The Journal of Wildlife Management 85(1):27–40; 2021; DOI: 10.1002/jwmg.21960

Research Article

Simulating Strategic Implementation of the CRP to Increase Greater Prairie-Chicken Abundance

KALYSTA ADKINS,[1,2] *Minnesota Cooperative Fish and Wildlife Research Unit, University of Minnesota, 1980 Folwell Avenue, 200 Hodson Hall, St. Paul, MN 55108, USA*

CHARLOTTE L. ROY, *Minnesota Department of Natural Resources, 1201 E Highway 2, Grand Rapids, MN 55744, USA*

ROBERT G. WRIGHT, *Minnesota Information Technology Services at Department of Natural Resources, 5463-C W Broadway, Forest Lake, MN 55025, USA*

DAVID E. ANDERSEN, *U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit, 1980 Folwell Avenue, 200 Hodson Hall, St. Paul, MN 55108, USA*

ABSTRACT The Conservation Reserve Program (CRP) has the potential to influence the distribution and abundance of grasslands in many agricultural landscapes, and thereby provide habitat for grassland-dependent wildlife. Greater prairie-chickens (*Tympanuchus cupido pinnatus*) are a grassland-dependent species with large area requirements and have been used as an indicator of grassland ecosystem function; they are also a species of conservation concern across much of their range. Greater prairie-chicken populations respond to the amount and configuration of grasslands and wetlands in agriculturally dominated landscapes, which in turn can be influenced by the CRP; however, CRP enrollments and enrollment caps have declined from previous highs. Therefore, prioritizing CRP reenrollments and new enrollments to achieve the greatest benefit for grassland-dependent wildlife seems prudent. We used models relating either lek density or the number of males at leks to CRP enrollments and the resulting landscape structure to predict changes in greater prairie-chicken abundance related to changes in CRP enrollments. We simulated 3 land-cover scenarios: expiration of existing CRP enrollments, random, small-parcel (4,040 m^2) addition of CRP grasslands, and strategic, large-parcel (80,000 m^2) addition of CRP grasslands. Large-parcel additions were the average enrollment size in northwestern Minnesota, USA, within the context of a regional prairie restoration plan. In our simulations of CRP enrollment expirations, the abundance of greater prairie-chickens declined when grassland landscape contiguity declined with loss of CRP enrollments. Simulations of strategic CRP enrollment with large parcels to increase grassland contiguity more often increased greater prairie-chicken abundance than random additions of the same area in small parcels that did not increase grassland contiguity. In some cases, CRP enrollments had no or a negative predicted change in greater prairie-chicken abundance because they provided insufficient grassland contiguity on the landscape, or increased cover-type fragmentation. Predicted greater prairie-chicken abundance increased under large-parcel and small-parcel scenarios of addition of CRP grassland; the greatest increases were associated with large-parcel additions. We suggest that strategic application of the CRP to improve grassland contiguity can benefit greater prairie-chicken populations more than an opportunistic approach lacking consideration of the larger landscape context. Strategic implementation of the CRP can benefit greater prairie-chicken populations in northwestern Minnesota, and likely elsewhere in landscapes where grassland continuity may be a limiting factor.

KEY WORDS Conservation Reserve Program, grasslands, greater prairie-chicken, landscape, Minnesota, *Tympanuchus cupido pinnatus*.

Greater prairie-chickens (*Tympanuchus cupido pinnatus*) are an area-dependent, grassland-obligate prairie grouse (Robel et al. 1970) that experienced population declines and local extirpations from landscape-scale conversion of grasslands to agriculture. In the midwestern United States, conversion of tallgrass prairie to agricultural land uses sum to between 83% and >99% of the original area of grasslands, and this change affected grassland-dependent wildlife, including bobolink (*Dolichonyx oryzivorus*), eastern meadowlark (*Sturnella magna*), a variety of sparrow species, and greater

Received: 13 December 2019; Accepted: 31 August 2020

[1]*E-mail: kadkins24@gmail.com*
[2]*Current affiliation: Oregon Department of Fish and Wildlife, 3701 13th Street, The Dalles, OR 97058, USA*

prairie-chickens (Noss et al. 1995, Steiner and Collins 1996, Ryan 2000, Burger et al. 2006, Ribic et al. 2009). Greater prairie-chickens were once considered the leading gamebird in central North America (Robel et al. 1970, McNew et al. 2015) and were found in 17 states in the United States but are now in danger of extirpation in 7 of the 11 states where they are still found (Schroeder and Braun 1993, Ross et al. 2006, Niemuth 2011). In Minnesota, USA, where <2% of the former tallgrass prairie area still exists as tallgrass prairie (Minnesota Prairie Plan Working Group 2011), greater prairie-chicken abundance has declined since the early twentieth century and greater prairie-chickens are now listed as a species of special concern (U.S. Department of Agriculture [USDA] 2005).

A variety of state and federal programs have been developed and implemented to mitigate the widespread loss of grasslands in agricultural landscapes. The Conservation Reserve Program (CRP) is the largest federal private land retirement program in the United States (Stubbs 2014), providing financial incentives to reseed agricultural land to sod-forming or native vegetation for 10–15 years. Established in 1985 with the Food Security Act, the CRP authorizes removal of land from crop production to reduce soil erosion, improve water quality, and restore and protect wildlife habitats. Within the CRP, different programs focus on different types of wildlife habitat restoration including field buffers, bottomland hardwood forestland, pollinator habitat, restoring farmed wetlands, and riparian plant communities (Riley 2004), some of which can increase the amount of tallgrass prairie and other grassland cover types in agricultural landscapes. Even programs that are not focused specifically to benefit wildlife may offer an opportunity for grassland restoration as large contiguous tracts of land are enrolled or connected (Riley 2004, Herkert 2009).

The CRP can be an essential component of habitat restoration for species that use grasslands and that have declined or have been extirpated from their historical ranges because of land-use conversion to agriculture. Establishment of CRP grassland can provide critical breeding habitat for grassland birds, in particular grassland-obligate birds (Ryan et al. 1998*a*, *b*; Heard et al. 2000; Ryan 2000; Herkert 2009). Similarly, researchers conducting studies in New Mexico, western Kansas, Colorado, Oklahoma, and Texas, USA, reported that the CRP benefitted lesser prairie-chickens (*Tympanuchus pallidicinctus*) when CRP grassland was placed in proximity to existing grasslands in landscapes already dominated by grasslands (Rodgers and Hoffman 2005, Sullins et al. 2018). Additionally, in Washington, USA, habitat models for greater sage-grouse (*Centrocercus urophasianus*) indicated that 66% of predicted greater sage-grouse habitat would be reduced without the CRP and that strategic concentration of CRP enrollment could increase habitat area 63% above existing levels (Shirk et al. 2017). Greater prairie-chickens have also been listed as one of the high priority species identified in a Minnesota-specific, area-limited program within the CRP (Back Forty Pheasant Habitat CRP-SAFE practice; USDA 2008), with the objective of increasing their abundance in agricultural landscapes.

The amount of land enrolled in the CRP is declining across the United States and in landscapes that currently support greater prairie-chickens in northwestern Minnesota. The area enrolled in the CRP has declined nationwide since its peak enrollment of approximately 149,000 km^2 in 2007 (Stubbs 2014). Within the area systematically surveyed for greater prairie-chickens in northwestern Minnesota, the area enrolled in all Conservation Practice codes of the CRP declined 16–52% from its peak (Adkins et al. 2019). Additionally, nationwide, the enrollment cap of the CRP has decreased 40% from the first year of the program in 1985 to 2020 (Glaser 1986, USDA 2020). Because of these reductions, it is timely to consider whether strategic implementation of the CRP to benefit wildlife species of conservation concern may be more effective than the current method of opportunistic implementations.

To better understand the relationship between CRP enrollments and greater prairie-chicken populations, Adkins et al. (2019) quantified the association between greater prairie-chicken abundance (lek density and males/lek) and CRP enrollments in the context of landscape structure and composition in northwestern Minnesota during 2004–2016. Greater prairie-chickens require a mosaic of vegetation types and structural components (Jones 1963, McNew et al. 2015) and in Minnesota use a variety of areas including cropland or hay fields for feeding, disturbed grasslands with short cover for courtship, and undisturbed grasslands with dense cover for roosting and nesting (Svedarsky 1979, Svedarsky et al. 2000). Greater prairie-chickens may also use a variety of wetlands throughout the year, especially for roosting, ranging from ephemeral wet meadows to lowland marshes with low water levels during summer (Svedarsky 1979, Svedarsky et al. 2000). Adkins et al. (2019) reported that the amount of CRP grasslands and wetlands and the contiguity of grasslands were positively related to lek density (leks/km^2) at the landscape scale (41-km^2 block survey units). Similarly, at the lek scale (2 km around each lek; Merrill et al. 1999, Hovick et al. 2015), the amount of CRP grasslands and wetlands and the contiguity of CRP grasslands were positively related to the number of males at leks. These models provided insights into the landscape features that potentially influence greater prairie-chicken abundance but also can be used to predict how greater prairie-chicken populations might respond to future landscape conditions, especially with projected losses of CRP grasslands through expiration and changes in enrollment caps.

Understanding the influence of CRP enrollments at multiple scales will assist efforts to target CRP enrollments where they will be most effective for conservation of greater prairie-chickens and landscapes that support greater prairie-chicken populations. We used the models of Adkins et al. (2019) to predict the potential effects of grassland CRP enrollments and expirations on greater prairie-chicken populations in northwestern Minnesota at the landscape and lek scales. Based on Adkins et al. (2019), we expected that measures of greater prairie-chicken abundance at the landscape and lek spatial scales would decline with continued scheduled grassland and wetland CRP expirations and consequential conversion to agricultural production. We expected the greatest declines when all CRP enrollments were allowed to expire. We also expected that greater prairie-chicken abundance would increase with strategic enrollments that increase the amount and contiguity of grassland and wetland on the landscape.

STUDY AREA

We evaluated greater prairie-chicken–habitat relations in an 8-county region approximately 24,000 km^2 in size in northwestern Minnesota (Fig. 1). Historically, this area was dominated by tallgrass prairie, but during the study period (2004–2016), land use in this region was primarily agricultural with soybeans, corn, and wheat comprising the predominant crops (USDA-National Agricultural Statistics Service [NASS] 2016). A mixture of herbaceous cover (i.e., herbaceous wetlands, pasturelands, grasslands), forested areas, shrublands, and developed areas comprised the remaining land cover throughout the study area. Native grass and sedge species within fragmented grasslands and wetlands included big bluestem (*Andropogon gerardii*), side oats grama (*Bouteloua curtipendula*), and fox sedge (*Carex vulpinoidea*), occurring with broad-leaf forbs and low shrubs. This region supported a variety of fauna including mesocarnivores such as coyote (*Canis latrans*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), and raccoon (*Procyon lotor*), and grassland birds such as dicksissel (*Spiza americana*), eastern meadowlark, and grasshopper sparrow (*Ammodramus savannarum*). Our study area exhibited low relief, with elevation ranging from approximately 100–300 m. The climate is seasonal with average low temperatures in the winter (defined here from winter solstice to spring equinox) below −12°C and average high temperatures in the summer (defined here from summer solstice to fall equinox) above 27°C. Weather during the study period was similar to the long-term climate patterns. Annual greater prairie-chicken surveys have been conducted in this region since 2004 using a standardized protocol (Roy 2019) coordinated by the Minnesota Department of Natural Resources (MNDNR).

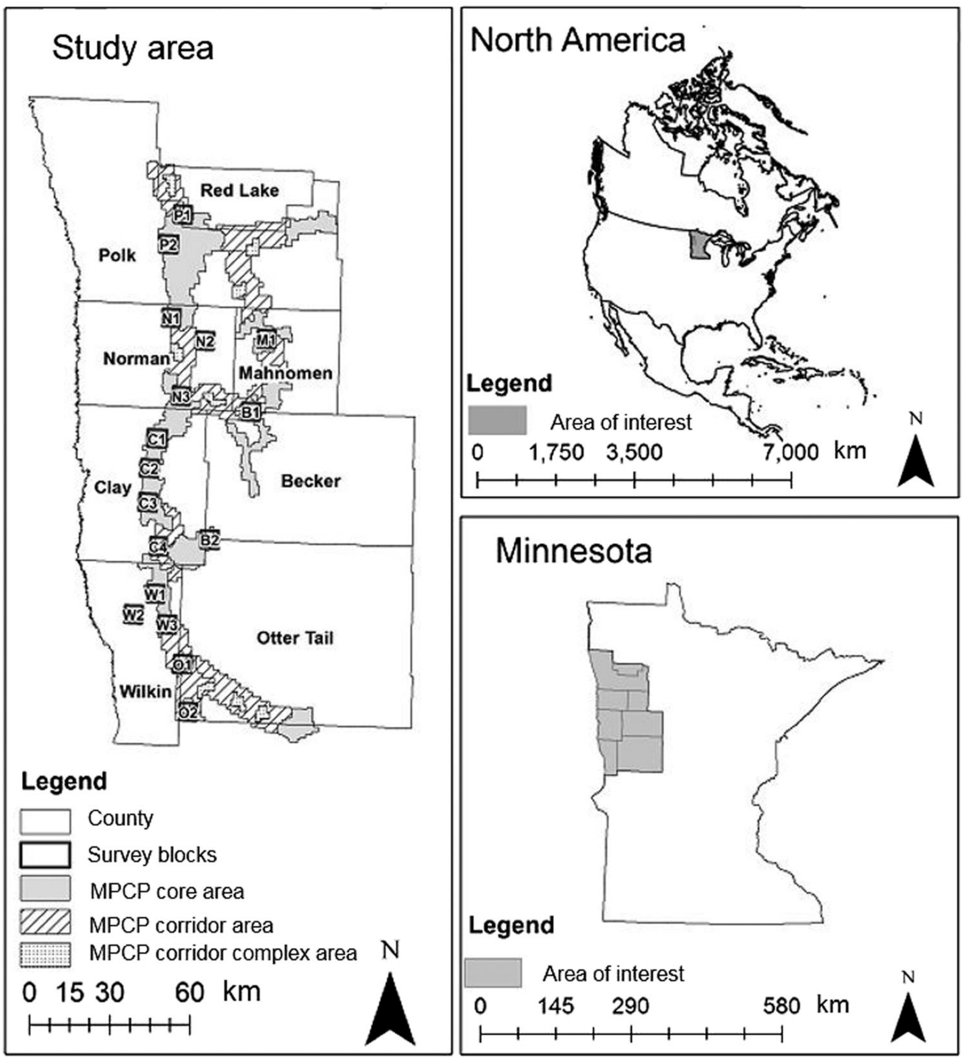

Figure 1. Location of the 17 greater prairie-chicken survey blocks (black bordered squares, 41-km^2) and Minnesota Prairie Conservation Plan (MPCP) core (gray fill), corridor (hatch fill), and corridor complex (stipple fill) areas in northwestern Minnesota, USA, 2004–2016. Survey blocks are labeled with the first letter of the respective county (black border) and corresponding number (from north to south).

METHODS

We used a layered approach in an information-theoretic framework (Burnham and Anderson 2002) to create models relating landscape metrics to greater prairie-chicken indices of abundance (lek density and number of males/lek; Adkins et al. 2019). We derived greater prairie-chicken indices of abundance from surveys of 17 41-km^2 blocks conducted from 2004–2016, coordinated by the MNDNR (Roy 2019; Fig. 1), that adhered to animal welfare standards in place at the time surveys were conducted. Survey blocks were nonrandomly selected to represent different grassland ownerships that varied in management approaches across the greater prairie-chicken range in Minnesota (Giudice 2004). Land in grassland cover types was composed of a majority of state and federally managed properties in 2 of the 17 blocks; was mostly under CRP enrollments in 1997 in 5 blocks; and was a combination of CRP and holdings owned and managed by the State of Minnesota (primarily the MNDNR), the United States Government (primarily the U.S. Fish and Wildlife Service), and The Nature Conservancy (TNC) in 10 blocks. Models of greater prairie-chicken abundance represented 2 scales: landscape (41-km^2 survey-block) and the lek scale. We defined the lek scale with a fixed buffer of 2 km around each lek to represent the breeding-cycle habitat radius of greater prairie-chickens (Merrill et al. 1999, Hovick et al. 2015; lek buffers). Adkins et al. (2019) provides data collection and land-cover classification details. The best-supported model of lek/km^2 at the landscape scale included the areas of CRP grasslands, grasslands managed with a long-term conservation focus (state-, federal-, and TNC-managed), CRP wetlands, wetlands managed with a long-term conservation focus (state-, federal-, and TNC-managed), other wetlands managed with variable or no continuity in conservation goals, the contiguity of grasslands, and the number of patches of grasslands and wetlands in each survey block in each year (Adkins et al. 2019). All covariates except the area of other wetlands and the number of grassland patches had a positive relationship with the abundance of greater prairie-chickens. The best-supported model of males/lek (log-transformed) at the lek scale included the percent areas CRP grasslands, grasslands with a long-term conservation focus (state-, federal-, and TNC-managed), CRP wetlands, wetlands managed with a long-term conservation focus (state-, federal-, and TNC-managed), other wetlands, forests, developed lands, shrublands, and the contiguity of grassland CRP (Adkins et al. 2019). All covariates except the percent areas of other wetlands, forests, and developed lands had a positive relationship with the abundance of greater prairie-chickens. We used the best-supported models at the landscape and lek scales to predict the density of lek/km^2 and males/lek based on different land-cover scenarios.

Land-Cover Scenarios

We developed 3 land-cover scenarios representing losses and gains of CRP grasslands within the study area using the models of Adkins et al. (2019) to predict greater prairie-chicken abundance at the landscape and lek scales, similar to the approach used by Princè et al. (2015) to model grassland bird abundance and Shirk et al. (2017) to evaluate the influence of changes in CRP enrollments on greater sage-grouse. Our scenarios included expiration of existing CRP enrollments; random, small-parcel (4,040 m^2) addition of CRP grasslands; and strategic, large-parcel (80,000 m^2) addition of CRP grasslands, which is the average enrollment size in Minnesota within the context of a regional prairie restoration plan (described below) in northwestern Minnesota. We compared these scenarios to conditions present in 2016 as a baseline of no change in CRP enrollments in northwestern Minnesota at the landscape and lek scales. We viewed differences between or among scenarios to be meaningful if 95% confidence intervals around predicted differences did not include zero. We also considered the proportion of survey blocks or leks for which there were predicted increases in greater prairie-chicken abundance compared with predicted abundance under current conditions as an indication of an effect of CRP grasslands on greater prairie-chickens.

We used FRAGSTATS (McGarigal et al. 2012) to calculate the area of CRP grasslands, the area of CRP wetlands, the contiguity of grasslands, and the number of patches of grasslands and wetlands in each survey block for each land-cover scenario and used these measures to derive predictions of greater prairie-chicken abundance (leks/km^2) from the landscape-scale model of Adkins et al. (2019). The area of grasslands and wetlands represented abundance of greater prairie-chicken habitat, contiguity represented the spatial distribution of habitat, and the number of patches of grasslands and wetlands represented fragmentation of habitat in our study areas. We quantified contiguity using a contiguity index on a scale of 0 to 1, which represented the size and connectivity of patches of a given land-cover type. Large, contiguous patches of the same land-cover type resulted in contiguity index values closer to 1 (McGarigal et al. 2012). We similarly calculated the percent area of CRP grasslands, the percent area of CRP wetlands, and the contiguity of CRP grassland within a fixed, 2-km lek buffer around each traditional lek (leks that had >1 displaying male recorded in >50% of the period studied; Merrill et al. 1999) and used these metrics to derive predictions of greater prairie-chicken abundance (males/lek) from the Adkins et al. (2019) lek-scale model. Using these predictions, we calculated the average number of leks/km^2 or males/lek and associated confidence intervals (see below for details) for each of the survey blocks or traditional leks. Traditional leks represent those that persisted on the landscape for a majority of the study period.

CRP expiration scenario.—We considered CRP enrollments present at the beginning of 2016 as a baseline, and simulated 15 years of cumulative scheduled CRP expirations of enrollments (starting with those expiring in Sep 2016) until all scheduled expirations were completed in 2030. The simulated landscape resulting from loss of all CRP enrollments represents what might exist in the absence of land-conservation programs in this agricultural landscape. Predicted landscape configurations prior to 2030 represent conditions intermediate between current conditions and those in landscapes lacking federal farm land-retirement programs. We used these predicted landscapes to assess the effects of removing CRP enrollments on landscape composition, configuration, and fragmentation, and consequent effects on greater prairie-chicken abundance. We modified the 2016 land-cover map by reclassifying expiring CRP enrollment areas to cropland and calculated leks/km^2 or males/lek and associated confidence intervals for expiration scenarios using the average normalized root mean square error (NRMSE) from the predictive models of Adkins et al. (2019).

CRP enrollments scenarios.—We evaluated 2 approaches to adding CRP enrollments to the landscape in northwestern Minnesota in the context of the core and corridor goals of the Minnesota Prairie Conservation Plan (MPCP; Minnesota Prairie Plan Working Group 2011): small (4,040 m^2) parcels added randomly and large (80,000 m^2) parcels added strategically to increase connectivity and decrease fragmentation as prescribed in the MPCP. This 25-year plan was developed in 2011 by a consortium of conservation organizations in Minnesota, using guidance of existing resource plans (e.g., pheasant [*Phasianus colchicus*; MNDNR 2005], duck [MNDNR 2006], and wildlife area management plans), and includes distinct goals for core and corridor areas to create a connected landscape within Minnesota's prairie region from Canada to Iowa, USA. The MPCP identified prairie core areas as areas with a high concentration of native prairie, other grasslands, wetlands, or shallow lakes that maintain a minimum of 40% grassland and 20% wetland cover (core goal). Corridors connecting large prairie core areas were also designed to include stepping stones of core prairie complexes of 23.3 km^2 at 9.7-km intervals within the corridors (corridor complex goal). These core prairie complexes also had a goal of a minimum of 40% grassland and 20% wetland cover (corridor area goal). For the remainder of corridors, a minimum of 10% of each 2.6 km^2 was grasslands (Minnesota Prairie Plan Working Group 2011). For both the small- and large-parcel approaches, we simulated meeting the minimum area required for each MPCP goal listed above by adding grassland and wetland CRP enrollments to the existing grasslands and wetlands within the survey block or lek buffer. For the small-parcel approach, we performed 100 simulations in which we randomly added the prescribed amount of grasslands and wetlands to reach the MPCP goals in 4,040-m^2 patches at the landscape and lek scales. The amount of grasslands and wetlands added to survey blocks to meet MPCP goals ranged from 0–8.37 km^2. The amount of grasslands and wetlands added to 2-km lek buffers to meet MPCP goals ranged from 0–4.63 km^2 (Appendix A).

To assess the influence of meeting the landscape prescriptions of the MPCP, we first identified the intersection of survey blocks and the 2-km lek buffers with areas contributing to core, corridor complex, and corridor area goals of the MPCP. Portions of 15 of the 17 survey blocks and 25 of the 26 lek buffers were included in ≥1 of areas defined by the core, corridor complex, and corridor area goals identified in the MPCP (Fig. 1). We then clipped the 2016 land-cover raster with the intersection areas and calculated the existing percentages of each land-cover type of interest (i.e., croplands, grasslands, and wetlands), and how much cropland needed to be converted to grassland or wetland CRP to meet each goal defined above.

We then randomly generated 100 different iterations of small-parcel (4,040 m^2) enrollments for each of the 15 survey blocks and the 25 lek buffers to meet the minimum core, corridor complex, and corridor area goals. We converted the cropland areas in the 2016 land-cover raster map within the 15 survey blocks and 25 lek buffers to polygons and then divided these polygons into 4,040-m^2 areas using the fishnet tool and the intersect tool in ArcGIS (Esri 2015). We then randomly selected the area needed to meet each goal, reclassified this area to CRP grasslands or wetlands, and integrated the reclassified land cover back into the 2016 land-cover raster map using the is null and con tool in ArcGIS (Esri 2015). After generating 100 random iterations for each of the 15 survey blocks and 25 lek buffers to meet the core, corridor complex, and corridor area goals, we used FRAGSTATS (McGarigal et al. 2012) to recalculate landscape metrics. We then used these values to predict the number of leks/km^2 or males/lek from the 100 iterations for each of the 15 survey blocks or 25 lek buffers. Finally, we calculated the average number of predicted leks/km^2 or males/lek and associated 95% confidence intervals for each of the 15 survey blocks or 25 traditional leks included in the MPCP core, corridor complex, and corridor area goals.

We compared the results of this simulation to one where we added large parcels (80,000 m^2; the average size of a CRP enrollment in northwestern Minnesota) for each of the 15 survey blocks and 25 lek buffers to simulate strategic conversion of existing croplands to CRP grasslands or wetlands to meet the landscape prescriptions of the MPCP with maximum contiguity. We created large patches by combining the previously created 4,040-m^2 polygons into contiguous 80,000-m^2 areas using the dissolve tool in ArcGIS (Esri 2015). We calculated the number of 80,000-m^2 cropland areas needed to be converted to CRP grasslands or wetlands to meet each goal defined above and used the near tool to calculate the distance of each 80,000-m^2 area to an existing grassland or wetland patch on the landscape. We selected the 80,000-m^2 areas with the shortest distance to the nearest existing grassland or wetland cover to simulate conversion to grasslands or wetlands to meet the landscape prescriptions of the MPCP. We then reclassified these selected 80,000-m^2 areas to CRP grasslands or wetlands and integrated them back into the 2016 land-cover raster map using the is null and con tools in ArcGIS (Esri 2015). The result was a scenario to meet the core, corridor complex, and corridor area goals using 80,000-m^2 areas with maximum contiguity to existing grassland and wetland cover on the landscape for each of the 15 survey blocks and 25 lek buffers. We calculated predicted leks/km^2 or males/lek and associated confidence interval for the large, strategically placed enrollment scenario using the average NRMSE from the predictive models of Adkins et al. (2019). Based on *k*-fold validation, the best-supported model at the survey-block scale had an average NRMSE of $13.15 \pm 0.27\%$ (SD). The best-supported model at the lek-scale had an average NRMSE of $17.38 \pm 0.11\%$.

No-change scenario.—To analyze the effect of potential changes in the amount and configuration of CRP grasslands and wetlands, we used values from the classified 2016 land-cover raster map to predict no-change estimates of lek density instead of using observed lek densities from 2016. This approach ensured that any observed effect resulted from the landscape change and not from an error in land-cover classification or model prediction. We calculated the predicted leks/km^2 or males/lek and associated confidence interval for the no-change scenario using the average NRMSE from the predictive models of Adkins et al. (2019).

RESULTS

At the landscape scale (41-km^2 survey blocks), all 17 survey blocks had predicted declines in lek density as the area of CRP enrollments declined (i.e., contracts expired; Fig. 2). The average change in number of leks/km^2 resulting from expiration of all CRP (2016–2030) in all survey blocks was −22.12% (NRMSE error ±2.91%). When we simulated small-parcel, random CRP enrollments at the landscape scale, 10 (67%) of 15 survey blocks (N2 and W2 were outside of the area included in the MPCP; Appendix A) had predicted increases in the point estimates of the number of leks/km^2. Thirteen of the same 15 survey blocks had predicted increases in the number of leks/km^2 associated with strategic CRP enrollments with large parcels selected to increase contiguity with existing grassland and wetland patches on the landscape.

At the lek scale, 25 of 26 leks had predicted declines in the number of males as the area of CRP enrollments declined (i.e., contracts expired; Fig. 3). The average change in the total predicted number of males/lek by 2030 in all survey blocks was $-7.15 \pm 1.24\%$ (NRMSE error). Twenty of the simulations of CRP enrollment scenarios with small-parcel random additions at the lek scale had predicted increases in the point estimates of the number of males/lek. Twenty-five leks had predicted increases in the number of males/lek associated with strategic CRP enrollment scenarios with large parcels selected to increase contiguity with existing grassland and wetland patches on the landscape.

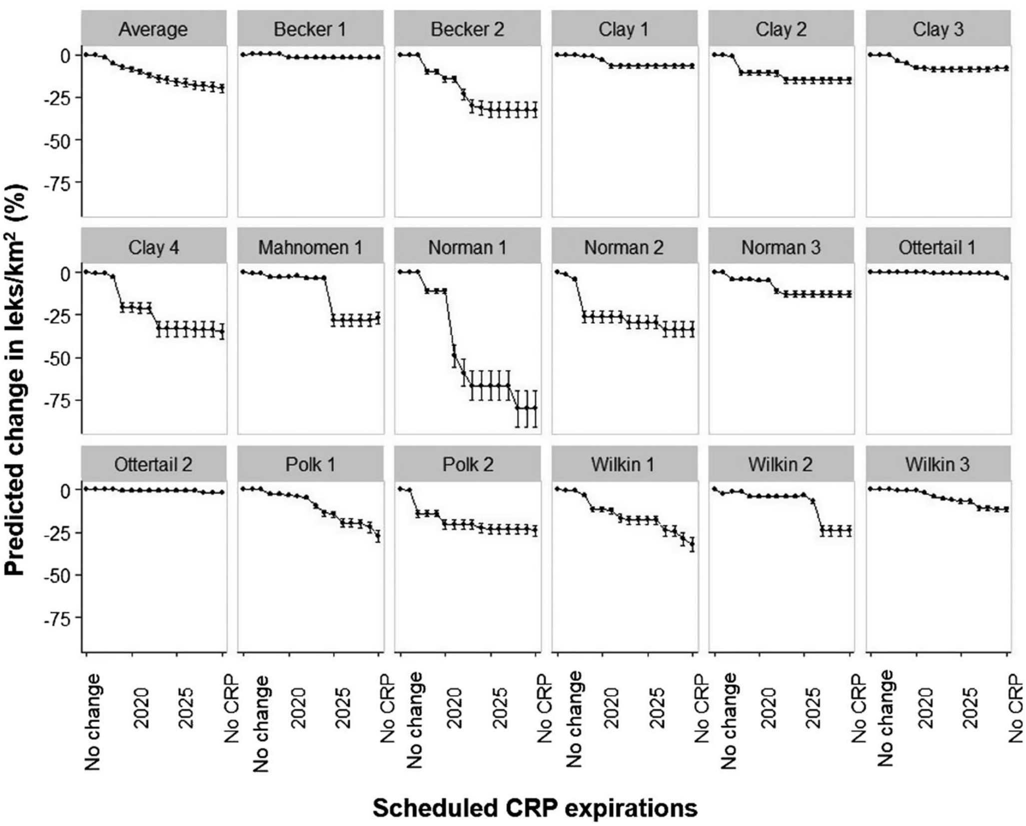

Figure 2. Predicted percent change in the number of greater prairie-chicken leks/km^2 from the number predicted based on cover-type composition present in 2016 using the landscape-scale model of Adkins et al. (2019) and predicted future landscape configurations for each of the 17 survey blocks and the average of all survey blocks in northwestern Minnesota, USA, 2004–2016. Landscape configurations include the 2016 mapped land cover with all Conservation Reserve Program (CRP) enrollments present in 2016 (no change); 2016 mapped land cover with CRP expirations scheduled from 2016 to 2029; and 2016 mapped land cover with no CRP enrollments remaining in 2030 (no CRP). Error bars (95% CIs) are derived from the normalized root-mean-square error (13.15%) calculated from the landscape-scale model of Adkins et al. (2019).

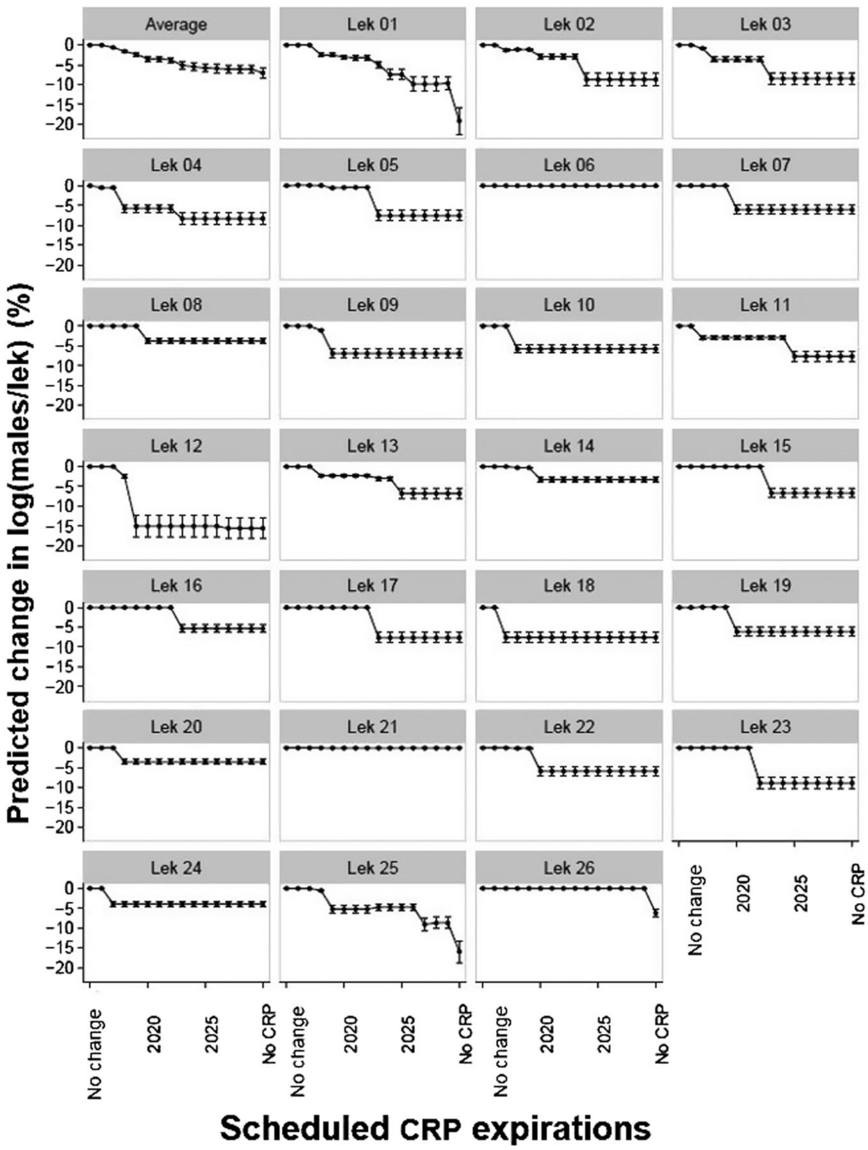

Figure 3. Predicted percent change in the number of male greater prairie-chickens (log [males/lek]) from the number predicted based on cover-type composition present in 2016 using the lek-scale model of Adkins et al. (2019) and predicted landscape configurations for each of the 26 traditional leks in the study area and the average of all traditional leks in northwestern Minnesota, USA, 2004–2016. Landscape configurations include the 2016 mapped land cover with all Conservation Reserve Program (CRP) enrollments present in 2016 (no change); 2016 mapped land cover with CRP expirations scheduled from 2016 to 2029; and 2016 mapped land cover with no CRP enrollments remaining in 2030 (no CRP). Error bars (95% CIs) are derived from the normalized root-mean-square error (17.38%) calculated from the lek-scale model from Adkins et al. (2019).

CRP Expiration Scenario

At the landscape scale, total changes predicted with the loss of all CRP ranged from $1.73 \pm 0.23\%$ (NRMSE error) to $80.18 \pm 10.54\%$ declines in the number of leks/km^2 (Fig. 2). Nine of the 17 blocks had predicted declines in lek density >20% (Fig. 2). On average across all survey blocks, the largest percent decline in number of leks/km^2 from the landscape configuration the previous year followed CRP enrollment expirations scheduled in 2018. In several years in all survey blocks, the predicted change in number of leks/km^2 from the previous year was zero because no CRP enrollments were set to expire in the survey block and therefore the landscape configuration did not change. The largest percent decline in number of leks/km^2 in any survey block from predictions the previous year was $-42.7 \pm 5.62\%$ following expirations scheduled in 2021 (survey block N1; Appendix A).

Lek 6 in survey block C3 (Appendix A) had no change in the predicted number of males because no CRP enrollments existed within the 2-km buffer around the lek location. Changes predicted in the number of males/lek with the loss of all CRP (i.e., by 2030) ranged from −0.03% (lek 21 in C1; Appendix A; ±0.01%) to −19.16% (lek 1 in P1; Appendix A; ±3.32%). Across all traditional leks, the largest average predicted percent decline in number of males/lek from the previous landscape configuration was following expirations scheduled in 2023 (Fig. 3). For all traditional leks, years occurred when the predicted change in number of males/lek from the landscape configuration in the previous year was zero because no CRP enrollments were set to expire in the survey block where the lek was located and therefore no landscape configuration change from the previous year was predicted to occur. The largest predicted percent decline in number of males/lek from the landscape configuration the previous year was −12.9% following expirations scheduled in 2019 (lek 12 in C4; Appendix A).

Enrollment Scenarios

Random addition of small parcels.—The mean difference of leks/km^2 associated with small-parcel, random enrollments from the no change scenario was 0.014 (95% CI = 0.0029–0.0248; Fig. 4). The associated 95% confidence interval did not include zero, indicating an increase in the number of leks/km^2 associated with the small-parcel, random enrollments scenario (Fig. 4). The largest predicted increase in lek density associated with meeting MPCP landscape configuration objectives in the small-parcel enrollments scenario was 59.6% (95% CI = 51.76–67.44%; O2) and the largest predicted decrease in lek density was −18.6% (95% CI = − 20.04 to −16.16%; N1).

At the lek scale, the mean difference of the number of males (log [males/lek]) associated with small-parcel, random enrollments from the no change scenario was 0.0242 (95% CI = 0.0118–0.0366; Fig. 4). The associated 95% confidence interval did not include zero, indicating an increase the number of males at leks under the small-parcel scenario (Fig. 4).

The largest predicted increase in the number of males/lek associated with meeting MPCP landscape configuration objectives in the small-parcel, random enrollment scenario was 15.05% (95% CI = 14.90–15.33%; lek 14 in survey block M1; Appendix A) and the largest predicted decrease was −1.01% (95% CI = − 1.02 to −1.00%; lek 11 in survey block C4; Appendix A).

Strategic addition of large parcels.—At the landscape scale, the mean difference in the predicted number of leks/km^2 under the large-parcel scenario compared with the scenario where CRP enrollments remained the same as in 2016 was 0.030 (95% CI = 0.0177–0.0420; Fig. 4), which was more than double the mean associated with small-parcel, random enrollments at the same scale. The associated 95% confidence interval for the mean did not overlap zero (Fig. 4). The largest predicted increase in lek density associated with the large-parcel, strategic enrollment scenario was 107.9% (±14.19 [NRMSE error]; O2) and the largest predicted decrease in lek density was −0.73% (±0.10; C3).

At the lek scale, the mean difference in the predicted number of males (log[males/lek]) under the large-parcel scenario compared with the scenario where CRP enrollments remained the same as in 2016 was 0.0332 (95% CI = 0.0221–0.0444; Fig. 4). The associated 95% confidence interval for the mean did not overlap zero (Fig. 4). The largest predicted increase in lek density associated with the large-parcel, strategic enrollment scenario was 16.08% (±0.14; lek 14 in survey block M1, Appendix A). No predicted decreases resulted from simulations of

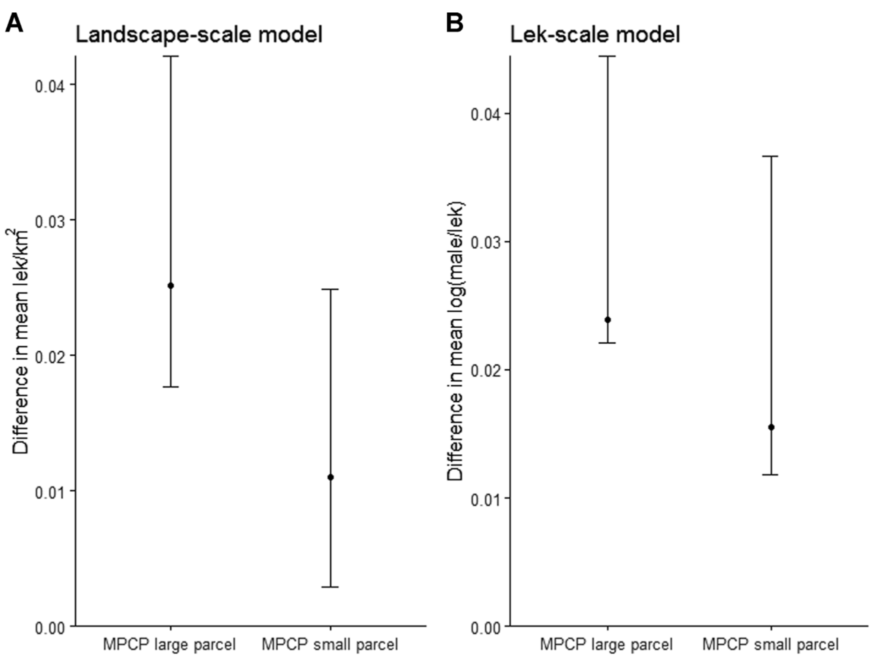

Figure 4. A) Difference between greater prairie-chicken lek abundance (leks/km^2) predicted under 2 scenarios for adding Conservation Reserve Program (CRP) grassland (small-parcel [4,040 m^2], random addition and large-parcel [80,000 m^2], strategic addition) in 15 survey blocks within the Minnesota Prairie Conservation Plan (MPCP) boundary in northwestern Minnesota, USA, 2004–2016, derived using the landscape-scale model of Adkins et al. (2019). B) Difference between the number of males at leks (log[males/lek]) predicted under the same 2 scenarios for adding CRP grassland at 25 traditional leks within the Minnesota Prairie Conservation Plan (MPCP) boundary in northwestern Minnesota, USA, 2004–2016, using the lek-scale model of Adkins et al. (2019). The associated error bars are 95% confidence intervals.

large-parcel, strategic enrollments designed to increase contiguity with existing grasslands and wetlands on the landscape.

DISCUSSION

The amount and distribution of grasslands and wetlands influenced the predicted future abundance of greater prairie-chickens at the landscape scale (41-km^2 block survey units) in northwestern Minnesota. The configuration in which grasslands and wetlands were added to the existing landscape, and not simply total area added, was an important consideration for increasing lek density. Adding larger patches of grassland and wetland to increase contiguity between existing grasslands and wetlands on the landscape had a larger effect than random addition of smaller parcels of the same amount of grasslands and wetlands. At the lek scale, the 2 scenarios (random, small-parcel addition of CRP grasslands and strategic, large-parcel addition of CRP grasslands) we considered did not produce different outcomes. A similar number of predicted males per lek in both addition scenarios likely occurred because adding grasslands and wetlands within the comparatively small lek buffers resulted in the proximal location of additional greater prairie-chicken habitat regardless of how it was added. More grasslands and wetlands in a small area generally increased contiguity. Greater prairie-chickens are area-sensitive and require large blocks of habitat $\geq$5.26 km^2 in size with patches >0.65 km^2 in area (Kirsch 1974; Merrill et al. 1999; Niemuth 2003, 2011). These area relationships were consistent with the results of our simulations and other published studies (Forman and Godron 1981, Bender et al. 1998). Andren (1994) concluded that in general, configuration of habitat only matters when landscapes are comprised of approximately $\leq$30% habitat. Both addition scenarios in our simulations created landscapes that were composed of >30% greater prairie-chicken habitat, as prescribed in MPCP goals. Our results suggest that CRP enrollments are likely to have the largest, positive effects on greater prairie-chicken abundance at the landscape scale when they are close to existing grasslands and wetlands in landscapes comprised of approximately 25–30% existing habitat.

We based our simulations in part on a regional conservation plan (the MPCP), which considers how to provide corridors and core areas for grassland-dependent wildlife in a Minnesota landscape formerly dominated by tallgrass prairie but currently dominated by agriculture. Even though all the simulated management scenarios we considered added the same amount of CRP grasslands or wetlands to the landscape, predicted declines in lek density occurred in a third of the survey blocks when those additions were in the form of random, small parcels. Conversely, strategic additions of large parcels to increase contiguity reduced the number of survey blocks with predicted declines in lek density, and the magnitude of those declines. In some survey blocks, randomly adding CRP grasslands and wetlands to the landscape to meet MPCP goals increased fragmentation and reduced contiguity of grasslands. This resulted in lower predicted lek density, indicating that there are some areas where greater prairie-chicken habitat is so sparse that even concentrated efforts to improve habitat may not have a positive effect (Jorgensen et al. 2014). Those areas are likely not places to prioritize for CRP enrollment, at least not if 1 of the objectives is to increase habitat suitability for greater prairie-chickens. The importance of the landscape context in which conservation efforts occur is gaining increasing attention as a means to explain a lack of desired wildlife responses to local habitat management (Jorgensen et al. 2014, Simonsen and Fontaine 2016).

The number of CRP enrollments larger than the average enrollment size in Minnesota (80,000 m^2) is smaller than in more western landscapes in the United States; thus, in other landscapes with larger CRP enrollments, the proximity of enrollments to existing grasslands and wetlands may have less benefit than in the midwestern landscape we evaluated (Farm Service Agency 2017). Although few CRP enrollments are as small as 4,040 m^2, our simulations of small-parcel, random additions helped quantify the influence of patch size and landscape configuration on greater prairie-chickens. Our findings indicated that random addition of CRP grasslands or wetlands to the landscape may not be sufficient to meet MPCP goals. This is consistent with current understanding of ecological needs of greater prairie-chickens because they require a large amount of habitat (Niemuth 2000, 2003, 2011; Larson and Bailey 2007; Hovick et al. 2015) in appropriate configuration (Merrill et al. 1999; Niemuth 2003, 2011).

The difference between our simulations of random and strategic addition of CRP grasslands and wetlands at the lek scale and the landscape scale likely resulted from the increased potential for higher contiguity at the scale of the 2-km radius around traditional leks compared to adding similar grassland area at the landscape scale. Survey blocks included areas that lacked sufficient grassland area ($\geq$5.26 km^2, Kirsch 1974; Merrill et al. 1999; Niemuth 2003, 2011) and contiguity to support greater prairie-chickens, with some blocks having no traditional leks (survey blocks N1, O1, and O2). At the lek scale (2-km radius around traditional leks), grassland patches of sufficient size (>0.65 km^2; Kirsch 1974; Merrill et al. 1999; Niemuth 2003, 2011) and contiguity to support a traditional lek must already be present; therefore, adding more grasslands in such a small area likely increases grassland contiguity regardless of how it is added, which is consistent with findings from other studies (Niemuth 2003). Landscapes surrounding leks consisted of a larger amount of grasslands ($\bar{x} = 25.5\%$) and wetlands ($\bar{x} = 25.6\%$) and less forests ($\bar{x} = 13.9\%$) and forage crops ($\bar{x} = 9.8\%$; e.g., alfalfa and hay) than landscapes surrounding random non-lek locations within landscapes that supported greater prairie-chickens (Niemuth 2003). Leks that are surrounded by habitat near the threshold amount necessary to support greater prairie-chickens would benefit most by addition of grasslands and wetlands, and such additions may serve to mitigate the effects of losses of other nearby grasslands. In such cases, the addition of CRP grasslands and wetlands could either address habitat deficits or help safeguard against deficits that might occur through additional grassland losses nearby. Leks with the highest predicted increases in the number of males occurred in areas with low CRP grassland abundance (0–4.3%) and contiguity and when simulated grassland and wetland additions increased contiguity by >100% (lek 14 in survey block M1, Appendix A).

Results of our simulations of CRP enrollment expirations at the survey-block and lek scales are consistent with current understanding of greater prairie-chicken ecology: that greater prairie-chickens are area sensitive and require large patches of habitat (Kirsch 1974; Merrill et al. 1999; Niemuth 2003, 2011). If CRP grasslands and wetlands currently make up a large percentage of greater prairie-chicken habitat, then declines in prairie-chicken abundance will be greater than if there are other (i.e., non-CRP) grasslands or wetlands available. At the landscape scale, the areas that seemed to be most affected by loss of CRP grasslands and wetlands included the northern and south-central part of the current Minnesota greater prairie-chicken range (Fig. 5). Our analyses suggested losses of over a third of the density of leks for these areas at both the landscape and lek scales. These losses are similar to population declines of greater prairie-chickens throughout the Midwest that led to loss of genetic diversity in populations in Wisconsin, USA (Bellinger et al. 2003), and a reduction of hatching success in populations in Illinois, USA (Westemeier et al. 1998). If similar habitat losses occurred in Minnesota, greater prairie-chickens in the state would be expected to follow the historical pattern of other small populations across their range (Johnsgard 1983, Toepfer et al. 1990).

Our study has several limitations. First, we did not simulate alteration of any land-cover types other than CRP grasslands or wetlands; however, CRP grassland and wetland gains and losses do not occur in the absence of other landscape changes. The amount, contiguity, and fragmentation of land-cover types other than CRP grasslands and

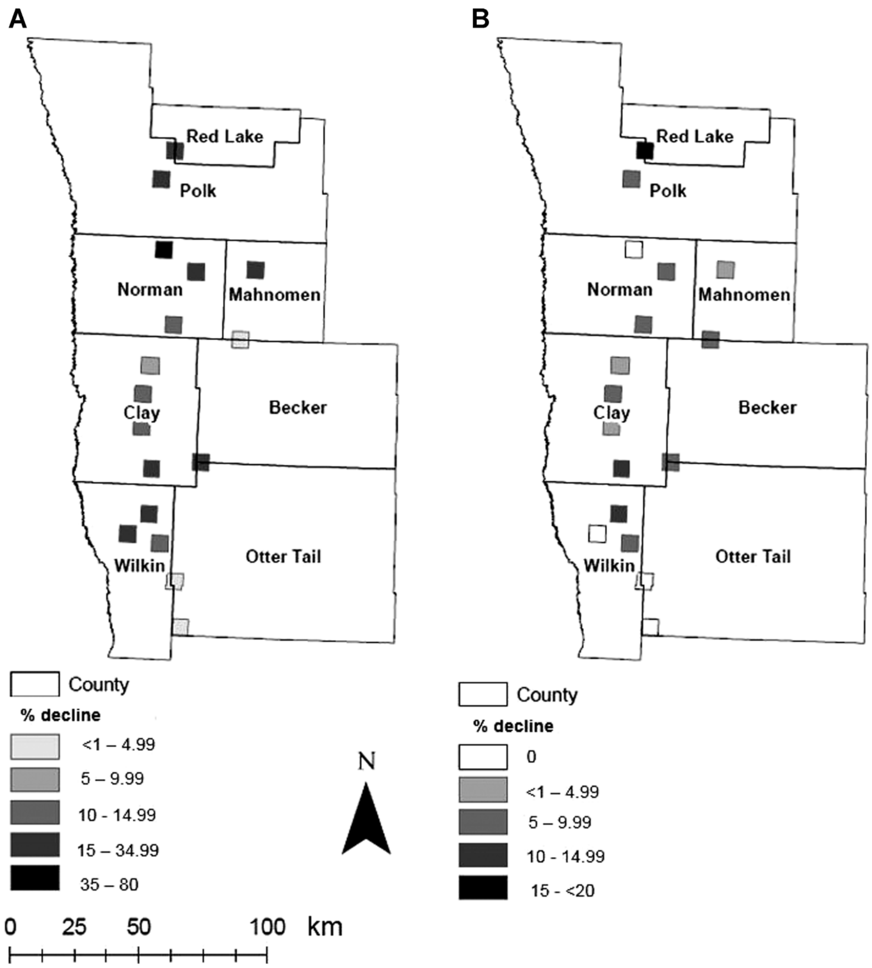

Figure 5. A) Total predicted percent change in the number of greater prairie-chicken leks/km^2 from the number predicted based on cover-type composition present in 2016 using the landscape-scale model of Adkins et al. (2019) and the predicted future landscape configuration following expiration of all Conservation Reserve Program (CRP) enrollments through 2030 for each of the 17 survey blocks in northwestern Minnesota, USA, 2004–2016. B) Total predicted percent change in the number of greater prairie-chicken males/lek averaged by survey block from the number predicted based on cover-type composition present in 2016 using the landscape-scale model of Adkins et al. (2019) and the predicted future landscape configuration following expiration of all CRP enrollments through 2030 for each of the 17 survey blocks in northwestern Minnesota, USA, 2004–2016.

wetlands may influence abundance of greater prairie-chickens, as can other factors such as weather, climate change, parasites, and disease (Flanders-Wanner et al. 2004, Peterson 2004, Princè et al. 2015). Likewise, our predicted greater prairie-chicken abundances were not based on a demographic model using vital rates for the year of expiration. Instead these were predictions based on projected landscape conditions and knowledge of relationships between greater prairie-chicken abundance and landscape composition in the current landscape. Therefore, our estimates of lek density and males/lek are not population projections.

The ability to target CRP enrollments in areas that will produce the greatest benefit for greater prairie-chicken populations becomes necessary because the cap on CRP enrollments is lower than when many of these contracts began. Our results suggest that conserving CRP enrollments in landscapes that currently have low levels of non-CRP grassland and wetland cover and targeting new enrollments that are contiguous with existing grasslands and wetlands are likely to have the most positive influence on greater prairie-chicken abundance. Breeding greater prairie-chickens have higher nest success and smaller home ranges in contiguous tracts of prairie of ≥65 ha than they do in a prairie mosaic (Ryan et al. 1998*a*). To better understand these landscape relationships in a more complex context, a more in-depth analysis of how cover types other than grasslands and wetlands might influence greater prairie-chicken population ecology (e.g., juxtaposition of crops used as food by prairie-chickens related to grassland and wetland cover) may be useful. For example, a threshold may exist for the ratio of crops to grasslands within a landscape, below which cropland is beneficial to greater prairie-chickens. Svedarsky et al. (2000) estimated this ratio to be 20–30% cropland intermixed with 70–80% grassland cover, but no blocks or leks in our study had 70–80% grassland cover. Furthermore, as with all predictive models, validating predictions with independent empirical data (Bahn and McGill 2013) would help identify which factors influence relationships between greater prairie-chickens and habitat most consistently and to the greatest extent. In addition, the ability of greater prairie-chickens to serve as an umbrella species for setting conservation priorities that benefit other grassland species is dependent on the quality and quantity of the data used (Poiani et al. 2001). Thus, additional data that improves understanding of greater prairie-chicken relationships to landscape variables, such as the amount of CRP grasslands and wetlands, may be important in improving conservation efforts for a suite of grassland species.

MANAGEMENT IMPLICATIONS

Our simulations of CRP expirations and enrollments provide several insights into how to improve landscape-level management for greater prairie-chickens. Loss of CRP enrollments due to expirations at the landscape scale could lead to reductions up to 80% of the number of leks/km^2 within survey blocks, which could lead to decreases in population size and further contraction of greater prairie-chicken range in northwestern Minnesota. Our results further suggest that CRP enrollments that are large and contiguous with existing grasslands and wetlands are likely to have the highest conservation value for greater prairie-chickens. The largest influence on greater prairie-chicken abundance might also be realized by increasing contiguity in areas with near-minimum area of habitat required by greater prairie-chickens ($\geq$5.26 km^2). Furthermore, maintaining existing CRP grasslands and wetlands in landscapes that currently have high levels of CRP grassland and wetland cover, both within landscapes with current high lek density and around traditional leks with high numbers of males, is likely to have the most positive influence on greater prairie-chicken conservation.

Our simulations also suggest that achieving the goals of the MPCP may have mixed effects on greater prairie-chicken abundance if new grasslands are not added strategically to increase existing grassland contiguity. To carry out a more strategic approach of implementing large, contiguous CRP enrollments, specific programs within the CRP could stipulate prioritization of both size and contiguity with existing grasslands and wetlands. Our projections could be used to prioritize and target neighboring property with eligible cropland for CRP enrollment or with enrollments set to expire adjacent to existing contiguous grassland areas for reenrollment. Encouraging groups of landowners to cooperate in priority areas likely to produce favorable management outcomes might also be possible.

ACKNOWLEDGMENTS

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States Government or the University of Minnesota. Annual greater prairie-chicken survey efforts were coordinated by MNDNR and conducted by many organizations, including the Minnesota Prairie Chicken Society, TNC, United States Fish and Wildlife Service, and individual volunteers. J. D. Forester supported quantitative analysis and editing. The Minnesota U-spatial help desk provided geospatial support. This research was conducted under a Memorandum of Understanding between the Minnesota Department of Natural Resources and the USDA Farm Service Agency. This project was funded through the Wildlife Restoration (Pittman-Robertson) Program W-69-S-13 Project 16 and conducted through the Minnesota Cooperative Fish and Wildlife Research Unit.

LITERATURE CITED

Adkins, K., C. L. Roy, D. E. Andersen, and R. G. Wright. 2019. Landscape-scale greater prairie-chicken habitat relations and the conservation reserve program. Journal of Wildlife Management 83:1415–1426.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355–366.

Bahn, V., and B. J. McGill. 2013. Testing the predictive performance of distribution models. Oikos 122:321–331.

Bellinger, M. R., J. A. Johnson, J. Toepfer, and P. Dunn. 2003. Loss of genetic variation in greater prairie chickens following a population bottleneck in Wisconsin. Conservation Biology 17:717–724.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology 79:517–533.

Burger, L. W., D. McKenzie, R. Thackston, and S. J. Demaso. 2006. The role of farm policy in achieving large-scale conservation: bobwhite and buffers. Wildlife Society Bulletin 34:986–993.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Esri. 2015. ArcGIS Desktop: release 10.3. Environmental Systems Research Institute, Redlands, California, USA.

Farm Service Agency. 2017. Number of CRP contracts by acres per contract. <https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/Conservation/PDF/CRP%20Contracts%20Arrayed%20by%20Acres%20per%20Contract%20Sep%202017.pdf>. Accessed 15 Dec 2018.

Flanders-Wanner, B. L., G. C. White, and L. L. McDaniel. 2004. Weather and prairie grouse: dealing with effects beyond our control. Wildlife Society Bulletin 32:22–34.

Forman, R. T., and T. A. Godron. 1981. Patches and structural components for a landscape ecology. BioScience 31:733–740.

Giudice, J. H. 2004. Minnesota Prairie-chicken Survey: 2004 Annual Report. Minnesota Department of Natural Resources, Saint Paul, USA.

Glaser, L. 1986. Provisions of the Food Security Act of 1985. U.S. Department of Agriculture, Washingtion, D.C., USA.

Heard, L. P., A. W. Allen, L. B. Best, S. J. Brady, W. Burger, A. J. Esser, E. Hackett, D. H. Johnson, R. L. Pederson, R. E. Reynolds, et al. 2000. A comprehensive review of Farm Bill contributions to wildlife conservation, 1985–2000. U.S. Department of Agriculture, Natural Resources Conservation Service, Wildlife Habitat Management Institute, Technical Report USDA/NRCS/WHMI-2000, Washington, D.C., USA.

Herkert, J. R. 2009. Response of bird populations to farmland set-aside programs. Conservation Biology 23:1036–1040.

Hovick, T. J., D. K. Dahlgren, M. Papeş, R. D. Elmore, and J. C. Pitman. 2015. Predicting greater prairie-chicken lek site suitability to inform conservation actions. PLoS ONE 10:e0137021.

Johnsgard, P. A. 1983. The grouse of the world. University of Nebraska Press, Lincoln, USA.

Jones, R. E. 1963. Identification and analysis of lesser and greater prairie chicken habitat. Journal of Wildlife Management 27:757–778.

Jorgensen, C. F., L. A. Powell, J. J. Lusk, A. A. Bishop, and J. J. Fontaine. 2014. Assessing landscape constraints on species abundance: does the neighborhood limit species response to local habitat conservation programs? PLoS ONE 9(6):e99339.

Kirsch, L. M. 1974. Habitat management considerations for prairie chickens. Wildlife Society Bulletin 2:124–129.

Larson, M. A., and W. Bailey. 2007. Identifying plots for surveys of prairie-chickens in Minnesota. Summaries of Wildlife Research Findings. Minnesota Department of Natural Resources, Saint Paul, USA.

McGarigal, K., S. A. Cushman, and E. Ene. 2012. FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, Amherst, USA. <http://www/umass.edu/landeco/research/fragstats/fragstats.html>. Accessed 14 Dec 2016.

McNew, L. B., V. L. Winder, J. C. Pitman, and B. K. Sandercock. 2015. Alternative rangeland management strategies and the nesting ecology of greater prairie-chickens. Rangeland Ecology & Management 68:298–304.

Merrill, M. D., K. A. Chapman, K. A. Poiani, and B. Winter. 1999. Land-use patterns surrounding greater prairie-chicken leks in northwestern Minnesota. Journal of Wildlife Management 63:189–198.

Minnesota Department of Natural Resources [MNDNR]. 2005. Long range plan for the ring-necked pheasant in Minnesota. Division of Fish and Wildlife, Saint Paul, Minnesota, USA.

Minnesota Department of Natural Resources [MNDNR]. 2006. Long range duck recovery plan. Division of Fish and Wildlife, Saint Paul, Minnesota, USA.

Minnesota Prairie Plan Working Group. 2011. Minnesota Prairie Conservation Plan 2010. Minnesota Prairie Plan Working Group, Minneapolis, USA.

Niemuth, N. D. 2000. Land use and vegetation associated with greater prairie-chicken leks in an agricultural landscape. Journal of Wildlife Management 64:278–286.

Niemuth, N. D. 2003. Identifying landscapes for greater prairie chicken translocation using habitat models and GIS: a case study. Wildlife Society Bulletin 31:145–155.

Niemuth, N. D. 2011. Spatially explicit habitat models for prairie grouse. Studies in Avian Biology 39:3–20.

Noss, R. F., E. T. LaRoe III, and J. M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. U.S. Department of the Interior, National Biological Service, Biological Report 28, Washington, D.C., USA.

Peterson, M. 2004. Parasites and infectious diseases of prairie grouse: should managers be concerned? Wildlife Society Bulletin 32:35–56.

Poiani, K. A., M. D. Merrill, and K. A. Chapman. 2001. Identifying conservation-priority areas in a fragmented Minnesota landscape based on the Umbrella Species Concept and selection of large patches of natural vegetation. Conservation Biology 15:513–522.

Princè, K., R. Lorrillière, M. Barbet-Massin, F. Léger, and F. Jiguet. 2015. Forecasting the effects of land use scenarios on farmland birds reveal a potential mitigation of climate change impacts. PLoS ONE 10(2):e0117850.

Ribic, C. A., M. J. Guzy, and D. W. Sample. 2009. Grassland bird use of remnant prairie and conservation reserve program fields in an agricultural Landscape in Wisconsin. American Midland Naturalist 161:110–122.

Riley, T. Z. 2004. Private-land habitat opportunities for prairie grouse through federal conservation programs. Wildlife Society Bulletin 32:83–91.

Robel, R. J., J. N. Briggs, J. J. Cebula, N. J. Silvy, C. E. Viers, and P. G. Watt. 1970. Greater prairie chicken ranges, movements, and habitat usage in Kansas. Journal of Wildlife Management 34:286–306.

Rodgers, R. D., and R. W. Hoffman. 2005. Prairie grouse population response to conservation reserve grasslands: an overview. Pages 120–128 *in* A. W. Allen and M.W. Vandever, editors. The Conservation Reserve Program—planting for the future: proceedings of a National Conference. USGS Biological Resources Division, Scientific Investigation Report 2005–5145. USGS Biological Resources Division, Fort Collins, Colorado, USA.

Ross, J. D., A. D. Arndt, R. F. C. Smith, J. A. Johnson, and J. L. Bouzat. 2006. Re-examination of the historical range of the greater prairie chicken using provenance data and DNA analysis of museum collections. Conservation Genetics 7:735–750.

Roy, C. 2019. 2019 Minnesota Prairie-chicken population survey. Minnesota Department of Natural Resources Survey Report, Saint Paul, USA.

Ryan, M. R. 2000. Impact of the Conservation Reserve Program on wildlife conservation in the Midwest. Pages 45–54 *in* W. L. Hohman and D. J. Halloum, editors. A comprehensive review of farm bill. A contribution to wildlife conservation, 1985–2000. U.S. Department of Agriculture Natural Resource Conservation Service, Wildlife Habitat Management Institute Technical Report USDA/NRCS/WHMI-2000, Washington, D.C., USA.

Ryan, M. R., L. W. Burger, and D. P. Jones. 1998*a*. Breeding ecology of greater prairie-chickens (*Tympanuchus cupido*) in relation to prairie landscape configuration. American Midland Naturalist 140:111–121.

Ryan, M. R., L. W. Burger, and E. W. Kurzejeski. 1998*b*. The impact of CRP on avian wildlife: a review. Journal of Production Agriculture 11:61–66.

Schroeder, M. A., and C. E. Braun. 1993. Greater prairie-chicken attendance at leks and stability of leks in Colorado. Wilson Bulletin 104:273–284.

Shirk, A. J., M. A. Schroeder, L. A. Robb, and C. E. Braun. 2017. Persistence of greater sage-grouse in agricultural landscapes. Journal of Wildlife Management 81:905–918.

Simonsen, V. L., and J. J. Fontaine. 2016. Landscape context influences nest survival in a Midwest grassland. Journal of Wildlife Management 80:877–883.

Steiner, E. M., and S. L. Collins. 1996. Prairie ecology-the tallgrass prairie. Pages 39–52 *in* F. B. Samson and F. L. Knopf, editors. Prairie conservation. Island Press, Washington, D.C., USA.

Stubbs, M. 2014. Conservation Reserve Program (CRP): status and issues. Congressional Research Service Report 7-5700 R42783, Washington, D.C., USA.

Sullins, D. S., J. D. Kraft, D. A. Haukos, S. G. Robinson, J. H. Reitz, R. T. Plumb, J. M. Lautenbach, J. D. Lautenbach, and B. K. Sandercock. 2018. Demographic consequences of conservation reserve program grasslands for lesser prairie-chickens. Journal of Wildlife Management 82:1617–1632.

Svedarsky, W. D. 1979. Spring and summer ecology of female greater prairie-chickens in northwestern Minnesota. Dissertation, University of North Dakota, Grand Forks, USA.

Svedarsky, W. D., R. L. Westemeier, R. J. Robel, S. Gough, and J. E. Toepfer. 2000. Status and management of the greater prairie-chicken (*Tympanuchus cupido pinnatus*) in North America. Wildlife Biology 6:277–284.

Toepfer, J. E., R. L. Eng, and R. K. Anderson. 1990. Translocating grouse: what have we learned? Transactions of the North American Wildlife and Natural Resources Conference 55:569–679.

U.S. Department of Agriculture [USDA]. 2005. Fish and wildlife habitat management leaflet: greater prairie-chicken (*Tympanuchus cupido*). National Resources Conservation Service, Washington, D.C., USA.

U.S. Department of Agriculture [USDA]. 2008. Farm program fact sheet: Minnesota CRP-SAFE Practices; CP38-Back forty pheasant habitat. Farm Service Agency, Saint Paul, Minnesota, USA.

U.S. Department of Agriculture [USDA]. 2019. 54th General Enrollment Period Environmental Benefits Index (EBI) Fact Sheet. U.S. Department of Agriculture, Washington, D.C., USA.

U.S. Department of Agriculture [USDA]. 2020. Farm program news release: USDA reminds producers of Feb. 28 deadline for Conservation Reserve Program general signup. U.S. Department of Agriculture, Washington, D.C., USA.

U.S. Department of Agriculture-National Agricultural Statistics Service [USDA-NASS]. 2016. Published crop-specific data layer. <https://nassgeodata.gmu.edu/CropScape/>. Accessed 11 Jan 2016.

Westemeier, R. L., J. D. Brawn, S. A. Simpson, T. L. Esker, R. W. Jansen, J. W. Walk, E. L. Kershner, J. L. Bouzat, and K. N. Paige. 1998. Tracking the long-term decline and recovery of an isolated population. Science 282:1695–1698.

Associate Editor: Adam Janke.

APPENDIX A. LAND-COVER METRICS

Table A1. Predicted changes in the density of greater prairie-chicken leks (lek/km^2) and land-cover metrics at the landscape associated with Conservation Reserve Program (CRP) expiration scenarios and Minnesota Prairie Conservation Plan (MPCP) enrollment scenarios. Predicted changes are relative to the predictions based on cover-type composition present in 2016 and derived from the models of Adkins et al. (2019). Land-cover metrics considered included percent CRP grasslands and CRP wetlands at the scale of survey blocks in northwestern Minnesota, USA, 2004–2016. Error at the landscape scale is derived from the normalized root-mean-square error (NRMSE; 13.15%) calculated from the landscape-scale model from Adkins et al. (2019). Survey blocks N2 and W2 were outside of the area included in the MPCP so no CRP was added to the landscape to meet the MPCP enrollment scenarios (NA).

	Expiration scenario				2016 Land cover		MPCP enrollment scenarios
Survey block	Change in leks/km^2 (%)	NRMSE error	Year with largest change in leks/km^2	Change in NP following all expirations (%)	Grassland CRP (%)	Wetland CRP (%)	CRP added to reach MPCP goals (km^2)
B1	−1.83	0.24	2020	9.76	0.45	0.83	5.36
B2	−32.41	4.26	2022	−22.38	4.84	0.12	1.55
C1	−6.64	0.87	2021	−2.02	1.99	0.52	0.28
C2	−15.03	1.98	2018	8.13	1.03	1.12	0.85
C3	−7.90	1.04	2018	4.94	1.72	1.68	0.59
C4	−34.93	4.59	2019	19.61	2.53	5.81	1.82
M1	−26.83	3.53	2025	20.59	1.57	1.36	8.37
N1	−80.18	10.54	2021	20.22	3.68	5.30	4.20
N2	−33.53	4.41	2018	20.49	1.18	6.87	NA
N3	−12.74	1.68	2022	9.94	1.40	2.84	4.84
O1	−3.75	0.49	2030	1.24	0.18	0.21	6.64
O2	−1.73	0.23	2028	1.70	0.02	0.29	4.43
P1	−27.10	3.56	2030	4.92	7.31	3.61	3.18
P2	−24.03	3.16	2017	−5.71	6.44	1.72	7.38
W1	−32.09	4.22	2019	18.13	2.06	8.15	3.74
W2	−24.02	3.16	2027	8.13	0.78	0.49	NA
W3	−11.25	1.48	2027	3.67	0.91	1.44	4.01

Table A2. Predicted changes in the density of greater prairie-chicken males/lek, and land-cover metrics at the lek scale associated with Conservation Reserve Program (CRP) expiration scenarios and Minnesota Prairie Conservation Plan (MPCP) enrollment scenarios. Predicted changes are relative to the predictions based on cover-type composition present in 2016 and derived from the models of Adkins et al. (2019). Land-cover metrics considered included percent combined CRP grasslands and wetlands and contiguity index of CRP grasslands at the lek scale in northwestern Minnesota, USA, 2004–2016. Error at the lek scale is derived from the NRMSE (17.38%) calculated from the lek-scale model from Adkins et al. (2019). We did not calculate number of patches (NP) for the lek scale because that model did not include that metric for predictions. Survey blocks N2 was outside of the area included in the MPCP so no CRP was added to the lek scale (a fixed buffer of 2 km around the lek) within those blocks to meet the MPCP enrollment scenarios (NA).

		Expiration scenario			2016 Land cover		MPCP enrollment scenarios
Lek	Survey block	Change in males/lek (%)	NRMSE error	Year with largest change in males/lek	CRP (%)	Contiguity of grasslands CRP	CRP added to reach MPCP goals (km^2)
1	P1	−19.16	3.32	2030	40.81	0.79	0.74
2	P2	−8.72	1.51	2024	13.77	0.78	0.09
3	P2	−8.47	1.47	2023	6.52	0.86	1.29
4	N2	−8.34	1.45	2018	9.24	0.42	NA
5	C2	−7.60	1.32	2023	6.51	0.43	0.63
6	C3	0.00	0.00	NA	0.00	0.00	1.11
7	C3	−6.08	1.06	2020	0.26	0.33	2.58
8	C3	−3.77	0.65	2020	2.59	0.36	1.71
9	C3	−6.90	1.20	2019	3.29	0.78	0.27
10	C3	−5.77	1.00	2018	3.49	0.40	0.24
11	C4	−7.63	1.32	2025	6.56	0.72	0.24
12	C4	−15.57	2.70	2019	13.72	0.42	0.11
13	B2	−6.79	1.18	2025	3.64	0.75	0.75
14	M1	−3.27	0.57	2020	1.11	0.31	4.30
15	W3	−6.68	1.60	2023	2.71	0.56	2.36
16	W3	−5.38	0.93	2023	1.85	0.54	3.92
17	N3	−7.68	1.33	2023	3.19	0.82	3.99
18	N3	−7.64	1.33	2017	4.87	0.43	1.04
19	B1	−6.15	1.07	2020	3.12	0.52	2.69
20	C1	−3.59	0.62	2018	0.28	0.67	0.68
21	C1	−0.03	0.01	2019	0.08	0.00	0.67
22	C1	−5.89	1.02	2020	2.47	0.79	0.10
23	N3	−8.87	1.54	2022	3.81	0.63	3.68
24	C2	−3.89	0.67	2017	0.18	0.31	1.46
25	W1	−15.95	2.77	2030	21.07	0.72	0.00
26	W1	−6.21	1.08	2030	4.11	0.88	2.08