Great Plains Landscape Conservation Cooperative Science Research Projects 2010 – 2015

Summary of Science Research Projects Funded by the Great Plains Landscape Conservation Cooperative Completed Through 2015

The Great Plains Landscape Conservation Cooperative funds science research to better understand the ecological processes required for conservation of wildlife within the Great Plains. These research project summaries were written by the Great Plains Landscape Conservation Cooperative to inform our partners and the greater public of the important research funded through the Great Plains Landscape Conservation Cooperative.

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Grassland Research

Decision Support for Climate Change Adaptation in the GPLCC: Data Products Summary

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Introduction:
This project provides the GPLCC and its partners with critically needed geospatial information products to understand how environmental impacts, especially climate, are affecting priority species populations and their habitats. The data products, tools, and models are a series of linked software programs in a user-friendly ArcGIS environment that allow managers, conservationists, and scientists direct access to powerful analysis. The goal is to provide enhanced predictive modeling capabilities to assess the impacts of climate change and other identified stressors in a flexible yet standardized suite of tools and products. This project is an extension of a project called EAGLES (Ecosystem Assessment, Geospatial analysis, and Landscape Evaluation System) which is jointly funded by NASA and the FWS and is applied to the GPLCC with new data products and species models.

Methods:
We provided existing and new geospatial data products at multiple spatial (30, 250, 1000, 4000, and 8000 meters) and temporal (daily, monthly, annual, and static) scales to conduct ecosystem assessments and provide explanatory variables (dynamic covariates, Tables 1-3) for species habitat models. to assess which locations, habitats, and temporal windows (days, seasons, years, decades) were impacted by various climate parameters and their secondary impacts on ecosystem properties such as plant productivity.

Products:
CASA_Express: CASA_Express (Table 1) is a set of ArcGIS toolbox equation models designed to allow end-users to run an ecosystem model at spatial and temporal resolutions. Users can apply the toolkit to transform a Landsat (or MODIS) multi-spectral satellite image into monthly and seasonal predictions of plant biomass growth and forage production.

Table 1. CASA_Express Data Products

CASA_Express Data Products	Description	Temporal Resolution	Temporal Extent	Spatial Resolution	Spatial Extent
NPP	Net Primary Productivity	Monthly	2000 to 2009	250 m	GPLCC
Soil Moisture 0	Surface water in inundated soil layer	Monthly	2000 to 2009	250 m	GPLCC
Soil Moisture 1	Surface water in soil organic layer	Monthly	2000 to 2009	250 m	GPLCC
Soil Moisture 2	Surface water in top mineral soil layer	Monthly	2000 to 2009	250 m	GPLCC
Soil Moisture 3	Surface water in lower mineral subsoil layer	Monthly	2000 to 2009	250 m	GPLCC
PET	Potential Evapotranspiration	Monthly	2000 to 2009	250 m	GPLCC
SWE	Snow Water Equivalent	Monthly	2000 to 2009	250 m	GPLCC
NPP	Net Primary Productivity	Annually	2000 to 2004	4 km	GPLCC

TOPS: The Terrestrial Observation and Prediction System (TOPS, Table 2) is a data and modeling software system designed to seamlessly integrate data from satellite, aircraft, and ground sensors with weather/climate and application/assimilation models to produce gridded, raster datasets for analysis and modeling applications.

Table 2. TOPS Data Products

Data Set and Name	Description	Temporal Resolution	Temporal Extent	Spatial Resol.	Spatial Extent
TOPS	Maximum Temperature	Daily	1980 to 2009	8 km	Lower 48
TOPS	Minimum Temperature	Daily	1980 to 2009	8 km	Lower 48
TOPS	Precipitation	Daily	1980 to 2009	8 km	Lower 48
TOPS	Short Wave Solar Radiation	Daily	1980 to 2009	8 km	Lower 48
TOPS	Vapor Pressure Deficit	Daily	1980 to 2009	8 km	Lower 48
TOPS	Dew Point	Daily	2000 to 2007	8 km	Lower 48
TOPS	Gross Primary Productivity	Daily	2000 to 2009	8 km	Lower 48
TOPS	Snow Cover	8 day	2000 to 2010	8 km	Lower 48
TOPS	Land Surface Temp. & Emissivity	8 day	1980 to 2009	8 km	Lower 48
TOPS	Vegetation Indices (EVI, NDVI)	16 day	1980 to 2009	8 km	Lower 48
TOPS	LAI and FPAR	8 day	1980 to 2009	8 km	Lower 48
TOPS-MODIS	Snow Cover	8 day	2000 to 2010	500 m	GPLCC
TOPS-MODIS	Land Surface Temp. & Emissivity	8 day	2000 to 2010	1 km	GPLCC
TOPS-MODIS	Land Cover Type	Yearly	2000 to 2010	1 km	GPLCC
TOPS-MODIS	Vegetation Indices (EVI, NDVI)	16 day	2000 to 2010	1 km	GPLCC
TOPS-MODIS	Thermal Anomalies and Fire	8 day	2000 to 2010	1 km	GPLCC
TOPS-MODIS	LAI and FPAR	8 day	2000 to 2010	1 km	GPLCC
TOPS-MODIS	GPP	8 day	2000 to 2010	1 km	GPLCC
TOPS-MODIS	NPP	Yearly	2000 to 2010	1 km	GPLCC
TOPS	Maximum Temperature	Daily	1970 to 2005	1 km	Lower 48
TOPS	Minimum Temperature	Daily	1970 to 2005	1 km	Lower 48
TOPS	Short Wave Solar Radiation	Daily	1970 to 2005	1 km	Lower 48
TOPS	Vapor Pressure Deficit	Daily	1970 to 2005	1 km	Lower 48
TOPS	Dew Point	Daily	1970 to 2005	1 km	Lower 48

Table 3. Additional Data Layers

Data Set Name	Description	Temporal Resolution	Temporal Extent	Spatial Resol.	Spatial Extent
Trend/Anomalies	TOPS anomaly detection & trend analysis	Varies	1980 to 2009	8 km	Lower 48
NLCD	National Land Cover Database 1992	Single year	1992	30m	GPLCC
NLCD	National Land Cover Database 2001	Single year	2001	30m	GPLCC
PRISM	Minimum Temperature	Monthly	1895 to 2010	4 km	Lower 48
PRISM	Maximum Temperature	Monthly	1896 to 2010	4 km	Lower 48
PRISM	Average Temperature	Monthly	1897 to 2010	4 km	Lower 48
PRISM	Percent Normal Precipitation	Monthly	1898 to 2010	4 km	Lower 48
BioClim	Annual average precipitation	Yearly	1980 to 1997	1 km	GPLCC
BioClim	Annual average temperature	Yearly	1980 to 1997	1 km	GPLCC
BioClim	Annual temperature range	Yearly	1980 to 1997	1 km	GPLCC
BioClim	Average diurnal range in temperature	Monthly	1980 to 1997	1 km	GPLCC
BioClim	Average temperature of coldest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Average temperature of driest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Average temperature of warmest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Average temperature of wettest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Mean diurnal range/Annual temp. range	Yearly	1980 to 1997	1 km	GPLCC
BioClim	Maximum temperature of warmest month	Monthly	1980 to 1997	1 km	GPLCC
BioClim	Minimum temperature of coldest month	Monthly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of coldest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of driest month	Monthly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of driest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation seasonality	Seasonal	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of warmest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of wettest month	Monthly	1980 to 1997	1 km	GPLCC
BioClim	Precipitation of wettest quarter	Quarterly	1980 to 1997	1 km	GPLCC
BioClim	Temperature seasonality	Seasonal	1980 to 1997	1 km	GPLCC
NSEcol. Systems	Vegetation Classification and Land Use	Single	N/A	30 m	GPLCC
STATSGO	U.S. General Soil Map	Single	2006	N/A	GPLCC
Future Climate Grids	Globally Downscaled Climate Projections historic temperature	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model a1b temperature	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model a1b precipitation	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model b2 temperature	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model b2 precipitation	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model a2 temperature	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global
Future Climate Grids	Globally Downscaled Climate Projections model a2 precipitation	Monthly	1961 to 1990, 2041 to 2060, 2081 to 2100	17 km	Global

Decision Support for Climate Change Adaptation in the GPLCC: Species Models Summary

Robert Crabtree[1], J.W. Sheldon[1], Kenneth Wilson[2], Christopher Potter[3], Brandt Winkelman[1], Daniel Weiss[1], Sharon Baruch-Mordo[2], Gordon Reese[2]
[1] Yellowstone Ecological Research Center, 2048 Analysis Drive, Bozeman, MT 59718,
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Introduction:

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Methods:

All species models were developed using an EAGLES tool called the "RSPF tool" to implement Resource Selection Probability Function (RSPF) models. We used the logit link function, and chose an appropriate covariate order based on univariate model fitting for each of the selected covariates. We evaluated model performance with the area under a modified receiver operating characteristic curve (AUC). Two sampling approaches were used to obtain availability points for each location. In the first method, habitat availability was determined from a buffer around each species occurrence. In the second method, habitat availability was determined by the full study area extent.

Arkansas Valley evening primrose (Oenothera harringtonii). Presence data from 1998–2010 for the primrose were obtained from the Colorado Natural Heritage Program. Data resolution were the highest level available (arc seconds or approximately 100 m), and data were provided as presence polygons ranging from <0.01 to 2.53 km2 (x = 0.07, SE = 0.03). We extracted polygon centroids to represent presence locations (n = 118). Covariates used for model development were: elevation, slope, soil texture, average and standard deviation of shortwave radiation May-Aug, and average and standard deviation of precipitation May-Aug.

Swift fox (Vulpes velox). Presence data were obtained from capture-recapture occupancy surveys conducted in eastern Colorado from 2004–2005. The survey design consisted of overlaying eastern Colorado with a grid where each grid cell measured 6.4 x 8.0 km, selecting a random starting cell, and surveying every 50th cell (n = 51) using up to 20 systematically placed traps. Foxes were successfully captured at least once in 36 unique cells. Covariates used for model development were: elevation, slope, soil texture, amount of short grass prairie, and short grass prairie fragmentation.

Grasshopper Sparrow (Ammodramus savannarum). Data were provided by the Rocky Mountain Bird Observatory based on transect surveys conducted throughout Colorado from 1998-2007. Sampling was stratified by habitat types, with 30 transects randomly selected within each type and ≤20 point count locations were sampled in each transect. GRSP were detected in 48 unique transects. Covariates used for model development were: elevation, average and standard deviation of precipitation May-Aug, amount of short grass prairie, and short grass prairie fragmentation.

Results:

Arkansas Valley evening primrose (Oenothera harringtonii). We used first-order fits for all covariates in all analyses. Model results for the buffer approach suggested a positive relationship between plant occurrence and all explanatory variables with the exception of elevation. The parameter estimates for average slope and amount of favorable soil within a 2-km neighborhood were significant (pslope = 0.008, psoil = 0.002, respectively) and their 95% confidence intervals did not overlap zero. The parameter estimates for the remaining covariates were non-significant ($p > 0.28$), and the model had an AUC of 0.60.

The study-extent approach suggested a similar positive relationship between occurrence and all explanatory variables with the exception of elevation and precipitation. Parameter estimates were significant ($p < 0.0001$) for all explanatory variables except for elevation ($p = 0.17$) and SD_PPT ($p = 0.49$), and the AUC statistic for the model was 0.95.

Swift fox (Vulpes velox). Using the buffer approach, fox occurrence had a negative relationship with elevation, slope, and amount of soil, and a positive relationship with the amount of shortgrass prairie, but no parameter estimates were significant ($0.14 < p < 0.97$). For models using the study-extent approach, fox occurrence had a negative relationship with elevation and slope, and a positive relationship with amount of favorable soil type and amount of shortgrass prairie. Amount of shortgrass prairie was the only estimate showing some significance ($p = 0.052$, 95% confidence intervals did not overlap zero); all other parameter estimates had $p > 0.15$. Model fit was better for the model sampling availability across the study extent (AUC = 0.78) compared to sampling availability with the buffer approach (AUC = 0.65).

Grasshopper Sparrow (Ammodramus savannarum). Regardless of availability sampling method, GRSP occurrence had a negative relationship with elevation, and precipitation variables, and a positive relationship with the amount of shortgrass prairie variable. The buffer approach model had an AUC statistic of 0.60, while the study-extent model had an AUC of 0.65

Evaluating Population Connectivity for Species of Conservation Concern in the American Great Plains: Summary

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Introduction

This project was designed to predict and map core habitat and fracture zones, and identify potential movement corridors for three species of conservation concern in the American Great Plains. Swift fox (Vulpes velox) lesser prairie-chicken (Tympanuchus pallidicinctus) and massasuaga (Sistrurus catenatus) are identified as species of conservation concern across the Great Plain Region. Reliable knowledge about population distribution and connectivity is essential to guide effective conservation actions for these species.

We used resistant kernel and least-cost path approaches to evaluate habitat area, fragmentation, and corridor connectivity for these three species across the full extent of the Great Plains Landscape Conservation Cooperative. We had three specific objectives: (1) estimate the extent of connected habitat and map dispersal corridors among core habitat patches; (2) identify key geographical locations that are most important to maintaining population connectivity and facilitating movement; (3) evaluate how well protecting areas important for population connectivity for one species could simultaneously protect population connectivity for the others.

Methods

Focal species. Swift fox, lesser prairie-chicken, and massasuaga were chosen because they are species of high regional conservation concern, they cover a broad taxonomic range, and represent a wide range of dispersal abilities. We used all records since 1970 in the NatureServe database for these species and for which precise locational data were available. These data provided 3,567 occurrence records of lesser prairie-chicken, 8,454 records of swift fox, and 2,441 records of massasauga within the study area.

We assessed broad scale population connectivity, including the extent and pattern of core habitat areas, the location of fracture zones, barriers and corridors between core habitat patches, which enabled us to integrate the effects of differential sensitivity to landuse and differential dispersal ability on population connectivity. Instead of computing pair-wise corridors between a priori defined sources, we combined resistant kernel and factorial least-cost path approaches to predict spatially synoptic patterns of connectivity and identify all-directional dispersal, providing a more complete picture of connectivity across continuous space. In addition, we evaluated scale dependency across three dispersal distances, corresponding to an eightfold range in dispersal ability, enabling us to evaluate the sensitivity of individual species' connectivity to dispersal ability. By combining a range of alternative resistance models with multiple dispersal distances, we quantified the relationships between dispersal ability and ecological characteristics in driving multi-species connectivity across a large area of the American Great Plains.

Results

We mapped nine different alternative models for each species consisting of the factorial of relative landscape resistance (high, med, low) and dispersal ability: 20, 40, 80 km (lesser prairie-chicken); 10, 30, 60 km (swift fox); and 2, 4, 6 km (massasauga).

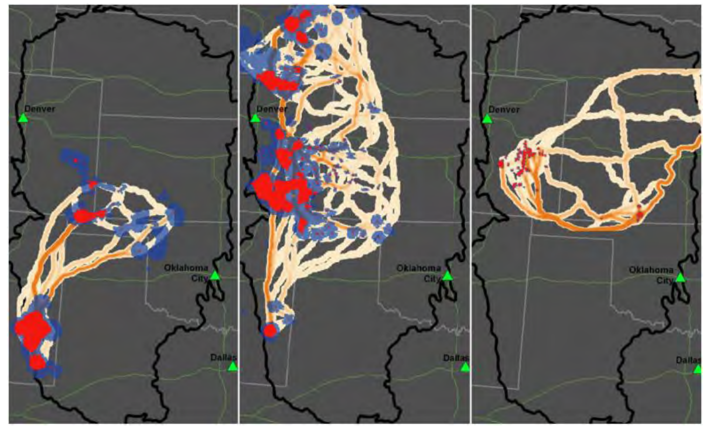

Figure 1. Select modeled habitat connectivity: lesser prairie-chicken (left), swift fox (center), massasauga (right)

We found relatively limited ability to simultaneously optimize protection for connected habitat for all three species. Specifically, there was relatively little overlap of predicted connected habitat among the three species. Less than 1/3 of the total extent of connected habitat across the three species is simultaneously connected for two of the three species, and less than 10 % provides connected habitat for all three species simultaneously.

Discussion

Our mapping of core habitat, fracture zones, and corridor areas in the GPLCC for the three focal species indicated that the populations of all three species are fragmented. The massasauga would appear to be the most vulnerable to fragmentation given its highly limited dispersal ability. However, the apparently aggregated distribution of this species may reduce this effect. The main core population appears to be relatively well connected, with a few internal fracture zones and gaps spanned by potentially important corridors. We believe, therefore, that the main risks to massasauga are related to limited population size and area of occupied habitat, and conservation actions may be most effective if they focus primarily on protecting and expanding core habitat areas.

Lesser prairie-chicken and swift fox have relatively large dispersal abilities, which should help mitigate the effects of habitat fragmentation. However, the scale at which the populations of these species are broken into patches may produce severe fragmentation.

For both species, the main areas of occupied core habitat are separated by large gaps that are wider than the predicted dispersal abilities of the species, which may increase local extinction risk. For these species, mitigating areas of limited connectivity among core habitat patches and enhancing potential linkage corridors may be nearly as important as protecting core habitat. Protecting core habitat we feel should usually be the first priority, but for these species increasing connectivity between isolated core patches also could be critically important.

Climate change planning for the Great Plains: Wildlife vulnerability assessment & recommendations for land and grazing management: summary

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Introduction:

A stated purpose of the Great Plains Landscape Conservation Cooperative (GPLCC) is to conduct applied science and make information accessible to on-the-ground managers to help the community of decision-makers in the GPLCC understand how to approach landscape-scale management in light of stressors such as climate change. To address this need, we executed a short-term project for the GPLCC to assess the vulnerability of grassland-dependent wildlife to climate change impacts in the GPLCC geography with the following as deliverables: 1) Vulnerability assessments for key grassland wildlife; 2) Workshop of experts for a climate change adaptation planning exercise; and 3) Summary report and draft outreach materials.

While we assessed the vulnerability of a number of different wildlife and plant species to climate change, none of those species exhibited high vulnerability to changes projected for the region and there was limited differentiation in vulnerability between the individual species. Given this shared level of vulnerability to climate change, we chose to focus our adaptation planning on grassland birds as they represent a large group with a diversity of habitat needs. These birds are obligate grassland wildlife species which have great potential to act as indicators for habitat quality since different species have distinct habitat structure needs. In the full report, we highlight the results of the vulnerability assessment (Fig. 1), discuss the workshop and its products, and summarize the entire project.

Methods:

We used the NatureServe Climate Change Vulnerability Index (CCVI) tool to conduct an assessment for a set of grassland species, focusing primarily on the species of concern listed in the wildlife action plans of the states within the GPLCC. The tool yields a relative ranking of the vulnerability of the species analyzed to future projections of climate change for the geographic area. We stress that the NatureServe CCVI tool is designed for use in conjunction with NatureServe conservation status ranks. Most grassland species are already in serious decline and we assessed how climate change may further stress grassland wildlife.

We assembled 25 science and management experts on grassland species and systems from government agencies and conservation science non-government organizations for a three-day Climate Change Adaptation Planning Workshop during September 8-10, 2010. The workshop followed several steps in a particular approach for translating general recommendations on climate change adaptation strategies into practical, specific actions for a given landscape called the Adaptation for Conservation Targets (ACT) Framework. WCS is working with a number of partner agencies and organizations across the United States to apply and continually refine the ACT Framework.

To start the climate change adaptation planning process, workshop participants identified a broad management goal for grassland habitats relevant for grassland wildlife: "To sustain populations of grassland birds across the GPLCC by maintaining and enhancing the availability of areas sufficient in extent and quality." Participants recognized that the provision of sufficient high quality habitat is not the only factor necessary to support sustainable grassland bird populations, but agreed to limit discussions at the workshop to climate change impacts on and recommendations for managing grassland habitat for birds. Further discussion of additional factors relevant for sustaining bird populations could be addressed in subsequent meetings of GPLCC partners.

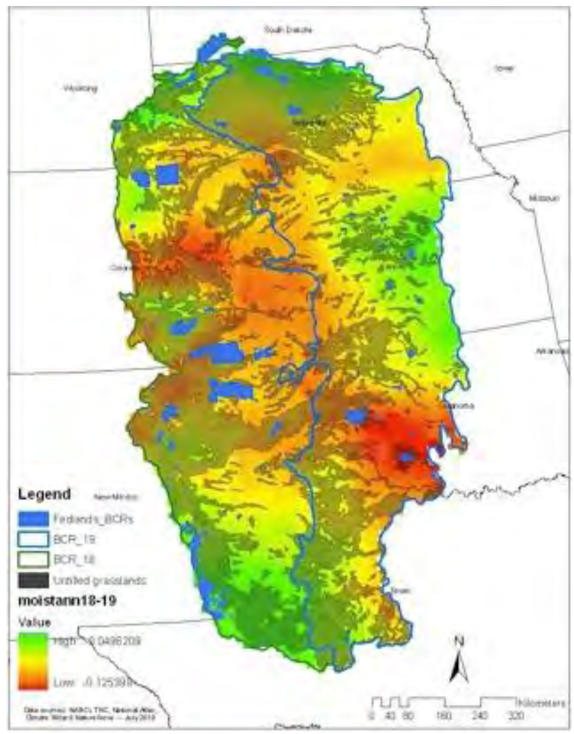

Figure 1. Moisture Availability Projected for 2050(AET:PET), Untilled Grasslands, and Federal Lands in the Great Plains LCC

Results:

We found that few species appear vulnerable solely to climate change, in part due to the historically extreme conditions that characterized grassland systems in the GPLCC and the adaptive capacity of associated wildlife. Our vulnerability assessment was presented to a group of experts and can be reviewed relative to similar efforts in the region. More importantly, our assessments provided a starting point for climate change adaptation and more general conservation planning for the GPLCC, toward which we feel that our workshop was an early step. Workshop participants identified many needs in land conservation and management, policy development, research and monitoring, and outreach. We feel that one of the strongest needs to fulfill is that of creating demonstration sites where basic connections between management and wildlife can be clearly exhibited and then shared with habitat and grazing managers. Such direct research and outreach would greatly aid grassland conservation efforts both now and in light of future climate changes.

Great Plains Landscape Conservation Cooperative Monitoring Grid: Summary

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Introduction:
Understanding ecological processes at landscape levels will make conservation efforts more efficient and improve management responses to regional conservation issues, such as climate change and habitat fragmentation. A major challenge while addressing regional conservation issues is coordinating efforts across partner agencies and organizations. A monitoring framework at the regional level was identified as a science need for the Great Plains Landscape Conservation Cooperative (GPLCC). Our objectives are to create a monitoring grid that biologists can use to monitor a variety of taxa at multiple scales and develop strata that can be used for landbird monitoring. When developing a regional monitoring grid, we consider the following key elements: spatial extent, datum and projection, scalability and standards. A grid with a familiar datum and projection will facilitate use among multiple partners, and GIS layers are more compatible with a commonly used datum and projection. Rocky Mountain Bird Observatory and partners have identified the United States National Grid (USNG) as a potential standard for use in monitoring biological populations at regional levels.

Methods:
We obtained the USNG grid shapefiles from Delta State University; these grids were divided by state and UTM zone. We subdivided the grids in the GP LCC by Bird Conservation Region (BCR); the GP LCC is a combination of BCR 18 and 19 and exists in UTM zones 13 and 14. We assigned grid cells to a state, UTM zone, and BCR based on the location of the cell's centroid. We used the naming convention STATE_USNG_UTMxx_BCRxx.
Merging Cells. Along UTM zone boundaries, "zipper cells" occur because mapping the three-dimensional spherical earth on a two-dimensional plane creates distortions. The irregular cells less than 1 kilometer square would challenge our sampling effort and may bias estimates. These unequal area cells only comprise 0.33% of the total number of grids in the GPLCC. We merge the grid cells smaller than 0.95-kilometer square to neighboring cells. If the larger cells are selected for sampling we randomly place a 1km^2 cell within the larger cell. This solution allows for inference to the entire study area and maintains the spatial extent of the sampling frame. The grid is still scalable, and the increased cell size does not alter inclusion probabilities when conducting finite spatially-balanced sampling.
Grid Attribution. Attributes added to each grid include: x and y coordinates of cell centroids, NRCS Major Land Resource Areas (MLRA), federally owned and managed lands, National Hydrography Dataset (NHD) Strahler order, and National Land Cover Data (NLCD) land cover/vegetation types.

Results:
The product is a geodatabase containing a contiguous grid stratified by state and BCR for the GPLCC region (Figure 1). For our landbird monitoring program, we stratified the GPLCC by state and BCR. We chose our stratification schemes based on ecoregions, land ownership, and rivers.

Discussion:
Our goal for developing a landbird monitoring program was to have a stratification scheme that is relevant at the landscape level and is not subject to strata changing over long periods of time. Spatially explicit conservation models require a spatial extent for inference. A sampling grid provides an organized spatial extent partitioned into sampling units needed in spatially explicit models and is integral to research and monitoring. The landbird monitoring grid developed for the Great Plains LCC is based on the USNG standards. The USNG is a scalable national grid that may be used within and across LCC landscapes. The scalable nature of the USNG grid is useful for monitoring and research of multiple taxa. A standardized monitoring and research grid will decrease project costs, necessary labor, and duplicate sampling efforts. Using the GP LCC monitoring grid will improve partnership coordination at the landscape level to accomplish shared conservation goals.
An example of a monitoring program that can use the same grid developed for the GPLCC utilizes structured decision making (SDM). SDM analyzes a decision by breaking it into parts with the aim to identify the optimal decision in terms of specified objectives. In conservation the elements of decision making include: objectives, management actions, models of system behavior, a monitoring program to track system state and a method to identify the solution (Martin et al. 2009).

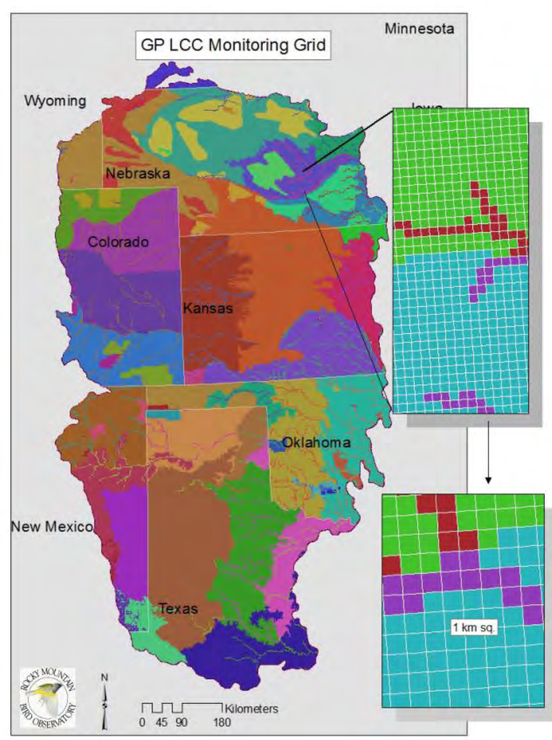

Figure 1. GPLCC monitoring grid stratified by state and BCR

Drought and Cooler Temperatures Are Associated with Higher Nest Survival in Mountain Plovers: Summary

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[3]U.S. Geological Survey Fort Collins Science Center

Introduction:
Native grasslands have been altered to a greater extent than any other biome in North America, resulting in the conversion of the once diverse grassland landscape into a collection of homogenous grassland fragments interspersed with agricultural fields. These alterations are likely to have contributed to the continental-scale declines in grassland avifauna, which have been steeper and more consistent than declines in any other avian guild over the past century. Although direct anthropogenic changes can contribute to loss and degradation of avian habitat in the North American prairies, shifts in weather patterns also may result in changes in the condition, quality, and viability of prairie ecosystems, and thus the distribution, phenology, and reproductive output of many grassland birds. Presumably by affecting food resources, habitat structure, or predator abundance and behavior, higher levels of precipitation favor reproductive success of several grassland and shrubland passerines. Precipitation, however, may not lead to higher reproductive output in the Mountain Plover (*Charadrius montanus*), a unique grassland species at the extreme of grassland bird habitat niches that prefers highly disturbed or exposed ground within the prairie ecosystems of North America.

We examined how seasonal and daily weather conditions influenced nest survival of Mountain Plovers across the eastern plains of Colorado during a 7-yr period. Our objectives were to distinguish whether temperatures and precipitation levels at seasonal or daily time scales influence the outcome of nesting attempts within the core range of Mountain Plovers, and secondly, to determine what weather conditions during the breeding season favored nest survival of Mountain Plovers. Knowledge of how mountain plovers respond to shifts in weather events across their breeding area will be invaluable to inform conservation practices and management agendas in the face of impending climate change.

Methods:
The study area covered 13 counties in the eastern plains of Colorado, USA consisting of private and public lands. Each year from 2001 to 2006 and in 2009, data collection began in mid-April and continued until the last nest hatched. Study plots were systematically searched for Mountain Plover nests ≥ 4 times throughout the nesting period. Nests were checked every 3-12 d until the eggs hatched or failed. Nests were considered successful if ≥ 1 egg hatched, regardless of the size of the clutch. In 2004-2009, nests were checked more often as hatch date approached, resulting in increased accuracy of hatch date estimation.

Daily nest survival (DNS), the probability that a nest will survive a single day, was calculated using the nest survival model in Program MARK, version 5.1. DNS could be influenced by a large number of patterns in daily and seasonal weather conditions. To limit the number of models evaluated, we developed a set of *a priori* biological hypotheses and used these to choose explanatory variables and guide construction of the model set. The types of weather variables that we considered to have the greatest potential influence on DNS, based on the scientific literature for plovers and other grassland and shrubsteppe bird species, were daily precipitation, daily temperature, seasonal precipitation, and seasonal temperature. Within each of these four categories, we included variables such as total daily precipitation, daily maximum temperature, total precipitation during the breeding season, and average daily maximum temperature during the breeding season, respectively. Two additional climate-related variables, time-in-season and year, were also included in the model set because previous studies suggested their importance to DNS.

We calculated nest success as DNS^x, where x is the number of days of incubation (29 in Mountain Plovers). Dates were scaled so that day 1 was the first date when a nest was found during the study. In total, we considered 94 candidate models and used the logit link function to evaluate covariate effects on DNS.

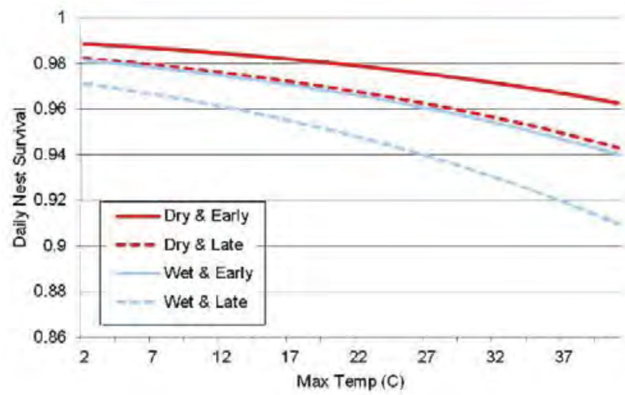

Fig. 1. Daily nest survival of Mountain Plovers in eastern Colorado, 2001-2009, as a function of daily maximum temperature, drought, and time-in-season. Dry periods were defined as droughts in which ≥ 10 consecutive days had ≤ 1 mm total precipitation, while wet periods had > 1 mm total precipitation. Days 21 (early = 8 May) and 58 (late = 14 June) were the 12.5% and 87.5% points in the nesting season and thus bound the middle 75% of nest activity. Nest survival over the entire nesting period = (daily nest survival)^29.

Results and Discussion:
Nest survival averaged 27.2% over a 7-yr period (n = 936 nests) and declined as the breeding season progressed. Nest survival was favored by dry conditions and cooler temperatures (Fig. 1). Climate-related responses in breeding performance of Mountain Plovers likely result from direct effects on eggs, chicks, and adults, as well as indirect effects on vegetation structure, insect availability, and predator abundance and behavior. Projected changes in regional precipitation patterns will likely influence nest survival, with positive influences of predicted declines in summer rainfall yet negative effects of more intense rain events. The interplay of climate change and land use practices within prairie ecosystems may result in Mountain Plovers shifting their distribution, changing local abundance, and adjusting fecundity to adapt to their changing environment.

Modeling Sediment Accumulation in North American Playa Wetlands in Response to Climate Change, 1940–2100: Summary

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Introduction:
Shallow depressional wetlands across the North American Great Plains provide important ecosystem services, including ground water recharge, storm-water retention, carbon storage, and provision of resources and habitats for the maintenance of biodiversity. These geographically dispersed and hydrologically isolated wetlands provide critical habitats for plants, invertebrates, and vertebrates, including many taxa of amphibians, mammals, and migrant wetland dependent birds. Collectively, prairie wetlands are highly vulnerable to land conversion, agricultural policies and practices, hydrology alteration, and water pollution. Today, ground-water withdrawal, increasing rates of sedimentation, and enhanced likelihood of drought due to climate change pose far-reaching conservation challenges for wetland-dependent biota. Precipitation-filled playa wetlands, or shallow ephemeral wetlands lined with an impermeable subsurface clay layer, dispersed across the west-central and southern Great Plains are especially affected by climate dynamics.
Climate predictions for this semi-arid area indicate reduced precipitation which may alter rates of erosion, runoff, and sedimentation of playas. Among many land use impacts, sedimentation is a primary threat to the continued existence of playas at the regional scale. Although sedimentation is a natural process, sediments accumulate at a faster rate in playas in agricultural settings than in grasslands as a result of runoff-borne materials. Sediment delivery represents a critical nexus between land-use patterns and weather because heavy precipitation on exposed soil causes erosion, overland transport and deposition of sediments. Therefore, the need for understanding sedimentation patterns and processes to develop soil conservation practices that consume little water is critical as climate change increases vulnerability of shallow depressional wetlands. To address this need, we examined the relative roles of projected changes in precipitation and land use context in the playa sedimentation process across the west-central Great Plains. We modeled rates of sedimentation, sediment depths, and resultant playa wetland depths from 1940 through 2100.

Methods:
The playa region of the west-central Great Plains extends from Nebraska through the panhandle of Texas, including parts of Colorado, New Mexico, Kansas, and Oklahoma. Because the area is generally encompassed by the Great Plains Landscape Conversation Cooperative (GPLCC), we used their boundary for our modeling extent. Our study period began in 1940 when irrigated agriculture intensified.
We used the Revised Universal Soil Loss Equation (RUSLE) to model sediment loss from uplands surrounding playas. The volume of sediment displaced from the upland was equal to the sediment deposited in the playa. Sediment depth was the volume of sediment divided by the area of the playa. We calibrated RUSLE results using field sediment measurements. RUSLE is appealing for regional scale modeling because it uses climate forecasts with monthly resolution and other widely available values including soil texture, slope and land use.
To examine area-wide precipitation patterns, we extracted average annual precipitation at 70 random locations across the study area for each of our comparison periods 1941–1970, 2011–2040, 2041–2070, 2071–2100 and calculated the difference of the average annual precipitation at those points from a reference period of 1971–2000. We used an analysis of variance (ANOVA) to test for the average difference in precipitation for the four periods and constructed 95 % confidence intervals on the mean difference by period to test for nonzero mean differences. We compared calibrated RUSLE predictions area-wide to field data. We used ANOVA on land use and period factors for mean sediment accumulation at playas which matched the previous field study's criteria that were unfilled by 2070 for two 50-year periods: 1940–1992 (historic precipitation) and 2010–2062 (average, driest scenarios, and wettest scenarios).

Results and Discussion:
Nearly 90 % of playas of the west-central Great Plains were vulnerable to sediment infill by 2100. Based on average future precipitation, land use had a stronger influence on sedimentation rates than precipitation (Table 1); sediment accumulation decreased by ca 4 cm across 50 years compared to an increase in sedimentation due to land use change from grassland to cropland of ca 24 cm across 50 years. Sediment accumulation in cropland settings also was significantly higher than in grasslands under both the driest and wettest scenarios. Sediment accumulation rates will continue near historic levels through 2070 and will be sufficient to cause most playas (if not already filled) to fill with sediment within the next 100 years in the absence of mitigation. Land use surrounding the playa, whether grassland or tilled cropland, is more influential in sediment accumulation than climate-driven precipitation change.

Table 1. Least squares means of sediment accumulation depth (95 % CI, cm) by land use and climate for a subset of playas (those predicted to fill after 2070, n=3,968) during historic (1940–1992) and future (2010– 2062) time periods with historic and predicted precipitation conditions (average, driest, and wettest). Playas were situated in either grassland or cropland settings

Time period	Surrounding upland: Grassland (*n*=1,148 playas)	Surrounding upland: Cropland (*n*=2,820 playas)	Difference between land uses
1940–1992	27.1 (24.6, 29.6)	51.8 (50.2, 53.4)	24.7 (21.7, 27.6)***
Average precipitation, 2010–2062	24.6 (22.1, 27.1)	47.7 (46.1, 49.3)	23.1 (20.2, 26.1)***
Difference from 1940–1992	−2.5(−6.1, 1.0)^{ns}	−4.1 (−6.3, −1.8)**	
Dry scenarios, 2010–2062	18.9 (16.4, 21.4)	35.6 (34.0, 37.2)	16.7 (13.7, 19.6)***
Difference from 1940–1992	−8.2 (−11.7, −4.7)***	−16.2 (−18.4, −13.9)	
Wet scenarios, 2010–2062	32.9 (30.4, 35.4)	63.3 (61.7, 64.9)	30.4 (24.5, 33.4)***
Difference from 1940–1992	5.77 (2.2, 9.3)**	11.5 (9.3, 13.8)***	

** $P<0.001$, *** $P<0.0001$, ns $P>0.05$
All $|t|>3.2$, $df\geq2296$

Broad-scale Relationships between shorebirds and landscapes in the Southern Great Plains: Summary

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Introduction:

Nearly half of the shorebird species in North America are in decline, and worldwide, nearly 50% of the shorebird populations with known trends may likewise be declining. Concerns over these apparent declines have led researchers to identify possible causes on breeding and wintering grounds, but recent studies have suggested that population limitation may also occur during migration. Shorebirds that migrate through the interior of North America may be more vulnerable to decline than oceanic or coastal migrants because of intrinsic factors associated with a transcontinental migration strategy. Moreover, many interior migrants depend on a wide variety of wetlands that have experienced extensive losses.

Differences among wetland habitat conditions influence the richness and abundance of migrating shorebirds among wetland stopover sites. Although the suitability of a wetland for migrating shorebirds depends on the habitat conditions within the wetland, the density of wetlands within the surrounding landscape may better explain the distribution patterns of migratory shorebirds in the interior of North America. The vagaries of annual and seasonal weather patterns cause wide spatiotemporal variation in the distribution of wetlands within this region.

Shorebird migrants of interior North America appear to have responded to high spatiotemporal variability in habitat by being highly agile and able to use habitats opportunistically. Researchers often recommend that conservation efforts maintain a diverse assemblage of wetlands within complexes to accommodate the niche requirements of the species assemblage of migrant shorebirds that move through a region. However, only recently have studies attempted to address this conservation challenge by focusing on the distribution patterns of multiple shorebird species at broad scales. One of the issues that researchers face when conducting these landscape-level analyses is designating an appropriate observational scale. At fine spatial scales, migrant bird distributions are closely related to food availability; but at broad spatial scales, migrant bird distributions may be more closely related to habitat availability. Thus, differences in the observational scale used among studies could lead to conflicting recommendations for conservation efforts.

We examined the relationship between migrant shorebird richness and abundance and the landscape composition of saturated and shallow-water habitats and other land-cover types in north-central Oklahoma. Specifically, our objectives were to (1) identify shorebird habitat and use successive habitat surveys to estimate the changing availability of these habitats within landscapes over time; (2) quantify the composition of semi-natural and developed land-cover types that were not defined as shorebird habitat within landscapes; and (3) examine landscape-level relationships between shorebird richness and the abundance of different shorebird groups, and the landscape composition of different shorebird habitats and nonhabitat land-cover types.

Methods:

The study area comprised 10 counties of north-central Oklahoma, which encompass a total area of 24,372 km2 and are characterized by intensively managed agricultural areas, grasslands, small forest stands, and broadly distributed urban and suburban developments. Wetlands within the study area range from more permanently flooded lacustrine and riverine wetlands to highly ephemeral palustrine wetlands and sheetwater in agricultural fields.

We used generalized linear modeling and an information-theoretic framework to identify local and landscape factors that best explained species richness, total abundance, and abundance of four groups of shorebirds classified by breeding status and migration distance. Total abundance and richness both increased with the area of wetland habitat within a landscape, regardless of the composition of semi-natural and developed land cover surrounding wetlands.

Results and Discussion:

Abundance of shorebird species with different migration strategies varied in relation to the composition of wetland types within a landscape. The amounts of various permanent and semi-permanent wetlands best explained abundance of resident species. Short-distance migrant abundance was best explained by the amount of permanent lacustrine wetlands. The amounts of temporary and semi-permanent floodwater habitats were important predictors for abundance of intermediate- and long-distance migrants, although permanent riverine habitats were also important for intermediate-distance migrants. Shorebird species richness was best explained by the amounts of floodwater habitats and permanent riverine wetlands (Fig. 1). Broad-scale studies thus provide important insights on use of stopover habitats by migratory shorebirds. Within this region, conservation of riverine habitats with a large complement of ephemeral habitats is necessary to provide the stopover habitat for migrating shorebirds.

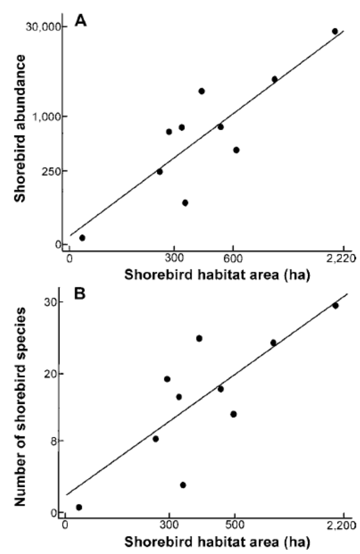

Fig. 1. Relationship between abundance and species richness of migratory shorebirds and the mean area of wetland shorebird habitat within a landscape. (A) Relationship between the number of migratory shorebirds and the mean area of wetland shorebird habitat within landscapes. (B) Relationship between the number of migratory shorebird species and the mean area of wetland shorebird habitat within landscapes.

Spatiotemporal scaling of North American continental interior wetlands: implications for shorebird conservation: summary

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Introduction:

Within interior North America, erratic weather patterns and heterogeneous wetland complexes cause wide spatio-temporal variation in the resources available to migrating shorebirds. Identifying the pattern-generating components of landscape-level resources and the scales at which shorebirds respond to patterns will better facilitate conservation for these species.

This study examined the relationship between shorebird habitat density and shorebird distribution among ten broad scale landscapes in north-central Oklahoma. Our objectives were to: (1) construct descriptive models that identified weather variables associated with creating the spatio-temporal patterns of shorebird habitat, (2) develop a metric capable of measuring the dynamic composition and configuration of shorebird habitat in the region, and (3) use field data to empirically estimate the spatial scale at which shorebirds respond to the amount and configuration of habitat.

Methods:

Our research focused on members of two suborders, *Scolopaci* and *Charadrii* (e.g., sandpipers and plovers). Within the study area, we randomly placed ten 10-km radius circles that we designated as broad-scale experimental units (BSU) to represent the total area a migrant shorebird may traverse to locate foraging habitat during a stopover event. Within each broad-scale unit, we visually located each potential habitat patch and delineated them as fine-scale experimental units (FSU). During each migration period (fall 2007, 2008 and spring 2007, 2008, 2009), we conducted four shorebird surveys on a unique sample of randomly selected (without replacement) FSUs within each BSU. During each field survey, we also estimated percent total cover of shorebird habitat within each FSU, determined wetland habitat type, and collected daily weather data.

We used linear time-series regression models to describe patterns in shorebird habitat incidence using the selected weather variables. We constructed descriptive models that identified weather variables associated with creating the spatio-temporal patterns of shorebird habitat in the ten BSUs. We developed a metric capable of measuring the dynamic composition and configuration of shorebird habitat in the region and used field data to empirically estimate the spatial scale at which shorebirds respond to the amount and configuration of habitat.

Results:

During this study, we surveyed 14,444 FSUs that represented a total area of 26,632 and found that shorebird habitat was present in 8,337 FSUs. Precipitation, temperature, solar radiation and wind speed best explained the incidence of wetland habitat, but relationships varied among wetland types. Shorebird occurrence patterns were best explained by habitat density estimates at a 1.5 km scale. This model correctly classified 86% of shorebird observations. At this scale, when habitat density was low, shorebirds occurred in 5% of surveyed habitat patches but occurrence reached 60% when habitat density was high. The average correct classification rate of the observed versus predicted shorebird use was 88% among all models. These results indicate that our final model was stable and capable of predicting occurrence of shorebirds across our large study area.

Discussion:

We found that the ability to predict the occurrence patterns of migrant shorebirds within the Southern Great Plains of North America depends on the scale at which the landscape structure of shorebird habitat is measured. Our results suggest that the 1.5 km scale represents the grain of resource configuration at which migrating shorebirds interact with landscape structure when making settling decisions during migration. Although it is interesting to find evidence of spatial dependence in these species, only by doing experimental manipulations can we rigorously determine the processes that influence settlement patterns during migration. We hypothesize that by selecting broad-scale complexes of high-density wetland habitat shorebirds can use more wetland resources with reduced searching cost. Under these conditions, shorebirds have increased access to greater foraging opportunities.

The prevailing theoretical model used to understand the process of stopover selection by migratory birds implies that birds initially rely on broad-scale cues and progress toward finer-scale characteristics. Our results suggest that broad-scale clusters of high-density habitat may provide an important initial cue for migratory shorebirds during the process of habitat selection. However, forecasts of a drier and warmer climate may negatively impact the availability of some wetland types within this region and have important implications at the spatial domain in which migratory shorebirds use broad-scale cues to select stopovers.

To preserve an adequate network of stopover resources for migrant shorebirds we must recognize the importance of both spatial and temporal dynamics within and among the wetland clusters of a migration stopover network and identify the domains of scale that are relevant to these birds within the region. Our findings indicate that conservation and management of migratory shorebird stopover habitats should aim to provide areas of potentially high-density habitat at a 1.5 km spatial scale. Preservation of wetland clusters that include a diverse mixture of different wetland types and inundation periods may best ensure that at least some adequate stopover resources are persistently present within this continually changing landscape.

Weather effects on avian breeding performance and implications of climate change: summary

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Introduction:
The influence of recent climate change on the world's biota has manifested broadly, resulting in latitudinal range shifts, advancing dates of arrival of migrants and onset of breeding, and altered community relationships. Climate change elevates conservation concerns worldwide because it will likely exacerbate a broad range of identified threats to animal populations. In the past few decades, grassland birds have declined faster than other North American avifauna, largely due to habitat threats such as the intensification of agriculture. Species endemic to the interior grasslands of North America have been exposed to extreme climate variability through evolutionary time and presumably have evolved mechanisms to cope with such variability. Knowledge of demographic parameters of bird populations across years of varying climatic conditions allows for the development of models that may prove to be highly informative in light of anticipated climate change in the Great Plains of North America. This manuscript presents a detailed analysis of the effect of local climate variation on reproductive parameters of an endemic prairie passerine, the Lark Bunting (*Calamospiza melanocorys*), and discussion of the implications of our findings relative to future climate predictions.

Methods:
This study was conducted on 27 study sites in and near the Pawnee National Grassland in northeastern Colorado, within an ecoregion dominated by shortgrass steppe. From mid-May to early-August 1997–2003, we located and monitored bird nests. We sampled vegetation structure and composition of sites. In addition to temperature and precipitation, we used several other predictive variables (nest age, clutch size, time in season, habitat structure) in our models. We determined the relationships among clutch size, nest survival, and productivity and their respective explanatory variables using general linear models (for clutch size and productivity) and the robust nest survival model in Program MARK, which uses generalized linear modeling based on a binomial likelihood. We selected the best expression for each variable of interest (nest age, time in season, habitat structure, daily and seasonal precipitation, and temperature, including quadratics and polynomials of time in season and nest age, respectively), then using the selected expressions, we formed balanced model sets with respect to the weather variables. After the preliminary analyses, we formulated sets of eight candidate models for clutch size and nest survival and four candidate models of productivity to explore the influence of climatic variables on reproductive parameters using covariates in all models to control for as much variability as possible. We tested for strong correlation among the independent variables contained in the same model to avoid using highly correlated predictor variables. Last, we applied the best-approximating models to predict clutch size, daily nest survival, and productivity with increases in temperature and declines in precipitation. We applied the models to 12 potential future climate scenarios.

Results:
During the seven breeding seasons of the study, we located and monitored 811 Lark Bunting nests. The balanced model set that we considered for clutch size contained time in season and habitat structure in all eight models. The balanced model set for nest survival contained nest age, clutch size, and habitat structure in all eight models. The best-approximating model of the balanced model sets for both clutch size and nest survival included all of the weather variables. Daily precipitation had a strong negative effect on nest survival. In contrast, seasonal precipitation had a strong positive effect overall on nest survival. The balanced model set for productivity contained clutch size and average grass height in all four models and evaluated two weather variables, seasonal precipitation and temperature. Temperature did not appear in the best-approximating model, although it did in a closely competing model. For all future scenarios, the number of young produced per 100 nests increased with increasing temperatures (due to increases in nest survival) but declined with reductions in precipitation. Under scenarios of rising temperatures and declines in seasonal precipitation to the minimum observed in our study, clutch size, daily nest survival, and productivity all declined by 12–14%, 27–40%, and 7–10%, at 2–3°C increases, respectively.

Discussion:
Declining summer precipitation may reduce the likelihood that Lark Buntings can maintain stable breeding populations in eastern Colorado although average temperature increases of up to 3°C (within the range of this study) may ameliorate declines in survival expected with drier conditions. Higher temperatures may enhance survival and growth rates of nestlings if they are better able to maintain body heat. Warmer temperatures may also be associated with greater insect activity and bird foraging success or allow for longer foraging bouts away from the nest. Drier conditions, on the other hand, may result in food scarcity and increased predation.

Historic climate variability in the Great Plains selects for a degree of vagility and opportunism rather than strong site fidelity and specific adaptation to local environments. These traits may lead to northerly shifts in distribution if climatic and habitat conditions become less favorable in the drying southern regions of the Great Plains. Distributional shifts in Lark Buntings could be constrained by future changes in land use, agricultural practices, or vegetative communities that result in further loss of shortgrass prairie habitats.

Our data and analyses demonstrate the costs (lower reproductive output) of breeding in an area during a drought, and thus the costs of highly altered landscapes that constrain movements because there is no habitat suitable for immigration. Protection of grasslands through easement programs and management through the use of grazing and fire would provide a buffer against climate change by allowing the Lark Bunting to shift into suitable areas as needed.

Development of Regional Planning Tools to Assess the Impacts of Climate and Land Use Change on a Sensitive Grassland Bird: Summary

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Introduction:
Globally, the extent and integrity of grassland ecosystems are declining due to anthropogenic pressures and climate change. In the Great Plains, persistent or increasing pressures of agriculture, livestock production, natural resource extraction, and climate change will cause losses to biodiversity unless proactive conservation and management plans are in place. The Great Plains Landscape Conservation Cooperative (GPLCC; Region 7) encompasses portions of eight states including: South Dakota, Nebraska, Kansas, Oklahoma, Texas, New Mexico, Colorado, and Wyoming. Within the region six habitat types have been identified as conservation priorities: 1) short grass and mixed grass prairies, 2) playa wetlands, 3) riparian streams, 4) prairie rivers, 5) cross timbers savannahs, and 6) shrub land/sand dune systems. Within each system a list of key indicator species of conservation concern have been developed to help guide research and management actions.
Within grassland communities of the GPLCC one such key indicator species is the Lesser Prairie-Chicken. Lesser Prairie-Chicken range extends across the southern portion of the GPLCC area throughout Texas, Oklahoma, New Mexico, and Kansas. Lesser Prairie-Chickens are a good target species because they are widely distributed across the southern GPLCC, are a species of conservation concern, have large home ranges, and are likely sensitive to anthropogenic disturbances. Similarly, the Greater Prairie-Chicken, is a species of conservation concern, with large home range, distributed across the northern portion of the GPLCC including portions of Oklahoma, Kansas, Nebraska, South Dakota, and Colorado. Moreover, many of the general habitat requirements of Lesser Prairie-Chicken will be similar to those required for Greater Prairie-Chickens. Thus tools and models developed for use with Greater Prairie-Chickens should be easily modified for effective use with Lesser Prairie-Chicken.
Our LCC proposal had 3 objectives. Objective 1 was to produce a map of critical habitat for an indicator species, the Greater Prairie-Chicken, across the GPLCC. Objective 2 of this project was to create a map of dispersal habitat, which we defined as habitat necessary to allow movement and connectivity among populations. Objective 3 has two aspects. The first aspect was to modify the critical habitat model to include climate data from the WorldClim data set and to join the critical habitat model with the connectivity habitat model to create a comprehensive geographic model of critical conservation areas for the Greater Prairie-Chicken across LCC region 7, the Great Plains Landscape Conservation Cooperative.

Methods:
To predict lek occurrence across the GPLCC, we used logistic models of presence and absence for estimating pseudo absence data. We employed a hierarchical approach to model selection to identify environmental variables with high predictive power. Environmental variables were organized by the spatial scale at which they were estimated and entered into separate logistic regression models; significant factors were combined into a global model that pooled important variables across multiple.
Climate data for the year 2000 was obtained from the WorldClim climate model for each lek location, and then edited to the extent of the GPLCC. We used three climate variables: maximum annual temperature, minimum annual temperature, and average annual precipitation. Using the same subset of random point locations used for model development, we used logistic models to predict lek occurrence from climatic data. We used BIC model selection to choose the best climate model and then entered the parameters of this model into a new round of regression and model selection for multi-scale models. Variables included in the best performing model were then included as additional co-variates along with the variables from the best performing multi-scale combined model from objective 1 in ecological niche modeling using MaxEnt.

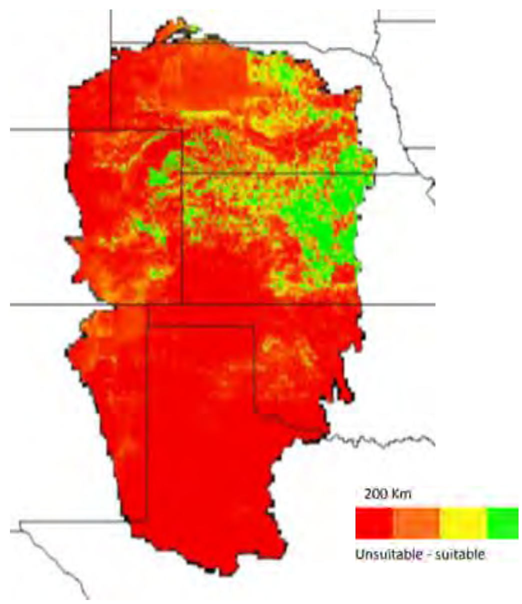

Figure 1. Predicted habitat suitability index from ecological niche modeling of Greater Prairie-Chicken lek locations

Results and Discussion:
Our modeling efforts delineated areas of high, moderate, and low Greater Prairie-Chicken conservation priority across the GPLCC (Fig. 1). Our final critical habitat model matched the lek location data well: 100% of our validation points were located in areas predicted by our model to be of high to moderately high habitat suitability.
The values we estimated for environmental conditions in areas of high critical habitat suitability allow us to set specific management targets for other regions of moderate or lesser quality critical habitat. Understanding the characteristics of highly suitable habitat will allow us to set specific habitat management goals for moderate to low suitability areas.

Black-tailed Prairie Dog Habitat Suitability Modeling for the Southern Great Plains: Cross-scale Analysis of Soils, Topography and Climate: Summary

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Introduction:
Black-tailed prairie dog (BTPD) conservation and management lies at the core of many conservation efforts in the region because of BTPD function as ecosystem engineers and keystone species in Great Plains grasslands. Although many social and economic factors influence where BTPD complexes can be conserved or expanded, a suite of critical abiotic and biotic factors also controls BTPD habitat suitability. In particular, climate, soils, topography and vegetation structure vary widely across the GPLCC and directly influence BTPD persistence and expansion.

Methods:
Study Area. We studied BTPD habitat suitability in the western portion of the Great Plains LCC. Our analyses focused on BTPD colonies occurring with 7 study sites consisting of National Grasslands or geographically distinct sub-units of National Grasslands in Colorado, Kansas, Oklahoma, New Mexico, and Texas. Within the administrative boundaries of each study site, land ownership consists of a mosaic of private, state, and federal lands.
Modeling Approach. We evaluated habitat selection using two different metrics: colony presence (colony clusters at 2km and 0.5km scales) and colony expansion pattern (distance from center of colony to maximum colony extent during expansion + 90m). These two metrics correspond, respectively, to analyses of second-order habitat selection: selection of a home range by an individual or social group within the available area defined by the geographical range; and third-order habitat selection: selection of habitat components within the immediate vicinity of an individual or social group's home range. We used general linear mixed models fit with the Laplace approximation method to assess relative BTPD habitat suitability. All models included a random intercept term that treated each colony cluster (clusters defined as a group of colonies within a 0.5 or 2 km neighborhood of one another) as a subject to account for the nesting of used and available pixels within colony clusters, and to account for variation in sample sizes among colony clusters. Models based on quantitative soil and topographic variables considered 8 possible predictors: slope (SL), topographic wetness index incorporating the effect of solar insolation on evaporation (TWIsi), mean soil sand content to 1 m depth (SAND), mean soil clay content to 1 m depth (CLAY), soil organic matter content (OM), soil pH (pH), and soil depth to a restricted layer (DTR).
Modeling Selection. We used a 3-stage approach for considering and selecting within sets of candidate models with and without interaction terms. First, we evaluated the set of candidate models that only included the 7 possible topoedaphic predictors (no interaction terms) using backward selection and minimization of AIC. Second, we evaluated a set of candidate models that included all predictors in the best model identified in the first step, but that also considered interactions between topographic variables (TWIsi and Slope) and those soil characteristics that could influence soil moisture and hence site productivity (SAND, CLAY, OM). Third, we evaluated a set of candidate models that included all predictors in the model identified in the second step, but that also considered interactions between 4 topoedaphic variables (TWIsi, SAND, CLAY, OM) and the climatic variables that vary across the study region (PRECIP = mean annual precipitation, and TEMP = mean maximum monthly temperature). When comparing models with versus without climate variables, we considered both area-under-the-receiver-operator-curve (AuROC) and AIC in model selection.

Results:
Global Second-order Habitat Selection. The final selected global model for colony presence considered factors at the 2km scale and performed with an AuROC of 0.6418, AIC of 484582.3, and used 1 random coefficient. With the coefficients shown in Table 1 the model is expressed as follows: TWIsi + Slope + Sand + Clay + OM + pH + DTR + TWI*Sand SL*OM Precip + Clay*Precip
Third-order Habitat Selection. The final selected colony expansion model performed with an AuROC of 0.5960, AIC of 330665.4, and used 2 random coefficients. With the coefficients shown in Table 1 the model is expressed as follows: TWIsi + Slope + Sand + Clay + OM + pH + DTR + TWIsi*Clay Slope*OM + Temp + Temp*OM + Precip + Precip*Clay

Table 1. Coefficients and associated standard errors for the best global second-order and third-order models.

	Coefficient	Std Error	Coefficient	Std Error
Intercept	5.6411	0.4356	2.8934	2.7608
TWIsi (range 1-30)	0.06968	0.002067	0.07622	0.005554
Slope (degrees)	-0.08081	0.007802	-0.1316	0.02084
Sand (1m depth, %)	-0.01085	0.000495	-0.0051	--
Clay (1m depth, %)	-0.2531	0.005908	-0.1576	0.00893
OM (1m depth, %)	0.4315	0.01087	-0.4982	0.1529
pH (1:1 soil:water)	0.3203	0.01075	0.2499	0.01883
DTR (depth to restriction layer, cm)	0.000555	0.000099	-0.00042	--
TWIsi*Sand	-0.00083	0.000047	--	--
TWIsi*Clay	--	--	-0.00251	--
Slope*OM	-0.06223	0.006028	-0.05797	--
Temp (mean monthly max. 1980-2010, C°)	--	--	-0.06196	0.09925
Temp x OM	--	--	0.04676	0.007904
Precip (mean annual 1980-2010, mm)	-0.02261	0.001121	-0.01275	0.003679
Precip x Clay	0.000675	--	0.000528	--

For local and ecological site second order models and break downs of habitat by county, consult the full document.

Agricultural Research Service

Patterns and Processes of Dispersal of Black-Tailed Prairie Dogs in a Heavily Managed Landscape of the Great Plains Landscape Conservation Cooperative: Summary

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Introduction:
To better understand how land use practices and grassland productivity affect individual dispersal and population connectivity, we conducted a population genetic analysis of black-tailed prairie dogs (*Cynomys ludovicianus*) across the longitudinal breadth of the Great Plains Landscape Conservation Cooperative (GPLCC), from the core of their distribution in the short grass prairie of Colorado to the eastern periphery of their distribution in the mixed grass prairie of Kansas.

Methods:
We collected 1127 samples that represent the east to west distribution of black-tailed prairie dogs within 14 locations. From the 4 locations with large complexes of prairie dogs, we randomly placed 3-4 10-km circles. As colonies separated by ≤10-km likely exchange migrants, we referred to these circles as complexes. Each complex contained at least 3 colonies and was separated from neighboring, sampled complexes in the same regional location by 10 and 30 km. Within each complex, we selected 3 colonies and sampled ~30 individuals from each colony. Of the collected samples, DNA was successfully extracted from 1099 individuals, representing all 14 regional locations. All extractions were diluted to a concentration of 0.25 ng/uL prior to primer optimization of microsatellite loci. For multi-locus microsatellite genotyping, we selected 30 microsatellite loci from previously published literature. Of those 30, we optimized primers for and genotyped individuals at 19 loci.

Statistical Analyses and Results
Objective 1a. Determine the frequency of long distance dispersal. To identify patterns of connectivity within and among our 14 regional locations, we first conducted analyses of molecular variance (AMOVAs). Results from our AMOVAs suggested that limited spatial structuring occurs because high dispersal rates and high levels of gene flow among populations within the core keep the genetic structure among colonies admixed. In eastern peripheral populations where grassland productivity is higher, and the distance between colonies is great due to poisoning, there was evidence that colonies were experiencing some genetic drift due to reduced gene flow, but the effect was smaller than anticipated and clearly indicated that gene flow occurred within peripheral populations and among core and peripheral populations.
Objective 1b. Estimate the average dispersal distance for emigrants of each colony and complex. Spatial autocorrelation analysis revealed that related individuals were found up to 60 km apart from one another. While related individuals could take more than one generation to disperse 60 km, this radius can be thought of as the basis for the genetic neighborhood within which gene flow and connectivity is great. Using both spatial autocorrelation separated by sex or using a single sex assignment test we found no significant difference in dispersal capability between males and females.
Objective 1c. Estimate the connectivity of regions over multiple generations. To estimate the connectivity among our regional locations, we used Bayesian inference to determine migration rates. Our results suggest high rates of migration occur within the core region; however, those migration rates are asymmetrical. This result might be tied to the slyvatic plague history of the core region.
Compared to migration within the core region (M = 79.4), migration within the periphery (M = 11.1), from the periphery to the core (M = 11.7), and into the periphery from the core (M = 35.4) occurs at a lower rate. These findings further reinforce that despite the relative isolation of peripheral populations compared to colonies in the core, regions within the periphery still exchange migrants regularly with other regions in our study.
At the broadest spatial scale, migrants from core regions to the periphery (M = 35.4) outnumber migrants from the periphery to the core (M = 11.8). Although this result isn't surprising given the larger colonies and populations in the core compared to the periphery, differences in grassland productivity may contribute to this asymmetrical migration pattern among the regions we sampled.
Objective 2a. Determine habitat suitable for dispersal among colonies but within regions. We first investigated whether isolation by distance could be detected at a fine spatial scale:
within locations and among complexes. We conducted Mantel tests of pairwise genetic and geographic distances separating colonies within our hierarchically sampled regional locations. We found that, in general, isolation by distance was not overwhelmingly predictive (R2=0.05-0.17) of genetic distance at this fine spatial scale. We next investigated whether including habitat information could improve our model. We created isolation-by-resistance models to predict gene flow among colonies within the same region based on a recent study that found water bodies/wetlands acted as barriers to movements and roads in urbanized areas act as semipermeable barriers. Our results indicate, with the exception of one region, there was little to no improvement over isolation-by-distance models suggesting that roads may not act as barriers to dispersal in rural locations.
Objective 2b. Determine the ecological processes responsible for maintaining connectivity or isolation among ecoregions.
We investigated whether isolation by distance alone could explain the observed genetic structure at our broadest spatial scale: among regions. We conducted a Mantel test, comparing pairwise Fst values and pairwise geographic distance among all colonies in which >2 individuals were collected. We found a significant, strong positive correlation (R2=0.41) between geographic and genetic distance at this broad scale. Consequently, we concluded that isolation by distance was likely the most significant ecological process affecting connectivity among ecoregions.

Lesser Prairie-Chicken Nest Selection, Microclimate, and Nest Survival in Association with Vegetation Responses to a Grassland Restoration Program: Summary

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Introduction

Climate models predict that the region of the Great Plains Landscape Conservation Cooperative (GPLCC) will experience increased maximum and minimum temperatures, reduced frequency but greater intensity of precipitation events, and earlier springs. These climate changes along with different landscape management techniques may influence the persistence of the lesser prairie-chicken (*Tympanuchus pallidicinctus*), a candidate for protection under the Endangered Species Act and a priority species under the GPLCC, in positive or negative ways. The objectives of this study were to conduct (1) a literature review of lesser prairie-chicken nesting phenology and ecology, (2) an analysis of thermal aspects of lesser prairie-chicken nest microclimate data, and (3) an analysis of nest site selection, nest survival, and vegetation response to 10 years of tebuthiuron and/or grazing treatments.

Methods

The study area included privately owned lands in Cochran, Hockley, Terry, and Yoakum counties in Texas and privately and publicly owned lands in Roosevelt County, New Mexico. The New Mexico study area was partitioned into 16 plots of about 65 hectares (ha), each assigned one of four combinations of herbicide and grazing treatments: treated not grazed (T-NG), treated and grazed (T-G), not treated and grazed (NT-G), and a control of not treated and not grazed (NT-NG).

Subadult and adult lesser prairie-chickens were captured on leks with walk-in funnel traps, rocket nets, and drop-nets each spring from 2001–12. We banded each captured individual with a New Mexico Game and Fish or Texas Parks and Wildlife Department aluminum blunt-end leg band and equipped with a 13-gram, loop style radio-transmitter. We relocated radio-tagged hens daily by triangulation. We approached the hen via homing to determine nest locations when locations remained unchanged for 3 days or more. We counted the number of eggs in each nest and then marked nest locations with a hand-held Global Positioning System unit.

Microclimate Analysis. We placed one Maxim Integrated Semiconductor data logger ("ibutton") inside the nest bowl and one outside of the nest bowl to record ambient air temperature and relative humidity (hereafter RH) at 10-minute intervals (categories hereafter are nest temperature, nest RH, outside temperature, outside RH). We collected the ibuttons within 3 days of nest failure or success.

Thermal Stress. We used video surveillance of lesser prairie-chicken nests to assess if a hen was exhibiting signs of thermal stress via gular fluttering. We programmed each camera to record one photograph every five seconds in 2010 and every 10 min in 2011–12; we modified the image capture rate in 2011–12 to allow for longer periods of data collection without nest visit and possible disturbance and to be consistent with the time interval at which thermal and humidity data were being collected.

Vegetation Response. We measured precipitation, soil moisture, and percent composition in each treatment plot from 2001–10. A weather station was placed near the site to monitor daily weather conditions. We measured soil moisture in April and June in each plot from 2001–10 with a quick-draw soil moisture meter with the exception of April 2002, June 2002, and June 2008.

Results and Discussion

We found few reports in the literature containing useful data on the nesting phenology of lesser prairie-chickens; therefore, managers must rely on short-term observations and measurements of parameters that provide some predictive insight into climate impacts on nesting ecology. Our field studies showed that prairie-chickens on nests were able to maintain relatively consistent average nest temperature of 31 °C and nest humidities of 56.8 percent whereas average external temperatures (20.3–35.0 °C) and humidities (35.2–74.9 percent) varied widely throughout the 24 hour (hr) cycle. Grazing and herbicide treatments within our experimental areas were designed to be less intensive than in common practice. We determined nest locations by radio-tagging hen lesser prairie-chickens captured at leks, which are display grounds at which male lesser prairie-chickens aggregate and attempt to attract a female for mating. Because nest locations selected by hen lesser prairie-chicken are strongly associated with the lek at which they were captured, we assessed nesting habitat use on the basis of hens captured at individual leks, and then for all leks pooled. There was no clear pattern of selection for treatment type for nest placement among hens associated with individual leks; however, when hens from all leks were pooled, we found nesting lesser prairie-chickens selected control plots for nesting over plots that were grazed, treated with tebuthiuron, or were both grazed and treated with tebuthiuron. Overall, the probability of a nest surviving the incubation period was 0.57 for this study and did not vary significantly among treatment types. In contrast to nesting preference for untreated habitats, lek use exhibited no noticeable selection of treatment type.

Over the 10 years of the habitat management study, there was 91 percent less sand shinnery oak (*Quercus havardii*) in treated areas than untreated areas. The removal of sand shinnery oak made environmental soil moisture more available for grasses and forbs to germinate and grow. Grasses increased by 149 percent and forbs increased by 257 percent in treated areas as compared to untreated areas throughout the study period. Our combined results, including our habitat selection analysis at the individual lek level, indicated that reduced rates of herbicide and short-duration grazing treatments were not detrimental to nesting lesser prairie-chickens and that populations of lesser prairie-chickens in shrub-dominated ecosystems may benefit from reduced rates of herbicide application and short duration of grazing that results in increased habitat heterogeneity.

Assessment of Lesser Prairie-Chicken Use of Wildlife Water Guzzlers: Summary

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Introduction:
Man-made water sources have been used as a management tool for wildlife, especially in arid regions, but the value of these water sources for wildlife populations is not well understood. In particular, the value of water as a conservation tool for Lesser Prairie-Chickens (*Tympanuchus pallidicinctus*) is unknown. However, this is a relevant issue due to a heightened conservation concern for the species and its occupancy of an arid landscape anticipated to experience warmer, drier springs and winters. We assessed if Lesser Prairie-Chickens would use commercially available wildlife water guzzlers and if there was any apparent selection between two design types. We confirmed that Lesser Prairie-Chickens would use bird friendly designed wildlife water guzzlers. Use was primarily during the lekking-nesting period (March–May) and the brood rearing period (June–July) and primarily by males.

Methods:
Water Guzzler Selection. We selected water guzzlers for this study based on the following criteria. First, we presumed that a guzzler requiring construction or complicated assembly and installation would be less attractive to landowners. Therefore, we considered only water guzzlers that were prefabricated, appeared to be easily installed, and were readily available from suppliers. Second, we wanted to assess water guzzlers that were designed for, but not necessarily exclusive to, upland game bird use. Third, given speculation that Lesser Prairie-Chickens may avoid vertical structures, we only considered units that could be installed below ground so that the top was at or near (<30 cm) level with the ground surface. Our final criterion was to select guzzlers of different trough design to assess differences in use by Lesser Prairie-Chickens.

We selected two wildlife water guzzler designs to test, one produced by Wildlife Water Guzzlers LCC and the other produced by Rainmaker Wildlife. The first guzzler was a 200 gallon circular reservoir and collection cover with 1.83m long trough extending from the unit. The second guzzler was 500 gallon rectangular reservoir with a trough built into the cover.

Water Guzzler Placement. Our study was located on a large private ranch in Cochran County, Texas. The area falls within the Southern High Plains, and is topographically flat terrain with intermixed sand dunes. We selected three leks (hereafter Leks 1, 2, and 3) that did not have an available water source (e.g., spring, stock tank) within 1.5 km radius. All three leks were known to have been active display grounds for Lesser Prairie-Chickens in 2011. We installed pairs of each wildlife water guzzler type 30 m apart and at a distance of 100 m from the edge of each of the three leks. Guzzlers were flush with the ground; this set-up allowed for guzzler types to be equally available to Lesser Prairie-Chickens. We placed fencing around each guzzler to exclude cattle, wild hogs, and deer.

Trail Camera Monitoring. We used motion activated cameras with infrared nighttime flash to monitor Lesser Prairie-Chicken use of the guzzlers. We scanned through all pictures searching for images of Lesser Prairie-Chickens. To distinguish visits by different birds from continual presence and use during one visit by the same bird, we did not record a new visit unless there was a fifteen minute gap between sightings of the species. If a prairie-chicken was present for longer than fifteen minutes and a new prairie-chicken arrived, we counted it as the same visit but increased the total count of individuals using the guzzler. When a Lesser Prairie-Chicken was detected, we recorded the date and time, number of individuals, and sex (when discernible).

Results:
We collected data from March 2012 through July 2013, with 514 camera trap days at Lek 1, 510 camera trap days at Lek 2, and 478 camera trap days at Lek 3. We recorded 27,261 digital photographic images at the Lek 1 guzzlers, 61,753 images at the Lek 2 guzzlers, and 31,810 images at the Lek 3 guzzlers. We only detected Lesser Prairie-Chickens visiting guzzlers at Lek 1 and Lek 2. Although all three leks were active in 2011, we subsequently confirmed that Lek 3 was inactive in 2012, which may explain the lack of any visits by prairie-chickens to the Lek 3 guzzlers. Therefore, we removed the Lek 3 guzzlers from all subsequent data analysis.

When considering only Leks 1 and 2, we conducted 1024 camera trap days and recorded 8,914 digital photographic images. Few of the images were of our target species, but we confirmed 43 visits by Lesser Prairie-Chickens to guzzlers with 1.34 (± 0.11 SE) prairie-chickens (n ± 58) detected per visit. The majority of Lesser Prairie-Chicken visits occurred during the lekking and brood rearing periods of 2012. Only 3 visits were detected in the non-breeding period and no detections occurred during the lekking or brood rearing periods of 2013. We were able to identify 46 visiting prairie-chickens as male, 9 as female and 3 as unknown. Although male prairie-chickens were detected across several months, females were identified at guzzlers only during June 2012. There was a clear bimodal pattern of visits to guzzlers by prairie-chickens, with 74% of visits occurring between 0534 and 0919 hrs, and 26% of visits occurring between 1747 and 2033 hrs. Although Lesser Prairie-Chickens used both guzzler types, the majority of detections (81%) were at the gray guzzlers. A test for homogenous frequencies indicated the difference in use was significant (χ^2 = 22.34, $P < 0.001$).

Discussion:
We were able to confirm that Lesser Prairie-Chickens will use wildlife water guzzlers designed for game bird use. Although Lesser Prairie-Chickens will use commercially manufactured guzzlers, we reject our second hypothesis that there would be no difference in use of game bird-friendly model types; indeed, we found substantial difference in use between the two models we examined.

For more information please refer to the full project report.

Results of the 2012 Range-wide Survey of Lesser Prairie-chickens (Tympanuchus pallidicinctus): Summary

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Introduction:
Within the five states of its range (Texas, Oklahoma, Kansas, New Mexico, and Colorado), the lesser prairie-chicken Tympanuchus pallidicinctus, LEPC) remains present on sand sagebrush (Artemesia filifolia), mixed- and short- grass prairies of western Kansas and eastern Colorado, through portions of northwest Oklahoma, the northeast Texas panhandle, and into the shinnery oak (Quercus havardii) and sand sagebrush habitat of eastern New Mexico and western Texas. Our objectives were to develop common, statistically robust survey and analysis methods to monitor LEPC population size and trends within the region and apply those methods in a pilot study in spring of 2012. This survey is the first statistically valid, comparable survey conducted across the entire LEPC range.

Methods:
Survey Area. The 2012 primary study area consists of the 2011 estimated occupied LEPC range (Southern Great Plains Crucial Habitat Assessment Tool) expanded by additional areas in Kansas with high probability of lek occurrence identified by the Western Governors' Association (Online Lesser Prairie-chicken Habitat Mapping Tool).
Survey Design. The study area was divided into 536 (15 x 15 km) survey blocks where at least 50% of the block area fell within the expanded LEPC range (Stratum 1). Blocks were ranked from 1 to 536 by an equal probability sampling procedure known as Generalized Random Tessellation Stratified (GRTS) sampling. The initial sample of 180 blocks was supplemented by 40 additional blocks from the GRTS list in Kansas and 36 blocks from the GRTS list in Region 1 (SOPR) in New Mexico and western Texas for a total sample size of 256 probabilistically selected blocks for aerial survey.
Survey Methods. Aerial surveys were conducted by helicopter accommodating two observers in the left and right rear seats, and a third observer in the front left seat. Transects were flown north to south or south to north at nominal values of 60 km per hour and 25 m above ground. Surveys were conducted between March 30 and May 3 2012 from sunrise until 2.5 hours after sunrise during the peak period of lek attendance. Two 15 km north-south transects, separated by 7.5 km, were selected in each of the survey blocks. The starting point of the first transect was randomly located in the interval [200 m, 7300 m] on the base of the block and the second transect was located 7500 m to the right of the first transect. Double observer (mark-recapture) sampling trials were conducted on the left side of the aircraft to help estimate the probability of detection of prairie-chicken groups. In addition to the number of individuals counted, other covariates recorded for each observation included: number of prairie-chickens sighted, date of the observation, activity (strutting or flushed), whether leks were man-made or natural, and habitat type. Surveys were conducted at 25 m above ground level, except when necessary to avoid obstacles.
Observers alternated seats between flights, allowing for estimation of an "average probability of detection by the average observer" for each position in the helicopter. Detection of five or more prairie-chickens in a group was classified as an active lek. If fewer than 5 individuals were observed, ground surveys were conducted to identify whether the birds were associated with a lek or otherwise classified as a "non-lek". If the observation was in Region 4 where LEPC, GRPC, and HPC were found, locations of all prairie-chicken observations were visited on the ground to determine if the observed groups of birds were all LEPC, all GRPC, or a mixture of lesser and greater prairie-chickens.

Results:
We observed 36 lesser prairie-chicken leks, 26 greater prairie-chicken leks, 5 mixed leks and 85 non-leks for a total of 152 prairie-chicken groups less than 300 m from the transect lines during surveys of 256 blocks. We post stratified the survey data into 4 regions (Stratum 1¯ collectively) and estimated the density of LEPC leks in each region and the overall density for Stratum 1¯ giving equal weight to blocks surveyed within regions. The estimated densities of LEPC leks in Stratum 1¯, unadjusted for probability of detection, were computed using the area surveyed per block (2×15km×0.6 km = 18 km2), the number of blocks flown, and number of LEPC leks detected. To adjust for the probability of detection, the unadjusted estimates were divided by the estimated average probability of detection, Plek = 0.296. The estimated total abundances of LEPC leks were computed using the estimated densities and the total areas of the regions (Table 1). Using the habitat region-specific mean group sizes for leks, we estimated total abundance of LEPC (Table 2).

For additional analysis of probability of detection and density/abundance by strata, region and species consult the full document.

Table 1. Estimated total abundance of LEPC leks in Stratum 1.

Habitat Region	Area of Blocks in Stratum 1 (km^2)	LEPC Leks Estimate	LEPC Leks CV	LEPC Leks 90% CI Low	LEPC Leks 90% CI High
1 - SOPR	27,675	428	0.43	125	736
2 - SSPR	13,500	105	0.99	16*	278
3 - MGPR	39,600	877	0.38	339	1,432
4 - SGPR	39,825	1,764	0.4	610	2,923
Total	120,600	3,174	0.29	1,672	4,705

Table 2. Estimated total abundance of LEPC in Stratum 1.

Habitat Region	Area of Blocks in Stratum 1 (km^2)	LEPC Estimate	LEPC Total CV	LEPC 90% CI Low	LEPC 90% CI High
1 - SOPR	27,675	3,699	0.4	1,254	6,144
2 - SSPR	13,500	1,299	0.77	110*	3,172
3 - MGPR	39,600	8,444	0.42	2,637	14,250
4 - SGPR	39,825	23,728	0.25	15,076	34,651
Total	120,600	37,170	0.22	23,632	50,704

Playa Research

Holocene records of environmental change in High Plains playa wetlands, Kansas, US: Summary

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Introduction:
Holocene environmental change has been poorly characterized throughout much of the High Plains because of a paucity of sites with dated high-resolution archives of environmental proxies. Playas, relatively small, shallow, depressional, ephemeral wetlands, are sites that are especially useful for reconstructing environmental change on the High Plains for several reasons. Because of their small size and ephemeral nature, playas are sensitive to environmental change and can preserve evidence of small-scale and large-scale environmental change. Playas are unique in that they are influenced by fluvial, lacustrine, and eolian processes, with the dominant geomorphic process at a given time being dependent upon prevailing environmental conditions. Playas are also the lowest points within internally drained and geographically and hydrologically isolated watersheds, such that playas are the primary sink for sediment within these watersheds. As a result, playas contain some of the most comprehensive sedimentary records for the central and southern parts of the High Plains, including buried soils, loess, eolian sand, lacustrine muds, and alluvium accumulated under different climates and by distinct geomorphic processes. Additionally, playas are ubiquitous, with more than 80,000 playas distributed throughout the High Plains region of Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska.

Methods:
Playa research sites for this study are located in Cheyenne, Finney, Scott, and Thomas counties, all on the High Plains region of western Kansas. A single soil core was collected near the center of playas to a depth of 119 cm at Thomas playa, 121 cm at Finney playa, and 600cm at Cheyenne playa (only the upper 365cm was analyzed). Two cores were collected from eastern grassed portion of Scott playa to depths of 597 cm (core S1) and 385 cm (core S2). Thomas and Finney playa cores were selected for in-depth analysis, while Scott and Cheyenne playa cores were used to provide corroborating data. Thomas and Finney playa cores were described in detail using standard methods of the USDA National Soil Survey Center, that is, soil horizonation, Munsell color, soil structure, redoximorphic features, carbonate occurrence, root and root-trace size and density, and pore size and density.

Magnetic susceptibility was also measured for the Thomas and Finney cores. Magnetic susceptibility should be greatest during mesic periods in which there is sufficient moisture to support dense plant growth, while extended arid or aquic conditions reduce magnetic susceptibility. Arid and aquic conditions were differentiated based on the absence/presence of redoximorphic features and stable carbon isotope data.

Cores from all four playas were sampled for stable carbon isotope analysis. Stable carbon isotope data were used to reconstruct past vegetation and, by inference, associated climatic conditions. The carbon isotopic ratio ($\delta 13C$) of plant material can be used to distinguish between C3 and C4 photosynthetic pathways since C3, cool, moist-season adapted vegetation has an average $\delta 13C$ value of −27‰, while warm, dry-season adapted C4 vegetation has an average $\delta 13C$ value of −13‰.

Discussion:
Radiocarbon, litho- and magneto-stratigraphic, and stable carbon isotope ($\delta 13C$) data indicate significant change occurred throughout the Holocene, which had profound impacts on playa ecosystem functions (e.g. groundwater recharge, surface water storage, and habitat). Minimum $\delta 13C$ values and buried soils observed during the Pleistocene–Holocene transition suggest sufficient moisture to support vegetative cover and promote pedogenesis. Low magnetic susceptibility, rapid increase in $\delta 13C$, and weak pedogenic alteration in overlying deposits suggest early Holocene aridity with increased landscape instability and sediment deposition. Early to middle Holocene stratigraphy transitioned from loess with little pedogenic modification into overlying buried soils; $\delta 13C$ values indicate playa vegetation was composed of as much as 90% C4 plants. Maximum magnetic susceptibility and buried soils in late Holocene deposits indicate sufficient moisture to support vegetative cover and promote pedogenesis.

Conclusions:
Records of Holocene environmental change preserved within High Plains playas are in close agreement with environmental records collected from a variety of other High Plains settings including upland loess deposits. Lack of hydric soil characteristics throughout soil cores suggests that the entire Holocene was dominated by arid to mesic conditions in which the playas were subaerially exposed most of the year in most years. Eolian processes dominated during the more arid early Holocene, while fluvial processes were enhanced during the late Holocene. Pedogenesis within seasonally inundated playas characterized the P-H transition and much of the middle and late Holocene. Playas did not store water for prolonged periods at any point in the Holocene, so lacustrine processes were minimal. Playas provided the greatest ecosystem functions during the P-H transition and the earliest early Holocene, when moisture availability was greatest. From the early Holocene to early–middle Holocene, playa ecosystem functions were greatly inhibited by prolonged arid conditions that resulted in high sediment accumulation rates on subaerially exposed playa floors. A return to more mesic conditions during the middle Holocene, and continuing into the late Holocene, delivered more water to playas and enhanced playa ecosystem functions, at least seasonally.

Understanding Landowner Attitudes, Opinions and Willingness to Participate in Playa Conservation: Summary

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Introduction:
DJ Case and Associates, in cooperation with the Great Plains Landscape Conservation Cooperative, Playa Lakes Joint Venture, Rainwater Basin Joint Venture, and a host of other partners, conducted 13 focus groups with farmers and ranchers in six states throughout the Playa Lakes Region in late summer, 2013. The goal of this research was to better understand landowner attitudes and opinions about playa conservation (with emphasis on impediments to conservation behaviors) to inform agencies' strategies to encourage and enhance conservation of playas on private lands.

Primary objectives:

1) Understand what functions and values landowners seek from their lands.
2) Identify what motivates landowners' management behavior on the landscape.
3) Understand what landowners in target areas think, feel, and believe regarding playas and playa conservation.
4) Pinpoint what incentives/disincentives are effective for landowners.

Additional objectives:

1) Assess the effectiveness of ongoing conservation messages and current media placements.
2) Provide assistance to the entire conservation community in working with landowners to achieve playa conservation.
3) Strengthen landowners' confidence in conservation organizations and programs.

Methods:
This study uses a qualitative focus group approach to gain insight into why people think (or behave) as they do. In addition to collecting in-depth information from participants, focus groups also serve as powerful communication tools in their own right. By asking questions and facilitating discussion, researchers share large amounts of critical information in a non-threatening and communicative way.

To prepare for the focus groups, staff from the PLJV and Rainwater Basin Joint Venture (RWBJV) conducted meetings and phone calls to solicit input from key partners, including the Natural Resources Conservation Service, Farm Service Agency, state wildlife agencies, water conservation districts, and landowner-led conservation groups to inform the development of discussion topics and a list of key landowners to invite to the focus groups. Based on information gathered from the initial meetings and discussions, DJ Case worked with PLJV and RWBJV staff to develop a topic guide/script to elicit landowner attitudes and opinions about land use, current participation in landowner programs, barriers to conservation, information they use for decision making, and sources of information they trust. The topic guide gave sideboards and direction to the focus group conversations. Similar issues were discussed at each focus group, but the questions asked and topics covered were customized from group to group.

PLJV and RWBJV staff selected locations for fourteen focus groups in key areas in six states. Locations were selected in areas with large playa clusters as identified by PLJV's Playa Decision Support System. Conducting focus groups in areas of high playa density not only directed attention to areas with the most playas, but also to areas most important for habitat connectivity.

The moderator began each focus group with an explanation of the process and ground rules. After that, the moderator showed participants six photos of playas in various different stages and conditions, to ensure everyone had a similar understanding of what playas are and to create a context for the discussion. Seven discussion items followed, and the moderator ended each focus group by playing and discussing an audio file of a 4 ½-minute episode of the Playa Country Radio Show.

Results:
Seventy-two of the 122 individuals (59%) who we recruited over the telephone actually participated in the focus groups. The scope of landowner attitudes and opinions were remarkably similar across all focus groups.

Landowners had both positive and negative impressions of playas. When considering playa conservation and program enrollment landowners primarily identified economics, aquifer recharge, contract duration, management activities prohibited by enrollment, playa size and location, and government distrust and convenience. Aquifer conservation and recharge was extremely important to landowners, however few landowners were aware of the connection between playas and aquifer recharge. There was wide skepticism from landowners about the amount of aquifer recharge through playas but also strong interest in having more information of the process from credible sources. Landowners were more willing to conserve playas based on aquifer recharge rather than potential benefits to wildlife.

Recommendations:
Based on landowner responses, DJ Case and Associates makes the following recommendations. These recommendations are numbered for ease of discussion and do not represent priority order. Some would need to occur simultaneously and/or are closely related to each other:

1) Work in small, prioritized "focal areas", 2) conduct intensive, not extensive communication efforts, 3) create Landowner Advisory Groups, 4) when contacting and working with landowners, try to minimize the sense of (further) government entanglement that landowners fear might come with playa conservation, 5) work with partners to help deliver information about playas and playa conservation programs (and how to enroll) to landowners, 6) maximize and promote the economic incentives for playa conservation, 7) work with agencies and partners to adjust existing playa conservation programs to better meet landowner needs, 8) create new or supplemental programs to enhance economic incentives, 9) Engage as many different partners as possible to assist with playa conservation efforts, 10) use local terms, 11) focus on aquifer recharge, then wildlife benefits, 12) use pride of ownership as a supporting message, 13) reconsider/repurpose the Playa Country Radio Show, 14) expand/upgrade websites.

Examining Playa Wetland Inundation Conditions for National Wetland Inventory, Soil Survey Geographic Database, and LiDAR Data

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Introduction:
Inundation is a critical parameter of wetland hydrologic performance. Many recent studies have adopted geospatial modeling to simulate wetland inundation dynamics, however, these models or methods are essentially theoretical predictions without comparisons to actual wetland conditions. Two data sources are currently used to define wetlands at the national level: the hydric soil footprints in the Soil Survey Geographic (SSURGO) database and the wetlands in the National Wetland Inventory (NWI). Although both datasets are not intended to be used for regulatory purposes, in fact, they have been widely used as management tools in wetland conservation programs. Little research has been done to compare the actual wetland inundation conditions with these two major national wetland datasets. Light Detection and Ranging (LiDAR) technology provides a new data source with accurate spatial parameters to help with wetland delineation and mapping.

In this study, LiDAR data were used to examine the effectiveness of theoretically-calculated hydrological depressions by using the real inundation conditions in playa wetlands. The study used geospatial analysis methods to discover the differences between the actual wetland inundation performance and the wetland information from the three datasets: the hydric soil footprints from the SSURGO data, the wetlands from the NWI data, and the depressions produced from LiDAR data. The degree to which the NWI, SSURGO, and LiDAR data predicted where ponding in playas will occur during the peak of the spring waterfowl migration was assessed. Wetland inundation and hydric vegetation coverage conditions were analyzed to examine the correlation of these three datasets with wetland inundation conditions. Evidence-based recommendations are provided to improve wetland mapping and guide wetland conservation programs.

Methods:
This study uses Annual Habitat Survey (AHS) data collected between 2004 and 2012 in the Rainwater Basin region of south-central Nebraska to examine differences between the actual inundation conditions and three datasets: the NWI, the SSURGO, and LiDAR-derived depressions. The AHS data are derived from color-infrared photography collected during flight surveys and field verification, when needed. The AHS documents spring habitat conditions in Rainwater Basin wetlands during the peak of spring waterfowl migration. The Annual Habitat Survey map two types of wetland information: inundation and hydric vegetation. This study used ArcGIS 10.1 to overlay and compare the hydric soil footprints in SSURGO data, the NWI data, and the LiDAR-derived depression layer with the AHS inundation and/or hydric vegetation layer(s).

Results:
The results show that current wetland inundated areas were well overlaid with these datasets. Over 99.9 % actual inundated areas were located in the hydric soil footprints of SSURGO data, 67.9 % of inundations were reflected in NWI data, and 87.3 % inundations were captured by LiDAR-derived depressions. However, the hydrologic degradation of playa wetlands was not reflected in these datasets. In the SSURGO data, only 13.3 % of hydric soil footprint areas were inundated and 26.6 % of footprint areas were covered with hydric vegetation during this period. For playa wetlands identified in NWI data, only 30.7 % were inundated during this period and 60.5 % were covered by hydric vegetation. A significant portion of the playa wetlands were not functioning with either ponding water or supporting hydric vegetation during the peak of the waterfowl spring migration season in the Rainwater Basin.

Discussion:
This study used the ground-truthed AHS inundation data to verify wetland dataset effectiveness. The hydric soil footprints in the SSURGO data reflect historic conditions, so the current degraded wetland and watershed hydrology were not evident. This is consistent with prior research that indicated the total area of wetlands classified by the SSURGO dataset is greater than that of the NWI data. The results of this study and prior research suggest that the NWI data often underestimate the size of wetlands and tend to miss small or linear wetlands. Additionally, many man-made water features are counted as wetlands in the NWI data. These areas can only host runoff and their functions are not the same as natural depressional playa wetlands. We verified that actual inundation can be well captured by a LiDAR-derived layer. However, LiDAR data may not be accurate in some wetland areas due to water body reflection and dense vegetation. In addition, LiDAR data cannot capture some complex systems such as underground culverts and ditches. More research is needed to further examine the effectiveness of LiDAR data in wetland mapping.

These findings confirm that watershed-level hydrologic restoration and within-wetland restoration is crucial to recover the inundation conditions of playa wetlands. The majority of the playa wetlands had no inundated water or hydric vegetation during the spring bird migration season over the 8-year study period. The current inundation condition is a result of landscape-level land use changes and wetland modification post-settlement. The natural process of playa wetlands has been dramatically shifted to an agricultural-dominated hydrologic process that has caused the degradation of historical hydric soil footprints. Playa wetland hydrology has been significantly altered at the watershed scale and within the wetlands.

Drainage Structure Datasets and Effects on LiDAR-Derived Surface Flow Modeling: Summary

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Introduction:

Digital Elevation Models (DEMs) are the most critical datasets to the success of surface hydrologic modeling applications. These datasets can be used to produce critical topographic and hydrologic derivatives, such as slope, aspect and flow accumulation. The accuracy of derived hydrological features is largely dependent on the quality and resolution of DEMs. However, the DEMs typically derived from airborne LiDAR only reflect the topographic features on the ground and are therefore explicitly topographic DEMs. Such LiDAR-derived topographic DEMs are, in some cases, not suitable to use for hydrologic modeling. For example, ground features such as bridges and roads over drainage structures may be modeled as "digital dams" in a topographic DEM, affecting the modeled drainage passage and flow accumulation over the land surface. The problem becomes more acute for hydrologic features derived at the local scale. For instance, it was found that the LiDAR-derived surface flows could spill erratically in the wrong location if flow barriers were not removed from the elevation data.

The major objective of this paper is to propose a method for developing LiDAR-derived hydrologic DEMs, which includes collecting data on drainage structures (i.e., culverts and bridges), and the preprocessing and burning of the drainage structures. This method was demonstrated in a study area where surface runoff contributes to several wetlands. Based on the case study, a data model for a drainage structure dataset to be used for hydrologic burning is proposed. The hypothesis is that hydrologic burning of drainage structures such as culverts can result in differences in simulated surface water derivatives.

Methods:

To create the drainage structure dataset, the geographic coordinates of inlets and outlets of culverts and/or center points of the edges of bridges were collected using a GPS unit along with their corresponding geometrical parameters (i.e., diameter of the culvert pipe, bridge span and depth to bottom). The data were stored as vector point features. However, the point data are not directly applicable for burning LiDAR-derived DEMs since roads or bridges present significant width or spans. The point features must be converted into linear features before the burning process. In this study, the collected paired feature points were assigned with the same Structure IDs (e.g., 1, 2, 3, …, etc.) then converted to line features. This process can be implemented using the Points to Line tool of ArcToolbox in ArcGIS 10.

The linear drainage structure features can be burned into the DEMs using different approaches. In this study, the elevation of DEM grids corresponding to the drainage structures were reduced using specialized GIS tools, such as DEM Reconditioning in the ArcGIS Hydrology toolbox. The DEM Reconditioning tool was developed based on the AGREE algorithm which drops the elevation of the DEM cells corresponding to user-defined buffers of drainage structures. The elevation drop and the number of cells for the stream buffer were determined based on the collected geometrical attributes of depth to bottom and culvert diameter and bridge span over the river channels. The number of cells (stream buffer) is equal to the rounded value of the half culvert diameter divided by the cell size of the DEM. If the diameter is smaller than the cell size, the number of cells for the stream buffer was assigned as 1.

The proposed method to burn drainage structures in the LiDAR-derived topographic DEMs was applied to a case study in Nebraska. Differences between the simulated catchment size, drainage lines, and depression storage volumes were compared.

Results:

The modeling results shown in the case study confirmed the hypothesis that burning hydraulic structures, such as road culverts, can affect hydrologic modeling using LiDAR-derived DEMs. The simulation conducted in Figure 1 shows that the catchment size can be affected by incorporating the culverts into the LiDAR-derived topographic DEMs. The simulated drainage lines aligned well with the locations of the culverts that were burned into the LiDAR-derived topographic DEMs. The topographic DEMs (without culverts burnt) resulted in drainage lines with incorrect placement, because the process of filling sinks caused by road obstruction tends to create continuous surface flow spilling over the roads at the wrong locations or rerouted erratically along the road ditches. DEMs without burning culverts resulted in more depressions, most of which were bounded by roads.

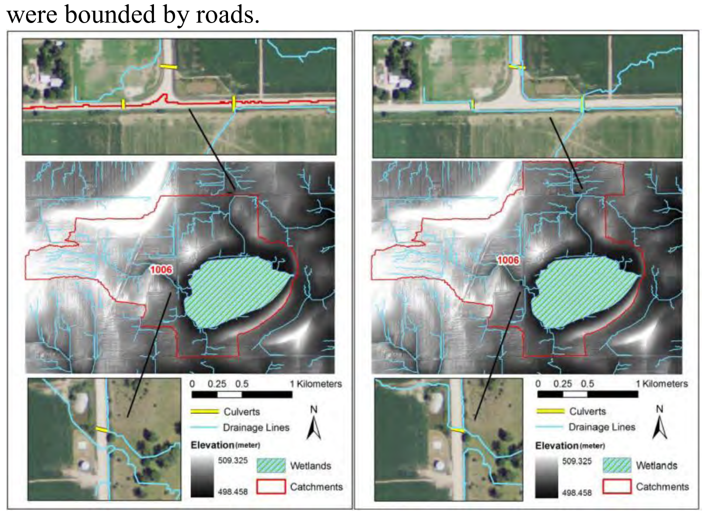

Figure 1. One study site showing the topographic (LiDAR) DEM on the left and the Hydrologic (LiDAR corrected with culverts) DEM on the right. The top inset map shows a digital dam error caused by the roadway and the bottom inset illustrates a local scale drainage line error.

Prairie Rivers and Streams Research

Water Availability Strongly Impacts Population Genetic Patterns of an Imperiled Great Plains Endemic Fish: Summary

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Introduction:
Wildlife and fisheries management has traditionally focused on the demographic properties of populations, however determining which type of action is best-suited for the target species requires understanding the interactions between demography, genetics, and the environment. Stream fishes in metapopulations are particularly sensitive to habitat fragmentation because persistence depends on dispersal and colonization of new habitat but dispersal is constrained to stream networks. Great Plains streams are increasingly fragmented by water diversion and climate change, threatening connectivity of fish populations in this ecosystem. The Arkansas darter (*Etheostoma cragini*) is a Great Plains fish species that is threatened by anthropogenic impacts to its stream habitats. In eastern Colorado, the western-most part of their range, Arkansas darters are currently only found consistently in approximately 10 stronghold sites out of 50 locations at which Arkansas darters have been collected within the last 20 years. Previous conservation efforts included an extensive history of translocations and stocking by Colorado Parks and Wildlife (CPW), assessment of taxonomic status based on mitochondrial DNA, mark-recapture methods to estimate demographic parameters, and occupancy analysis to determine the scale and specific habitat features influencing Arkansas darter site occupancy. Our study builds on these efforts to understand and improve Arkansas darter population dynamics by using a conservation genetics approach to describe population and landscape genetic patterns.

Methods:
During the summer of 2010, we sampled 19 sites with the highest probability of Arkansas darter occurrence in Colorado. Pelvic fin samples were collected from 477 Arkansas darters from 12 natural sites and 137 individuals from hatchery broodstock. Habitat surveys were conducted at each site in order to estimate Arkansas darter occupancy at naturally established sites and to test whether the same landscape variables that influence occupancy also play a role in shaping genetic diversity patterns. We measured or estimated stream distance, available habitat, average water depth and temperature, and percent vegetation cover, wetted area, intermittency, and cultivated crops. We tested the effects of habitat variables on three within-site genetic diversity indices (allelic richness, effective population size, and expected heterozygosity). We tested the effect of between-site landscape variables (total stream distance, % intermittency, and % cultivated crops) on pairwise genetic differentiation (F_{ST}). We included all three landscape matrices to determine the relative importance of each landscape variable. To assess the genetic contribution of hatchery genotypes into wild populations we first compared (F_{ST}) values between the hatchery and natural sites that have varying stocking histories (un-stocked, stocked natural site, established by hatchery) and second, conducted an admixture analysis.

Results:
We found small effective population sizes (range: 20-47), low levels of genetic diversity within populations, and high levels of genetic structure, especially among basins. Grouping by basin explained more of the remaining genetic variation (14.8 %; $p<0.001$) than variation among sites (9.6 %; $p<0.001$). Despite overall low levels of genetic diversity within Arkansas darter sites, we found that characteristics associated with Arkansas darter habitat quality had positive relationships with genetic diversity. Both at- and between-site landscape features were associated with genetic diversity and connectivity, respectively. Available stream habitat and amount of continuous wetted area were positively associated with genetic diversity within a site. We identified stream distance and intermittency as the most consistent influences on genetic differentiation among pairs of sites. We detected some evidence for hatchery introgression into the wild, but hatchery contribution was overall low.

Discussion:
Our results suggest that Arkansas darters in southeastern Colorado occur in small populations that are highly differentiated from one another. Low levels of genetic variation and small effective population size are both signs that Arkansas darter populations are potentially vulnerable to the negative effects of inbreeding depression and reduced ability to adapt to environmental change. The distribution of genetic variation is an important consideration for delineating conservation units. Our landscape genetic results suggest that reducing drying at both local and basin-level scales is the most important factor for improving the quality of Arkansas darter sites and facilitating connection between populations. At the local scale, restoration efforts should be directed towards securing or restoring stream flow and maintaining permanent refugia by reducing water withdrawals or planting streamside vegetation. At the broadest scale, conservation of this species might require not only protecting the immediate habitat supporting key populations, but also ensuring—for example through easements and private lands programs—that groundwater aquifers and hydrologic dynamics providing connectivity at larger spatial and temporal scales are maintained. Additionally, designing supplementation programs in which natural populations with high fitness are used to infuse genetically depauperate populations may be necessary to reinforce isolated populations and maintain genetic diversity across the landscape. Finally, we encourage additional studies aimed at understanding genetic and adaptive variation across the full range of the Arkansas darter. If change to the Great Plains region continues as expected, understanding the adaptive potential and protecting adaptive variation of the species is crucial. Further integration between genetic and demographic studies will allow evolutionary ecologists and managers to better understand the mechanisms underlying the distribution, abundance, and adaptive dynamics of stream fishes and other organisms.

Consequences of Stream Fragmentation and Climate Change for Rare Great Plains Fishes: Summary

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Introduction:
Historical and contemporary patterns in stream fragmentation combined with projected changes in climate present a substantial conservation challenge for pelagic-spawning cyprinids in the Great Plains. Quantifying fragmentation and determining threshold values for the longitudinal stream length necessary for imperiled species persistence will ultimately benefit management plans by providing information on the probability of long-term success of decisions. Specific objectives of this project included: 1) documenting the extent to which Great Plains riverscapes inhabited by this guild of fishes are fragmented; 2) evaluating threshold values for riverscape fragmentation that correspond with declines or extirpations of each species; 3) quantifying specific parameters of flow regime that are necessary for conservation and recovery of declining communities; 4) prioritizing regions in need of increased connectivity or where climate change is most likely to negatively impact extant populations.

Methods:
Objective 1: The large-order rivers located in the Great Plains region were selected as an area of focus for the study. The longitudinal stream length between barriers was used to define fragment length and was quantified using the stream layer associated with the National Hydrologic Dataset (NHD). In cases where upper reaches of large rivers were fragmented by a downstream barrier, but not an upstream barrier, fragment lengths were measured from the confluence of major tributaries defining the giving river, or the upper most historical collection of pelagic-spawning cyprinids. Some stream fragments were defined according to stream desiccations, in which stream beds remained dry for greater than 100 days of the year for the period 1969-2009. At least one USGS streamflow gauge had to be present within each fragment to allow for comparisons among contemporary and historical flow regime components and fragments had to be currently or historically inhabited by at least one of eight species of confirmed or suspected pelagic-spawning cyprinid.
Objective 2: For the initial analysis, we used recursive portioning in the form of Classification Tree Analysis to assign conservation status based on stream fragment length. For extinction threshold analysis, declining and stable populations of species were combined to represent fragments capable of supporting pelagic-spawning species. Finally, we tested for a relationship between cumulative extirpation within pelagic-spawning cyprinid communities and stream fragment length by regressing proportion of community extirpation as a function of stream fragment length. We tested for significance of the slope using polynomial logistic regression and quantified the correlation coefficient using a Nagelkerke R^2 value.
Objective 3: Fragment (n = 45) lengths ranged 120-711 km and percent of extirpations ranged 0% to 100%. Contemporary (1969-2009) streamflow data were downloaded from USGS gauges and analyzed using Indicators of Hydrologic Alteration (IHA) software to examine 13flow parameters for each of the 45 fragments. Among these fragments, we factored out the influence of stream fragment length by treating the parameter as a covariable and conducting a partial ordination in the form of Principal Components Analysis to determine streamflow parameters that explained the most variation in flow regimes. We then considered historical changes in streamflow parameters with large loadings (a measure of variation explained within multivariate space) and the relationship to percent extirpation among pelagic-spawning cyprinid communities.
Objective 4: Given the association between flow magnitude and persistence of pelagic-spawning cyprinid communities, we quantified future changes in streamflow (i.e., discharge) projected under climate change scenarios. Specific values for percent change in evapotranspiration and precipitation differ according to climate change models, and depend upon model assumptions concerning future rates of anthropogenic carbon dioxide emissions, solar variability and volcanic activity. To address these differences, we used the average projected percent change in streamflow according to 12 climate models.

Results and Discussion:
Our findings supported extirpation from a majority (i.e., >50%) of fragments included in this study for the flathead chub (61%), silver chub (64%) and sturgeon chub (75%), and values that closely match previously reported extirpation rates for the Arkansas River shiner (79%) and peppered chub (88%). Within the Great Plains, we found estimated minimum thresholds in fragment length varied among eight species, but were consistently >100 km in length. Suspected pelagic-spawning shoal chub exhibited the shortest threshold in longitudinal length (103 km), which supports research that indicates the speckled chub *Macrhybopsis aestivalis* require relatively shorter longitudinal stream lengths for completion of life history. Similarly, our estimated minimum thresholds for Arkansas River shiner and peppered chub (217 and 205 km, respectively) were consistent with previous conclusion that 220 km represents the near minimum length required for completion of life history. We found percent of extirpated populations among eight species of suspected or confirmed pelagic-spawning cyprinids was positively correlated with estimated minimum thresholds in fragment length, strongly suggesting stream fragmentation has played a role in observed declines in abundance and distribution. Imperilment associated with stream fragmentation provides a parsimonious mechanism that links widely dispersed literature accounts of pelagic-spawning cyprinid declines and explains over 70% of variation in extirpation among eight highly imperiled Great Plains fishes.
For a full discussion of results and implications for pelagic-spawning cyprinid conservation, consult the full document.

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Introduction:
The newly established Great Plains Landscape Conservation Cooperative (GPLCC) is faced with the immense task of having to quickly compile and manage extensive databases or inventories of the biodiversity that it has been charged to manage and sustain, and then with the task of analyzing those huge data sets and capitalizing on them to develop sound, science-based management plans. The basic task of inventorying biodiversity has actually been under way for many years. Existing natural history museum collections, like those in which we work, can provide major contributions to such inventories in the form of valuable historic organismal occurrence records, and their specimens can be used in many ways for basic research and applied conservation planning. Unfortunately, much of the wealth of information stored in natural history collections requires substantial investment to be made accessible and useful to natural resource managers and researchers.
We were charged by the GPLCC with providing some of the inventory data that will be required, and to assess what other data may be available and what will be required to make it useful. From databases that we and our collaborators manage, we compiled extensive, high quality data sets on occurrences of fishes, aquatic reptiles and amphibians, freshwater mussels, and cave invertebrates from the Texas, New Mexico, Colorado and Oklahoma portions of the GPLCC. In the full report we deliver these >76,000 complete, standardized and normalized records, over 55% of them georeferenced and in a format that should make them immediately useful to the GPLCC.
Once the GPLCC obtains the extensive biodiversity inventories it requires, it is by no means easy to integrate such massive data sets into management planning. However, we demonstrate how raw occurrences for diverse sets of organisms can be effectively combined in computer models with diverse environmental data (including past, present and future) in ways that greatly facilitate planning at the landscape level. Our methods also allow incorporation of complex information on socioeconomic factors that in practice always complicate on-the-ground management into such planning. We do this by first developing powerful predictive computer models of each species' distribution (Fig. 1). These models provide a continuous coverage of probabilities of occurrence of each species for all cells of a fine-scale grid extending across the landscape of interest, thus "filling in the blanks" between the actual occurrences that are limited by many factors such as historic factors, accessibility, and landowner permission.

Methods:
Our models were developed with recent occurrence records and recent climate data, and were thoroughly tested and demonstrated to be powerful predictors of actual occurrences under current conditions. While our demonstration was done statewide for Texas, it uses species that occur in, and are of particular interest to, the GPLCC, and our methods could be used by the GPLCC for its geographic area once appropriate occurrence data are obtained.

Results and Discussion:
We provide to the GPLCC biodiversity inventory data and an assessment of other datasets that may be available and what will be required to make them useful. From databases that we and our collaborators manage, we have compiled extensive, high quality data sets on occurrences of fishes, aquatic reptiles and amphibians, freshwater mussels, and cave invertebrates from the Texas, New Mexico, Colorado and Oklahoma portions of the GPLCC. While support for this project enabled us to utilize such high quality data for Texas in the rigorous modeling analyses (Fig. 1), these additional primary data could eventually be used by the GPLCC to perform such analyses for its own geographic scope.
In the short time frame allowed by this grant, we explored the consequences of climate change for seven selected freshwater fishes and generated techniques for quantitative and robust estimates of climatic-based shifts in habitat suitability. Generally, species model projections showed substantial southerly shifts in suitability. This is especially apparent in species with distributions centered in Texas and the southern extent of the GPLCC area (e.g., in the Edwards Plateau and southern Rolling Plains ecoregions), with two species (*M. treculii* and *P. carbonaria*) losing nearly all suitability within the study region by 2100 in the A2 climate scenario. Species with distributions centered in the northern areas of the extent (e.g., *N. oxyrhynchus* and *H. placitus*) generally showed model projections with expanded suitability into the study area under both conservative and aggressive climate scenarios. This raises questions of possible pressures due to climate on the northern portions of their range outside of the extent considered in this analysis. One exception to the southerly shifting suitability pattern observed was the result of *Cyprinodon variegatus* models, the range of which increased under both climate change scenarios, expanding up-drainage and eastward.

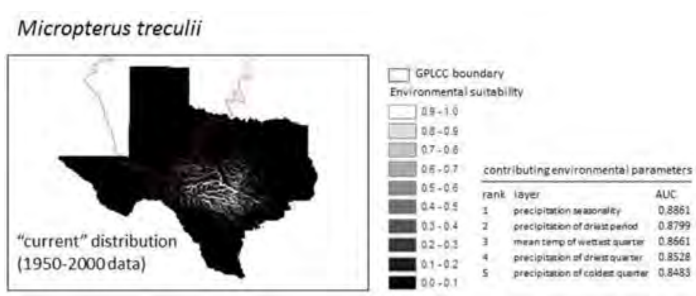

Figure 1. Micropterus treculii:Species distribution model for Texas

Evaluating the Reproductive Success of Arkansas River Shiner by Assessing Early Life-History Stage Dispersal And Survival at a Landscape Level: Summary

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Introduction:
The rivers and streams of the Great Plains ecoregion have experienced dramatic changes over the past 100-150 years due to changing land cover patterns, landuse practices, and climatic shifts. Under natural conditions, these aquatic systems were characterized by extremes in flows and other biotic conditions, yet supported a diverse endemic fish fauna adapted to the unique challenges of this environment. However, anthropogenic activities have resulted in high levels of fragmentation, loss of channel complexity, reductions in stream discharge and high flow events, and elevated temperatures resulting in new conditions, different from the prevailing extremes that formerly characterized prairie rivers and streams.
The rapid decline of pelagic broadcast-spawning cyprinids has been attributed to a range of factors including fragmentation, altered flow regimes, and invasive species. This study examined how environmental changes across the landscape of the Great Plains and associated ecoregions impacted the persistence of members of the pelagic broadcast spawning guild. We used one of the better-studied species, Arkansas River shiner *Notropis girardi*, as a model and assessed how landscape changes altered the distribution of these fishes.

Methods:
Our approach was to construct SDMs for two time periods relevant to the decline of Arkansas River shiner. We combined distribution structuring variables, e.g., geology, climate, alongside functionally relevant covariates and movement-related descriptors, e.g., discharge, unfragmented river length. We used over 80 years of fish presence data collected from the Great Plains and associated ecoregions, to investigate the relative influence of changing environmental factors on the historic and current truncated distributions of Arkansas River shiner. Historic (n = 163 records) and current (n = 47 records) species distribution models were constructed using a vector-based approach in MaxEnt by splitting the available data at a time when Arkansas River shiner dramatically declined. Model validation was performed using a data partitioning method: a ten-fold cross validation, which divides the data into ten mutually-exclusive subsets. Each subset is removed sequentially and the model is fit against the retained data and tested against the removed subset. Model fit was evaluated using area under the curve (AUC), where a value close to one indicates a very good model fit. To evaluate the predictive accuracy of our models, we backcast and forecast each model to the alternative time period to assess whether the model could correctly predict Arkansas River shiner presence in individual segments. This approach also allows an assessment of whether the universal relationships between the species locations and environmental parameters were consistent between the two time periods. Spatial congruence between the two models in each time period was assessed using Spearman's rho correlation to test the relative rank of each segment across the two models.

Results:
Discharge, stream order, landuse, and geology provided the greatest contribution to the current model, whereas stream order, mean temperature of the coldest quarter, and precipitation in the driest month had the highest permutation importance (>15%). The model predicted a high probability of presence (>50%) for 343 individual river segments including a large section of the Canadian River, with areas of particularly high probability (>80%) near the confluence of Revuelto Creek, New Mexico.
Stream order, discharge, mean temperature of the wettest quarter and slope contributed the most to the predictive ability of the historic model. Discharge, stream order and precipitation seasonality had permutation importance values > 15%. A much greater area was predicted as having > 50% (1312 individual river sections across 20 rivers) probability of presence for Arkansas River shiner. Areas of particularly high presence probabilities (>80%) again included the Canadian River near the confluence of Revuelto Creek, New Mexico and north of Minco, Oklahoma and near Norman, Oklahoma (Figure 1).

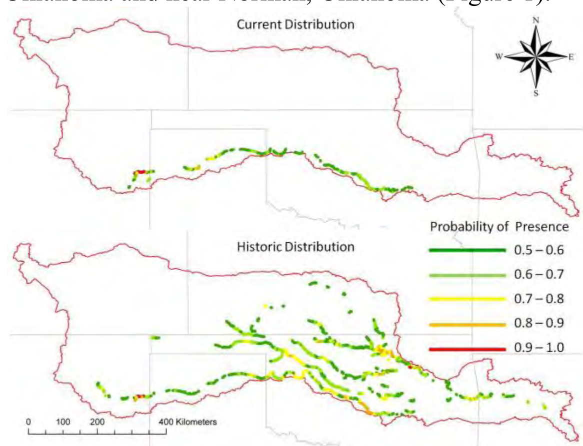

Figure 3. Current and historic probability of presence for Arkansas River shiner.

Discussion:
Discharge and stream order were significant predictors in both models, however the shape of the relationship between the predictors and species presence varied between time periods. Drift distance (river fragment length available for ichthyoplankton downstream drift before meeting a barrier) was a more important predictor in the current model and indicated river segments 375-780 km had the highest probability of species presence. Performance for the historic and current models was appropriate; however forecasting and backcasting to alternative time periods suggested less predictive accuracy than when using standard validation techniques. Our results identify fragments that could be considered refuges for endemic plains fish species and we highlight significant environmental factors that are reasonable targets to address recovery. Our results also emphasize the need for development of ecologically-significant metrics.

Interacting Effects of Discharge and Channel Morphology on Transport of Semibuoyant Fish Eggs in Large, Altered River Systems: Summary

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Introduction:

Habitat fragmentation and flow regulation are significant factors related to the decline and extinction of freshwater biota. Pelagic-broadcast spawning cyprinids (pelagophils) are a reproductive guild of small minnows that require moving water and some length of unfragmented stream to complete their life cycle. The life history of pelagophils renders them particularly sensitive to river fragmentation, because it may cause the ichthyoplankton to be washed into unsuitable habitats, such as reservoirs, where they risk being smothered in sediment or subjected to increased predation risk. It is unknown how discharge and habitat features interact at multiple spatial scales to alter the transport of semi-buoyant fish eggs. Our objective was to assess the relationship between downstream drift of semi-buoyant egg surrogates (gellan beads) and discharge and habitat complexity. We hypothesized that downstream drift of egg surrogates would be controlled by the interaction of the flow regime and river geomorphology, with drift rate reduced in reaches with greater habitat complexity.

Methods:

In March 2013, we quantified transport time of a known quantity of beads at each of seven locations on the North Canadian and Canadian rivers in Oklahoma. Analyses of aerial photographs were used to select from a pool of 13 potential sites by using a scoring and ranking system based on three landscape metrics: (1) total landscape area, (2) mean shape index (the complexity of patch shapes in comparison to a square) and (3) mean contagion index (level to which patches were dispersed across the landscape). Selected study sites represented a range of the habitat complexity available. As the sand bed rivers of the Great Plains can undergo changes in physical structure in a short amount of time, we field validated the accuracy of aerial photography habitat classifications at each site by assessing habitat classification at 25 random points: sand, water (shallow and deep combined) or vegetation. Habitat complexity was also assessed by calculating width:depth ratios at each site. Discharge was measured at each site using the velocity-area methods at one or more points where the river formed a single channel. Discharge was also assessed using gage measurements at the time of the bead release from the closest U.S. Geological Survey gage on the same river.

Gellan beads have similar physical properties including shape and specific gravity to the eggs of pelagic-broadcast spawning cyprinids. Two or three egg collectors were placed 500 m downstream from the bead release points. Transport time was assessed based on median capture time (time at which 50% of beads were captured) and sampling period (time period when 2.5% and 97.5% of beads were captured).

Results:

Median time of egg capture and length of sampling period were both negatively correlated to site discharge. Length of sampling period was also related to habitat complexity, particularly the dispersion and interspersion of habitat patches within the landscape. The length of time taken to capture the majority of the beads was greater in river reaches with multiple interspersed areas of shallow and deep water and in channel features such as sandbars and islands.

Discussion:

Our results highlight the interaction between hydrology and geomorphology in driving transport times, but also indicate that higher dispersion of habitat patches relates to increased retention of beads within the river. In the Great Plains, fragmentation linked to water supply reservoir construction has resulted in channel narrowing of braided downstream reaches, leading to decreased habitat complexity and thus, increased particle transport rates. However, dam construction has also led to a reduction in mean annual discharge in many Great Plains rivers, which may somewhat offset the increased egg transport associated with low habitat complexity.

Several factors pertinent to the persistence of populations of pelagic-broadcast spawning cyprinids were not included in this study. For example, individual eggs may have variable physical properties, such as buoyancy, that may affect transport distance. It is therefore likely that individual eggs will respond to the same stimulus differently. Additionally, future studies addressing the long-term viability of eggs retained in low-velocity areas would allow more robust calculations of channel length needed to sustain populations, although tracking such small particles over great distances would be extremely challenging.

These results could be used to target restoration activities or prioritize water use to create and maintain habitat complexity within large, fragmented river systems. Possible management options for cyprinid species include dam removal, restoring components of the natural flow regime and maintaining perennial base flows, which may re-establish channel forming processes. Where appropriate, habitat restoration could enhance habitat complexity and connectivity, thereby increasing egg retention.

Sampling Efficiency of the Moore Egg Collector: Summary

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Introduction:
Quantitative studies focusing on the collection of semibuoyant fish eggs, which are associated with a pelagic broadcast-spawning reproductive strategy, are often conducted to evaluate reproductive success. Many of the fishes in this reproductive guild have suffered significant reductions in range and abundance. However, the efficiency of the sampling gear used to evaluate reproduction is often unknown and renders interpretation of the data from these studies difficult. Our objective was to assess the efficiency of a modified Moore egg collector (MEC) using field and laboratory trials.

Methods:
Gear efficiency: *flume trials.* Our experimental studies were conducted in an outdoor concrete flume (29.26 m long, 1.83 m wide, and 2.44 m deep). We tested the efficiency of the MEC, a sluice box–like gear designed for the nondestructive capture of semibuoyant fish eggs, under five discharge scenarios (0.14, 0.28, 0.71, 1.42, and 2.12 m^3/s). The MEC was mounted in the center of the flume 28 m from the upstream end of the channel. Gellan beads, which have a similar shape and specific gravity, were used in place of Arkansas River Shiner eggs. Each trial consisted of 1,000 gellan beads being released at one of three equally spaced points across the channel (center channel, left, or right) 4 m downstream from the start of the channel. Trial length was dependent on discharge, 5 min being allowed for the 0.14 and 0.28 m^3/s treatments and 3 min for the 2.12 m^3/s treatment. Trial length was determined from preliminary releases and based on the time taken to observe all the gellan beads encountered and included a minimum of 1 min with no captures. A total of 57 trials was undertaken, 6 each at the two lowest discharges and 15 each at the three greatest discharges.
Gear efficiency: *field trials.* The efficiency of the MEC was also assessed using field trials. The MEC was deployed at a site on the Cimarron River upstream of State Highway 108 near Ripley, Oklahoma (36◦01_28.69_N, 96◦54_53.83_W). One thousand gellan beads were released upstream of the MEC, and we recorded the number of beads collected. During each sampling trip, five releases of 1,000 beads were made 45.72 and 91.44 m directly upstream from the MEC (n = 10). The sampling procedure was completed on five occasions (27 April, 11 May, 21 May, 31 May, and 11 July 2012). The sampling dates were chosen to assess the MEC efficiency under a range of river discharges (4.90, 8.38, 10.22, 16.28, and 17.61 m3/s).

Results:
Gear Efficiency: Flume Trials. The capture efficiency of the MEC in the flume trials ranged from 0.0% to 9.5%. Capture efficiency was related to discharge ($F_{4, 42} = 70.74$, $P < 0.001$) but not release point ($F_{2, 42} = 0.12$, $P = 0.89$) or the interaction between discharge and release point ($F_{8, 42} = 0.49$, $P = 0.86$). Tukey's HSD post-hoc test indicated that there were differences between two main groups, one group encompassing the three lowest discharges and the other encompassing the two highest discharges. No gellan beads were captured at the two lowest discharges; however, at 0.71 m^3/s efficiency ranged between 0.0% and 3.3%. At the two highest discharges, captures were considerably higher (2.1– 9.5% at 1.42 m^3/s and 4.5–6.6% at 2.12 m^3/s). As expected, the velocity of water passing through the MEC was almost perfectly correlated with the discharge setting for the flume ($r = 0.9995$, $n = 5$, $P < 0.001$).
Gear Efficiency: Field Trials. The velocity of the water passing through the MEC ranged from 0.50 m/s to 0.85 m/s, which falls within the range of velocities of the three highest discharges tested in the flume experiments. Water velocity was not correlated with the gauge reading for the site; however, this was driven by a suspect reading at the highest discharge ($r = 0.865$, $n = 5$, $P = 0.058$). The efficiency of the MEC during the field trials varied from 0.0% to 3.6%. The number of gellan beads caught by the MEC was negatively related to discharge (gauge reading) and release distance from the MEC (likelihood ratio $\chi^2 = 21.564$, df = 2, $P < 0.001$). Bead captures approximately 270% higher at the 45.72-m release point, and captures decreased by 13.6% for every one-unit increase in discharge.

Discussion:
We found that factors such as discharge, velocity, and release distance resulted in dramatically different capture rates in both laboratory and field trials. Efficiency was zero at the two lowest discharges, suggesting that the gellan beads were not subject to gear capture (i.e., not traveling high enough in the water column); however, as discharge increased, so did efficiency.
Overall, the capture rates in the field trials were lower than those in the flume experiments. This reduction in capture efficiency between the simplified cross-sectional flume channel and the complex braided river site could be explained by greater retention of the gellan beads in the natural environment. Unlike in the controlled flume experiments, the capture rate was negatively related to discharge and was also highly influenced by release distance from the MEC. At lower discharges, the water within the river was confined to a limited number of channels, making areas of higher velocity and the predicted downstream route of the gellan beads easier to identify. Conversely, at higher discharges, the irregular and complex nature of the channel profile provided multiple routes for the gellan beads to travel. These results are important from a management standpoint because they clearly indicate that channel complexity has a strong influence on the efficiency of the MEC. The gellan beads were highly aggregated and concentrated at the bottom of the channel at the lower discharge. Despite less aggregated captures at the higher discharge, the gellan beads were still highly clumped and therefore failed a significant assumption for the use of the MEC. These results suggest that appropriate placement of the MEC in the channel is critical to obtaining an accurate and precise sample.

Historic and Current Habitat Use by Arkansas River Shiner in the South Canadian River in Central Oklahoma as Affected by River Flow: Predictions for Habitat Under Future Climate Scenarios: Summary

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Introduction:

The primary objective of this project was to evaluate potential effects of habitat and environmental change on Arkansas River shiner (ARS), *Notropis girardi*, by examination of habitat use and availability at several spatial scales using both historical and recently-collected data from seven sites within the South Canadian River. We examined variation in environmental factors over time and/or space and the relationship of that variation to river discharge and asked if variation in abundance of ARS in collections was explained by environmental variation.

Methods and Results:

Macrohabitat. We used data from two sources at the largest spatial scale: 1) Collections made by the Oklahoma Department of Environmental Quality (DEQ) over a period from 1976 to 2010 at two sites and 2) Collections made by the US Fish and Wildlife Service (USFWS) from 2007 to 2012 at seven sites.

Collections made by DEQ covered periods during which ARS were highly abundant in the South Canadian River (ca. prior to 1990) as well as the period since their major decline in the system (ca. post-1990), which allowed us to ask if there were differences in environmental factors that correlated with that decline. Analyses of these data showed the only environmental factor that explained number of ARS captured was air temperature, with fewer ARS captured when temperatures were low. This correlation very likely reflects seasonal variation in population size.

Analyses of collections made from 2007-2012 by the USFWS examined both spatial (among sites) and temporal (among years) variation in environmental characteristics. In 2007-2009, these collections were made in June, but in 2012, the collections were made in October. Although there was variation both within and among sites for the habitat variables measured in conjunction with these collections, there was no striking pattern of spatial variation in any environmental factor, but the abundance of Arkansas River shiners showed a distinct decline from upstream to downstream. Several environmental characteristics were related to discharge, although some of the relationships were only detected when the collections made in October 2012 were included. When all collections were included, the presence of submerged structure was more likely at lower discharge and conductivity was higher at higher discharge. Other environmental factors were related to discharge regardless of the collections included. These were: presence of backwaters, which was more likely at lower discharges, low turbidity at lower discharges and higher water temperature at higher discharge. When examined with respect to individual environmental variables, the percent of ARS in a given collection was positively related to water temperature and discharge (only when all collections were included). Regardless of the number of collections used, there was a positive correlation between the percent of Arkansas River shiners in a collection and conductivity recorded at the time of collection.

Mesohabitat. Specific mesohabitats identified for the South Canadian River and used in multiple studies include: backwaters, bank, main channel, submerged sand ridges, deep pools, and (for Matthews' study) lower creek channel. For these analyses we used four data sources: 1) Two (of six) collections made by USFWS in October 2012; 2) Historical data collected by William Matthews at one site in the South Canadian River from 1976-1977); and 3) Data collected by Karl Polivka at one site in South Canadian River from 1994-1996).

Analyses of collections made by USFWS in October 2012 with respect to mesohabitat use by ARS failed to detect any mesohabitat affinities. The Matthews and Polivka studies both showed that ARS used deeper pools at the highest percentage of occupancy (>80% occupancy by ARS in both studies). They also agreed that "bank" microhabitat had > 50% occupancy. The two studies differed in that Matthews found more use of backwater habitats (70% occupancy) and less use of the main channel at 40% occupancy (perhaps because of extremely harsh condtions in the main river channel in summer 1976), whereas Polivka showed more use of main channel (62% occupancy) and less in backwaters (33% occupancy). Differences between the two studies could relate to differences in conditions in the years of the two studies, to differences between the two investigators in some subjective decisions in describing mesohabitat types, or to the simple fact that ARS not only use a wide range of mesohabitat types within a year, but among years. The combination of the two studies underscores the value of deeper, potentially refuge, pools, often along river banks, for ARS.

Microhabitat. At the finest spatial scale, we examined distribution of ARS within small microhabitat areas, i.e., the physicochemical conditions and fishes taken within individual points and seine hauls in an area of only 10 m^2. Then fish were collected by seining a small area at that point approximately 2 m wide and 5 m long. Data in both studies were examined for relationships of ARS to individual microhabitat variables, and also to combinations of those variables in multivariate analyses (Principal Components Analysis), with graphical assessment of distribution and abundance of ARS on PCA axes, at different season or times of year. We also considered availability of different microhabitats at different times or river discharges, and the level of association of ARS with the other most common minnows, usually red shiner.

In Matthews' study, the widest array of available microhabitats was in May 1976, when discharge was highest (ca. 250 cfs). In August 1976 at lowest discharge (8 cfs) no creek habitat remained and the river channel was reduced to small pools with little connecting flow, and harshly high temperatures. In October 1976 at continued low flow (ca. 22 cfs), one long, shallow pool along the west bank of the river, with numerous deeper pools were crowded with huge numbers of ARS and red shiners. In winter 1976-77 discharge ranging from 29 to 48 cfs, lower creek microhabitats were available, and the river channel had substantial flow in braided channels.

Conservation Priorities for Great Plains Fish Communities Based on Riverscape Connectivity and Genetic Integrity of Populations: Final Report Summary

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Introduction:
On a global scale biodiversity within river networks is threatened by interactions between habitat fragmentation and altered hydrologic regimes. In the Great Plains of North America, stream networks are fragmented by >19,000 anthropogenic barriers and flow regimes are altered by surface water retention and groundwater extraction. Fragmentation and flow modification in stream networks alter the ecology of fishes occupying these habitats. Stream fish communities in Great Plains rivers have become increasingly homogenized during the past century associated with species invasions and losses. The goal of this study was to determine the relationship between broad-scale environmental alterations, stream fish community structure, and population genetic diversity within five Great Plains river basins.

Methods:
The Great Plains of North America is a semi-arid region historically dominated by grasslands, prairie, and steppe biomes situated between the Rocky Mountains to the west and extending eastward to at least the 95th meridian. We documented the distribution of anthropogenic barriers and dry stream segments using data from the 2012 National Anthropogenic Barrier Dataset in five basins covering the central Great Plains. We used an information-theoretic approach to rank competing models involving fragmentation, discharge magnitude, and percent of time streams had zero flow (i.e., desiccation) to test effects of environmental alterations on fish communities, guilds, and genes.

Results:
Fragmentation caused by anthropogenic barriers was most common in the eastern Great Plains, but stream desiccation became more common to the west where rivers are underlain by the depleted (i.e., extraction > recharge) High Plains Aquifer. Longitudinal gradients in fragmentation and desiccation contributed to spatial shifts in community structure from diverse communities dominated by pelagic reproductive guilds where fragmentation and desiccation were least, to homogenized communities dominated by benthic guilds where fragmentation and desiccation were common. Modeling results revealed these shifts were primarily associated with decline of pelagic reproductive guilds, notably small-bodied pelagophilic and lithopelagophilic fishes that declined in association with decreased fragment length and increased number of days with zero flow. Genetic analyses revealed little response in genetic diversity indices among fragments with varying lengths, discharge magnitudes, or percent of time with zero flows for Plains Minnow (*Hybognathus placitus*), Emerald Shiner (*Notropis atherinoides*), and Red Shiner (*Cyprinella lutrensis*).

Discussion:
Our results suggest that demographic processes far out-weight the effects of genetic constraints (e.g., inbreeding depression, accumulation of deleterious genes) in determining population persistence. Based on our data and considering Plains Minnow to be representative of small-bodied pelagophilic fishes, persisting populations might be used as sources for repatriation efforts assuming said repatriations occur within the boundaries of major river drainages. Patch-based graphs illustrated particular stream fragments characterized by greater lengths, discharge magnitudes sufficient to avoid desiccation, and persistence of small-bodied pelagophilic and lithopelagophilic fishes that might be prioritized for maintenance to enhance conservation of declining guilds. Furthermore, graph theory combined with a barrier prioritization approach revealed specific fragments that could be reconnected to allow recolonization of currently unoccupied fragments with the mitigation or removal of small dams (<10 m height). These barrier prioritization procedures may help restore longitudinal connectivity by targeting maximum gains in connectivity with minimal costs associated with barrier manipulation.

Our study represents one of the most comprehensive assessments of fish diversity responses to broad-scale environmental change in the Great Plains. The greatest challenge for natural resource managers charged with halting or reversing the prevailing pattern of declining fish diversity in the Great Plains will ultimately involve ensuring sufficient discharges to prevent desiccation in a region where climate change is expected to cause increased variability and overall declines in streamflow magnitude. In the future, regional water stress and associated effects on aquatic biodiversity and natural resource commodities will undoubtedly increase. Though natural and historical stream environments in the Great Plains conditioned fishes to withstand harsh conditions such as drought and desiccation, acceleration of the expansion and contraction of stream ecosystems by humans is beyond the range of conditions with which many fishes can contend. This is, in part, because hydrologic changes to stream ecosystems are coupled with shrinking habitat and population sizes which buffer environmental disturbances. Downstream wetted refugia that were historically available are now separated from upstream fish communities by >19,000 instream barriers, and fish diversity in the Great Plains is ratcheted down with every interaction between fragmentation and natural or anthropogenic hydrologic extremes involving low flows. In the absence of available upstream infrastructure capable of manipulating discharge magnitudes, we stress that increasing longitudinal connectivity to the extent possible should be among the top-ranked reactive conservation approaches aimed at preserving fish diversity in fragmented riverscapes.

Fragmentation and drying ratchet down Great Plains stream fish diversity: Summary

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Introduction:
Stream fragmentation alters the structure of aquatic communities on a global scale, generally through loss of native species. Among riverscapes in the Great Plains of North America, stream fragmentation and hydrologic alteration (flow regulation and dewatering) are implicated in the decline of native fish diversity. "Ecological ratchets" are self-reinforcing processes that involve forward movement (change) in a given response variable (e.g. species distributions) through space or time in response to natural or human disturbance(s) without reciprocal reverse movement (resetting of change), which is typically blocked through some introduced or derived mechanism(s) and ultimately results in continued or irreversible degradation.

This study applies an ecological ratcheting framework to changes in fish community structure brought on by habitat fragmentation and hydrologic disturbance in the Great Plains. The goal of this novel approach is to shed light on the mechanism(s) responsible for broad-scale and long-term declines among native and endemic Great Plains fishes. Specific objectives include: (i) testing for long-term (1950–2013) change in the probability of occurrence for cyprinid fishes belonging to common reproductive guilds in the central Great Plains; (ii) assessing change in fish community structure upstream and downstream of barriers that potentially fragment longitudinal connectivity; and (iii) evaluating fish response to hydrologic desiccation during drought disturbances. The objectives of the current study are related to each of the three key components of ecological ratcheting, including change in fish distributions (i.e. response variable), fish sensitivity to droughts (i.e. disturbance), and reinforcement of observed change by fragmentation of riverscapes (i.e. human-induced mechanism that blocks resetting).

Methods:
This study documents the spatio–temporal distribution of fish reproductive guilds in the fragmented Arkansas and Ninnescah Rivers of south-central Kansas using retrospective analyses of fish community data for the period 1950-2013. Cyprinid fishes reported in these databases were classified into four reproductive guilds based on spawning behaviour, habitat, and egg characteristics. First, we tested for long-term changes in the probability of occurrence for fishes. Then we assessed the effects of small barriers on fish community structure during the summers of 2011 and 2012 in river fragments upstream and downstream of small dams in each river. Finally, we evaluated fish reproductive guild responses to a major drought that occurred in 2011 and 2012. Drought and streamflow data were compared with fish occurrence probabilities to illustrate responses to desiccation disturbance. A conceptual model detailing the three components of an ecological ratchet at the sub-basin scale was used to synthesize findings.

Results:
Pelagic-spawning fishes declined throughout the study area during 1950–2013, including Arkansas River shiner (*Notropis girardi*) last reported in 1983, plains minnow (*Hybognathus placitus*) in 2006, and peppered chub (*Macrhybopsis tetranema*) in 2012. Longitudinal patterns in fish community structure in both rivers consisted of strong breaks associated with dams, and pelagic-spawning fishes were missing from shorter fragments upstream of those barriers. Among downstream and longer fragments, probability of occurrence for pelagic-spawning fishes declined or fell to zero during periods of drought.

Discussion:
Stream fish communities in the Great Plains changed considerably during the past half century owing to the effects of fragmentation and dewatering. Long-term patterns in the probability of occurrence for fishes in the Arkansas and Ninnescah rivers were characterized by declines among pelagic-spawning fishes and increases or no change among fishes in remaining reproductive guilds. Spatial variability in species occurrences suggest that pelagic-spawning and pelagic substrate-spawning fishes were sensitive to effects of small dams. Based on these data, interactions between fragmentation and drying are hypothesized as operating as an ecological ratchet mechanism in which forward movement toward pelagic-spawning fish extirpation occurs during desiccation, and reciprocated reverse movement toward recolonization following return of flows is blocked by fragmentation. The ratchet mechanism is capable of explaining the long-term "ratcheting down" of fish diversity in Great Plains rivers and has implications for managing biodiversity in fragmented riverscapes where water is scarce or might be in the future.

Conservation actions can counter the effects of the described ecological ratchet in at least four ways. First, longitudinal connectivity might be improved through prioritized removal of barriers. Second, flow regimes might be manipulated to enhance recruitment and persistence of stream organisms. Third, if streamflow cannot be augmented, rescuing individuals from drying stream fragments and holding them in captivity until flow recovers is an option. However, such reactive approaches will not be effective in perpetuity and require significant resources. Fourth, for stream fragments in which environmental conditions have improved following disturbance, repatriation of extirpated fishes obtained from genetic reservoirs is an emerging technique. However, the long-term outlook for re-establishing populations will depend on slowing down ratcheting so that genetic reservoirs for declining species persist. As slowing ratcheting will become increasingly challenging under the expected warmer and drier climatic conditions of the future, implementing sustainable water management approaches aimed at conserving freshwater resources is crucial.

Fragmentation and dewatering transform Great Plains stream fish communities: Summary

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Introduction:
Biodiversity in stream networks is threatened globally by interactions between habitat fragmentation and altered hydrologic regimes. In the Great Plains of North America, stream networks are fragmented by >19,000 anthropogenic barriers, and flow regimes are altered by surface water retention and groundwater extraction. Fragmentation and flow modification in stream networks alter the ecology of fishes occupying these habitats and stream fish communities in Great Plains rivers became increasingly homogenized during the past century.

We documented the distribution of anthropogenic barriers and dry stream segments in five basins covering the central Great Plains to assess effects of broad-scale environmental change on stream fish community structure and distribution of reproductive guilds. Specific objectives were to (1) document the distribution of anthropogenic barriers and dry stream segments in the Platte, Kansas, Arkansas, Canadian, and Red River basins, (2) evaluate variation in the proportion of benthic- vs. pelagic-spawning fishes across a gradient of stream fragments characterized by various lengths, discharge magnitudes, and percentage of days without flow, and (3) assess change in the probability of occurrence for specific reproductive guilds using a set of competing models to test which environmental alterations best explain observed changes in fish community structure.

Methods:
For this study, we focused on portions of the Platte, Kansas, Arkansas, Canadian, and Red River basins. Stream fragmentation in each basin was assessed using data from the 2012 National Anthropogenic Barrier Dataset. We assessed stream desiccation by extracting data from the extensive network of U.S. Geological Survey stream flow gages distributed throughout the study area. We selected 39 stream fragments distributed among the five basins and including all large-order (e.g., greater than fourth order) stream segments historically inhabited by pelagic-spawning fishes. We assessed fish community structure among the 39 fragments by combining recent collections for the 20-yr period between 1993 and 2013. Fishes were classified into reproductive guilds to test how reproductive strategy influenced species responses to fragmentation and desiccation. We included a measure of network-scale habitat connectivity for each of the five basins. We used an information-theoretic approach to rank competing models in which fragmentation, discharge magnitude, and percentage of time streams had zero flow (a measure of desiccation) were included to predict effects of environmental alterations on the distribution of fishes belonging to different reproductive guilds.

Results:
Fragmentation caused by anthropogenic barriers was most common in the eastern Great Plains, but stream desiccation became more common to the west, where rivers are underlain by the depleted High Plains Aquifer. Longitudinal gradients in fragmentation and desiccation contributed to spatial shifts in community structure from taxonomically and functionally diverse communities dominated by pelagic reproductive guilds where fragmentation and desiccation were least, to homogenized communities dominated by benthic guilds where fragmentation and desiccation were common. Modeling results revealed these shifts were primarily associated with decline of pelagic reproductive guilds, notably small-bodied pelagophilic and lithopelagophilic fishes that declined in association with decreased fragment length and increased number of days with zero flow. Graph theory combined with a barrier prioritization approach revealed specific fragments that could be reconnected to allow fishes within these guilds to colonize unoccupied fragments with the mitigation or removal of small dams.

Discussion:
These findings are useful for natural resource managers charged with halting or reversing the pattern of declining fish diversity in the Great Plains. Our study represents one of the most comprehensive assessments of fish diversity responses to broad-scale environmental change in the Great Plains and provides a conservation strategy for addressing the simultaneous contributions of fragmentation and flow alteration to the global freshwater biodiversity crisis.

Maintaining existing diversity in stream fish communities will require preserving specific fragments in which environmental settings are appropriate for persistence of a diversity of imperiled fishes. Appropriate environmental settings include, at a minimum, sufficient longitudinal connectivity and discharge magnitudes to prevent decline of pelagic fish guilds. Our findings also suggest achieving the goal of reversing diversity declines will require reestablishment of appropriate environmental settings where they do not currently exist. This is achieved through barrier prioritizations and manipulations that target maximum gains with minimal costs. We provide such an approach within the constraints of barriers that are of little value to human water security. In the future, regional water stress and associated effects on aquatic biodiversity and natural resource commodities will undoubtedly increase. We stress that increasing longitudinal connectivity and allowing access to downstream wetted refuge habitats should be among the top-ranked conservation aims for preserving fish diversity in fragmented riverscapes.

Comparative riverscape genetics reveals reservoirs of genetic diversity for conservation and restoration of Great Plains fishes: Summary

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Introduction:

Over the last 150 years, river fish communities have been drastically altered by habitat alteration and landuse changes that negatively affect habitat, causing decline of biodiversity at the local and regional scale. Previous studies have shown refuges that could potentially help restore fish communities if management actions are taken. Management actions will depend on an understanding of genetic diversity among repatriates for successful reintroduction. Genetic diversity on the landscape is determined by three broad classes of factors: geological processes, intrinsic traits, and contemporary landscape features. We used comparative riverscape genetics to examine the relative roles of historical events, intrinsic traits, and landscape factors in determining the distribution of genetic diversity of river fishes across the Great Plains. The goal of this study was to characterize the relative roles of geological and landscape factors in shaping diversity across species with different life-history strategies. We assessed three species of river fish occurring among five major tributary basins in the Great Plains. Two of these species are sensitive to habitat fragmentation while the third species is more tolerant to changes.

Methods:

Spatial patterns of diversity were overlaid on a patch-based graphical model and then compared within and among three species that co-occurred across five Great Plains watersheds.
Three river fish species were selected based on their reproduction methods: plains minnow (*Hybognathus placitus*, pelagic broadcast spawning), emerald shiner (*Notropis atherinoides*, pelagic-substrate spawning), and red shiner (*Cyprinella lutrensis*, substrate spawning). Sampling sites were selected based on maximum variation in dewatering and the limited distribution of *H. placitus*. Forty-five large stream fragments were selected during summer 2013. We sampled fishes by seining all available habitats for at least two hours or until a minimum of 30 samples were collected. Genomic DNA was extracted from air-dried caudal fin clips using standard proteinase-K digestion and standard phenol/chloroform methods. Standard genetic diversity measures were calculated from microsatellite data. To examine the genetic response to historical features, statistical analysis focused on allelic diversity and latitude. Population structure was evaluated to determine if genetic variance could be attributed to differences between major basins. Population structure was also assessed in a spatial context to illustrate genetic clusters in a heat map for each species. Genetic response to contemporary landscape features was investigated based on discharge, fragment length, and days with zero flow. The linkage disequilibrium method was used to estimate the effective number of breeders from microsatellite DNA data.

Results:

H. placitus and *N. atherinoides* were found to occur in fragments with a longer length and those that were wet 90% of the time. *C. lutrensis* was persistent in all fragments with no apparent pattern of reduced occurrence. Diversity metrics did not differ significantly among tributary basins for either *H. placitus* or *N. atherinoides*, but allele diversity was higher for *C. lutrensis* in southern tributary basins. For *C. lutrensis* and *H. placitus*, allele diversity increased in a southern direction with latitude describing most of the variation. For all species, there was significant divergence among fragments within tributary basins and among fragments irrespective of tributary basins. Mathematical models and analyses suggested that differences in genetic diversity could not be attributed to human alteration for sampled sites. The estimated number of breeders was highly variable across species and tributary basins.

Discussion:

A comparative landscape genetic framework was used to examine the relative roles of geological processes, intrinsic differences among species, and contemporary landscape changes. The greatest factor shaping patterns of genetic diversity for *C. lutrensis* and *H. placitus* was the historical features of past climates and geology. Local conditions can explain some genetic diversity, but generally diversity increases with decreasing latitude. Higher diversity in populations at southern latitudes suggests that populations survived in situ where habitats were likely more benign and harbored stable populations over time. Hierarchical patterns of population genetic structure differed somewhat between the three species examined. Geological and climatic processes, including glaciers, river incisions, and valley aggradation, have caused different population clusters to form. No relationship was detected between contemporary landscape alterations and genetic diversity, possibly due to truncated sampling across key gradients. Fragmentation and dewatering affected the persistence of each species differently with the pelagic spawning species (*H. placitus* and *N. atherinoides*) more vulnerable than substrate spawning species (*C. lutrensis*). Stochastic environmental events, such as drought, can cause local extinction of a species before genetic effects become apparent in rivers. Mathematical analyses showed that longer and wetter river fragments retain higher genetic diversity than drier, shorter fragments. This can be important when identifying conservation priorities and strategies. Cross-tributary restocking could be used to raise genetic diversity in the north, but could interrupt local gene complexes. Proactive restoration and conservation strategies must be employed to stem predicted losses of diversity due to global warming. Genetic diversity is concentrated in longer and wetter reaches and restoration efforts should focus on restoring connectivity to help restore both species and genetic diversity.

Great Plains Landscape Conservation Cooperative

Final Report: Conservation assessment and mapping products for GPLCC priority fish taxa

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Introduction:
Steep declines in biodiversity are expected in the coming decades. This is especially true in freshwater environments where aquatic fauna face pressure from human development-related stream fragmentation, flow regulation, water extraction, pollution, exotic introductions, and changing climates. We do not have the resources to protect everything in the face of increasing pressures. Conservation constituents across the globe are finding it economically beneficial to refine strategic conservation plans and design networks of priority areas to anchor proactive management. Mapping areas of importance, also known as performing a conservation assessment, is decision support for conservation planning and is the first of four conceptual stages for proactive conservation of broad, multi-species landscapes. Here we present a workflow and sequence of assessments aimed at providing managers a spatial perspective for allocation of conservation action towards the persistence of native freshwater fishes of the Great Plains, USA.

Methods:
The extent chosen for this analysis was the intersection of the Great Plains Landscape Conservation Cooperative's extent with a modified version of the United States Geological Survey's Hydrologic Unit Code 4 boundaries. Species distribution models for 28 priority fish species were created and incorporated into a prioritization framework using the open source software Zonation, accounting for species-specific connectivity needs and current fish habitat condition. Multiple additional assessments were then produced that i.) identify distinct species management units based on distance and compositional similarity of stream segments containing priority species, ii.) compare results of ranking species' conservation values at the local and global scale, and iii.) provide bang-for-buck perspectives, emphasizing richness of priority species, at state and major basin scales.

Results:
We provide species distribution modeling products in various formats. For each of the 28 species modeled, a map of occurrence records used in modeling and mainstreamed figures of the unrestricted and restricted model are displayed and symbolized. Mainstreamed figures are complex planning products formatted and designed for visual inspection and interpretation to aid communication among stakeholders. Model images are displayed as symbolized rasters layered over a shapefile of major streams. Analysis products produced with the conservation assessment software Zonation are provided in two formats: mainstreamed figures intended to communicate results and raw data provided for maximum utility.

Discussion:
These assessments constitute a critical component of the broader process of conservation planning. To bridge the assessment-implementation gap in conservation planning, conservation assessment products must be complemented with an implementation strategy. This can be achieved by mainstreaming of the planning products, a process that requires continuous input and feedback from stakeholders involved. We used the assessment products produced by this project and a three-level hierarchy and terminology to provide a spatial strategy for application of conservation assessment and planning, an example of which can be seen in Figure 1.

These analyses are intended to aid managers in effective allocation of conservation action with regards to imperiled fishes of the Great Plains. Implementation of a broad-scale multi-species approach such as this complements traditional reactive management and restoration by encouraging cooperation and coordination among stakeholders and partners, increasing efficiency of future monitoring and management efforts.

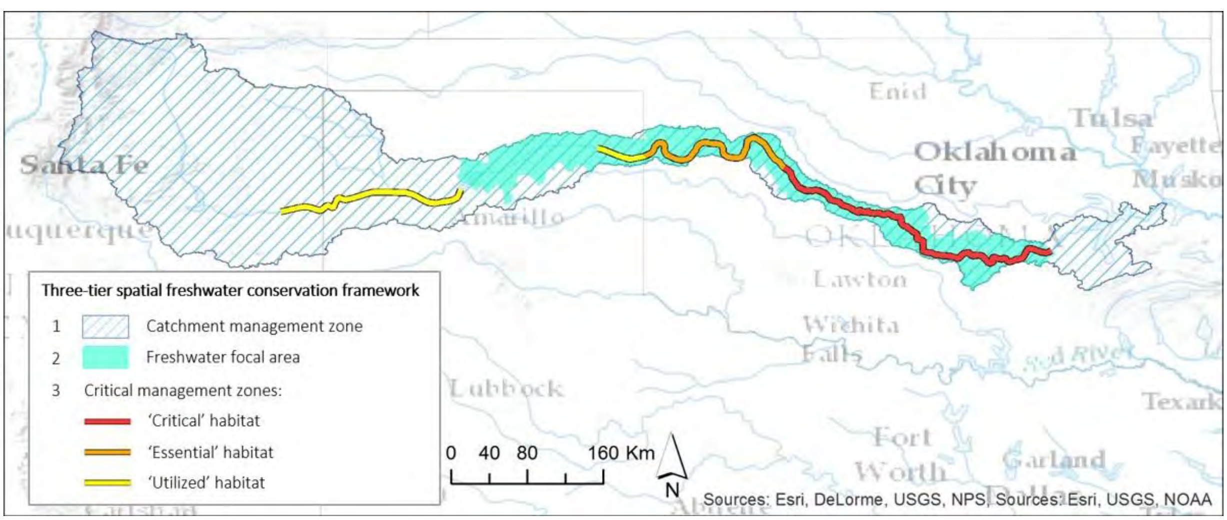

Figure 1. A species-specific example (*Notropis girardi*) of integration of the species management unit product into a three-tier freshwater conservation framework.

Implications for Connectivity and Movement of Lotic Great Plains Fishes in the Face of Climate Change: Summary

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Introduction:
Many lotic ecosystems of the Great Plains are not well-suited for accommodating fish distributional shifts that will occur as a result of climate change because of the lack of nearby hydrologic connectivity with higher latitude and elevation habitats generally associated with climate change-induced range shifts. Despite uncertainty in precisely how Great Plains fish species distributions may be effected by a warming climate, we predict that this lack of hydrologic connection may lead to additional climate related stress (e.g., thermal and hydrologic stressors) on fish communities in the Great Plains compared to other regions of North America. Anthropogenic activities such as bridges and culverts could also limit fish movements. We therefore sought to understand how potential barriers, such as dams and road-stream crossings (RSX) may interact with climate change to limit movements of Great Plains fish species as they seek thermal and habitat refugia.

Methods:
We used the Missouri River Basin as the largest spatial scale for our analysis and as a proxy for the Great Plains because a majority of the land area of the Great Plains is contained within the Missouri River basin. The state of Nebraska (the focus of our smaller spatial scale analysis) is also entirely contained within the Missouri River Basin. The river networks within this basin also provide a sound ecological and evolutionary backdrop for understanding fish distributions.

In this study, we sought to identify the magnitude of potential in-stream barriers to fish movement. We used data from publically available sources to estimate and map dam and RSX locations in the study area and to predict current and future (2050 and 2100) fish species distributions under climate change scenarios. Conceptually, we overlaid down-scaled Global Climate Model data to assess climatic conditions with fish species thermal tolerance data and potential barrier to movement data to predict future fish species distributions and/or identify species that may be vulnerable to climate projections.

Results:
Changes in predicted species distributions from current data ranged from little to no change to drastic shifts in where conditions would be suitable for survival in 2050 and 2100. Most (67%; n = 130) of the fish found in Nebraska and the Great Plains appear to have at least some resilience to thermal and hydrological variability, but we projected reductions in range for two of the 10 species for which we successfully modelled. We also predicted eight additional species as especially vulnerable to climate change. Our results suggest that the Missouri River landscape is densely populated with potential barriers spanning almost every conceivable spatial scale. There are approximately 819,000 RSX and 12,000 dam locations in the study area.

Discussion:
Great Plains species, in general, may be more resilient to climate extremes given their evolutionary development (e.g., they evolved in rivers and streams that have historically exhibited substantial variability in temperature and water availability). However, some species will be at risk of extirpation in Nebraska and the Great Plains if temperature and precipitation patterns change as projected.

We conclude a better understanding of conditions under which RSX influence fish behavior, especially movement, is warranted. Specific efforts should be directed toward designing new or mitigating existing RSX sites where fish movement could be prohibited across the landscape.

Collection of additional point of occurrence data for fish species distributions and thermal tolerance would improve predictive capabilities. Our approach inferred thermal maxima from laboratory studies, empirical observation in existing data, and correlating air temperatures to water temperatures. A better understanding of thermal regime as well as how adaptable fish are to projected changes would improve model predictive capacity. Increased availability of stream water temperature data will also be important to understanding the effects of climate change.

The identification of fish species vulnerability to predicted climate changes can be at least qualitatively accomplished using a thermal and flow tolerance limits matrix as we have done here. However, these results should be viewed as a starting point for further understanding of any species response to its environment rather than an endpoint.

This immense volume of potential barriers and high variability surrounding the level of fragmentation associated with RSX precluded our ability to use these structures as a means to stop distributional shifts in our predictive models. However, these data also suggest that further assessment of the types of barriers and means with which they may or may not prevent fish movement should be further evaluated given their abundance on the landscape.

Species conservation and management efforts should consider that some species may have a reduced capacity to complete their life-cycle given the presence of dams and RSXs in nearly all of the measurable streams and rivers within the Great Plains. Recent studies have shown the importance of considering the river network in a more holistic way for benefitting fish populations and communities. Therefore, considering barriers that inhibit the historically connected stream network is crucial to meeting the challenges of an uncertain future.

Intrafragment riverscape conservation for an imperiled, small-bodied, pelagic broadcast spawning minnow: speckled chub (*Macrhybopsis aestivalis*) Summary

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Introduction:

River fragmentation, altered streamflow regimes, and habitat loss threaten riverine fishes. Identification of critical habitat features is necessary to conserve imperiled species in river fragments where they persist. Appropriately scaled studies can provide a more detailed understanding of habitat features that promote or limit population persistence. Intrafragment ecology is little studied for imperiled riverine fishes although river fragmentation and habitat loss increasingly threaten sensitive species, such as the speckled chub (*Macrhybopsis aestivalis*). The population ecology of this species is unstudied, but based on information available for close relatives, it is presumably a short-lived (i.e., <2 years) fluvial specialist that prefers shallow habitats and is typically represented by a single, dominant year class. The goals of this study were to document intra-fragment population ecology for speckled chub and identify environmental factors associated with persistence. We assessed intra-fragment patterns in recruitment and year-class strength in relation to distributional patterns, flow-regime characteristics, and air temperature.

Methods:

A long-term population monitoring program in the Pecos River, New Mexico, provided detailed data for 15 annual cohorts (1994-2008) of speckled chub. Longitudinal habitat change created three distinct river reaches: discontinuous, relict-ecosystem, and channelized. The flow regime reflected operations of four upstream dams. Fish population sampling occurred during daylight hours via single-pass seining (3mm mesh) among available mesohabitats that are readily recognized, distinct areas with uniform depth–velocity and substrate characteristics. Typically, 10 to 20 mesohabitats were seined per sample. Data from a companion study were used to assess length-related patterns of depth and velocity use and to determine potential for intercohort mesohabitat segregation. Data used to determine temporal patterns in cohort distributions, recruitment, and year-class strength were generated from routine fish population surveys. To study lifespan, cohort densities and mean length were ordered sequentially by sampling trip from first to last detection and plotted. Recruitment and year-class strength were found to be density independent, so potential influence of single-environmental factors on recruitment and year-class strength was explored. Analyses were focused on factors that, based on perceived threats to *M. aestivalis* and published literature, had potential to influence recruitment.

Results:

Cohorts avoided the degraded discontinuous reach. Age-1 and older individuals had distributions consistently centered within a central, relict-ecosystem reach that contained high-quality habitat. Age-0 individuals were widespread within the relict-ecosystem reach and the channelized reach downstream. Distributional patterns suggested some individuals that recruited in the channelized reach dispersed upstream into relict-ecosystem habitat thereafter. One cohort always numerically dominated the population because cohorts never lived beyond 2 years. Recruitment was density-independent and predicted year-class strength. No aspect of the flow regime explained variation in recruitment. Year-class strength was consistent among cohorts because of apparent density-dependent mortality.

Discussion:

Density-independent recruitment and opportunistic reproduction appeared to promote persistence of *M. aestivalis,* such that no single environmental factor regulated the population. The relative stability of year-class strength, due to density-dependent age-1 mortality, contrasted dramatically with high variability in recruitment. This could reflect density-dependent increases in intracohort competition or in spawning mortality. Based on previous studies, reservoir releases and natural flash floods elevate spawning activity. Booms of pelagic broadcast-spawning fishes are expected to occur when propagule retention is high and synchronous with forage production. Hence, an optimal flow regime for *M. aestivalis* presumably includes sequential, short-duration flow peaks that maximize retention of pelagic broadcast propagules and likely invigorate ecological productivity set apart by intervening flow-recession periods of adequate duration for recruitment.

Macrhybopsis aestivalis did not demonstrate unrestrained upstream dispersal. Individuals were concentrated in, but widespread throughout relict-ecosystem habitat and were very rare in the upstream discontinuous reach. Pelagic eggs, larvae, and age-0 individuals had less control over their distribution and were widespread in relict-ecosystem and channelized habitats.

The study fragment appeared to be a high-quality refuge for *M. aestivalis*, consistent with persistence of other endemic species and long-term stability of the flow regime. This supports prior management recommendations including: (1) preservation of high-quality habitat within the relict-ecosystem reach, (2) habitat restoration in the channelized reach, (3) restoration of streamflow in the discontinuous reach, (4) avoidance of streamflow intermittence throughout, and (5) reduced prevalence of extended "block" reservoir releases.