A_{\text{total\_landscape}}}{A_{\text{total\_suitable}}} \cdot m_{\text{eff}} = \frac{461{,}503.972\ \text{km}^2}{87{,}570.45\ \text{km}^2} \cdot 14.233\ \text{km}^2 = 75.01\ \text{km}^2$$

using the values from Table 7. Similarly, the value of m_{eff}=25.443 km^2 in FG1 is the product of the two components

$$\frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}} = \frac{183,242.042\ \text{km}^2}{461,503.972\ \text{km}^2} = 39.71\%$$

and $m_{\text{eff\_per\_se}}$=64.079 km^2, indicating that the degree of fragmentation *per se* of remaining suitable area is actually higher in FG1 than in FG4.

Comparison with grassland classification in the SpATS data

The SpATS data distinguish "natural grassland" and "planted grassland" (IWWR, DUC 2011). SpATS defines "natural grassland" as "a mixture of native and tame grasses, forbs and shrubs that were not planted. Species occur either naturally or invaded. All wetland margins, most "native" pastures and roadside ditches would be considered natural grasslands" (IWWR, DUC 2011, p. 123) and "planted grassland" as "areas seeded to grasses. Most planted grasslands are used for grazing" (IWWR, DUC 2011, p. 123). After 2009, the SpATS dataset break down their grassland class even further into native, planted, and other grassland. However, since the AAFC data date from 2009, we decided to compare the AAFC data with the 2008 SpATS data.

Comparing three study sites of differing fragmentation levels allowed us to explore how a more detailed definition of grasslands influences the resulting degree of fragmentation. It also reveals how close these two datasets are in their mapping of grasslands in the Prairie Ecozone. SpATS has a much finer resolution of 2.5 m compared to 56 m for the AAFC data. The first study site selected (DAN_GUE_2008) is located in Saskatchewan in an area of high grassland fragmentation in FG4. The second site (KIL_BOI_2008) is from Manitoba, with no grassland present according to FG4. The third site (MIR_MIL_2008) is in a part of Alberta where grassland fragmentation is low according to FG4 (Fig. 7).

We created two FGs using the SpATS data. The first FG, called FG4a, includes both natural and planted grasslands as the only suitable areas, corresponding closely to the AAFC grassland class, as the AAFC data do not distinguish between natural and non-natural grasslands. The second FG, called FG4b, includes only "natural grasslands" as suitable area to observe the difference in grassland fragmentation when solely considering "natural grasslands" (for a full list of land covers included in FG4a and FG4b see A11 in ESM).

The comparison between the SpATS and the AAFC data demonstrates how the classification of grasslands and the resolution of a dataset can impact the degree of grassland fragmentation (Table 8). Just with these three study sites, three different situations emerged. For the DAN_GUE_2008 study site, the m_{eff} in FG4 is in between the values of FG4a and FG4b. However, for the KIL_BOI_2008 study site, the m_{eff} in FG4 is lower than the values of both FG4a and FG4b, while for MIR_MIL_2008 the m_{eff} in FG4 is higher than the values of both FG4a and FG4b. This result underlines that FG4 provides only a best estimate of the actual degree of grassland fragmentation at the resolution of 56 m, and that the true level of grassland fragmentation at a finer scale could indeed be somewhat lower or higher, assuming that the SpATS data are more accurate (which is supported by the maps in Fig. 7).

The differences between FG4a and FG4b indicate that there is significantly less grassland, and therefore, a higher degree of grassland fragmentation, when only considering "natural grasslands" as suitable area (FG4b). In all three study sites, the m_{eff} values were lower in FG4b than in FG4a. For the DAN_GUE_2008 study site, this decrease was 0.570 km^2, for KIL_BOI_2008 it was 0.027 km^2, and for MIR_MIL_2008 it was 0.385 km^2. Even though these differences may seem quite low, one has to consider the size of these study regions (which are between 41 and 43 km^2). If the SpATS data covered the entire Prairie Ecozone, these differences would be notably greater.

Discussion

Indicators for detecting changes in grassland fragmentation in an efficient way are needed in order to apply appropriate and reliable management strategies before the remaining grassland patches may be forever lost or become degraded beyond repair (White et al. 2000). Understanding how grasslands have changed over time and knowing their remaining extent and distribution allows for more informed and targeted conservation efforts. The quality of this information may depend to some degree on the datasets and methods being used. The results of this study quantify for the first time the current degree of fragmentation of the Canadian Prairies. Scientists and policy makers can now turn to the continued monitoring of grassland fragmentation, and design suitable conservation strategies.

Differences among regions

Comparisons among ecoregions reveal how the level of grassland fragmentation observed depends on their location. The Southwest Manitoba Uplands region (sometimes erroneously referred to as "Boreal Transition" in some datasets) exhibits the highest level of grassland fragmentation in all four FGs. The values of m_{eff} are much lower than the total amount of grassland area, which indicates their excessive degree of fragmentation. The lowest levels of grassland fragmentation (for all four FGs) are found in the Cypress Upland, followed by the Mixed Grassland and Fescue Grassland ecoregions. The comparison of the m_{eff} values with the total area of grassland demonstrates that the grasslands are highly fragmented even in these ecoregions, with ecoregions having a greater proportion of grasslands exhibiting a lower level of fragmentation.

Even though FG1 has more suitable area than FG4, the additional land cover types considered in FG1 are in fact highly scattered throughout the Prairie Ecozone. Intuitively, one might expect that their inclusion would create larger patch sizes as mentioned in the "Current degree of fragmentation of the Canadian Prairies" section; however, this is often not the case. For example, Manitoba and the outer edges of the Prairie Ecozone have many small patches of grasslands, but when additional land covers are added as suitable area, they themselves result in even tinier patches because they do not always touch the grassland patches. Therefore, FG1 is comprised of many more small patches of suitable area than FG4, which results in a higher level of fragmentation *per se* (and a lower $m_{\mathrm{eff\_per\_se}}$ value; Table. 7). Comparing m_{eff} values between reporting units provides additional insights into the degree of fragmentation. It is important to not only look at natural reporting units like ecoregions and watersheds but to also explore the anthropogenic reporting units such as municipalities, as these are more often referred to in political and policy-related activities. For different organizations, different reporting units may be of interest and therefore it is best to provide information for a number of reporting units to meet the requirements of a range of organizations and their goals.

The values of m_{eff} are much lower than the total amount of grassland/suitable area in all reporting units in all FGs, which indicates their extreme degree of fragmentation. The question may arise what values of fragmentation should be considered as "natural", "undisturbed", "normal", or "acceptable". However, our comparisons of high and low fragmentation levels are based on only one point in time (2009). Therefore, it is unknown what the "natural" level of fragmentation would be. Further studies are required to tackle this issue; but the lack of detailed historic maps of grasslands makes this task difficult (see "Feasibility of measuring grassland fragmentation levels for historic points in time" section).

Comparison with other studies

The total area of the land cover type "grassland" in FG4 is 87,570.45 km^2 out of a possible area of 461,503.97 km^2, i.e. 18.98 % of the study area. The corresponding percentages are 39.71 % for FG1, 36.74 % for FG2, and 23.48 % for FG3 (Table 7), somewhat similar to estimates given in the literature. The study by the Federal, Provincial and Territorial Governments of Canada (2010) stated that mixed and fescue grassland cover over 110,000 km^2. This is well in the range provided by the four FGs from 87,570.45 km^2 (FG4) to 183,242.04 km^2 (FG1) of our study.

Gauthier and Wiken (2003) estimated that 25–30 % of the native grasslands remain in the Canadian prairies and parklands. Our value of 87,570.45 km^2 seen as the 25–30 % estimate of remaining grasslands would imply an original total area between 148,869.76 and 153,248.28 km^2 for FG4 and between 309,811.46 and 320,673.57 km^2 for FG1, meaning that 69.48–67.13 % of the Prairie Ecozone was once covered by grasslands. However, the AAFC land cover data does not distinguish between native and non-native grasslands. Therefore, this calculation cannot be done for the area of native grasslands alone.

Suitability of the effective mesh size/density method for monitoring grassland fragmentation

Indicators that are suitable for monitoring various ecosystems are in high demand. This is the first study to apply the m_{eff} method to grasslands. With that, our results have shown that the m_{eff} is highly suitable for measuring grassland fragmentation due to its many strengths ("Effective mesh size and effective mesh density" section) and is therefore recommended for long-term monitoring of the grasslands in the Canadian Prairies. Many countries have already implemented m_{eff} or s_{eff} as an indicator for environmental monitoring. Some examples are Switzerland (Bertiller et al. 2007; Jaeger et al. 2007, 2008), Germany (Schupp 2005; Federal Ministry for the Environment and Nature Conservation and Nuclear Safety BMU 2007), California (Girvetz et al. 2008), South Tyrol (Tasser et al. 2008), Baden-Württemberg (State Institute for Environment, Measurements and Nature Conservation Baden-Württemberg 2006), and on the European level (EEA and FOEN 2011). Most recently, it has been included in the *City Biodiversity Index* (CBI) (also called the *Singapore Index on Cities' Biodiversity*) of the Conference of the Parties to the Convention on Biological Diversity (Chan and Djoghlaf 2009) as an indicator of connectivity of natural areas in cities on a global scale (CBI User Manual 2011/

12; Asgary 2012). It can also be used for the design of habitat networks in cities (Deslauriers 2013).

Other useful applications of the m_{eff} method are: exploring how new roads or urban areas or the removal of roads would affect the degree of grassland fragmentation. The m_{eff} method can be extended to include the permeability of barriers for animals moving in the landscape (i.e. filter effect; Jaeger 2002, 2007) and can help indicate where the addition of a wildlife corridor or conservation area would be particularly beneficial to landscape connectivity.

The difference between m_{eff} and $m_{\text{eff\_per\_se}}$ denotes the difference between the suitable area accessible on average to an individual being placed *anywhere in the landscape* without having to cross a barrier (m_{eff}) and an individual being placed *anywhere inside a patch of suitable area* without crossing a barrier ($m_{\text{eff\_per\_se}}$). The addition of barriers can reduce or increase the value of $m_{\text{eff\_per\_se}}$, whereas the value of m_{eff} will always be reduced. For example, loss of small grassland patches will *increase* $m_{\text{eff\_per\_se}}$, indicating that fragmentation *per se* has been reduced, but the grassland area has decreased. The m_{eff} combines these two components and decreases when grassland patches of any size are lost. Changes in $m_{\text{eff\_per\_se}}$ will therefore only be interpreted correctly as a positive or negative change when the change in grassland amount is considered at the same time. Changes in m_{eff} are easier to interpret: a decrease in m_{eff} always indicates a higher level of fragmentation, due to either a breaking up of patches, or a loss of grassland area, or (usually) a combination of both. As a consequence, the values of m_{eff} are ordered as $m_{\text{eff.FG1}} > m_{\text{eff.FG2}} > m_{\text{eff.FG3}} > m_{\text{eff.FG4}}$, but this is not the case with $m_{\text{eff\_per\_se}}$. For monitoring grassland fragmentation, all three values should be reported (proportion of suitable area, m_{eff}, and $m_{\text{eff\_per\_se}}$) to be able to distinguish between habitat amount and fragmentation *per se*. Alternatively to m_{eff} and $m_{\text{eff\_per\_se}}$, the respective effective mesh densities, $s_{\text{eff}} = \frac{1}{m_{\text{eff}}}$ and $s_{\text{eff\_per\_se}} = \frac{1}{m_{\text{eff\_per\_se}}}$ can be used, where $s_{\text{eff\_per\_se}} = \frac{A_{\text{total\_suitable}}}{A_{\text{total\_landscape}}} \cdot s_{\text{eff}}$.

Feasibility of measuring grassland fragmentation levels for historic points in time

Historical data are of great interest for estimating past rates of fragmentation increase and changes in trends. However, when accessible GIS data layers are updated the previous versions are usually not accessible any more. There may be printed maps or aerial photographs available that include historic information. However, their use would require aerial photo interpretation and digitization of historic maps (beyond the scope of this study).

The oldest land cover dataset we found that is suitable for calculating grassland fragmentation was the WGTPP Generalized Land Cover from 1993/95 (Data Basin 2010a). The next oldest is the Geobase 2000 dataset (Centre for Topographic Information, Earth Sciences Sector and Natural Resources Canada 2009). The main constraint for these two points in time is the lack of additional barrier data (e.g. road and railway data). As CanVec does not have an archive system, it is currently impossible to retrieve older datasets. Therefore, the barrier data used from CanVec do not go that far back. In fact, their first edition dates back to 2007. Therefore, comparisons without these barriers would not be meaningful. Another concern is that the changes over just 15 years (between 1993/95 and 2009) may be too small to be detected reliably. The most important changes occurred before 1990 (and most significantly before 1930). In addition, there are differences in resolution (in space and in land cover class definitions), which could make meaningful comparisons impossible. However, hard paper topographic maps could be digitized or aerial photographs could be georeferenced to retrieve older land cover, road, and railway data. Therefore, a historical analysis is in principle feasible in future studies.

Feasibility of monitoring grassland fragmentation in the future

The suitability assessment for the 11 grassland datasets revealed the combination of the Crop Inventory Mapping of the Prairies and the CanVec dataset to be the most suitable for monitoring grassland fragmentation if both datasets continue to be updated in the same way (i.e. classes and spatial resolution) as is expected. Therefore, monitoring grassland fragmentation in the future is indeed possible and recommended.

The selection of the most appropriate FG for monitoring generally depends on a study's context and objectives. The combination of all four FGs may be more appropriate than any single FG. However, if all four FGs could not be considered for any particular reason, then FG4 would be the most appropriate. In addition, FG1 may serve as a suitable representation of grassland fragmentation in a broad sense.

Conclusions

Recommendations for controlling grassland fragmentation

This study shows that the remaining grasslands in the Canadian Prairies are heavily fragmented. Therefore, conservation efforts need to focus on grasslands before they degrade further and their qualities are forever lost. There are various conservation initiatives currently in operation that aim to protect remaining grassland areas. One of them on the national level is the Canadian Council on Ecological Areas (CCEA) that created the Conservation Areas Reporting and Tracking System (CARTS) in March 2004 (CCEA 2010). This program helps regularly and systematically track and report on the status of Canada's protected areas. Protected areas are defined in CARTS as: "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Vanderkam 2010, p. 1). To determine to what degree these protected areas overlap with the remaining large patches of grassland, we overlaid the CARTS regions with the map of the remaining patches of grassland habitat and their fragmentation. This could indicate the need for the creation of additional CARTS regions to better control the degradation and fragmentation of the grasslands. In the Prairie Ecozone, there are 382 conservation areas resulting in a total protected area of only 21,038 km^2 or 4.56 % of the total area of the Prairie Ecozone. Out of 25 ecozones in Canada, the Prairie Ecozone is the tenth lowest protected ecozone (Environment Canada 2011). The CARTS protects only 11.60 % of grassland area identified in FG4, representing 48.27 % of the total CARTS areas within the Prairie Ecozone.

The majority of the CARTS areas are located in the province of Saskatchewan. In Saskatchewan, the larger grassland patches are usually associated with a conservation area, which indicates that these CARTS areas are helping limit grassland fragmentation and therefore, increasing the CARTS areas would prevent further degradation and fragmentation of these remaining grassland patches. Alberta and Manitoba, however, have very few CARTS regions and those that are present are rarely associated to a grassland area. Interestingly, some of the largest remaining grassland patches are located in Alberta, with only a few of these areas being protected under CARTS. Therefore, we recommend that these CARTS areas be expanded considerably to cover substantially more of the remaining patches of grassland habitat.

On a provincial basis, the Saskatchewan Representative Areas Network (RAN) Program was established in 1997 by Saskatchewan Environment. The program once completed, will comprise a network of approximately 7.8 million hectares (or 12 % of the province of Saskatchewan). The RAN aims at conserving representative and unique landscapes in every ecoregion within Saskatchewan. The major gaps of these representative landscapes coincide with the agricultural areas of the province, which are located in the Mixed Grassland, Moist Mixed Grassland, and the Aspen Parkland ecoregions. Challenges arise in establishing conservation areas here, especially in the Mixed Grassland and the Moist Mixed Grassland ecoregions as most of this land has already undergone cultivation (80 % in the Mixed Grassland ecoregion and 50 % in the Moist Mixed Grassland ecoregion), or the land is privately owned or under long-term lease agreements (Saskatchewan Environment 2005). Concerns of ever being able to meet the 12 % protection targets for these two ecoregions are high. These two ecoregions have the highest amount of grassland area (in FG4). While the m_{eff} of the Moist Mixed Grassland region is the highest among all the ecoregions (m_{eff}= 34.541 km^2), the Mixed Grassland ecoregion has a m_{eff} value of only 0.611 km^2, i.e. it is the second most fragmented ecoregion (the most fragmented is the Southwest Manitoba Uplands ecoregion). This demonstrates the urgent need to protect these remaining patches in the Moist Mixed Grassland ecoregion and the Mixed Grassland ecoregion before they become further reduced in size and quality.

Even though these conservation initiatives are essential and constitute an important step towards the protection of remaining grasslands and other natural areas, they are clearly not sufficient to address all the threats against the Prairie grasslands (Table 2) because they do not cover enough area and are not sufficiently supported by regulations for grassland protection. Conservation efforts should not only protect the remaining large unfragmented areas, but also prevent further fragmentation of areas where grasslands are already highly fragmented to preserve biodiversity in these places as well. The long response times of many species to changes in landscape structure present a particular challenge globally (Tilman et al. 1994; Kuussaari et al. 2009; Dullinger et al. 2013). The current population densities may not reflect their response to the current grassland patterns but to earlier grassland patterns decades ago, and wildlife populations may continue to decline for many years even when the degree of grassland fragmentation does not increase any more (Helm et al. 2006; Lindborg and Eriksson 2004). Given that many negative effects of habitat fragmentation and isolation only become apparent after several decades, further population losses will be incurred in the coming decades as a result of the changes that have already taken place in the past (Findlay and Bourdages 2000).

The implementation of effective mesh size as an indicator of fragmentation for grassland monitoring and management is an increasingly pressing issue as the degree of fragmentation in the Prairie Ecozone continues to rise and the remaining grassland habitat patches continue to decrease and disappear. A quantitative metric of grassland fragmentation can help set measurable targets or limits for regions or provinces to guide management efforts; the m_{eff} (or s_{eff}) metric is highly suitable for quantifying this indicator. We recommend that the fragmentation values be updated on a regular basis to document trends and detect changes in any trends in grassland fragmentation.

As an example, what measures are suitable and feasible for bringing about a trend reversal in grassland fragmentation caused by roads and other transportation infrastructure? Generally, four types of measures can be distinguished: (1) to minimise negative impacts during the planning and construction stages of new transportation infrastructure, (2) to restore connectivity across existing transportation infrastructure, (3) to prevent further increase of the density of the transportation network, and (4) to remove existing transportation infrastructure (EEA and FOEN 2011). Some useful measures to curtail grassland fragmentation from roads are:

1. Existing roads can be made more permeable for wildlife through tunnels, wildlife crossings (overpasses and underpasses), or by raising roads up on pillars so that wildlife can cross underneath. In general, the larger the areas linked together, the more effective the measures will be.
2. The widening of existing highways and higher traffic volumes will increase their barrier effect. However, the upgrading of existing highways is still less detrimental than the construction of new highways at another location in most cases, even if the new highways were to be bundled with existing transportation infrastructure. This has been demonstrated by a computer simulation model that determined probabilities of population persistence to compare these alternatives (Jaeger et al. 2006).
3. If bypasses (and other roads) are sited close to developed areas, their fragmentation effect is lower compared to bypasses away from settlements. The purpose of this measure is to preserve unfragmented areas that are as large as possible and thereby lessen the fragmenting impact of any new transport routes.
4. Transport infrastructure which is not urgently needed any more (e.g. due to the construction of new routes or changing requirements) should be removed. This is particularly important where existing infrastructure is located in an area of animal movement corridors, e.g. amphibian migration corridors.
5. Roads, on which traffic volumes have decreased due to the construction of other transportation infrastructure or due to changing conditions, should be downgraded and physically reduced in width. This means a reduction of their surface and their footprint on the ground through physical modification.

It is also necessary to limit the size of urban areas since built-up areas are themselves barriers to animal movement, and because urban sprawl and road construction mutually intensify each other: dispersed patterns of settlement areas lead to higher traffic volumes and more road construction, and roads attract urban development. Regional planning legislation should more effectively require local authorities to treat land sparingly in their land use plans. Regional and local authorities should limit the growth of built-up areas and instead encourage denser development within the boundaries of existing urban areas.

Measures for controlling grassland fragmentation can only be effective if there is an awareness of the problem and feasible solutions are proposed. Decision makers and the general public should therefore be made more aware of the problems of grassland fragmentation and habitat loss and need to be informed about suitable measures. The setting of limits can play an important role for this objective. For example, specific targets, benchmarks, and limits could be distinguished according to the respective type of landscape such as: (1) priority regions for large unfragmented areas; i.e. no further fragmenting elements are allowed here, and there is a priority for the removal of existing fragmenting elements, and (2) further fragmenting elements could be allowed in densely settled landscapes or along development axes up to a certain limit.

Our results can be used to set quantitative goals to provide a comparative basis, which can be reviewed through environmental monitoring: The degree of fragmentation can be recalculated after new roads have been built or existing roads have been removed, and compared to the targets or limits. This is already possible in the planning stages of the construction or removal of transportation infrastructure. Maps of planned transportation infrastructure can be combined with models for predicting future land use changes, and the resulting degree of fragmentation can be compared to the target. Thus, the use of quantitative data about grassland fragmentation as a tool for performance review of protection efforts is an approach for increasing awareness and guiding efforts for minimising grassland fragmentation. Such analysis and performance review is applicable with regard to both biodiversity and landscape quality.

Little is known about the exact fragmentation thresholds for the persistence of wildlife populations, and how these thresholds will shift due to diminishing resources, reduced genetic exchange, or changes in climate (Robinson et al. 2010). Other factors, such as the spatial distribution of habitats or changes in a population's birth or mortality rates may also influence these thresholds. As long as the knowledge about the thresholds of the effects of grassland fragmentation on wildlife populations and ecosystem services is insufficient, the precautionary principle should be applied (Kriebel et al. 2001). A particular challenge is given by the long response times of populations of long-lived animals to changes in landscape structure (Kuussaari et al. 2009). This situation makes it all the more essential that a precautionary approach is adopted that guides grassland fragmentation in the desired direction. The lack of knowledge about the exact location of the thresholds should not be used as an argument for postponing protective measures. Rather, targets and limits for the future degree of landscape fragmentation should be broadly discussed and implemented now. Such targets and limits are urgently needed by government offices and administrations to be able to act and justify their decisions and actions towards better protection of grasslands. These limits cannot be set in stone but should be region-specific and should consider the ecological, geographic, social, economic, and historic characteristics of each region.

Future research needs

Future studies should broaden our understanding of grassland fragmentation in the Canadian Prairies based on the results presented in this paper. Suggestions for such studies include the following:

1. To incorporate varying degrees of permeability of barriers within the current m_{eff} method. The probability of successful barrier crossings and the positive effect of wildlife passages on landscape connectivity can be included in a more detailed version of the m_{eff} (Jaeger 2007). This analysis would be based on the habitat requirements and sensitivity to various barriers of a certain species (or a range of species). This could be particularly relevant for species which are at risk of extinction as maintaining connectivity for ecological processes is a prerequisite for the conservation of species in fragmented landscapes (McRae and Beier 2007).
2. To conduct a historical analysis of grassland fragmentation for the Prairie Ecozone for multiple time steps (e.g. every 10–20 years), potentially going back to the 1930s or 1940s. This would reveal major changes in grassland fragmentation. It would entail large amounts of digitization and would be based on barriers that are documented in historical maps.
3. To incorporate additional features such as pipelines and transmission lines and to explore to what degree they increase the level of grassland fragmentation; this is important as certain species can be impacted by these additional barriers, through either avoiding these areas completely or being unable to move across these barriers. In addition, pipelines and transmission lines can contribute to the degradation of grassland habitat quality, which may have similar ecological repercussions as the direct removal of grasslands (e.g. reducing the probability of population persistence). These additional FGs may also be

relevant for humans in terms of landscape aesthetics and the recreational value of the landscape.

4. To compare the values of m_{eff} for all the locations for which SpATS data (120 study sites) are available with the Crop Inventory Mapping of the Prairies dataset. This comparison would allow for a fine-scale analysis of grassland fragmentation that distinguishes between native and non-native grasslands. It would provide higher spatial and thematic resolution and higher accuracy for 1.09 % of the area of the Prairie Ecozone.

All these efforts to improve the quality of the monitoring, however, will only contribute to a trend reversal in grassland fragmentation if the data are actually used for increasing problem awareness and for implementing more sustainable management policies than those that are in place today.

Acknowledgments We gratefully acknowledge the contributions of the following people who have provided valuable information and data: Mickey Currie (Alberta Sustainable Resource Development), ZuZu (Fawziah) Gadallah (Environment Canada), Scott Mitchell (Carleton University, Ottawa), John Riley (Nature Conservancy of Canada), Susan Witherly (Ducks Unlimited), Patrick Rollin (Agriculture and Agri-Food Canada), Alexis Dorais (Univ. de Montréal) and David Beauchesne (Concordia Univ. Montréal). We also thank everyone who replied to our inquiries about available datasets, two anonymous reviewers for their constructive comments, and Environment Canada for financial support.

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