Biological Conservation 217 (2018) 121–130

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Grassland connectivity in fragmented agricultural landscapes of the north-central United States

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ARTICLE INFO

Keywords:
Connectivity
Dispersal
Graph theory
Movement
Network analysis
Grassland
Fragmentation

ABSTRACT

In the prairies of North America, remnant native grasslands are threatened by continuing agricultural extensification. Fragmentation of the remaining grassland isolates patches and limits the potential for dispersal of native species. We explored these impacts by analyzing the spatial pattern of native grassland habitats in the Prairie Coteau region of eastern South Dakota and western Minnesota, USA. Undisturbed grasslands were mapped using a GIS database of land use history combined with manual interpretation of high-resolution aerial photographs. Network analysis based on graph theory was used to examine how connectivity changed depending on the potential movement distances of organisms and to identify important patches that made large contributions to connectivity throughout the broader network. Interpatch movement was assessed using Euclidian distance as well as cost-weighted distance that assigned lower movement cost to grasslands than to human-modified land cover types. Much of the undisturbed grassland was concentrated in a single large cluster, which was connected to other habitat concentrations via corridors of "stepping stone" patches. A small number of "keystone patches", whose loss would have a disproportionately large effect on overall connectivity, were also identified. The locations of the major corridors were relatively consistent across different movement distances. Information about patch-level importance for overall network connectivity should be taken into account when prioritizing conservation and restoration. Future studies can build on this research by conducting more detailed assessments focused on particular species of concern and portions of the study area where connectivity is most limited.

1. Introduction

The prairies of North America are perhaps the most threatened terrestrial ecosystem on the continent, and these vanishing grasslands are a priority for conservation. Nearly 98% of the native northern tallgrass prairie vegetation has been lost, mainly through conversion to annual row crops and planting of non-native grasses to support livestock production (Samson et al., 2004). Although much of this conversion took place in the late 19th and early 20th centuries, the trend of native grassland loss has continued to the present day. Beginning in the early 2000s, higher crop prices driven in part by increasing demands for production of ethanol and other biofuels have led to high rates of grassland conversion to croplands, particularly at the edges of the Midwestern Corn Belt (Lark et al., 2015; Wright et al., 2017; Wright and Wimberly, 2013). Most of the recently converted grassland has been on land enrolled in the Conservation Reserve Program (CRP), which provides farmers with a yearly rental payment in exchange for removing environmentally sensitive land from agricultural production and planting perennial grasses. However, substantial conversion of native grasslands has also occurred in the eastern Dakotas (Wimberly et al., 2017). There are significant concerns about the negative impacts of agricultural expansion and grassland loss on wetland habitats, populations of native species, and carbon sequestration (Ahlering et al., 2016; Brennan and Kuvlesky Jr, 2005; Johnston, 2013; Mushet et al., 2014; Swengel et al., 2011). This paper contributes to our understanding of these environmental impacts by analyzing spatial patterns and connectivity in a network of undisturbed native grassland patches located at the western edge of the Corn Belt.

The process of fragmentation, through which contiguous grasslands are broken apart into smaller and more isolated patches, is intrinsically coupled with grassland loss. Habitat fragmentation generally leads to a loss of biodiversity in the remnant patches (Haddad et al., 2015). In the

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http://dx.doi.org/10.1016/j.biocon.2017.10.031
Received 27 June 2017; Received in revised form 12 October 2017; Accepted 29 October 2017

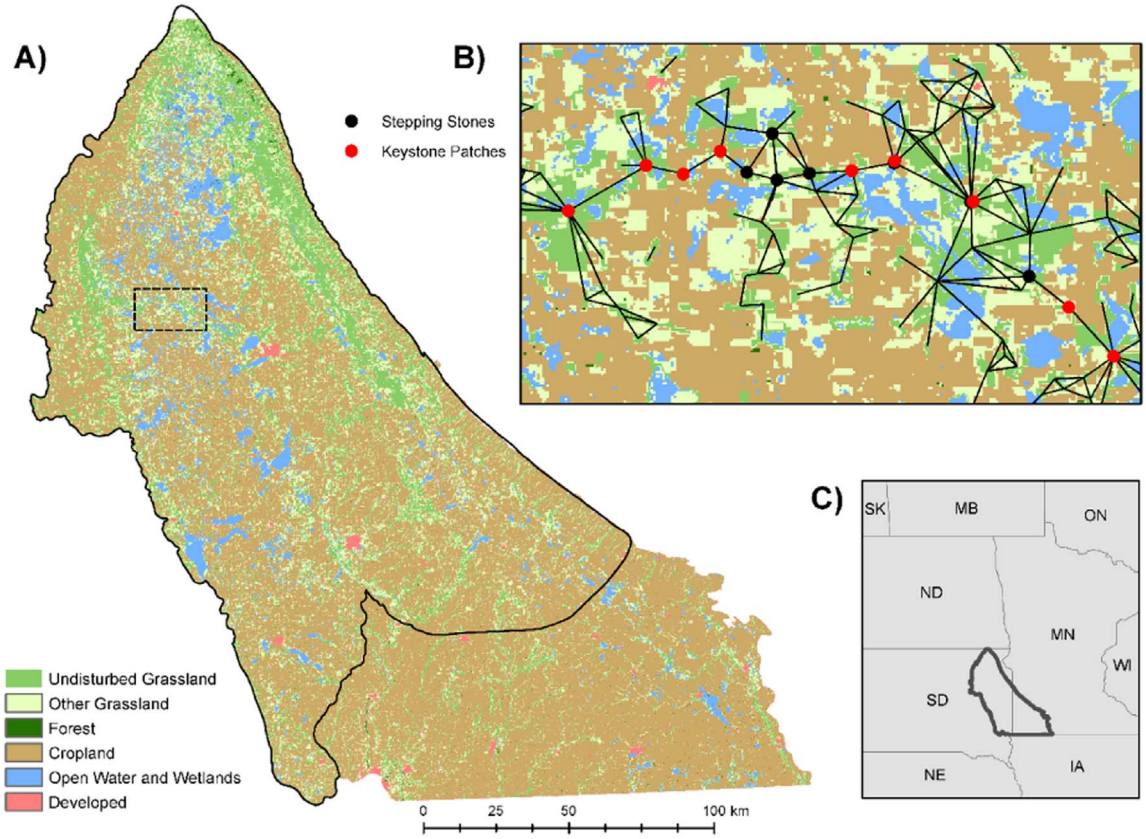

Fig. 1. A) Major land cover types within the study area. Dashed black line represents the boundary of subfigure B. Solid black line represents the boundary of the Prairie Coteau ecoregion. B) Zoomed map of major land cover types with patch connections shown for a maximum cost-weighted movement distance of 1300 m. C) Study area location in the north-central United States.

fragmented grasslands of North America, patches of remnant prairie vegetation are often surrounded by croplands that provide low-quality habitat for most native species. Thus, many organisms including birds (Herkert, 1994; Johnson and Igl, 2001; Winter et al., 2006), insects (Davis et al., 2007; Swengel and Swengel, 2015), and plants (Wagenius et al., 2010; Wagenius et al., 2007) are sensitive to grassland patch size as well as the spatial pattern of the surrounding landscape. To a large degree, species respond to landscape patterns because they move within and between habitat patches to carry out activities necessary for survival and reproduction. These activities can include foraging, seeking shelter, finding a mate, seeking prey, avoiding predators, defending territory, dispersal, and migration. There has been considerable research on how fragmentation affects various species, and these studies have typically characterized landscape patterns using patch-based indices that measure the sizes and shapes of habitat patches, proximity to other habitat patches, and the contextual effects of the landscape matrix (Kupfer, 2012).

A major drawback of these patch-based metrics is that they characterize the structural connectivity of the landscape itself, but do not necessarily capture important functional aspects of the landscape related to the behavior and movement of organisms (Kupfer, 2012). In response to this limitation, the development of graph-based methods focused on landscape connectivity has become a major research thrust in the field of landscape ecology (Galpern et al., 2011). An important goal of this approach is to quantify the degree to which landscape patterns facilitate or impede movement through the larger habitat network. Various connectivity metrics have been developed by combining elements of graph theory (Urban and Keitt, 2001), electrical circuit theory (McRae et al., 2008), and least-cost distance analysis (Adriaensen et al., 2003) to assess movement potential in heterogeneous landscapes. These techniques allow for the assessment of potential connectivity (Calabrese and Fagan, 2004) by incorporating information about species dispersal distances as well as the suitability of dispersal habitat. This approach has been widely applied to assess connectivity of a variety of habitat types including forests (Minor and Urban, 2008), shrublands (Ferreras, 2001), and wetlands (Bishop-Taylor et al., 2015; McIntyre et al., 2014; Wright, 2010).

Despite the burgeoning number of landscape connectivity studies, relatively few have been conducted in temperate grasslands (Correa Ayram et al., 2016). Given the high rate of recent grassland conversion in parts of the central United States (Lark et al., 2015; Wright and Wimberly, 2013), there is a particular need to understand the degree to which fragmentation limits the flow of organisms and their genes among prairie remnants. One reason for this dearth of studies is the difficulty of accurately mapping native grasslands. Although grasslands can be identified using medium-resolution satellite sensors such as the Landsat Thematic Mapper, Enhanced Thematic Mapper, and Operational Land Imager, it is difficult if not impossible to distinguish native prairie from tame pastures and other planted grasslands. The recent development of a pilot dataset characterizing the distribution of unplowed grasslands in eastern South Dakota using air photo interpretation and historical land use data provides a novel opportunity to study habitat connectivity in this rapidly changing region (Bauman et al., 2015; Bauman et al., 2016). The overarching goal of this study was to characterize the connectivity of the habitat network of undisturbed grassland patches in the Coteau des Prairies region of eastern South Dakota and western Minnesota. Specific objectives were to (1) identify the remnant grassland patches that are most important for facilitating movement through the habitat network and assess their current protection status, (2) determine whether these critical patches change with the maximum inter-patch movement distance, and (3) assess the sensitivity of these relationships to the effects of dispersal habitat quality in