Projected responses of Alberta grassland songbirds to climate change

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Preface:

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The primary goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province, the ABMI has assembled a massive biodiversity database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

The ABMI undertakes focused projects to apply this capacity to specific management challenges, and demonstrate the value of the ABMI's long-term monitoring data to addressing these challenges. In some cases, these applied research projects also evaluate potential solutions to pressing management challenges. In doing so, the ABMI has extended its relevance beyond its original vision.

The ABMI continues to be guided by a core set of principles – we are independent, objective, credible, accessible, transparent and relevant.

This report was produced in support of the ABMI's Biodiversity Management and Climate Change Adaptation project, which is developing knowledge and tools to support the management of Alberta's biodiversity in a changing climate.

Summary

Across North America, grassland songbirds have undergone steep population declines over recent decades, commonly attributed to agricultural intensification. Understanding the potential impacts of climate change on the future distributions of these species can support improved risk assessments and conservation planning for this otherwise vulnerable group. We used North American bioclimatic niche models to project future changes in suitable climate space for 15 Alberta grassland songbirds. Our climate suitability projections, combined with the current distribution of native and tame grassland and cropland habitats in Alberta suggest that some climate-mediated range expansion of many grassland songbirds in Alberta is possible. These projected expansions may hinge, however, on the stability of grassland songbird populations across North America. For more than half of the grassland songbird species in Alberta, a large proportion (more than 50%) of their historical climate niche was projected to remain suitable to the end of the century. However, some endemic grassland species with dramatic projected changes in suitable climate distribution, including Baird's Sparrow and Sprague's Pipit, have limited areas of climate stability in their historical niche and their expansion into new areas of suitable climate may be limited by the availability of suitable landcover.

Introduction

In the last four decades, grassland birds have undergone steep population declines across North America (NACBI 2014, Sauer and Link 2011). These declines have been linked to changes in land use, including conversion of native grassland to cropland, intensification of agricultural practices and fragmentation of native grassland by industrialization (Askins et al. 2007). As a result, grassland birds are increasingly identified as among the most at-risk groups in North America (National Audubon Society 2014). Examples of such species in Alberta include Sprague's Pipit (*Anthus spragueii*) and the Chestnut-collared Longspur (*Calcarius ornatus*), which are both listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) because of population declines and their vulnerability to the loss of large tracts of suitable grassland habitat (COSEWIC 2010; COSEWIC 2009). Further, in Alberta six songbird species associated with grassland habitats are currently listed as Sensitive by Alberta Environment and Sustainable Resource Development (AESRD 2010), and most have experienced population declines since 1970 (Table 1).

The impacts of recent and continued land use changes on grassland birds will be potentially compounded by the response of these species to global climate change (Staudt et al. 2013). Grassland bird population distributions are highly responsive to the climate and weather conditions on the Great Plains of North America (e.g., Niemuth et al. 2008, Rotenberry and Wiens 1991, Wiens 1974). This spatial responsiveness to short-term changes in habitat condition driven by inter-annual variation in weather, combined with the high mobility of these migrant species, may support distributional shifts in response to climate change as new areas of suitable climate and vegetation become available (Skagen and Adams 2012). Observed northward shifts in songbird ranges have already been attributed to climate change (Gillings et al. in press, Zuckerberg et al. 2009, Parmesan and Yohe 2003). Where the potential responses of North American grassland birds to climate change have been examined, projections indicate potential increases in the abundance of some grassland-associated species in the boreal regions of North America (Stralberg et al. 2015) and potentially severe declines in suitable habitat for some species like Baird's Sparrow (*Ammodramus bairdii;* National Audubon Society 2014). An improved understanding of the potential impacts of climate change on grassland songbird distributions can support long-term planning and management of these declining species.

We used bioclimatic niche models to project shifts in the distribution of 15 of Alberta's grassland songbirds in response to projected changes in climate over the next century. We generated models describing the current distribution of suitable climate from North American survey data and seven bioclimatic variables from the baseline historical period of 1969-1990. These models were used to project the future distribution of suitable climate for each species across North America for the baseline climate (1969-1990) and in each of three future time periods (2011-2040, 2041-2070, and 2071-2100), given projected future climatic conditions. We examined differences among time periods to identify the potential change in amount and location of suitable climate for these species, both across North America, and in Alberta specifically.

Our models relied on several assumptions, including: 1) that climate is the primary factor determining the current distribution of these species, and 2) that current songbird distributions are in equilibrium with climate (Araújo and Pearson 2005) and this equilibrium will continue to hold in the future (Sinclair et al. 2010, Wiens et al. 2009). However, site fidelity, limitations in dispersal ability, lags in vegetation transition (Stralberg et al. in review) and plant dispersal (Iverson et al. 2004), or changes in land use and management (e.g., grazing timing, frequency and duration) may prevent future projections of climate suitability from being fully realized by bird populations. Therefore, we identified regions of overlap between areas of currently suitable climate and future suitable climate in Alberta as a second component of assessing the potential impacts of climate change on Alberta's grassland songbirds. These climate change refugia are likely to continue to provide suitable habitat as climate change progresses (Ashcroft 2010), and may be particularly important for climate change adaptation if birds are not able to shift their distributions quickly in response to changing environmental conditions.

Projections of future climate suitability do not directly incorporate other species' requirements, like habitat availability, that must be met for climate-based projections of species distribution shifts to be realized. As climate change progresses, the current extent of native and tame pasture and cropland landcover in Alberta may support the expansion of grassland songbird distributions in the province, depending on the specific habitat requirements of each species - Use of agricultural landcover differs among species, however: Baird's Sparrows rarely occur in annual cropland for example, whereas Vesper Sparrows (*Pooecetes gramineus*) frequently make use of annual cropland, along with tame pasture and hayland (McMaster and Davis 2001, Best et al. 1995). In the absence of changes in landuse or management, native grasslands that currently support grassland songbird populations in Alberta are likely to remain as suitable landcover over the next century, as changes in native vegetation in response to climate will be limited primarily to shifts to vegetation communities currently in the Great Plains of the United States (Schneider 2013, Thorpe 2011). Similarly, current agricultural lands, including non-native, planted pastures, hay and annual cropland are likely to remain as suitable landcover for many species in the absence of changes in land use, such as transitions from pasture to annual cropland. If shifts in the distribution of suitable climate space for grassland songbirds are dramatic however, lags in native vegetation transition (e.g., the transition from forested to open habitat in the Boreal Natural Region; Schneider 2013), or lack of suitable open habitat for some species (e.g., cropland vs pasture) may prevent expansion to new areas from being fully realized by songbird populations. We examined how the projected changes in suitable climate for each species correspond to the current distribution of native grassland, tame pasture/hayland and cropland landcovers in Alberta to identify how the current distribution of these landcover types may facilitate or limit potential distribution shifts projected by future climate conditions.

Combined, these three examinations of projected changes in suitable climate space for Alberta's grassland songbirds provide insight into: 1) the total potential shift in suitable climate space for each species, 2) the regions where climate is likely to remain suitable for each species, and 3) how projections of suitable climate space might interact with the current distribution of native grassland and agricultural landcover in Alberta to limit or facilitate shifts in species distributions.

Methods

Avian Survey Data and Study Area

We compiled data for 15 Alberta grassland songbirds from avian point-count surveys conducted throughout Canada, the continental United States, and Alaska (Table 1). The compiled data consisted primarily of roadside point-counts conducted as part of the North American Breeding Bird Survey (Sauer et al. 2014) from 1967-2012, summarized at the route level. These data were supplemented with off-road point-counts from avian monitoring conducted by the Alberta Biodiversity Monitoring Institute (ABMI[1]; 2003-2011), and from research projects conducted in Alberta and Saskatchewan in 2005-2007 (Davis et al. 2013). The resulting data set included 56,401 point counts at 9,906 unique sites. Species observations were summarized across years as the presence of each species at each site; the number of observations of species presence ranged from 154 (McCown's Longspur) to 4,056 (Savannah Sparrow; Table 1).

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[1] www.abmi.ca

Table 1. Habitat use, conservation status, BBS trend estimates and number of presence observations used in modelling for Alberta grassland songbirds.

Species				Conservation Status			BBS Trend Estimate for Alberta[4] (lower limit, upper limit)		
Common Name (*Scientific Name*)	AOU Code	Habitat[1]	Specialization[2]	International (IUCN)[3]	National (COSEWIC)[4]	Provincial (AESRD)[5]	1970-2012	2002-2012	Presence observations
Baird's Sparrow (*Ammodramus bairdii*)	BAIS	G	Endemic	LC	SC	Se	-3.53 (-6.59, -0.649)	1.74 (-6.53, 11.1)	552
Bobolink (*Dolichonyx oryzivorus*)	BOBO	G	Secondary[*]	LC	Th	Se	-3.98 (-8.37, 0.378)	-3.4 (-14.7, 12.1)	1412
Brewer's Sparrow (*Spizella breweri*)	BRSP	G	Secondary	LC	NA	Se	0.804 (-3.89, 7.92)	7.11 (-4.3, 27.1)	630
Chestnut-collared Longspur (*Calcarius ornatus*)	CCLO	G	Endemic	NT	Th	Se	-8.58 (-9.45, -5.8_	-5.57 (-10, 0.389)	310
Clay-colored Sparrow (*Spizella pallida*)	CCSP	G	Secondary	LC	NA	S	-1.67 (-2.28, -1.12)	-2.04 (-3.45, -0.708)	1713
Grasshopper Sparrow (*Ammodramus savannarum*)	GRSP	G	Secondary	LC	NA	Se	-0.634 (-3.48, 2.36)	-0.01 (-3.96, 7.49)	1727
Horned Lark (*Eremophila alpestris*)	HOLA	G/C	Secondary	LC	NA	S	-3.85 (-5.1, -2.47)	-3.84 (-6.55, -0.828)	2746
Lark Bunting (*Calamospiza melanocorys*)	LARB	G	Endemic	LC	NA	S	-4.98 (-10.6, 1.07)	2.14 (-14.5, 22.6)	427
Lark Sparrow (*Chondestes grammacus*)	LASP	G	Secondary	LC	NA	S	-2.74 (-6.88, 1.27)	-2.33 (-12.8, 9.86)	1377
Le Conte's Sparrow (*Ammodramus leconteii*)	LCSP	G	Secondary[*]	LC	NA	S	-3.9 (-5.74, -2.05)	-4.21 (-8.79, 0.324)	618
McCown's Longspur (*Rhynchophanes mccownii*)	MCLO	G	Endemic	LC	SC	S	-7.49 (-10.8, -3.97)	-6.46 (-13.8, 4.41)	154
Savannah Sparrow (*Passerculus sandwichnesis*)	SAVS	G/C	Secondary	LC	NA	S	-1.59 (-2.39, -0.822)	-1.04 (-2.64, 0.604)	4056
Sprague's Pipit (*Anthus spragueii*)	SPPI	G	Endemic	Vu	Th	Se	-4.54 (-6.42, -2.63)	-6.17 (-11.1, -1.07)	829
Vesper Sparrow (*Pooecetes gramineus*)	VESP	G/C	Secondary	LC	NA	S	0.368 (-0.835, 1.24)	2.03 (0.493, 3.69)	2829
Western Meadowlark (*Sturnella neglecta*)	WEME	G	Secondary	LC	NA	S	-0.405 (-1.83, 0.357)	-0.306 (-1.97, 1.21)	3186

[1] G – Native and tame grassland/hay; C – Annual Cropland. Refer to Appendix 1 for classification rationale.

[2] Described by Knopf (1994). [*] Le Conte's Sparrow and Bobolink are not classified by Knopf (1994). Both species have widespread distributions beyond the North American Great Plains, however, so are classified as Secondary species here.

[3] IUCN – International Union for the Conservation of Nature 2014: LC – Least Concern; NT – Near Threatened; Vu – Vulnerable.

[4] COSEWIC – Committee on the Status of Endangered Wildlife in Canada 2014: NA – Not Assessed, SC – Special Concern, Th – Threatened.

[5] Alberta Environment and Sustainable Resource Development 2010: S – Secure, Se – Sensitive.

[6] Breeding Bird Survey; Environment Canada, 2014.

Species were classified according to their documented occurrence and nest success in native and tame grassland or pasture (G) and cropland (C; Table 1; Appendix 1), with particular reference to observations from Alberta and Canada.

The study area was limited to the extent of the surveyed locations (Fig. 1). The southern limit was defined by the Mexico-United States border and the northern limit by the level II ecoregions of North America (CEC 1997) that delimit the southern arctic. We included the southern subunits of the Tundra (Alaska Tundra, Brooks Range Tundra and Southern Arctic), but excluded the Northern Arctic subunit, from which survey data was lacking.

Climate Data

We used current and projected climate data for North America from ClimateNA (Stralberg et al. 2015; www.ualberta.ca/~ahamann/data/climatena.html). This data set comprises interpolated climate data at 4km resolution based on the PRISM model (Daly et al. 2008) for the 1961-1990 baseline period and projected future climate data for three consecutive 30-year periods (2011-2040, 2041-2070, and 2071-2100) based on global climate model (GCM) projections from the CMIP3 multi-model dataset associated with the fourth IPCC assessment report (Meehl et al. 2007). Twenty derived bioclimatic variables (Wang et al. 2012, Hamman 2013) and 36 monthly variables are available for the baseline period and for most GCM-emissions scenario combinations.

We selected four complementary global climate models (GCMs) that span a range of projected future climates for North America in general, and Alberta in particular (Stralberg et al. 2015, Stralberg 2012): the German ECHAM5/MPI-OM, the Canadian CCCMA-CGCM3.1(T47), the American GFDL-CM2.1 and the United Kingdom UKMO- HadGEM1. In addition, we used an ensemble model provided by ClimateNA, derived from 19 GCMs. We adopted the SRES A2 emissions scenario (IPCC 2001), which most accurately reflects the current trend in global carbon emissions (Friedlingstein et al. 2014).

We relied on a set of seven bioclimatic variables (Table 2), selected following the criteria of Stralberg et al. (2015), including relevance to vegetation, avoidance of co-linearity and a preference for seasonal over annual variables. The most highly correlated variables within the historical dataset across all of North America were the extreme minimum temperature over 30 years (EMT) and chilling degree days (DD0; $r = 0.95$). Within the model building dataset (background points, as described below), the most highly correlated variables were EMT and growing degree days (DD5; r=0.88) and summer climate moisture index (CMIJJA) and annual climate moisture index (CMI; =0.87).

Table 2. Bioclimatic variables, definitions and ranges used as predictors of climate suitability for 15 grassland songbirds

Variable	**Definition**
CMIJJApm	Summer (June to August) climate moisture index (Hogg 1997 modified Penman-Monteith method)
CMIpm	Climate moisture index (Hogg 1997 modified Penmnan-Monteith method)
DD0	Degree-days below 0 °C (chilling degree days)
DD5	Degree-days above 5 °C (growing degree days)
EMT	Extreme minimum temperature over 30 years (°C)
MSP	Mean summer (May to September) precipitation (mm)
TD	Difference between the mean temperature of the coldest month and the mean temperature of the warmest month, as a measure of continentality (°C)

Bioclimatic Niche Modelling

We used the maximum entropy (MaxEnt v. 3.3.3; Elith et al. 2011, Phillips et al. 2006) method of bioclimatic niche modelling to generate predictions of current climate suitability for the baseline period (1961-1990) and projections of climate suitability under each future time period. MaxEnt modelling is widely used as a robust approach to bioclimatic niche modelling based on species occurrence records (Elith et al. 2006). Although our dataset included absence information at the route (BBS data) or point (all other data sources) level, we could not assume absence at the 4-km x 4-km grid-cell level used to build models (based on climate data resolution). Thus, in the absence of detectability adjustments, we deemed a presence-only approach more suitable than presence-absence in this case. To accommodate sampling bias in the species occurrence data (e.g., associated with road-side sampling; Wellicome et al. 2014), we restricted our background points to the set of locations comprising the combined occurrences of the entire set of 15 species (*N*= 3910; i.e., target-group background points; Phillips et al. 2009; Fig. 1). Occurrence records were converted to species presence/absence at the 4x4 km resolution of the climate data, thereby reducing non-independence between records.

Species models were built from 10 bootstrapped replicates using linear, quadratic, product, and threshold features. In each replicate, occurrence data were randomly assigned into training (70%) and testing (30%) datasets. Average models for each species were projected onto the current and future climates across North America to predict climate suitability in each set of future climate conditions. We represented climate suitability as the Maxent cumulative output (from 0 to 100), in which each location is assigned the sum of all raw values less than or equal to the raw output value for that location (Phillips et al. 2006).

Model performance

Model performance was evaluated using the area under the curve of the receiver-operating characteristic (ROC AUC; Fielding and Bell 1997); an AUC >0.7 indicates good model performance, whereas an AUC=0.5 indicates a random model (Manel et al. 2001, Swets 1988). AUC is a widely used but imperfect measure of model performance for presence-absence and presence-only models (Lobo et al. 2008, Merow et al. 2013). For MaxEnt models, AUC is a measure of how the model distinguishes between occurrences and background points (Elith et al. 2011). Therefore, models of widespread, generalist species that occupy a large proportion of the background points (here all surveyed locations) will necessarily have lower AUC values than those of more specialist species (Lobo et al. 2008). In addition, our selection of background points for evaluation, those at which at least one grassland bird species was observed, will tend to reduce AUC values, relative to evaluation against a broader set of background points (e.g., from the boreal forest) with greater contrasts in avifauna and, as a result, greater discriminatory power.

Projected changes in climate suitability in North America

Species-specific thresholds balancing model specificity (correctly predicted presences) and sensitivity (correctly predicted absences; Pearson et al. 2004) were used to convert the continuous predictions of climate suitability into binary predictions of suitable/unsuitable climate, which can be considered the core suitable climate area for each species. The binary maps generated for the baseline period (1961-1990) were more restricted for some widespread species (e.g., Savannah Sparrow), but otherwise compared well with published North American range maps for most species (Poole 2005). This comparison indicates that this threshold was a reasonable choice, given our modelling goal of representing relative range changes over time, as mediated by climatic conditions. However, because threshold choice has a large influence on the interpretation of modelled suitable climate and shifts in suitable climate in response to climate change (Nenzén and Araújo 2011, Pearson et al. 2004), we emphasize relative trends over time and among species in our analysis of the binary maps.

For each species, time period and GCM, we calculated the core area of suitable climate predicted in North America by the average of each set of bootstrapped models.

Projected changes in climate suitability and climatic refugia in Alberta

North American projections were clipped to the Alberta extent. Core areas of climate suitability were calculated as for the North American extent.

Climatic refugia (areas of relative stability with respect to a species' climate niche requirements) were determined from the overlap between the baseline core areas of climate suitability and the projected suitable areas in each future time period for Alberta. For each species and GCM combination, we calculated the proportion of the historical suitable area that was also identified as suitable in each future time period.

Projected climate suitability correspondence with current landcover in Alberta

To examine the influence of species-specific landcover use and the current distribution of native and tame grassland and cropland landcover in Alberta on the possible utilization of projected suitable climate space, we calculated the total area of "suitable" landcover within the projected suitable climate space for each species over time.

We used the Agriculture and Agri-Food Canada Annual Crop Inventory (AAFC 2013) to classify landcover in the agricultural region of Alberta as "cropland", or "native and tame grassland/hay" (Fig. 2; Appendix 2). The AAFC data are generated at 30 m resolution from satellite inventory (Landsat-8 and Radarsat-2) and validated with provincial crop insurance data, distinguishing between annual crop and tame pasture/hay landcovers. While the AAFC data also distinguish between native grassland and tame pasture/hay landcovers, we combined these two classes over concerns that they were not well-differentiated. The "native and tame grassland/hay" class therefore contains all native and tame grassland and pasture landcover, including hay, while the "cropland" class is limited to annual row crops. We defined "suitable" landcover for each species according to their reported occurrence in these two classes of landcover (Table 1; Appendix 1).

For some secondary grassland species that currently occupy open habitats in the boreal region, like Savannah Sparrow and Le Conte's Sparrow, defining suitable landcover only by the species' use of native and tame grassland and cropland habitats may have underestimated the total suitable landcover in the province, but was consistent with our analysis of the remaining secondary and endemic species. Further, grassland songbird habitat selection is certainly more complex than the binary distinction between pasture/hay and annual cropland landcover; for example many species differentially occupy pasture in response to grazing intensity (e.g., Chestnut-collared Longspur; COSEWIC 2009) or distinguish between hay and pasture (e.g., Clay-colored Sparrow and Savannah Sparrow; McMaster and Davis 2001), and others, like Sprague's Pipit, are strongly associated with native grassland habitats (Davis et al. 2013). Provincial-scale landcover data that reliably distinguish among these landcover and land use types are not available; however, our binary analysis represents a first step towards understanding how interactions between landcover and climate suitability may limit or facilitate changes in the distribution of Alberta's grassland songbirds.

We represented current predictions and future projections as the average of the bootstrapped MaxEnt models for each species, GCM and time period. Means and standard errors presented were based on the projections of the four unique GCMs and thus do not represent the full range of uncertainty represented by variability in the bootstrap samples. Future projection maps were based on the ensemble climate data, but maps for each of the four individual GCMs are available upon request.

ArcGIS (v.10.0; ESRI) was used to process all species occurrence data and MaxEnt model outputs. Data analysis was conducted in R (v.2.15.2; R Core Team 2014).

Results

Model performance

The AUC values for the average models for 13 of 15 species were ≥0.7 (Table 3). The remaining two species, Savannah Sparrow and Horned Lark, are both widely distributed species that occupy a variety of open habitats (e.g., great plains, arctic tundra, alpine) across North America; they are also the species for which we had the greatest number of occupied 4x4 km cells relative to our background points (Table 3, background *N*=3910).

Table 3. Predictive performance of average MaxEnt models for each grassland songbird species. Average models are based on 10 bootstrapped replicates with a 70% -30% training-testing split of the occupied 4x4 km grid cells (*N*) in each replicate.

Species	***N***	**Test AUC**	**SD**
BAIS	249	0.949	0.007
BOBO	1270	0.802	0.009
BRSP	604	0.896	0.007
CCLO	205	0.952	0.009
CCSP	915	0.846	0.008
GRSP	1652	0.738	0.010
HOLA	2115	0.674	0.010
LARB	420	0.922	0.007
LASP	1336	0.793	0.009
LCSP	456	0.904	0.007
MCLO	95	0.958	0.010
SAVS	2308	0.665	0.009
SPPI	334	0.933	0.006
VESP	1875	0.701	0.010
WEME	1888	0.725	0.009

Suitable climate in North America

Four of the 15 grassland songbird species were projected to experience declines in core suitable climate area in the North American study region from the baseline period (1961-1990) to the end of the century (95% confidence intervals around the mean of the four GCM projections did not include zero). The species with the greatest projected proportional decline in core suitable climate was McCown's Longspur (Fig. 3; 2011-2040: -45 ± 8%; 2041-2070: -63 ± 5%; 2071-2100: -77 ± 8%). The three other species that are predicted to experience a reduction in core suitable climate area were Brewer's Sparrow (-32 ± 14%), Clay-colored Sparrow (-8 ± 1%), and Le Conte's Sparrow (-41 ± 11%).

Increases in suitable North American climate area by the end of the century were projected for seven species. Lark Sparrow had the greatest predicted proportional expansion in core suitable climate across all three time periods (Fig 3; 2011-2040: 30 ± 7%; 2041-2070: 62 ± 5%; 2071-2100: 88 ±15%). Bobolink

(40 ± 6%), Grasshopper Sparrow (21 ± 10%), Horned Lark (56 ± 8%), Lark Bunting (23 ± 11%), Savannah Sparrow (7 ± 2%), and Western Meadowlark (26 ± 10%) are also all projected to experience increases in suitable climate area. The projected changes in suitable climate area in North America for the remaining four species, Baird's Sparrow, Chestnut-collared Longspur, Sprague's Pipit and Vesper Sparrow were more equivocal, with greater variability among GCMs relative to the magnitudes of change projected.

In general, the spatial distribution of suitable climate space for the 15 grassland songbirds birds across North America was projected to shift northward, driven by expansion of suitable climate to the north and northward shifts of the southern margins, but the degree of shift was quite variable (Fig. 4). For example, core suitable climate area for the Chestnut-Collared Longspur was projected to shift gradually northward, while northward shifts in core suitable climate area for Sprague's Pipit and Baird's Sparrow were more dramatic, especially by the end of the century. The projected core area of suitable climate for McCown's Longspur declined dramatically because contraction at the southern edge was not complemented by expansion in the north (Fig. 4). In contrast, several species, including Lark Sparrow and Horned Lark had projections of expanding core suitable climate to the north, with little change at the southern edge, resulting in an overall projected expansion of core suitable climate space (Fig. 4).

Suitable Climate in Alberta

The majority (10 of 15) of Alberta grassland songbirds were projected to experience increases in core suitable climate area in Alberta by the end of the century. The greatest increases relative to the historical baseline period were projected for the two species that have small areas of predicted suitable climate in the baseline period, Grasshopper Sparrow (14 668 ± 5539%), and Lark Sparrow (20 585 ± 5324%; Fig. 5, Fig. 6). Bobolink was not predicted to have any core suitable climate area in Alberta for the baseline period, but was projected to experience an increase in suitable climate area over time (Fig 5, increase calculated relative to 2011-2041 period; Fig. 6). Only two species were projected, on average, to experience declines in core suitable climate area in Alberta by the end of the century (95% confidence intervals do not contain zero): Clay-colored Sparrow (-20 ± 6%) and Le Conte's Sparrow (-53 ± 15%; Fig. 5); both species are secondary grassland species with widespread core suitable climate areas in the baseline period that shift northward over time. The projected changes in suitable climate area in Alberta for three species, Baird's Sparrow, McCown's Longspur, and Sprague's Pipit were more equivocal, with greater variability among GCMs relative to the magnitudes of change projected.

While there was considerable variation within species in the magnitude of change in suitable climate area among the projections from the four unique global climate models, the overall trends in the patterns of change projected for each species were fairly consistent. Notable exceptions for which the direction of change in suitable climate area by the end of the century was different among GCM projections include: Baird's Sparrow, Brewer's Sparrow, McCown's Longspur, and Sprague's Pipit. For these four species, the individual climate models variably projected either increases or decreases in suitable climate area in Alberta to the end of the century. Of the four models, the warmest and driest scenarios represented by the United Kingdom model (UKMO-HadGEM1; hotter and drier) and the American model (GFDL-CM2.1; drier), generated the most distinct projected changes for Alberta (larger increases or decreases compared to the other three models and the ensemble model). These two drier scenarios also often resulted in projected changes in suitable climate area that were distinct from those produced by the wetter scenario represented by the Canadian model (CCCMA CGCM3.1).

In general, the spatial distribution of suitable climate space for the Alberta distribution of the 15 grassland songbirds was projected to expand towards the north, resulting in increases for most species (Fig. 6). The northward expansion in suitable climate area was frequently initiated by expansion in the NW portion of Alberta (e.g., Chestnut-collared Longspur, Horned Lark, Vesper Sparrow; Fig. 6). Seven of 15 species were also projected to experience a northward shift, to varying degrees, in the southern margin of suitable climate space in Alberta by the end of the century: Baird's Sparrow, Chestnut-collared Longspur, Clay-colored Sparrow, Le Conte's Sparrow, McCown's Longspur, Savannah Sparrow, and Sprague's Pipit (Fig. 6).

Climate Refugia in Alberta

For most species, the projected percent of baseline suitable climate area remaining in refugia declined over time as a result of the spatial shifts in suitable climate area, although most species were also projected to maintain nearly 50% of their baseline suitable climate area in Alberta by the end of the century (Fig. 7). The species that were projected to have large proportional refugia areas over time are those with limited losses of suitable climate space in southern Alberta, related to their current southerly distributions (e.g., Horned Lark, Lark Bunting, Lark Sparrow, Vesper Sparrow, and Western Meadowlark; Fig. 7). In 2011-2040, the three species with the smallest projected percent of baseline area remaining in refugia were Sprague's Pipit (74 ± 7%), McCown's Longspur (80 ± 13%) and Baird's Sparrow (83 ± 8%). In 2041-2070, they were Baird's Sparrow (51 ± 15%), Sprague's Pipit (54 ± 6%), and Le Conte's Sparrow (69

± 6%); by the end of the century, refugia for Baird's Sparrow and Sprague's Pipit were reduced to 11 ± 4% and 13 ± 7% of their baseline suitable climate areas, respectively.

Two of the species with consistently low areas of refugia over time are currently listed as sensitive species in Alberta: Baird's Sparrow (also listed as Special Concern Canada-wide) and Sprague's Pipit (also listed as Threatened Canada-wide; Table 1). The severe declines in projected refugia for both of these species over time were related to the projected northward shifts in the southern margin of suitable climate space in Alberta.

Projected Suitable Climate and Current Landcover in Alberta

The majority (8 of 15) of Alberta grassland songbirds were projected to experience an increase in area of suitable landcover within regions of projected suitable climate over time (Fig. 8). This pattern reflected the overall projected expansion of suitable climate area in Alberta for these species (Fig. 5; Fig. 6), and the relative correspondence between projected suitable climate space and the distribution of potentially suitable landcover (Table 1; Appendix 1), in the province.

Several species that occur in native and tame pasture but not in cropland were projected to experience declines in the area of current suitable habitat remaining in core suitable climate over time, however, including the endemic grassland species Baird's Sparrow, Sprague's Pipit and McCown's Longspur (Fig. 8A). By the end of the century, these three species were projected to have 13300 ± 5527 km^2, 6951 ± 3293 km^2 and 25028 ± 9753 km^2 of landcover currently classified as native or tame grassland or hay within their projected suitable climates by the 2080s. For McCown's Longspur, which has small baseline and projected future suitable climate areas with limited projected shifts with time, this suitable landcover area corresponded to 40% of the projected suitable climate area at the end of the century. In contrast, for Baird's Sparrow and Sprague's Pipit, this suitable landcover area corresponded to only 7% and 4% of the area of suitable climate, respectively, reflecting the northward shift in suitable climate space for both species into regions of the province dominated by unsuitable landcover, including cropland and forest (Fig. 6).

Two currently widespread, secondary grassland songbirds that typically do not occur in cropland, Le Conte's Sparrow and Clay-colored Sparrow, were also projected to experience declines in suitable habitat within their projected suitable climates as a result of northward shifts in suitable climate space into the forested regions of Alberta (Fig. 6); these northward shifts also resulted in an overall reduction in suitable climate space for these species in the province (Fig. 5, Fig. 6).

The three species that make use of cropland, in addition to native and tame grassland, had variable projected changes in suitable habitat overlap with suitable climate: Savannah Sparrow was projected to experience a decline and Horned Lark and Vesper Sparrow an increase over time (Fig. 8B.). For Savannah Sparrow, the decrease reflected the northward shift in projected suitable climate space out of the regions of Alberta that are currently grassland- and agriculture-dominated and into the forested regions in the north of the province (Fig. 6). In contrast, the increase in suitable habitat area projected for Horned Lark and Vesper Sparrow reflects the projections of persistent suitable climate in the grassland and agricultural regions of the province over time for these species (Fig. 6).

Discussion

We projected that the majority of Alberta grassland songbird species we considered would experience expansions in suitable climate space in the province over the next century. For many species, the projected future distribution of suitable climate also at least partly corresponds with broad landcover types that are currently suitable, and may remain suitable into the future, suggesting that climate-mediated range expansions in Alberta for many of these species may be possible. For others, including several species endemic to the grasslands, future suitable climate space does not correspond well with the current distribution of suitable landcover habitat in Alberta; these species may be more vulnerable to potential lags in vegetation transition in response to rapid climate change over the next century.

The potential for Alberta’s grassland songbirds to occupy projected suitable climate space in the future depends on a variety of factors. In addition to intrinsic species characteristics like site fidelity and dispersal ability, and external factors like prey availability, the rate at which vegetation in the forested parkland and boreal regions transitions to suitable grassland habitat will impact future songbird distributions. This is especially true for species that are heavily reliant on native grasslands, like Sprague’s Pipit (Davis et al. 2013). Predicting the rate and distribution of native vegetation transitions is complicated by factors like disturbance dynamics and forest succession, grass species’ dispersal abilities, and edaphic constraints.

Considering that drought tolerant grasses already exist in small patches and on drier, south-facing slopes in the Central Parkland (Schneider 2013, NRC 2006), vegetation models that combine future climate projections with disturbance estimates suggest that native grassland ecosystems have the potential to move into much of the Parkland Region in Alberta by mid-century (Schneider 2009). However, land use in the Central Parkland of Alberta is largely agricultural (Fig. 2), with existing vegetation communities increasingly dominated by non-native and invasive and grasses (Government of Alberta 2013). Given the persistence of these non-native species (e.g., Christian and Wilson 1999), opportunities for native grassland expansion in this region may be limited. Expansion of native grassland vegetation further north into the boreal region over a longer time-frame (e.g., end-of-century) may be supported by scattered grasslands along the Peace River lowlands in the northwest of the province (Schneider 2013). However, expansion of native grassland communities may be limited by the relative absence of dry-adapted grasses throughout the region more broadly, and again by competition with non-native grasses that have been seeded along roadsides and in other disturbed areas (Schneider 2013, Sumners and Archibold 2007).

The warming and drying that is predicted to push grassland climates and associated vegetation into Alberta’s parkland region will also drive native grassland plant communities from the Great Plains of the United States into Alberta (Schneider 2013, Thorpe 2011). Predicted changes in native grassland composition and structure, including a transition from mid- to short-grasses and potential changes in productivity (Thorpe 2011, Sauchyn and Karushetha 2008) may differentially alter native habitat suitability for songbird species; for example, habitat suitability may decline for species like Sprague’s Pipit that prefers taller and denser vegetation cover than species like McCown’s Longspur or Grasshopper Sparrow (Davis et al. 2014, COSEWIC 2010, With 2010, Dechant et al. 2002), for which habitat suitability might improve.

For the majority of Alberta’s grassland songbirds, which occupy tame pasture and hay or cropland in addition to native grasslands, the future availability of suitable landcover will also depend on changes in agricultural landuse in response to climate change. This includes potential transitions from crop cultivation to permanent cover in the current agricultural region and potential expansion of agriculture further into the Boreal region of the province (Thorpe 2011). Importantly, any future expansion of tame pasture landcover may not provide the same value for grassland songbirds as would preservation or expansion of native grassland habitat, as nest success of several species, including Chestnut-collared Longspur and Baird’s Sparrow, appears to be reduced in tame compared to native pasture (COSEWIC 2012, Lloyd and Martin 2005, Dale et al. 1997).

Given the complexity and uncertainty associated with projecting in detail the rate and distribution of vegetation transitions and land use that could generate suitable habitat for grassland songbirds in Alberta, climate-change refugia - areas of relative stability with respect to a species’ climate niche requirements – may be particularly important for species persistence in Alberta as climate change progresses. Our model projections suggest that more than half of the currently suitable climate space for the majority of grassland songbirds in Alberta will remain suitable over the next century. Species with the greatest projected proportional areas maintained in refugia over time in the province (e.g., Horned Lark, Lark Sparrow) were those whose current range extends far to the south. In the absence of human land use change (e.g., from native grassland to agriculture, or changes in grazing practices or intensity), these climate-change refugia are also likely to maintain relatively stable vegetation communities (Ashcroft 2010); as such, they may have the greatest potential to retain core populations of grassland songbirds, especially grassland specialists, in Alberta as climate changes.

For two species of concern nationally and provincially, Sprague's Pipit and Baird's Sparrow, our models projected large shifts in the distribution of suitable climate space in Alberta in the future, with only small core areas remaining as climate refugia. As species of concern with small population sizes, these species are among the least capable of expanding into new areas as they become suitable. Further, the more specific habitat requirements of these species and the limited projected overlap of future suitable climate space with grassland landcover also suggests that the future distributions of these species will rely heavily on the successful transition of first parkland and then boreal vegetation to suitable native or tame grassland vegetation. To the extent that: 1) the distribution of these species is directly related to climatic conditions, through physiological tolerances or primary productivity, for example (Wiens 1974), 2) vegetation transitions lag behind climatic shifts, and 3) potential expansion of native grassland habitat is limited by agricultural development or competition with invasive species, these projected shifts in suitable climate could exacerbate recent population declines in these species (COSEWIC 2012, COSEWIC 2010, COSEWIC 2009).

In contrast, for many like Grasshopper Sparrow, Lark Sparrow, and Lark Bunting, we projected expansions in suitable climate space in Alberta that coincides, at least in part, with areas of potentially suitable landcover (e.g., native and tame pasture and hay). Many of these grassland bird species with projected expansions, however, are currently represented in Alberta by populations at the northern fringe of their ranges, where populations may not be as robust as in the core of their ranges, and therefore potentially less able to expand into newly available suitable climate. Further, observed declines in grassland bird populations across North America and in Alberta (Sauer et al. 2011, Table 1) linked to intensification of agricultural practices and land use (National Audubon Society 2014; Askins 2007), suggests that their current habitats may not be saturated, possibly affecting the capacity of these species to expand into new areas. Successful expansion of grassland songbirds into new regions of suitable climate and landcover in Alberta may ultimately depend on the stability of their populations across North America.

The use of bioclimatic niche models for declining species can be inappropriate if their potential climatic niches are not fully occupied for other reasons (e.g., because of land use changes that are related to the decline, or because declining or small populations have not colonized suitable areas) – violating the assumption that the species are in equilibrium with their current climatic niches (Wiens et al. 2009, Araújo and Pearson 2005). Despite our use of the broadest possible spatial (North American wide) and temporal data (over 40 years of observations) in model calibration (Araújo and Peterson 2012) our models may have been prone to omission errors that would have underestimated the suitable climate space for grassland songbirds in Alberta (Wiens et al. 2009).

While climate has been found to be an important predictor of avian distributions (Araújo and Petersen 2012), including land use and landcover variables explicitly in species distribution models can refine projections of future suitable ranges, especially if future projections of land use and landcover change are available (Sohl 2014, Barbet-Massin et al. 2012).Our models of current and future climate suitability could be refined by the inclusion of additional variables relating to landcover and land use, especially for species that show strong positive or negative associations with agricultural land use or urbanization (Stralberg et al. 2015, Sohl 2014). Consideration of these associations may clarify the idiosyncratic projections of future suitable climate area we observed for some species, such as the lack of northward expansion of suitable climate area projected for McCown’s Longspur, a species associated with pastures under heavy grazing pressure (With 2010).

This analysis represents a first step towards understanding the potential consequences of climate change for Alberta’s grassland songbirds. While uncertainty remains around the precise magnitudes and rates of change in suitable climate for these species and the transitions in vegetation and landcover that would impact the availability of suitable habitat as climate change progresses, our projections suggest that some climate-mediated range expansion of many grassland songbirds in Alberta is possible. This projected expansion may hinge, however, on the stability of grassland songbird populations across North America. Endemic grassland species with dramatic projected changes in suitable climate distribution, like Baird’s Sparrow and Sprague’s Pipit, are less likely to expand. In the context of declining grassland songbird populations across North America, this improved understanding of the potential impacts of climate change on the northward edge of their current distributions can support long-term planning and management of these species.

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Appendix 1

Table A1. Habitat use preferences for Alberta's grassland songbirds

Species	Habitat[1]	Rationale
Baird's Sparrow (*Ammodramus bairdii*)	G	• Native mixed-grass and fescue prairie habitat (Green et al. 2002) • Occupies seeded pasture and hay (McMaster and Davis 2001; Davis and Duncan 1999; Davis et al 1999) • Breeding success can be poor in non-native habitats, but more tolerant of agriculture than other grassland obligates (COSEWIC 2012) • Not observed breeding in cropland (Martin and Forsyth 2003).
Bobolink (*Dolichonyx oryzivorus*)	G	• Tall-grass or mixed-grass prairie habitat (COSEWIC 2010a; Martin and Thomas 1995) • Not abundant in row crops; transition from forage crops to row crops is a contributing factor to decline (COSEWIC 2010a).
Brewer's Sparrow (*Spizella breweri*)	G*	• Grassland/shrubland habitat, especially with big sagebrush (Walker 2004; Rotenberry et al. 1999) • Typically not observed in cropland or other agricultural habitat (Rotenberry et al 1999)
Chestnut-collared Longspur (*Calcarius ornatus*)	G	• Short-grass and mixed-grass prairie habitat (Hill and Gould 1997; COSEWIC 2009) • Some preference for native over seeded pasture (Davis and Duncan 1999), but occurs in both (Lloyd and Martin 2005) • Does not typically nest in cultivated fields (Martin and Forsyth 2003; Owens and Myres 1973)
Clay-colored Sparrow (*Spizella pallida*)	G	• Use both native and tame pastures for nesting (Grant and Knapton 2012; Dechant et al. 2002a; Davis and Duncan 1999) • Cropland not used for breeding (Dechant et al. 2002a), and occurrence in cropland is lower than pasture (McMaster and Davis 2001).
Grasshopper Sparrow (*Ammodramus savannarum*)	G	• Moderately open grassland habitat (Vickery 1996) • Native and tame pastures used (Dechant et al. 2003) • Occasionally occupy cropland, but at very low density (Dechant et al. 2003; McMaster and Davis 2001).
Horned Lark (*Eremophila alpestris*)	G/C	• Common and widespread in open habitats, especially with some bare ground and short grasses (Beason 1995) • Frequently occupy cropland habitats (Dinkins et al. 2002; McMaster and Davis 2001; Owens and Myres 1973)
Lark Bunting (*Calamospiza melanocorys*)	G	• Grassland and shrub-steppe habitat (Shane 2000) • Breeds in native and tame pastures and cultivated hayfields (Dechant et al. 2002c) • Occasional use of cropland, but more common in tame pasture (Dechant et al. 2002c)
Lark Sparrow (*Chondestes grammacus*)	G	• Structurally open habitats including native and tame vegetation (Dechant et al. 2003a; Martin and Parrish 2000). • Preference for ecotones between grassland and shrub or forested habitats (Martin and Parrish 2000). • Some use of cropland, but mainly precluded by lack of woody vegetation (Dechant et al. 2003a; Martin and Parrish 2000)
Le Conte's Sparrow (*Ammodramus leconteii*)	G	• Open uplands and lowlands, including prairie and aspen parkland (Lowther 2005) • Nest in hayland, tame pasture and native vegetation (Dechant et al. 2003b) • Generally not detected in cropland (Dechant et al. 2003b)

McCown's Longspur (*Rhynchophanes mccownii*)	G	• Short-grass and mixed-grass prairie (With 2010) • Native and tame pastures used (Dechant et al. 2002d) • Some use of cropland has appeared since the 1990s with low productivity (Martin and Forsyth 2003; McMaster and Davis 2001), but may be an ecological trap (COSEWIC 2006)
Savannah Sparrow (*Passerculus sandwichnesis*)	G/C	• Uses a variety of tame pasture and native grassland habitats (Wheelwright and Rising 2008) • Successfully breeds in cropland (Martin and Forsyth 2003)
Sprague's Pipit (*Anthus spragueii*)	G**	• Associated with grazed native mixed-grass prairie in good condition (Davis et al. 2014) • Occurs and nests in tame pasture, but in lower numbers compared to native grassland (Davis et al. 2014; COSEWIC 2010b) • Rarely recorded in cropland (Davis et al. 2014)
Vesper Sparrow (*Pooecetes gramineus*)	G/C	• Occupies a broad range of grassland habitat types, including native and tame pasture and cultivated cropland (Jones and Cornely 2002; McMaster and Davis 2001; Davis and Duncan 1999)
Western Meadowlark (*Sturnella neglecta*)	G	• Open grasslands, prairies, meadows, some agricultural fields; Most common in native grasslands and perennial grassland cover (Davis and Lanyon 2008) • Uncommon in cropland (McMaster and Davis 2001; Owens and Myres 1973)

[1] Habitat: Native and tame grassland/pasture and hay (G); Annual cropland (C).

*Brewer's Sparrow primarily utilizes native shrubsteppe habitats dominated by big sagebrush (*Artemisia tridentata*). We include it in in our analysis because of occurrence records from the Dry Mixedgrass region of southeastern Alberta (ABMI 2014). It is classified as a grassland species here due to its absence from cropland habitat (Rotenberry et al. 1999).

**Sprague's Pipit is very closely tied to native grassland habitats in particular (Davis et al. 2014).

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Appendix 2

Table A2. Reclassification table for converting Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory[1] landcover classifications into two landcover types for Alberta: Cropland, and Native and Tame Grassland/Hay

AAFC Annual Crop Inventory Raster Attributes	AAFC Annual Crop Inventory Raster Codes	Reclassified Raster Attributes	Reclassified Codes
Agriculture (generalized), Too Wet to be Seeded, Fallow, Cereals, Barley, Other Cereals, Millet, Oats, Rye, Spelt, Triticale, Wheat, Switchgrass, Winter Wheat, Spring Wheat, Corn, Tobacco, Ginseng, Oilseeds, Borage, Camelina, Canola/Rapeseed, Flaxseed, Mustard, Safflower, Sunflowers, Soybeans, Pulses, Peas, Beans, Lentils, Vegetables, Potatoes, Sugarbeets, Other Vegetables, Sod, Herbs, Buckwheat, Canaryseeds, Hemp, Vetch, Other Crops	120, 121, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 160, 162, 167, 174, 175, 177, 178, 179, 192, 193, 194, 195, 196, 197, 198, 199	Cropland (row crops, low crops, not including orchards, vine crops)	1
Pasture/Forages	110, 122	Native and Tame Grassland/Hay	2
Cloud, Water, Exposed LandBaren, Urban/Developed, Greenhouses, Shrubland, Wetland, Fruits, Berries, Orchards, Other Fruits, Vineyards, Hops, Nursery, Forest, Coniferous, Broadleaf, Mixedwood	10, 20, 30, 34, 36, 50, 80, 180, 181, 188, 189, 190, 191, 194, 200, 210, 220, 230	No Data	NA

[1] AAFC (Agriculture and Agri-Food Canada). 2013. AAFC Annual Crop Inventory. Government of Canada, Ottawa, ON, http://www.data.gc.ca.

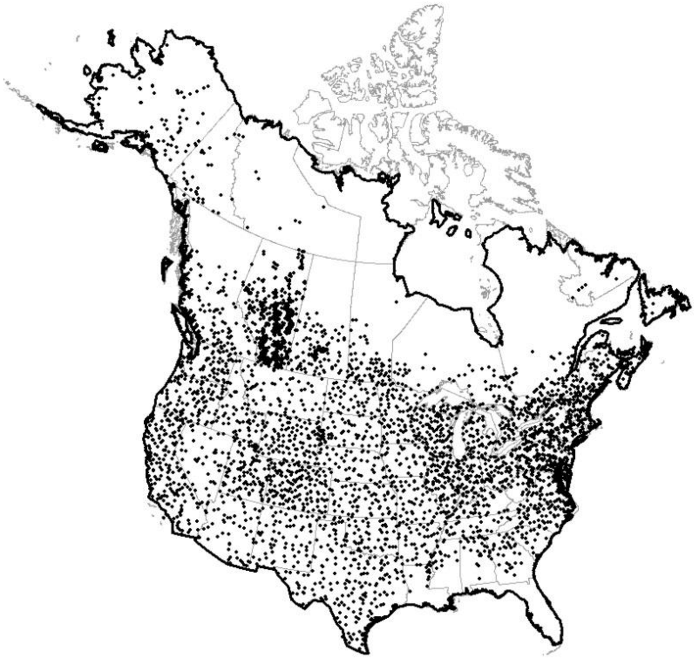


Figure 1. Study extent (heavy outline) and distribution of background points used to model climate suitability of grassland songbirds in North America.

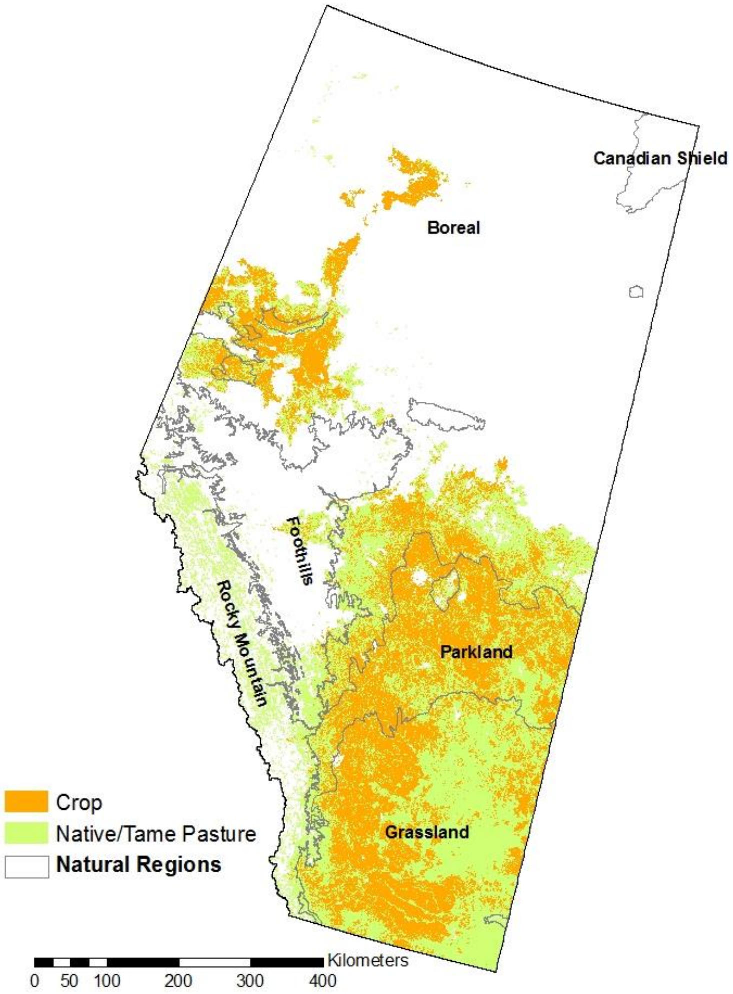


Figure 2. Distribution of crop and native/tame pasture landcover in Alberta's Natural Regions (AAFC 2013, NRC 2006).

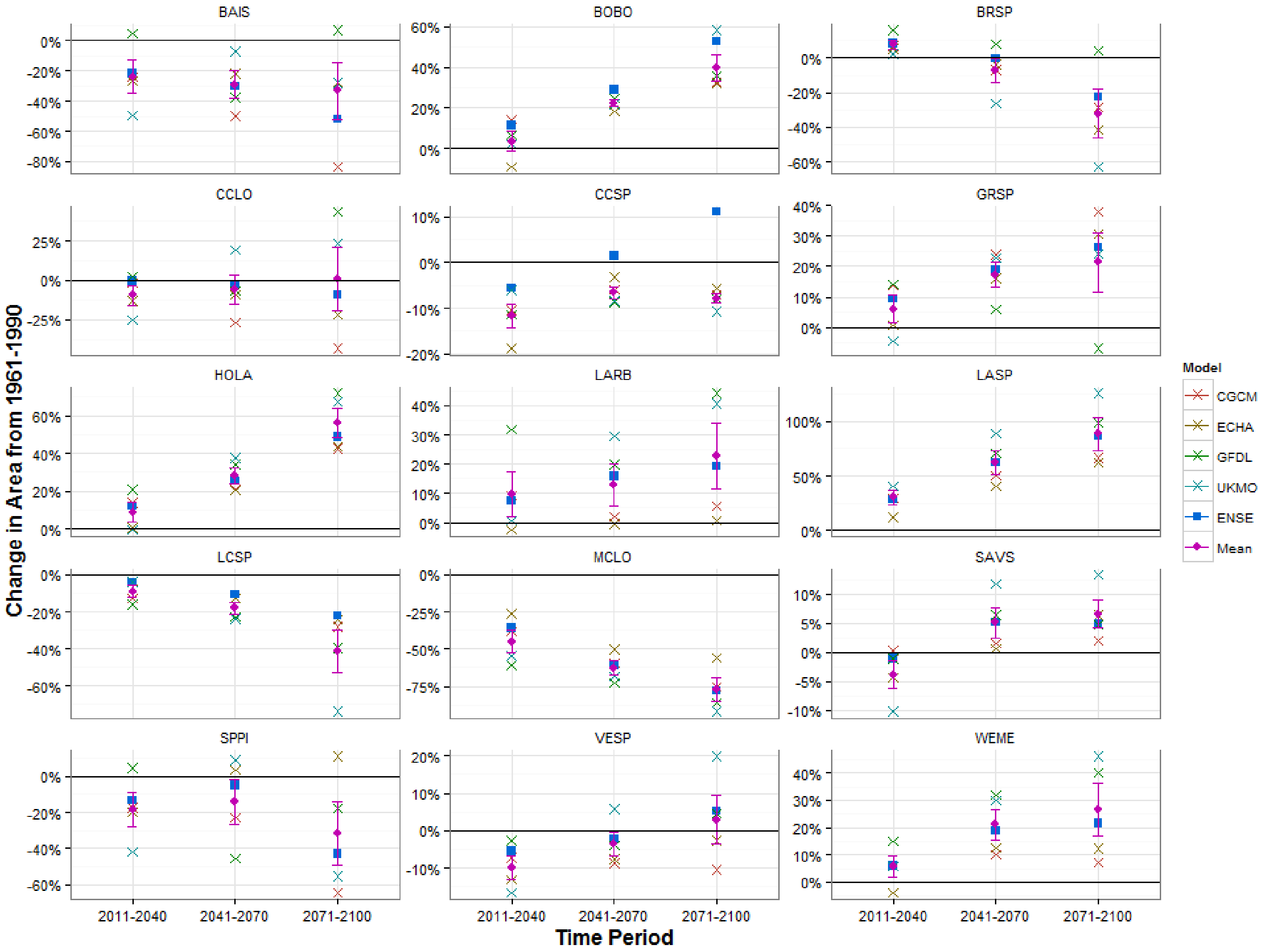
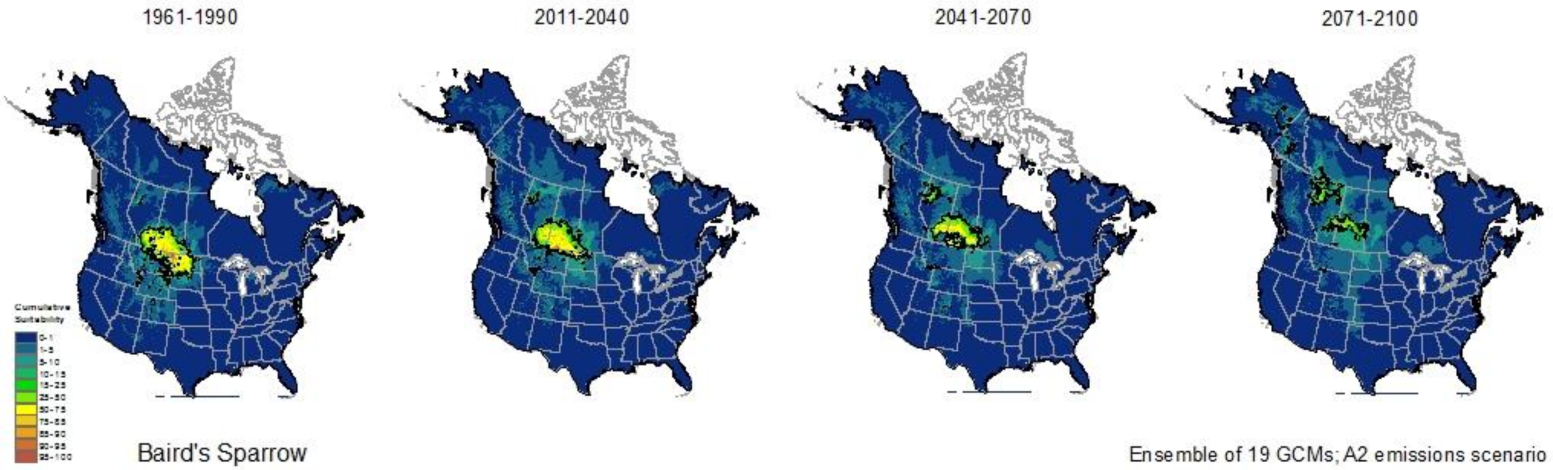


Figure 3. Projected change in core suitable climate area in North America from the historical baseline (1961-1990) for three future time periods. The mean change (± SE; pink circles) is determined from the four unique GCMs (CCCMA CGCM3.1; MPI ECHAM5/MPI-OM; GFDL CM2.1 ; UKMO-HadGEM1; crosses). Changes in areas projected by the ensemble climate data (ENSE; blue squares) correspond to the maps in Figure 4.



1961-1990

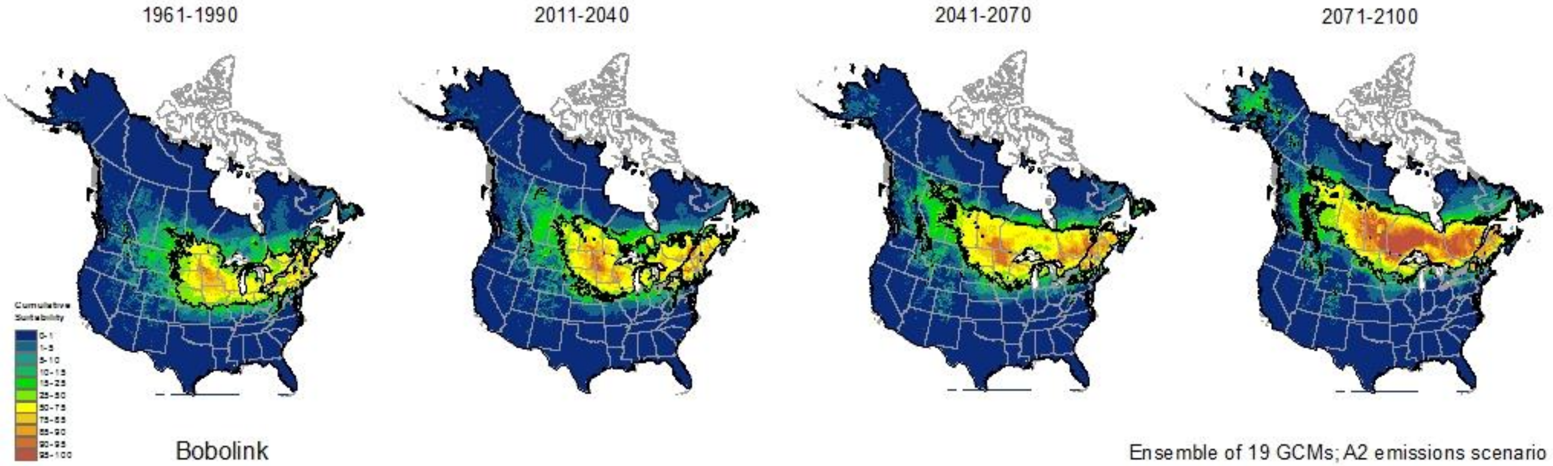
2011-2040

2041-2070

2071-2100

Baird's Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



1961-1990

2011-2040

2041-2070

2071-2100

Bobolink

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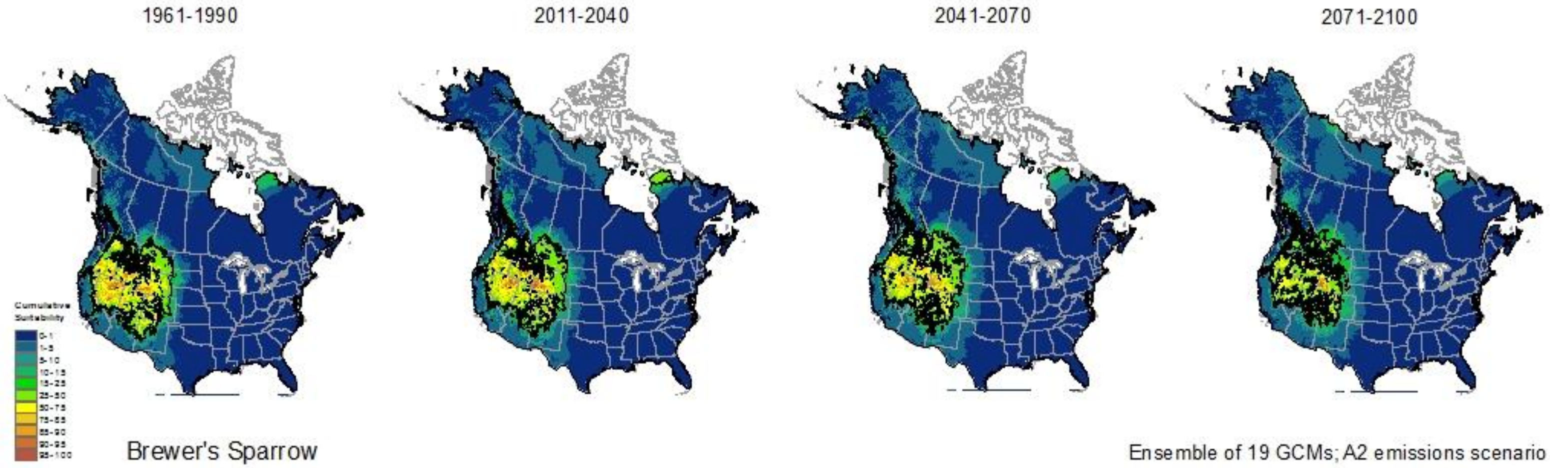

Brewer's Sparrow

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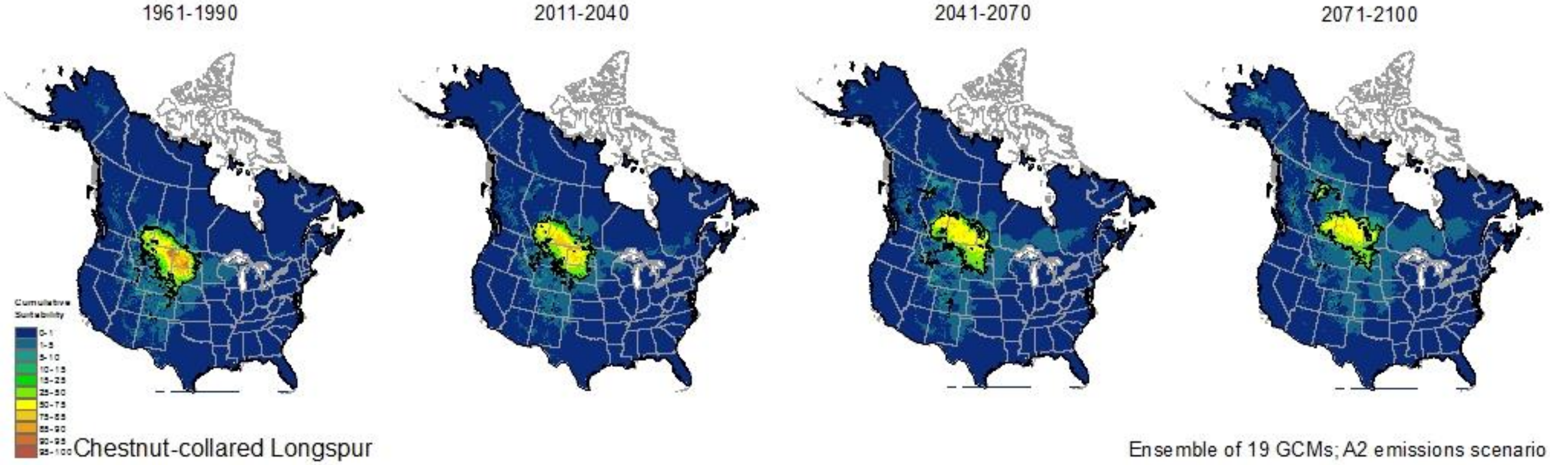
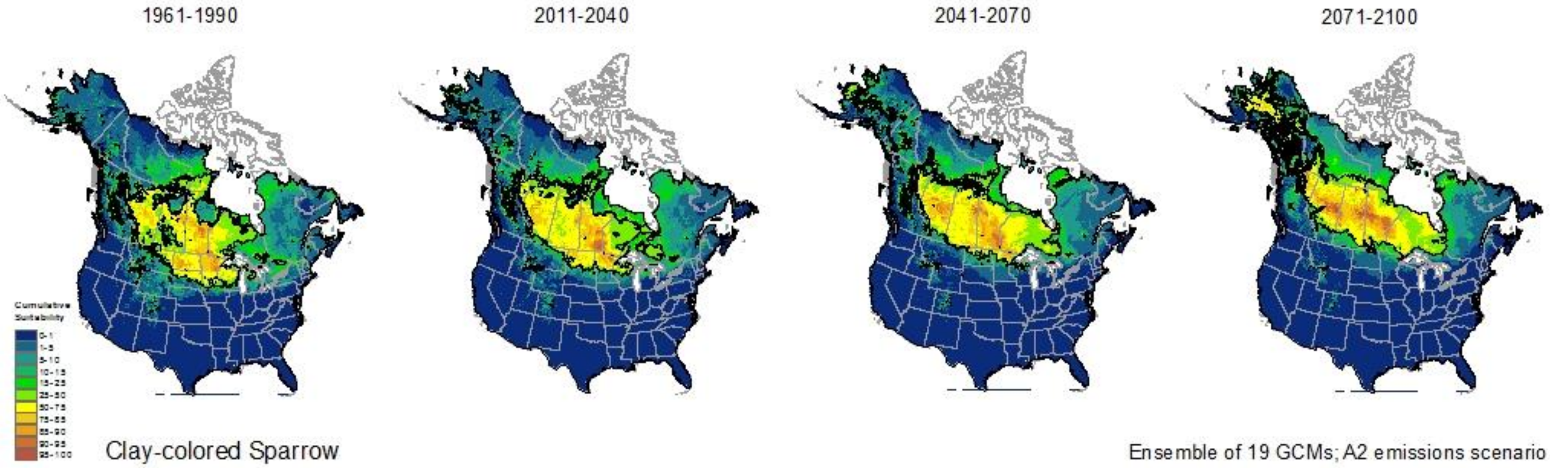


Chestnut-collared Longspur

Ensemble of 19 GCMs; A2 emissions scenario



Clay-colored Sparrow

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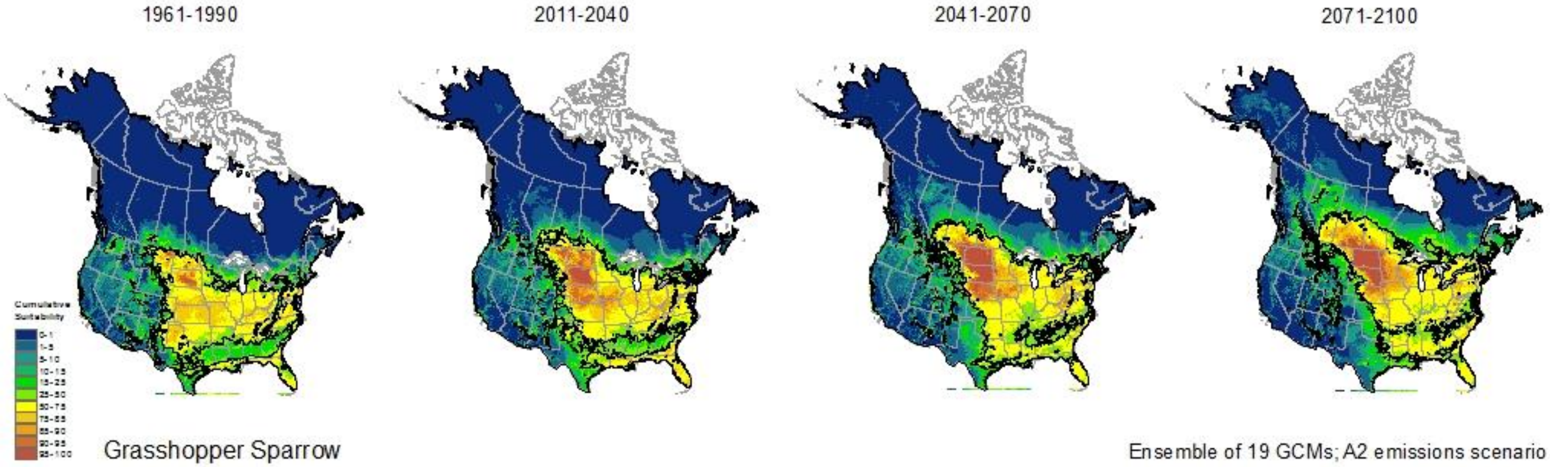
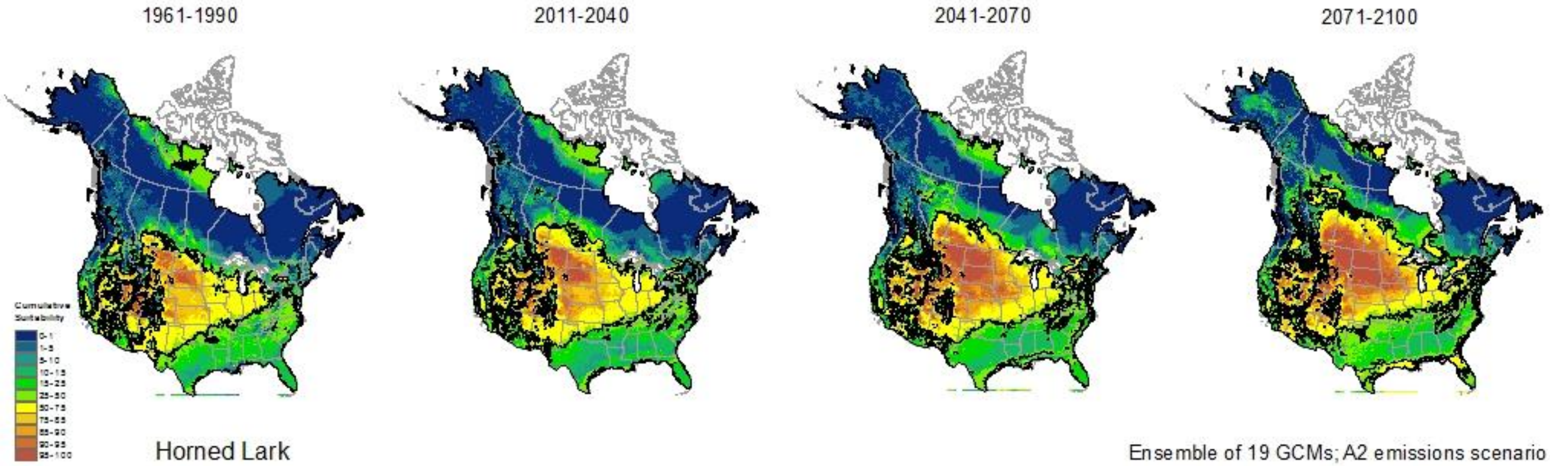


Grasshopper Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



Horned Lark

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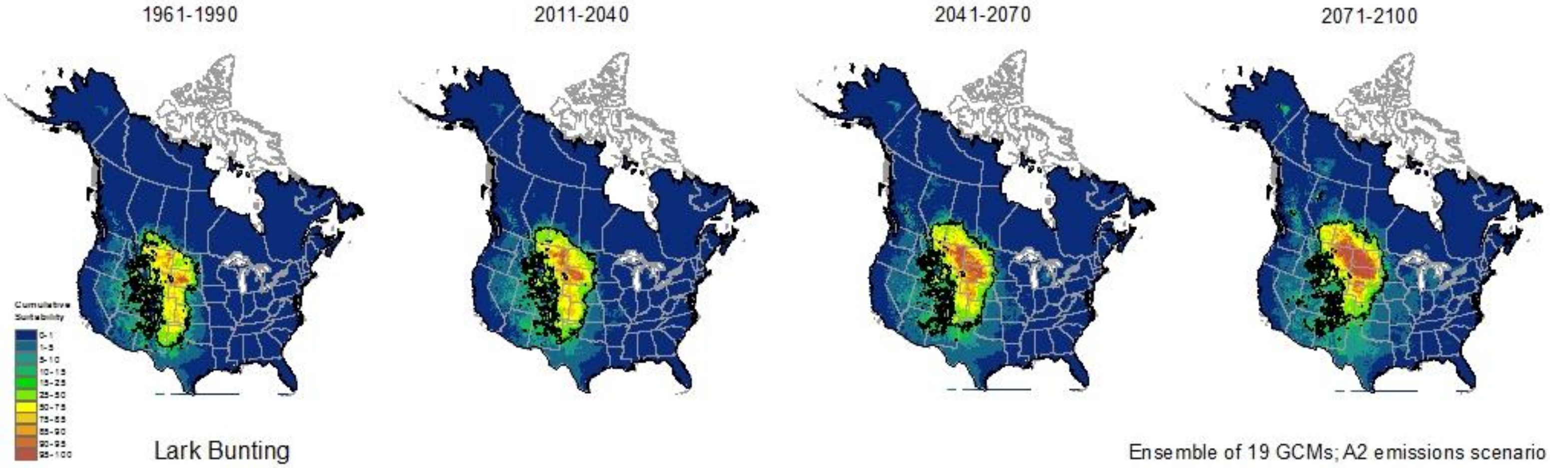
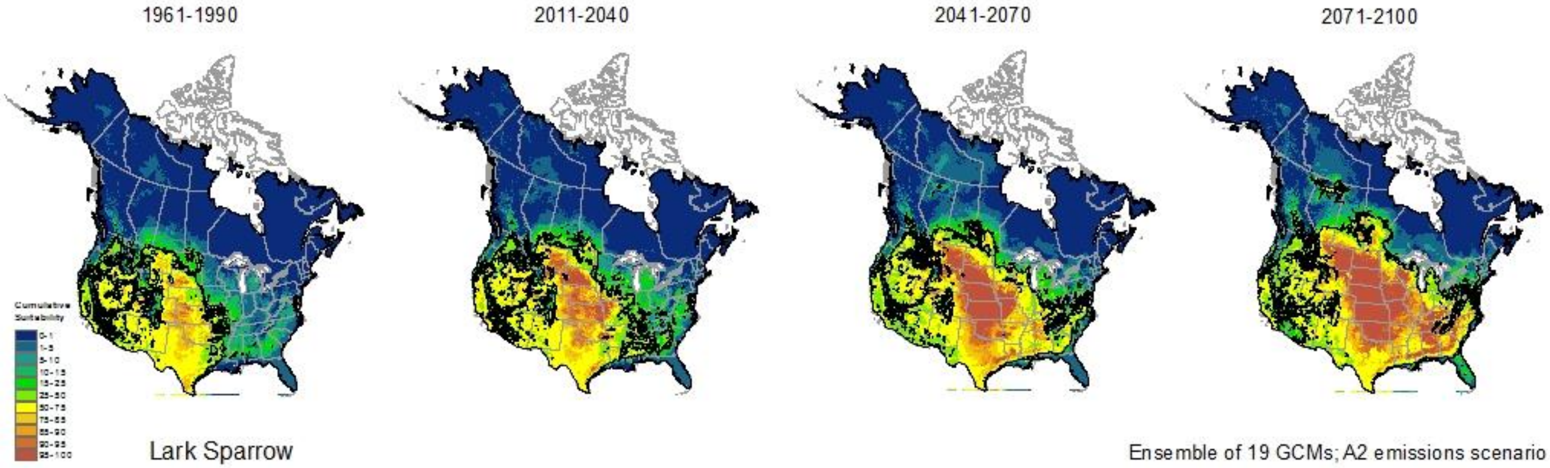


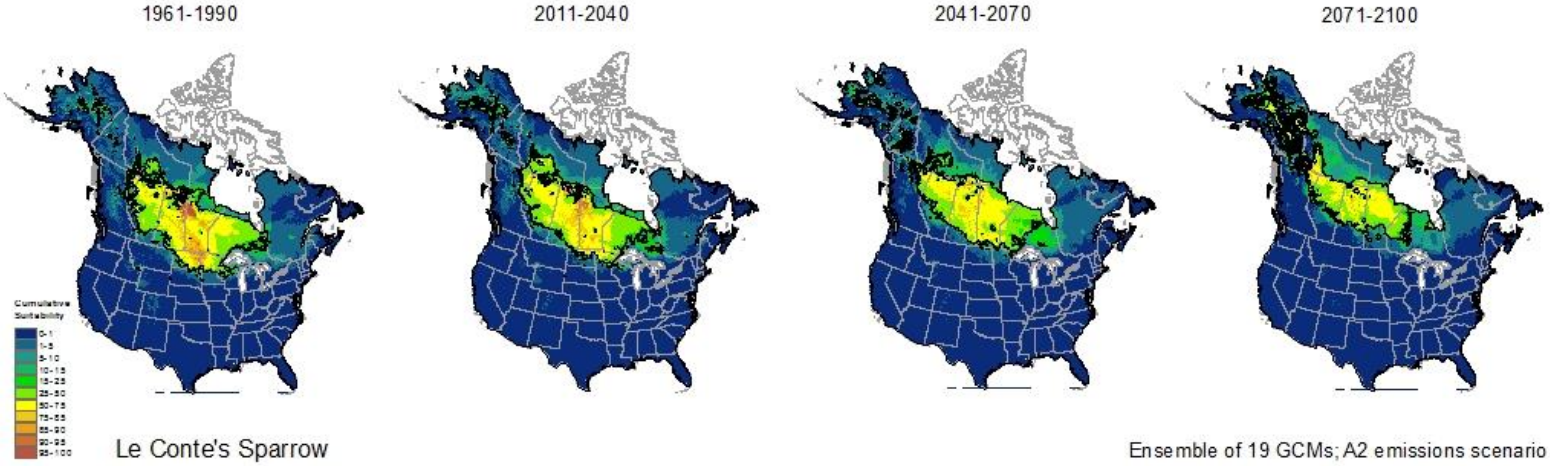
Lark Bunting

Ensemble of 19 GCMs; A2 emissions scenario



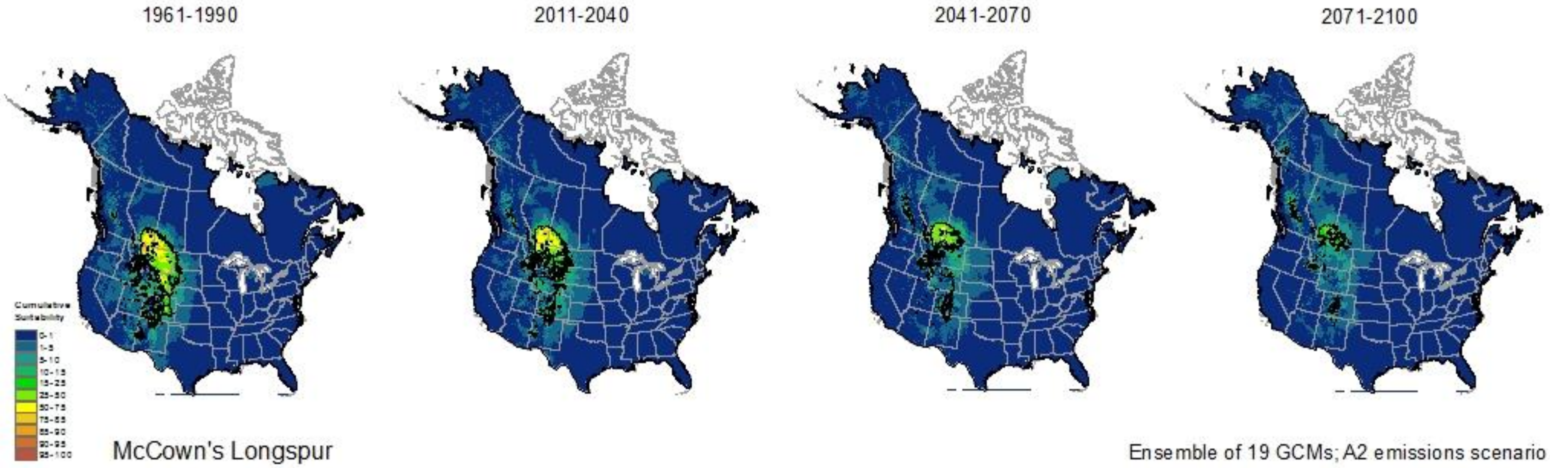
Lark Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



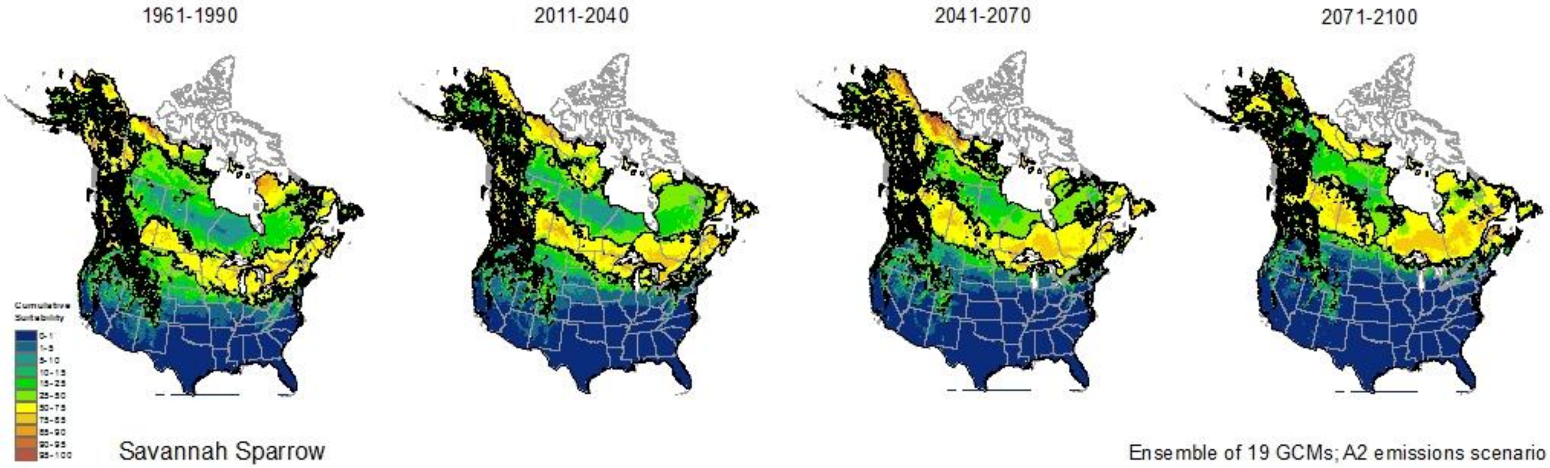
Le Conte's Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



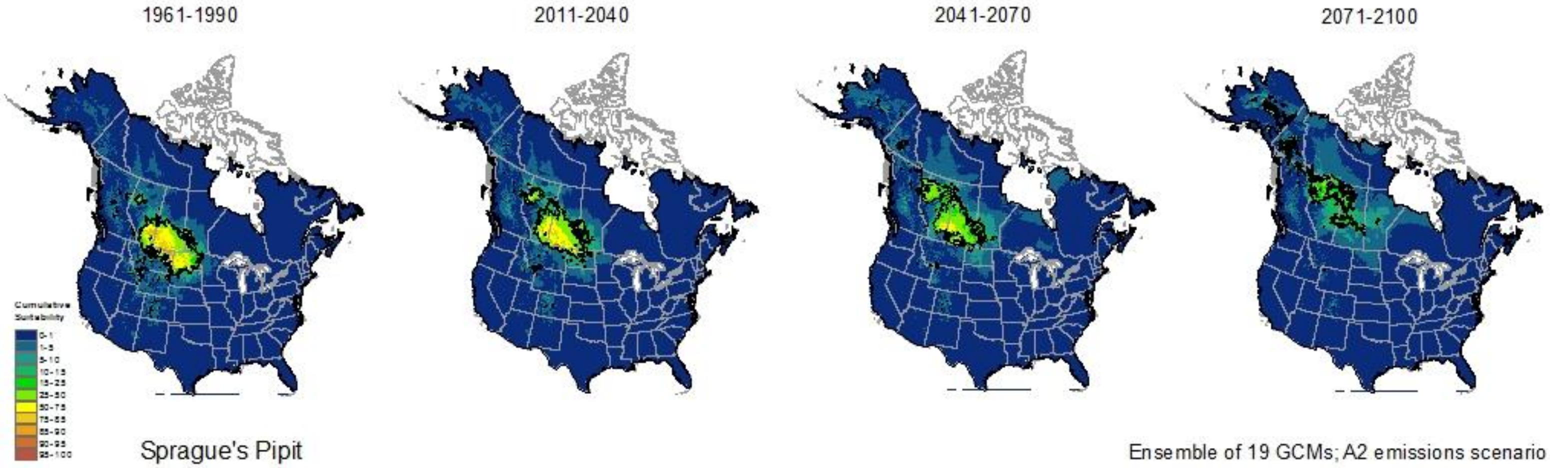
McCown's Longspur

Ensemble of 19 GCMs; A2 emissions scenario



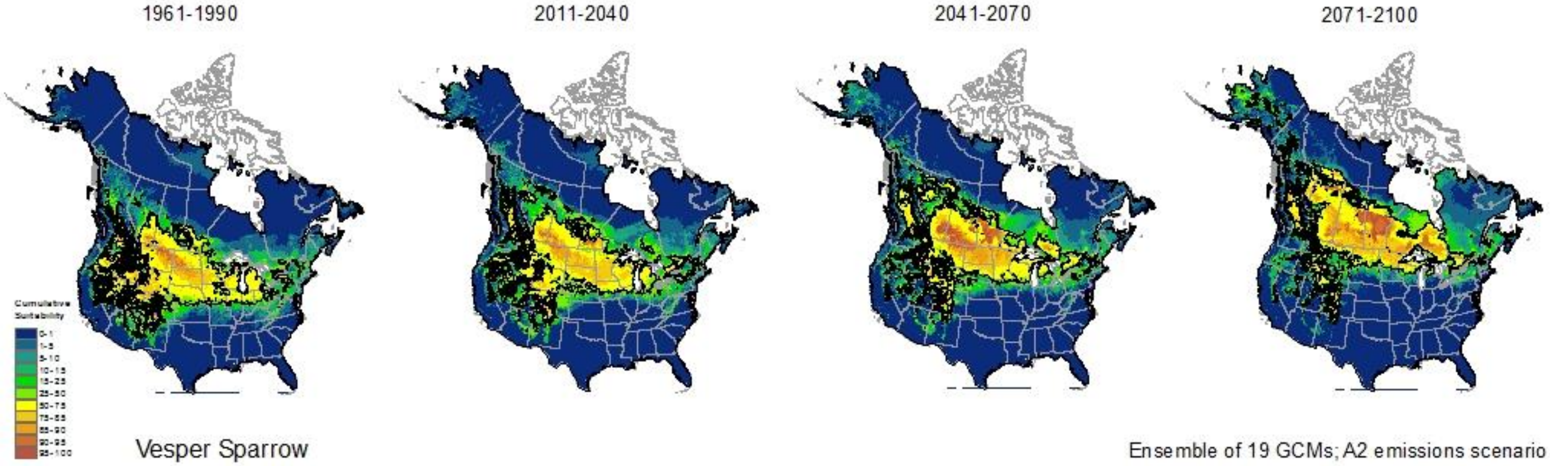
Savannah Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



Sprague's Pipit

Ensemble of 19 GCMs; A2 emissions scenario



Vesper Sparrow

Ensemble of 19 GCMs; A2 emissions scenario

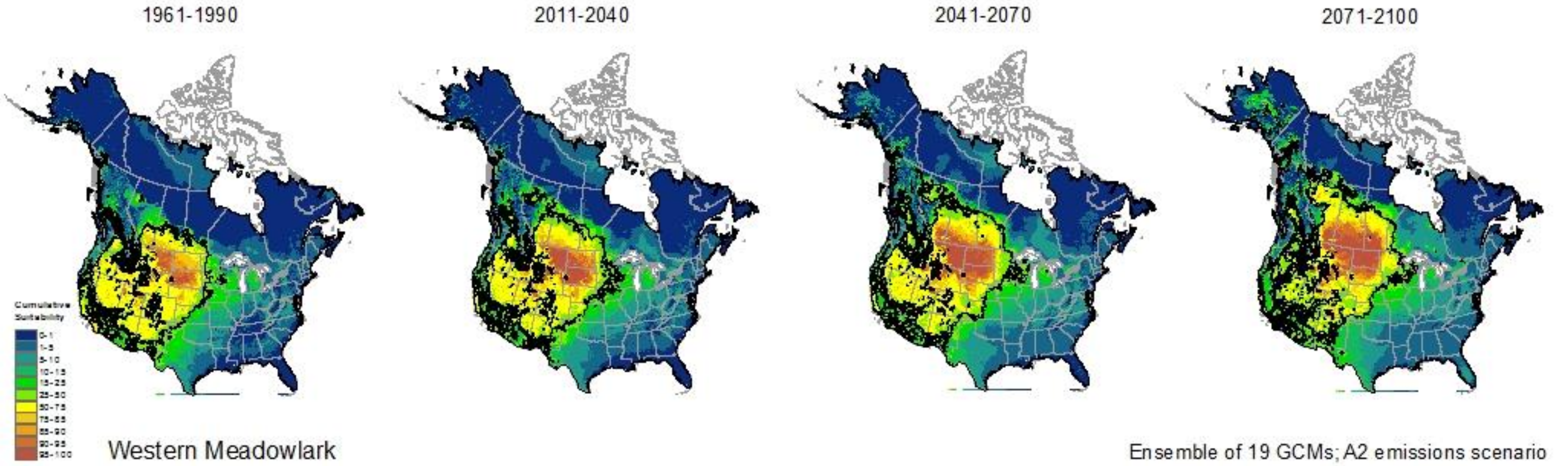


Figure 4. Baseline predictions (1961-1990) and future projections (2011-2040, 2041-2070, and 2071-2100) of climate suitability for 15 grassland songbirds in North America. The outlined areas represent core suitable climate area as determined by species-specific thresholds balancing model sensitivity and specificity. Future projections are based on an ensemble of 19 GCMs and the A2 SRES emissions scenario.

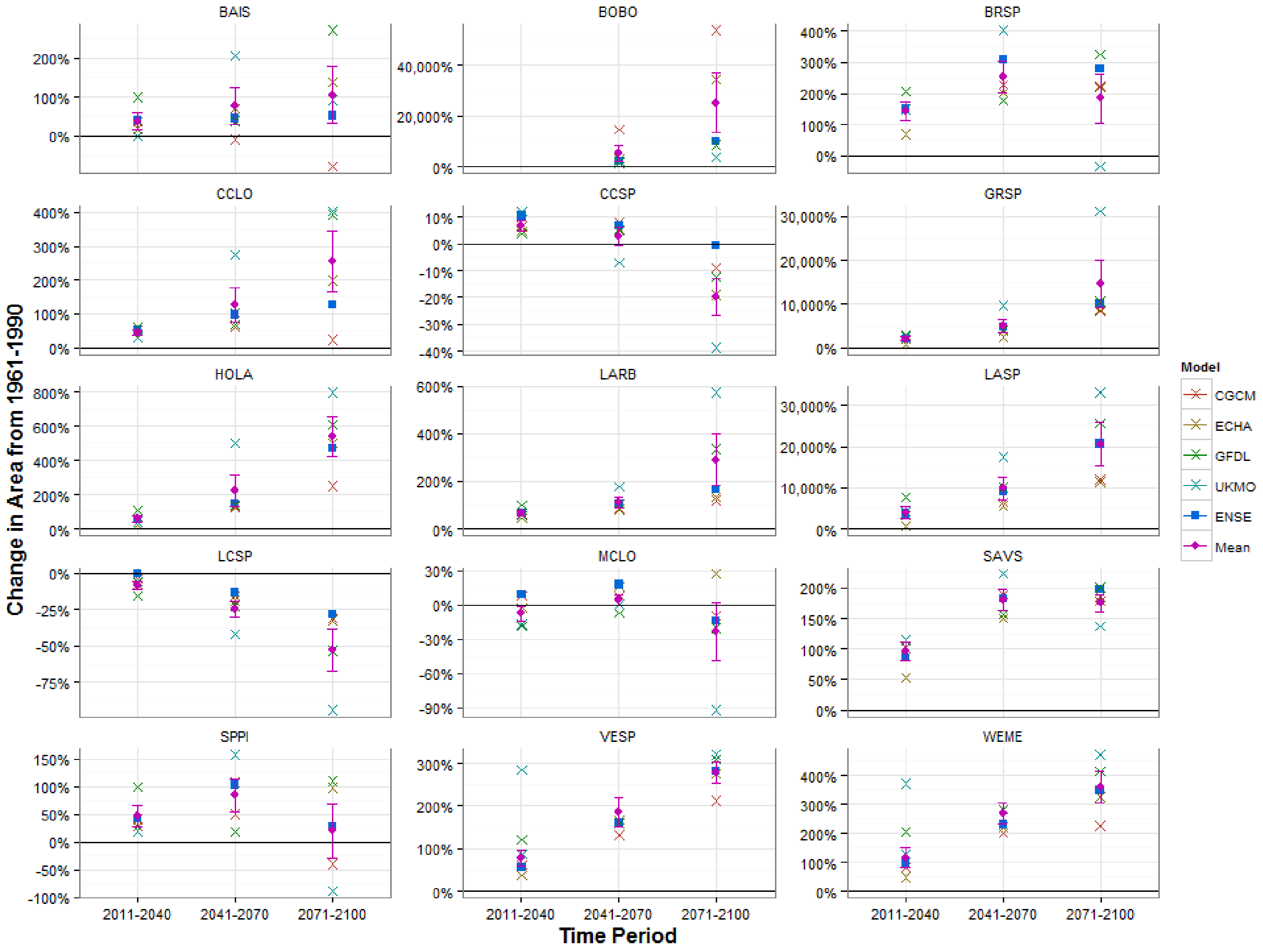
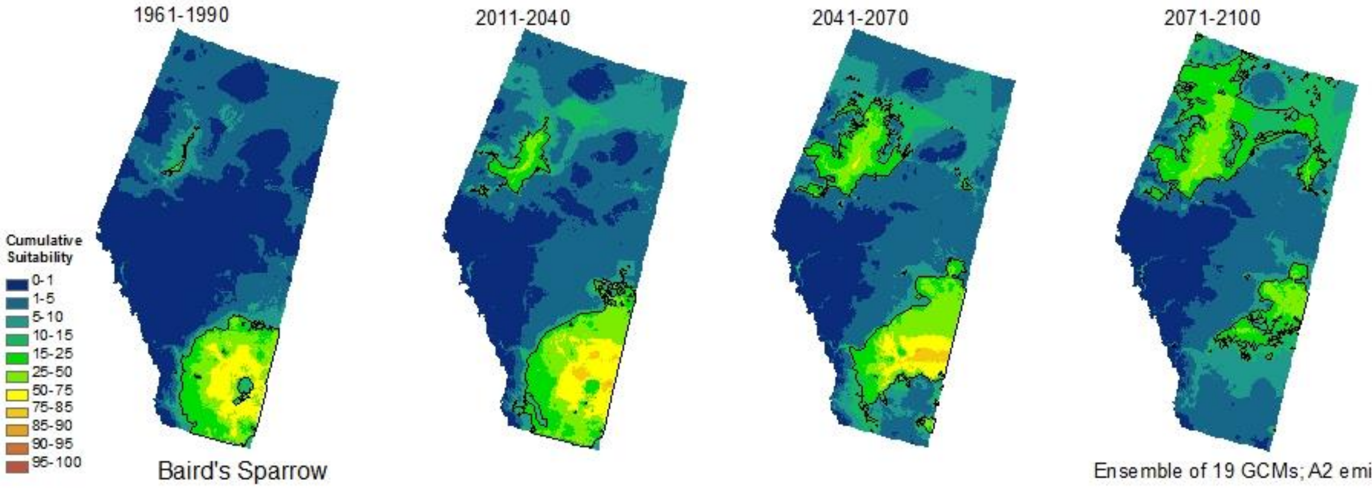
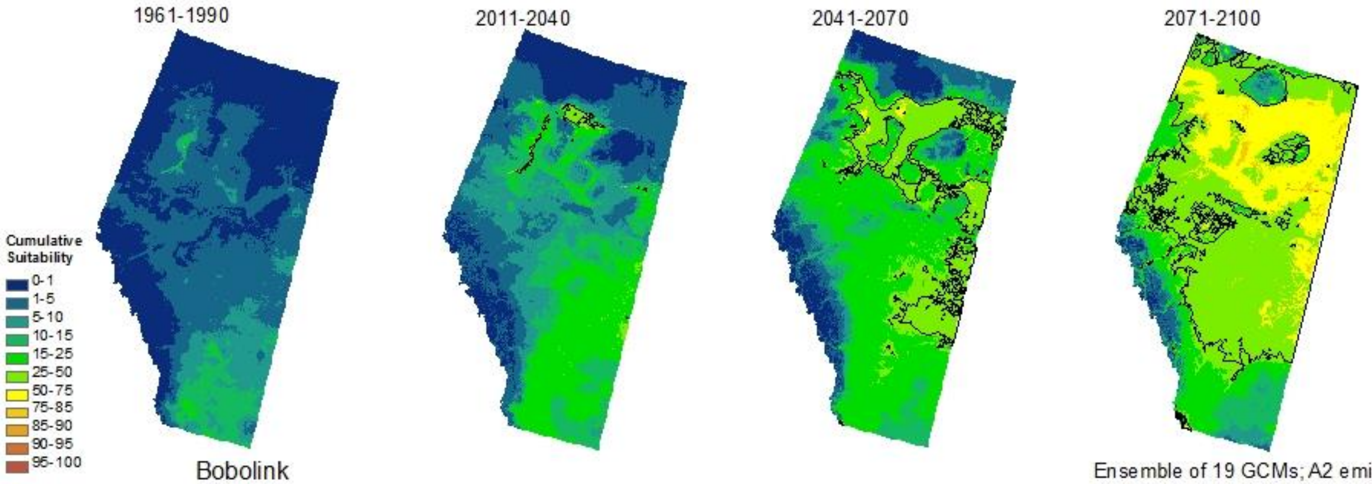


Figure 5. Projected change in core suitable climate area in Alberta from the historical baseline (1961-1990) for three future time periods. The mean change (± SE; pink circles) is determined from the four unique GCMs (CCCMA CGCM3.1; MPI ECHAM5/MPI-OM; GFDL CM2.1 ; UKMO-HadGEM1; crosses). Changes in areas projected by the ensemble climate data (ENSE; blue squares) correspond to the maps in Figure 6. Note that Bobolink (BOBO) had no predicted suitable climate area in Alberta in the historical baseline period; changes in suitable climate for that species are relative to the 2011-2040 projections



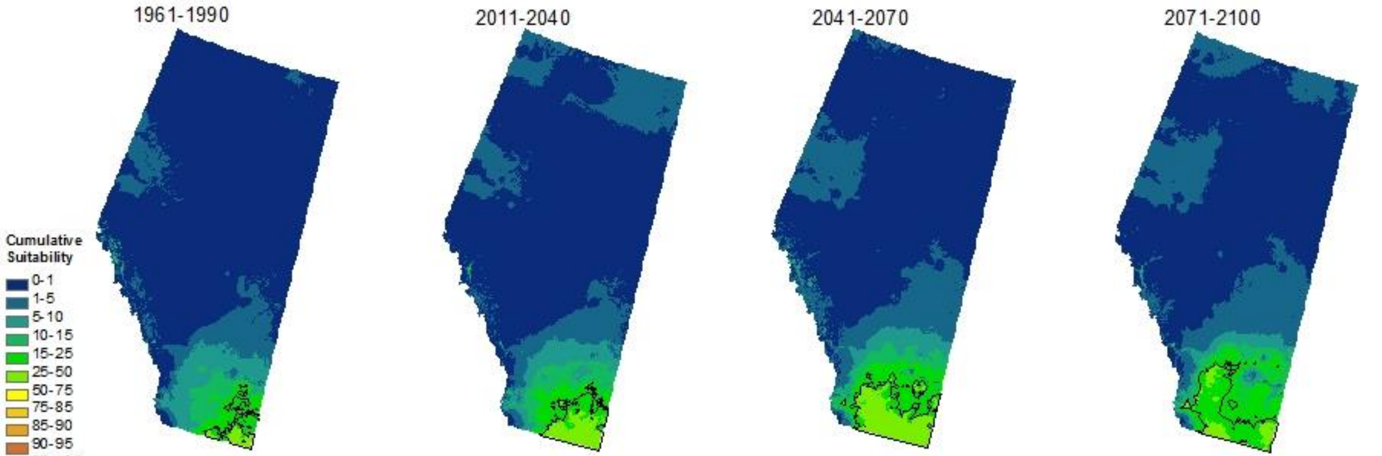
Baird's Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



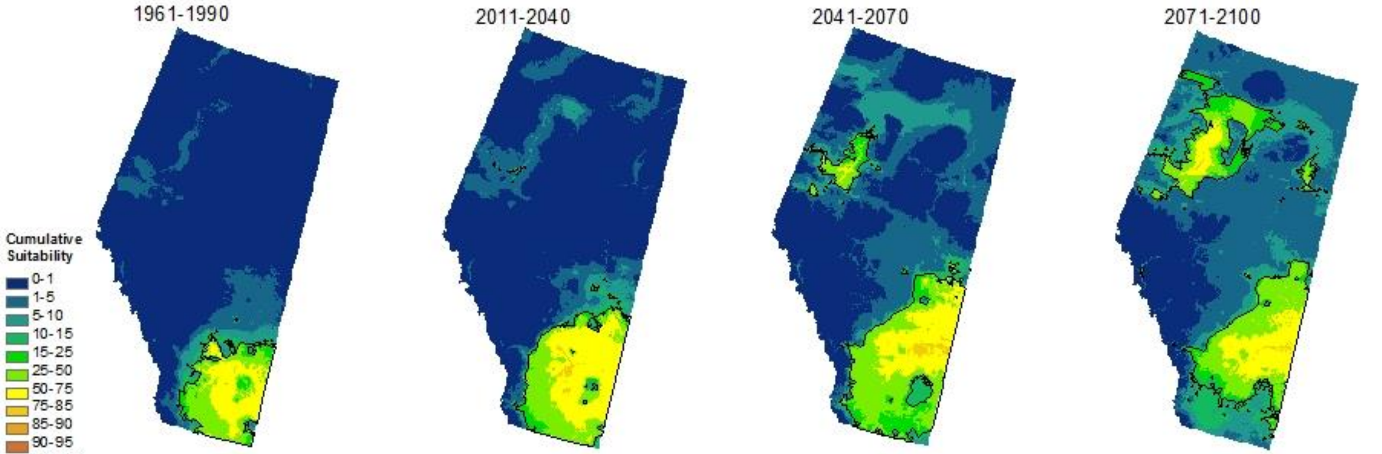
Bobolink

Ensemble of 19 GCMs; A2 emissions scenario



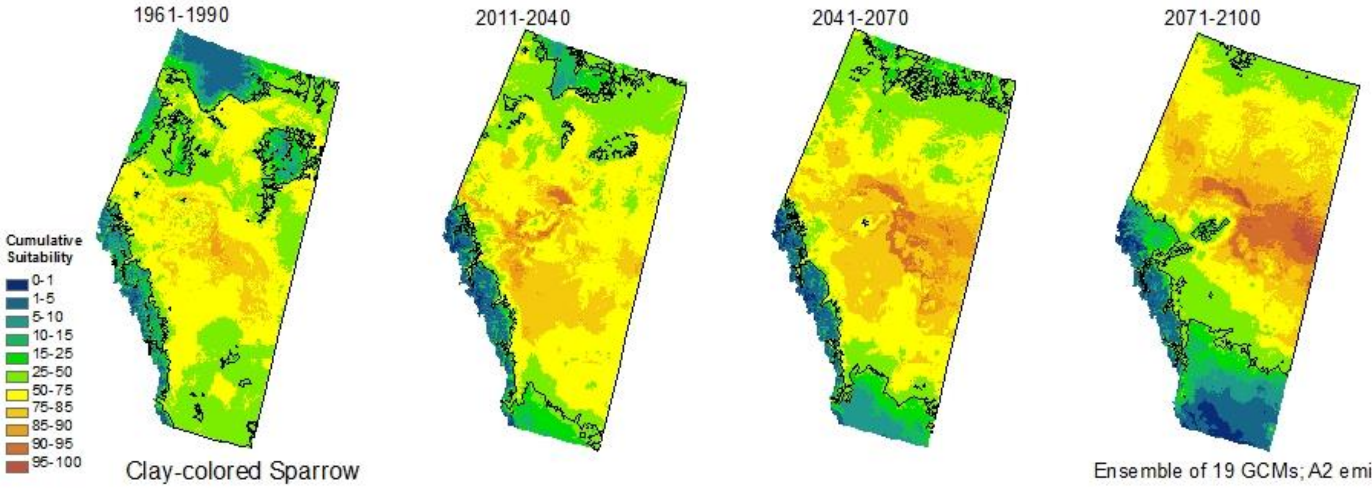
Brewer's Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



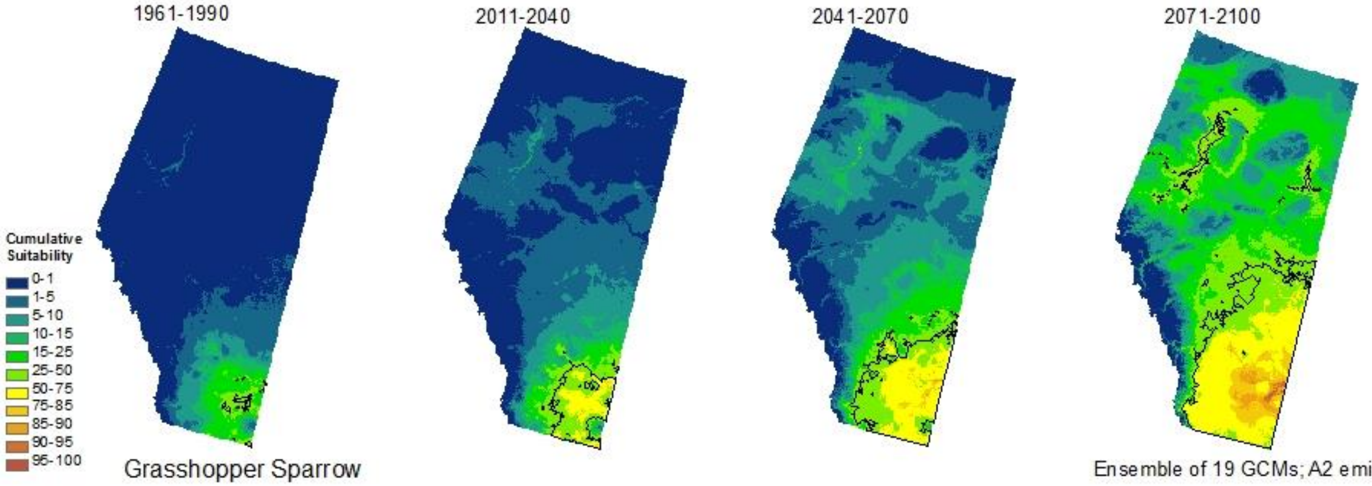
Chestnut-collared Longspur

Ensemble of 19 GCMs; A2 emissions scenario



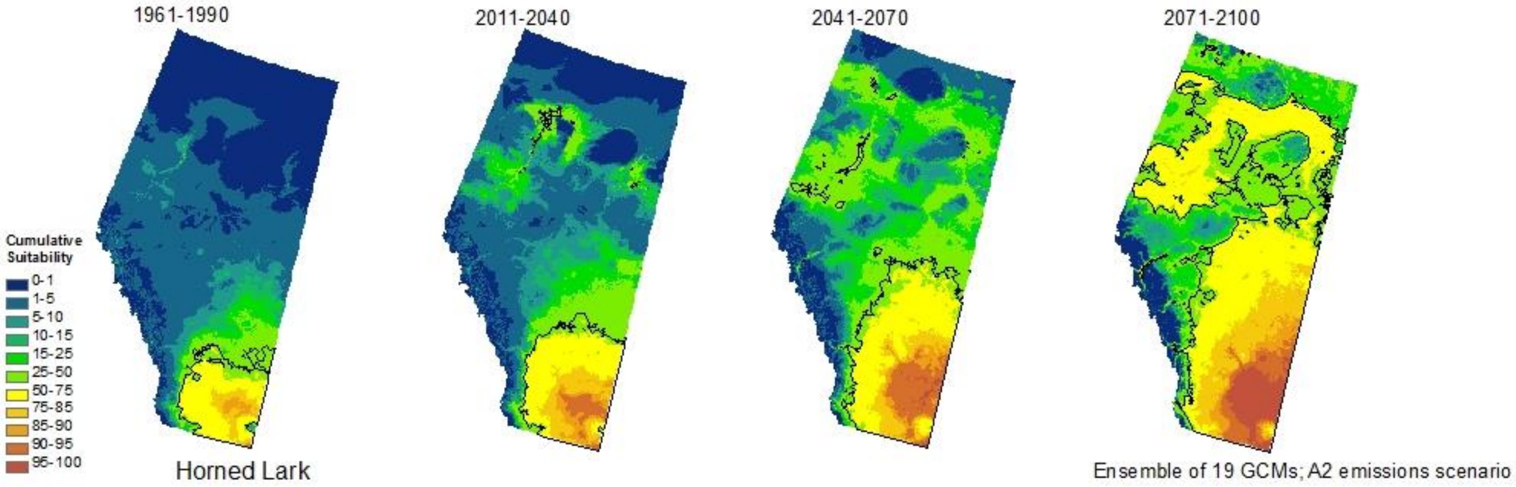
Clay-colored Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



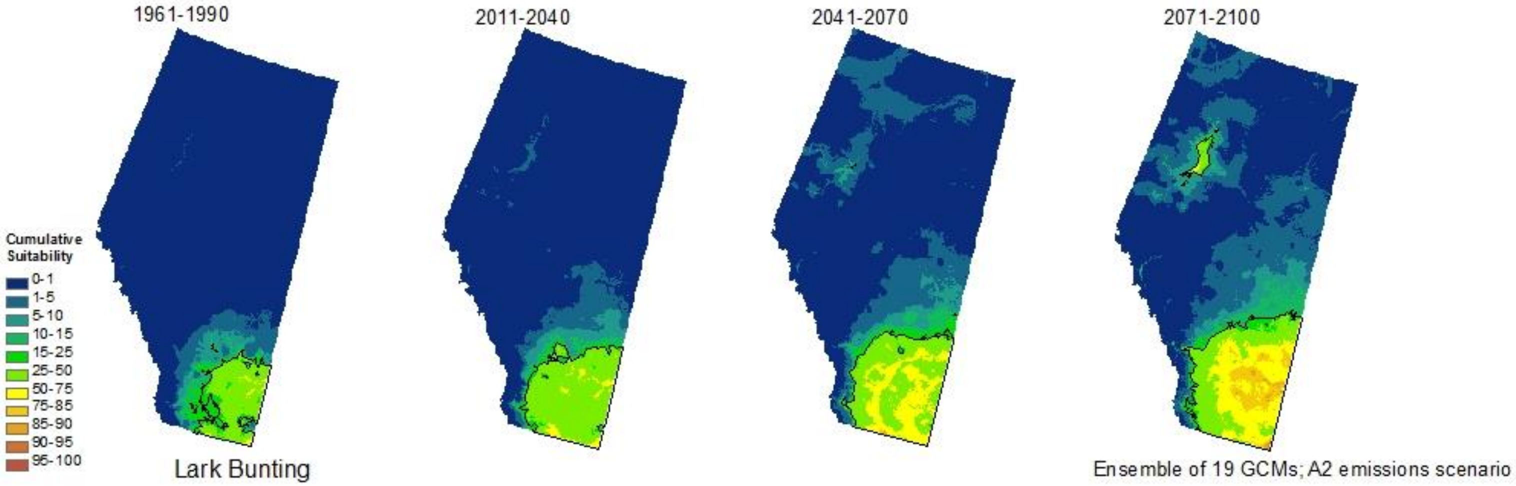
Grasshopper Sparrow

Ensemble of 19 GCMs; A2 emissions scenario



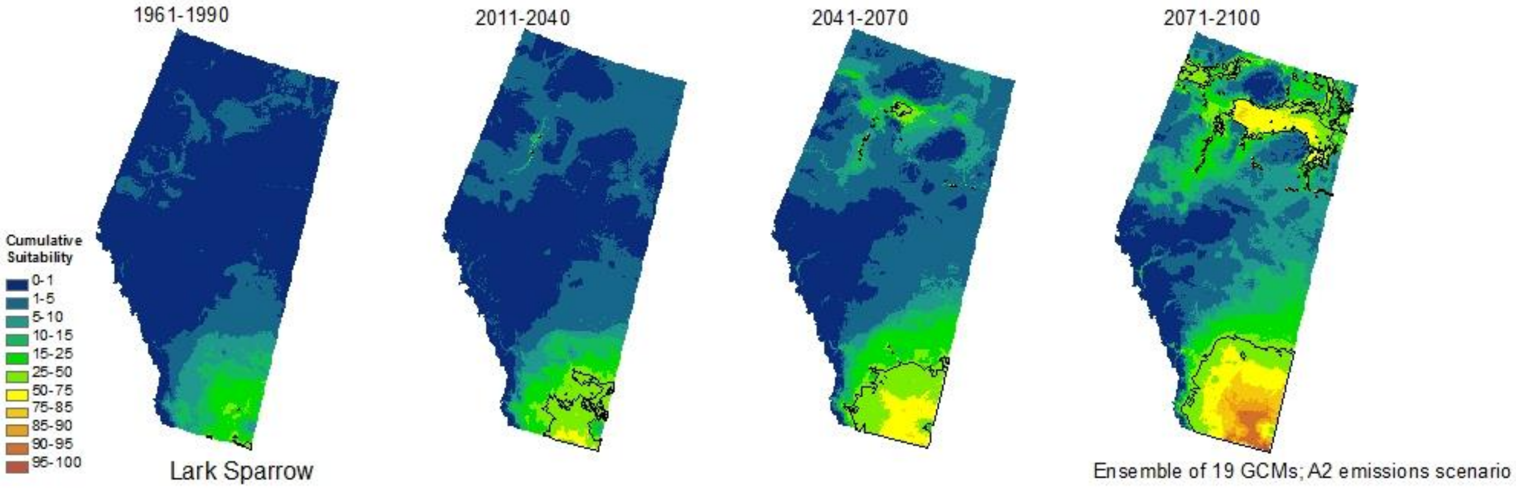
Horned Lark

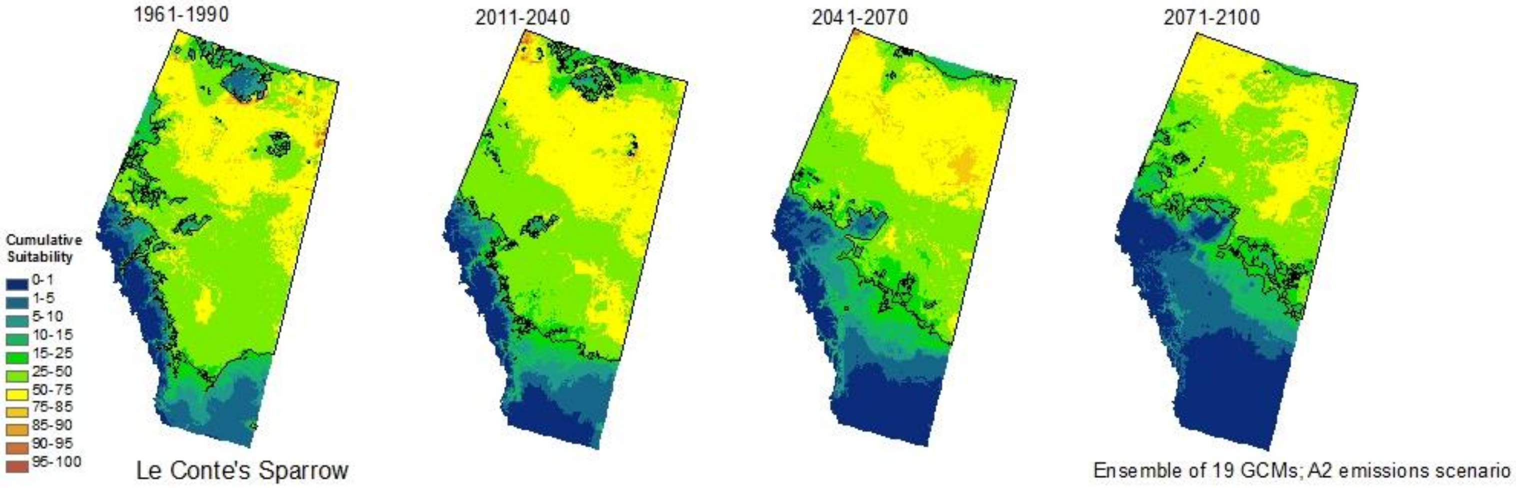
Ensemble of 19 GCMs; A2 emissions scenario



Lark Bunting

Ensemble of 19 GCMs; A2 emissions scenario


1961-1990
2011-2040
2041-2070
2071-2100
Cumulative Suitability
0-1
1-5
5-10
10-15
15-25
25-50
50-75
75-85
85-90
90-95
95-100
Lark Sparrow
Ensemble of 19 GCMs; A2 emissions scenario


1961-1990
2011-2040
2041-2070
2071-2100
Cumulative Suitability
0-1
1-5
5-10
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15-25
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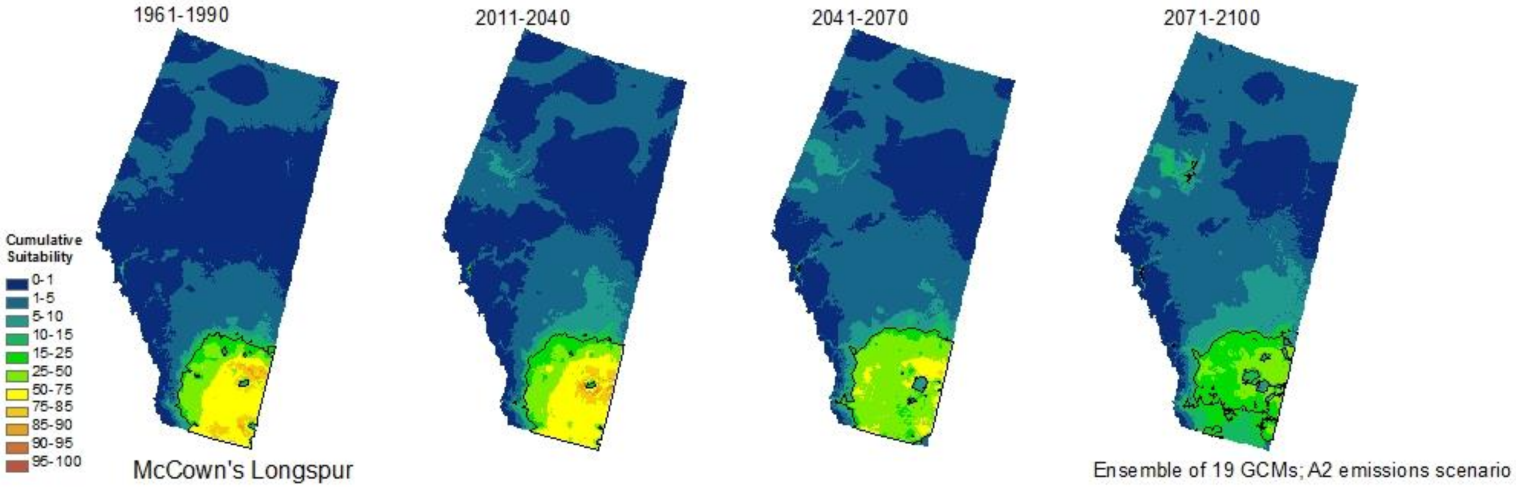
50-75
75-85
85-90
90-95
95-100
Le Conte's Sparrow
Ensemble of 19 GCMs; A2 emissions scenario


1961-1990
2011-2040
2041-2070
2071-2100
Cumulative Suitability
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1-5
5-10
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15-25
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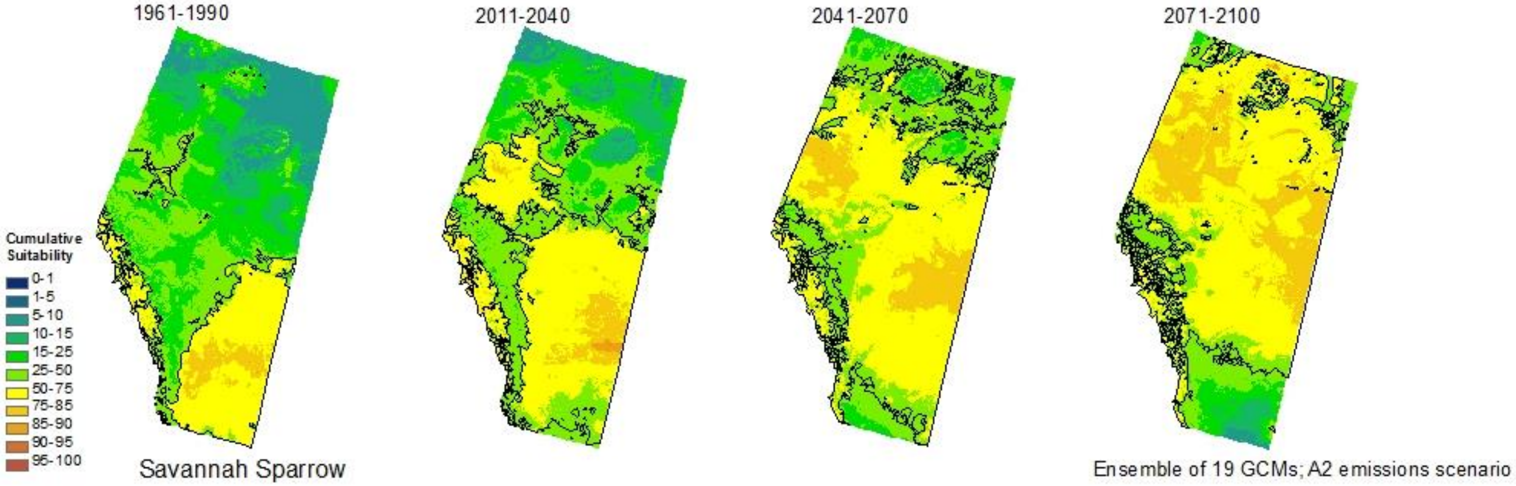
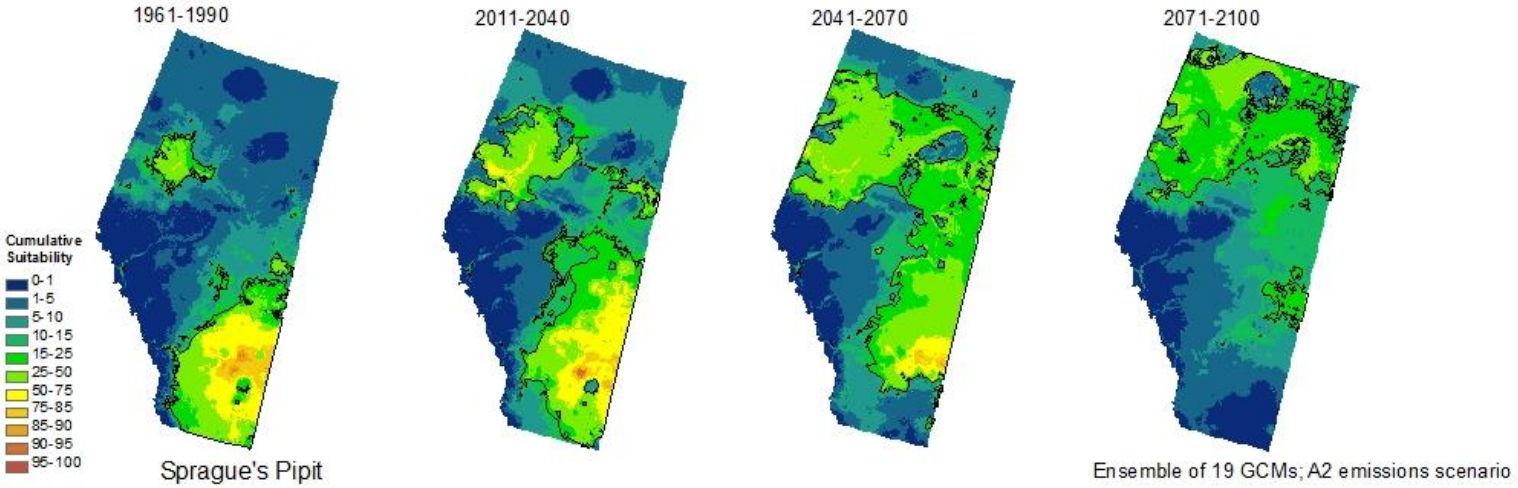
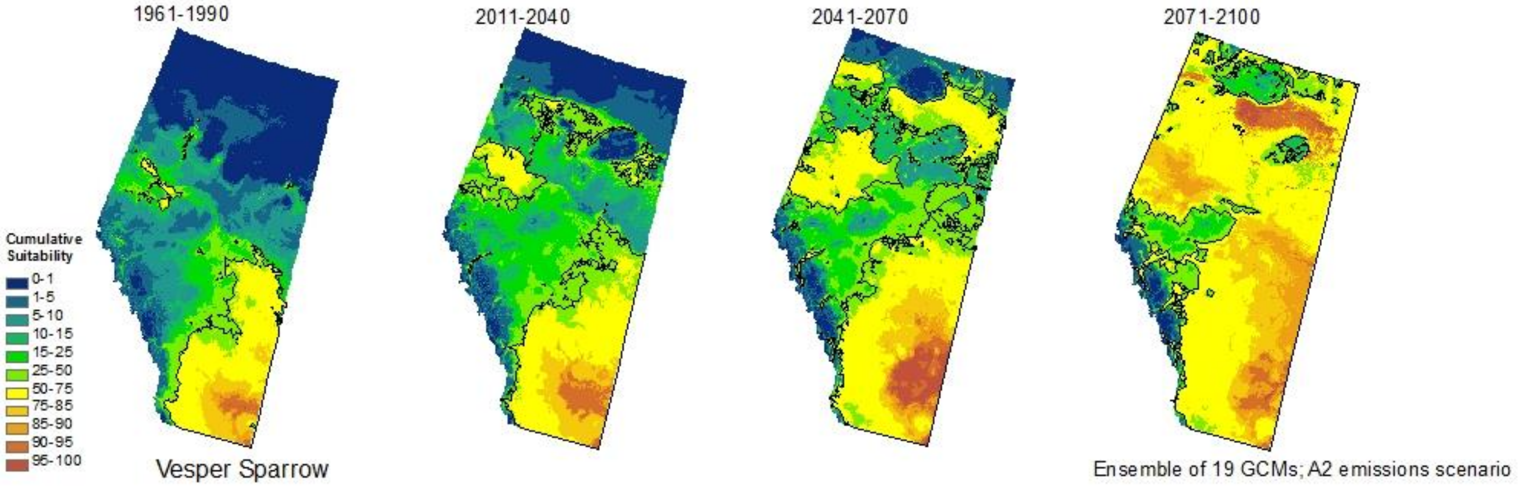
50-75
75-85
85-90
90-95
95-100
McCown's Longspur
Ensemble of 19 GCMs; A2 emissions scenario


1961-1990
2011-2040
2041-2070
2071-2100
Cumulative Suitability
0-1
1-5
5-10
10-15
15-25
25-50
50-75
75-85
85-90
90-95
95-100
Savannah Sparrow
Ensemble of 19 GCMs; A2 emissions scenario



Sprague's Pipit

Ensemble of 19 GCMs; A2 emissions scenario



Vesper Sparrow

Ensemble of 19 GCMs; A2 emissions scenario

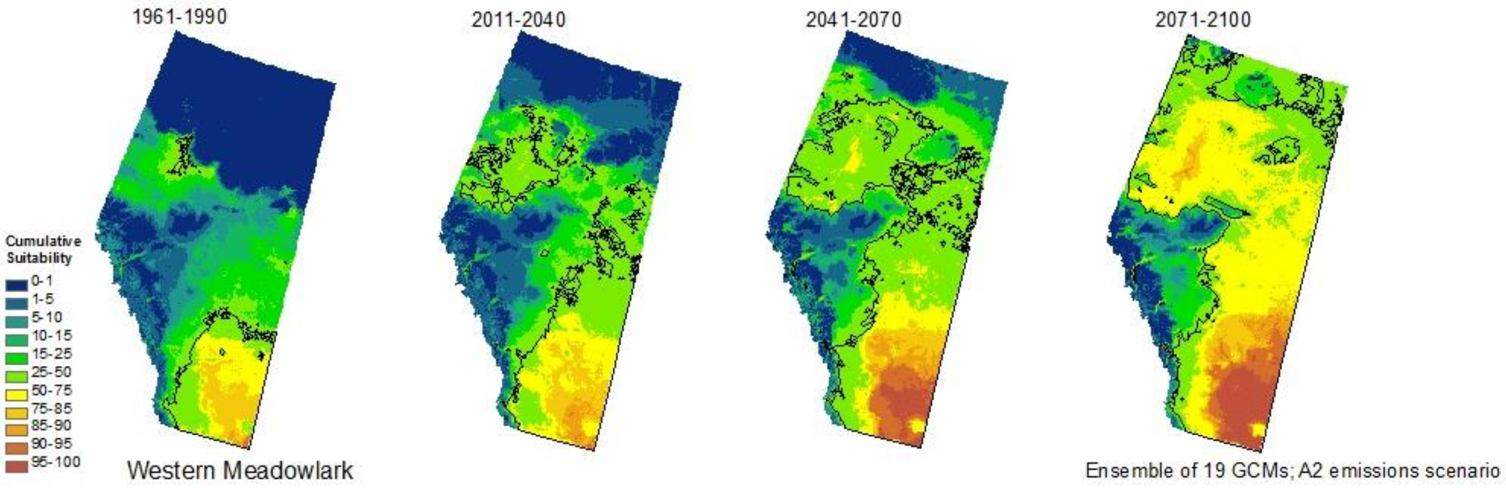


Figure 6. Baseline predictions (1961-1990) and future projections (2011-2040, 2041-2070, and 2071-2100) of climate suitability for 15 grassland songbirds in Alberta, from North American models. The outlined areas represent core suitable climate as determined by species-specific thresholds balancing model sensitivity and specificity. Future projections are based on an ensemble of 19 GCMs and the A2 SRES emissions scenario.

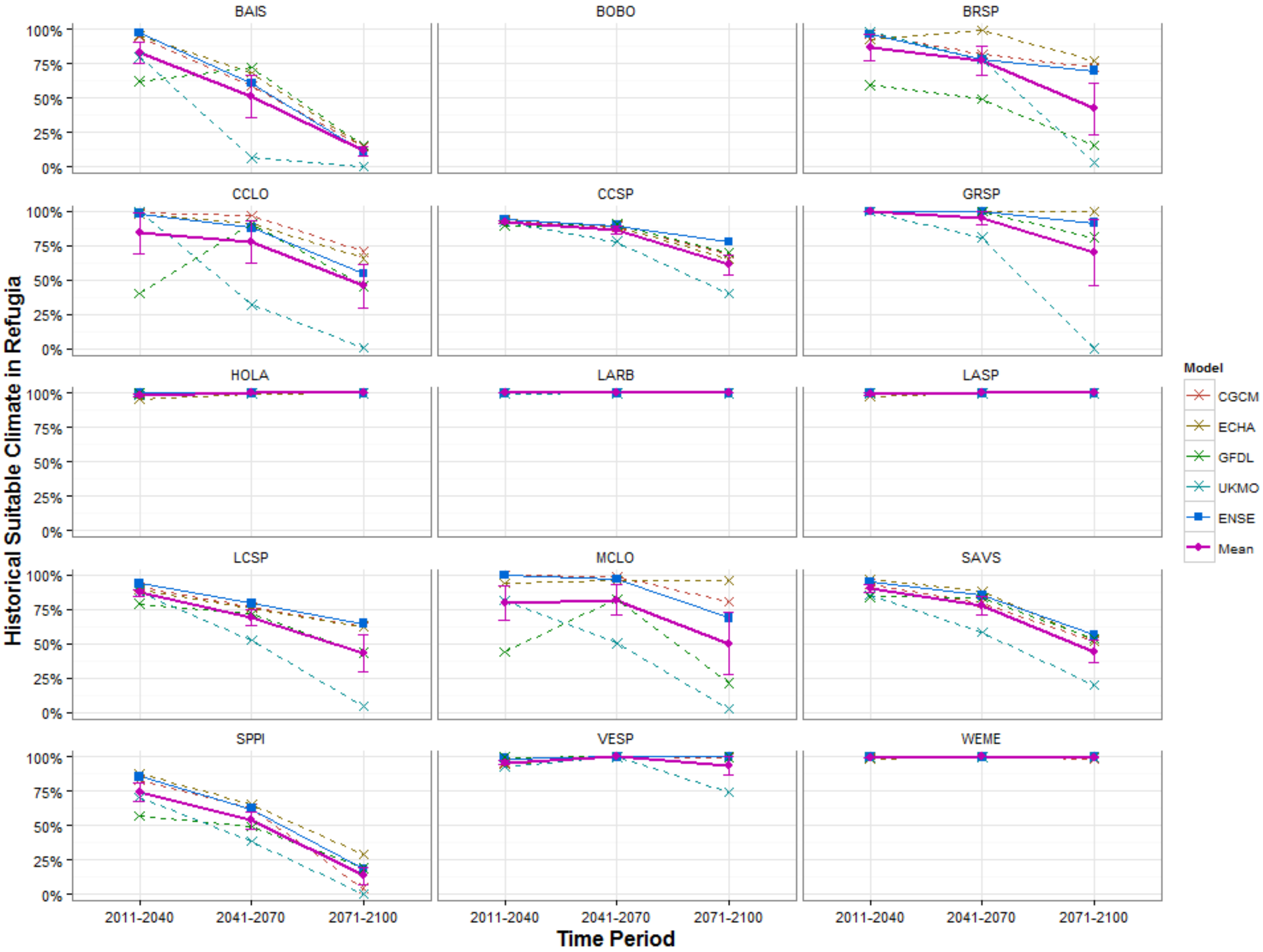
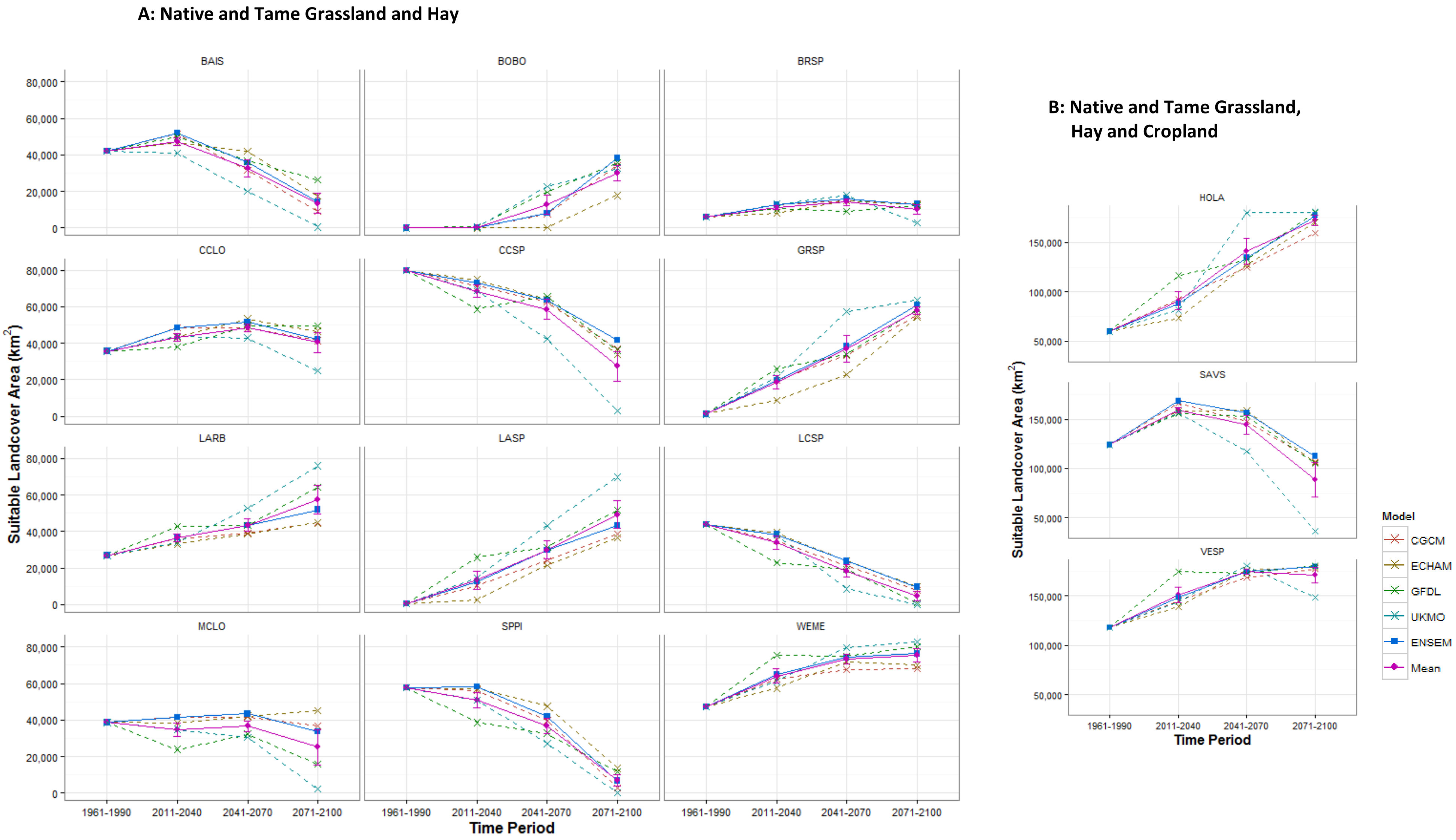


Figure 7. Percent of baseline (1961-1990) core suitable climate area in Alberta that is projected to remain suitable in future time periods ("refugia"; 2011-2040, 2041-2070, and 2071-2100) for 15 grassland songbirds, based on North American models. The mean percent area (± SE; pink, heavy line) is determined from the four unique GCMs (CCCMA CGCM3.1; MPI ECHAM5/MPI-OM; GFDL CM2.1 ; UKMO-HadGEM1 ; dashed lines). Note that Bobolink (BOBO) had no predicted core suitable climate area in Alberta in the historical baseline period and therefore has no identified climate refugia area.


A: Native and Tame Grassland and Hay

B: Native and Tame Grassland, Hay and Cropland

Figure 8. Areas of current suitable landcover in predicted core suitable climate for the baseline (1961-1990) and projected future (2011-2040, 2041-2070, 2071-2100) time periods for 15 grassland songbirds. The mean suitable landcover area (± SE; pink line) is determined from the four unique GCMs (CCCMA CGCM3.1; MPI ECHAM5/MPI-OM; GFDL CM2.1 ; UKMO-HadGEM1 ; dashed lines). Species are separated according to landcover use: (A) for twelve species that use both native and tame pasture and hayland, suitable landcover comprises only these landcover types, and (B) for three species that additionally use cropland, suitable landcover includes annual cropland in addition to native and tame pasture and hayland (Table 1). Note the difference in scales between panels.