Anthropogenic Climate Change in the Playa Lakes Joint Venture Region

Understanding Impacts, Discerning Trends, and Developing Responses

A report prepared for the Playa Lakes Joint Venture

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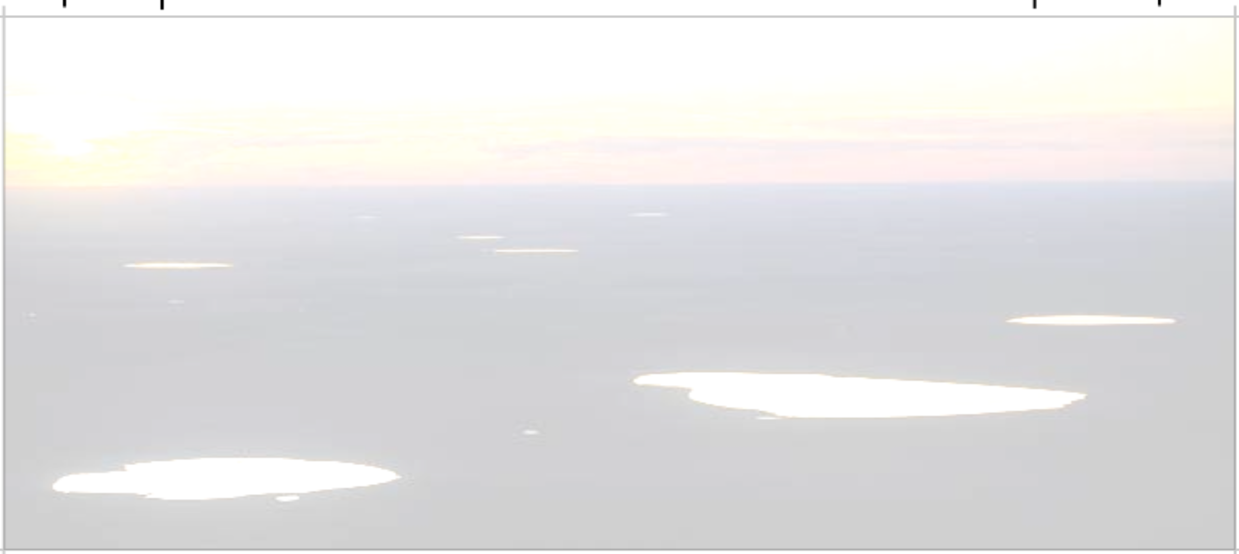

Abstract

Anthropogenic climate change has been driving regional climate shifts in the Playa Lakes Joint Venture zone since at least the mid 1970s. As a result, summers are becoming drier across the region and, in the northern and eastern regions, winters and springs are becoming wetter and warmer, while the southwestern and southern regions are drying out and potentially reaching “dust-bowl conditions” by mid-century. Throughout the area, extreme weather events are increasing in both severity and frequency with growing climate variability; floods and droughts in particular will become more frequent. Flooding and extreme precipitation events will elevate sedimentation runoff, effecting aquatic systems. Strong multiyear droughts will impact aquatic, terrestrial, and agricultural ecosystems severely. Ultimate wildlife impacts will be influenced by regional economic patterns and human land-use shifts, but many types of habitat will be transformed by mid century. Some may effectively be eliminated, while others will shift to the north and east. Most avian species are expected to respond with easterly shifts in migration patterns, changes in the timing of migration, and northerly shifts in overwintering and breeding ranges. However, not all species will respond at the same rate or in the same manner.

About the Author

John Matthews received his undergraduate degree from the University of Chicago in 1990 in cultural anthropology, worked in the publishing industry as an editor and writer for 12 years, and then enrolled in the Ecology, Evolution, and Behavior PhD program at the University of Texas. His dissertation work focused on large-scale connectivity and migration issues in aquatic macroinvertebrates, as well as climate change impacts on aquatic and migratory species. Twice he was a finalist with the David. H. Smith Conservation Biology Postdoctoral Fellowship for a proposal on climate change impacts on the playa lakes region. He received his PhD in 2007 and had a brief postdoc with the U.S. Geological Survey in Corvallis, Oregon, before being hired as a freshwater climate adaptation specialist with the World Wildlife Fund. Most of his current conservation work is currently in the Yangtze, Ganges, Thames, and Brazilian Pantanal basins.

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Purpose

To inform Playa Lakes Joint Venture (PLJV) habitat conservation partners of the realized and potential impacts of anthropogenic climate change to bird habitats and populations in the PLJV region, and to recommend appropriate habitat conservation actions to compensate for these impacts.

Objectives

a) Describe and compare climate change models and projections for Playa Lakes Joint Venture regional climate over medium- to long-term intervals (30 to 100 years);

b) Emphasize rates and types of change in the number and quality of important bird habitats as defined by PLJV staff (PLJV 2006);

c) Estimate assessments of any shifts in freshwater hydropatterns (hydroperiods and flow regimes) as a result of climate change;

d) Assess changes in agriculture important to birds as a result of climate change; and

e) Address changes to bird distribution and behavior as a result of climate change.

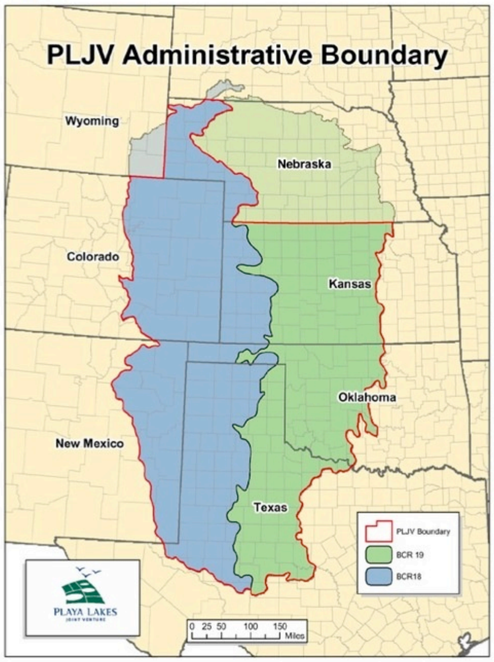
f) Suggest management responses that may be appropriate to mitigate negative climate-driven impacts on habitats, ecosystems, and species;

Introduction

Climate change already presents threats and opportunities to the ecosystems, economies, and livelihoods of the region covered by the Playa Lakes Joint Venture (PLJV; **Figure 1**). All of the human and natural systems in the PLJV will be impacted — indeed, many already are, even if no one is paying attention.

Anthropogenic climate change (often called global warming) is a novel type of impact for the PLJV region from a resource management perspective that has received little attention to date, even at the scale of the whole of the Great Plains. But climate change per se is not new to this area. Regional and global climates have always shifted, sometimes quite abruptly. The current era of climate change is different from past transitions for two reasons. First, the cause of the change is new. Humans have modified the global atmospheric composition as a result of massive greenhouse gas emissions, and these modifications are altering a wide range of meteorological variables.

Figure 1. The region covered by the Playa Lakes Joint Venture.



Second, the context of climate change is different for organisms experiencing the shift. In the past, most species appear to have responded to climate change by shifting their range of distribution (Parmesan 2006). Thus, during recent glacial periods many temperate and boreal species moved towards the equators. Changes in phenology (time-sensitive behavior) are also likely to have accompanied range shifts. Most of the landscapes we now see would only seem familiar over the past few thousand years at most, which is quite recent on evolutionary timescales. However, because humans have also extensively modified the rest of the environment, range shifts are now far more difficult than in the past except for highly vagile organisms such as birds, large mammals, and insects capable of long-distance flight. Given reduced levels of connectivity and additional pressures such as the introduction of invasive species, habitat fragmentation, and eutrophication of previously oligotrophic freshwater ecosystems, humans have effectively reduced the capacity of species to respond to anthropogenic climate change (Covich et al. 1997, Gibbs 2000, Parmesan & Yohe 2003).

From a conservation science and resource management perspective, this report is an attempt to summarize the state of the science of realized and potential climate change impacts on the PLJV region and in particular how these impacts are likely to affect bird species dependent on playas and other important habitats.

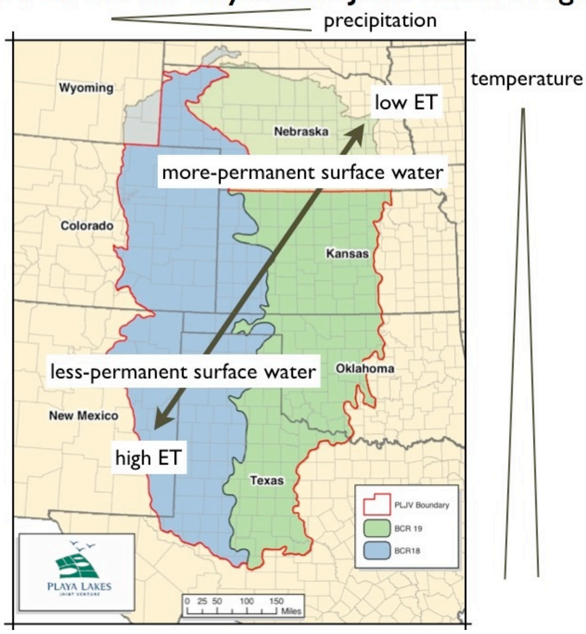


Figure 2. Twentieth-century generalized climate trends across the Playa Lakes Joint Venture region.

The concept of climate itself is perhaps useful to clarify. Climate represents "normal" weather patterns and levels of expected variability. Normal climate for the PLJV region over most of the twentieth century is shown in **Figure 2.** Attributing any single weather event to climate change is inaccurate and a misuse of the term *climate*. That said, several relatively new concepts are key to interpreting this report. First, conservation from this point forward must incorporate climate models, and I strongly advocate developing a program of **climate-aware conservation** (Matthews & Aldous in press)**.** Until recently, almost all conservation work was restoration: founded on picking some era of relative health in the past and using this state as a target for future conservation work. However, this model assumes that the current (and future) climate matches this past, and with few exceptions this assumption can no longer be maintained. Conservation programs cannot neglect the past, but they must also be able to look forward to new climates. Climate profoundly structures habitat, and major elements of what we have assumed until recently were stable states are rapidly evolving before our eyes. Ideally, as resource managers we should look forward to a series of new climate states. In essence, climate-aware conservation flows from the simple acknowledgment that living species (including humans) exist in a particular climate era, and that climate can change, is changing, and will continue to change — and these changes may be rapid. **Conservation programs that do not include a range of future climate regimes risk irrelevance.**

Second, when focusing on new, emerging climate regimes, we must consider the usefulness of **climate adaptation**. Certainly less than 20 years old, this term refers to the process of species, populations of species, and human systems responding in a positive manner to climate change; it does not strictly refer to adaptation in a Darwinian or more general evolutionary ecological sense.

Climate resilience is a related third concept, referring to the ability of natural and human systems to withstand negative impacts related to climate. Over short timescales, resilience may be tested by drought or other examples of shifting climate variability. Over long timescales, resilience may refer to the presence of a metapopulation structure that can withstand the extinction of populations at a landscape scale and re-establish these populations or found new more climatically favorable populations elsewhere.

Finally, **climate vulnerability** refers to the degree to which a species will be sensitive to shifts in some aspect of the historically recent climate regime. Species whose range already extends near some climate-defined limit or that do not disperse to new suitable habitat easily may be more vulnerable, for instance, than species whose range is limited more by interaction with other species or which are highly vagile.

It is worth noting that humans are, of course, a primate whose "habitat" is very flexible but can be constrained or modified by climate. Moreover, human economies and livelihoods are often highly sensitive to climate regimes. Thus, climate adaptation, resilience, and vulnerability are concepts that will also be applied to the agro-ecological systems found across the PLJV region.

Avian Responses to Climate Change

Birds are probably the most-studied vertebrate taxonomic group with regard to climate change impacts, particularly among terrestrial species (Parmesan & Yohe 2003, Parmesan 2006). However, the data on avian impacts is very mixed in detail and quality.[1] Studies based on birds fall into two general categories: tracking changes in range and/or phenology (e.g., the timing of seasonal behavior such as egglaying), or modeling studies of ranges and distributions. Few species worldwide have sufficiently detailed data for tracking research projects, so most studies are based on modeling. These focus on known ranges and statistical associations for selected climate variables and (in a few cases)

[1] Partners in Flight (PIF) maintains a comprehensive avian climate change bibliography: http://www.partnersinflight.org/climate_change/.

habitat traits (e.g., key plant species) within that range. They then project these associations based on one or more climate models into the future. There are some habitat-specific studies for particular regions (e.g., the northeastern U.S. in Matthews et al. 2004). However, these studies are not generally useful for understanding precise species-level impacts (Pearson & Dawson 2003, Beaumont 2007) and may even provide a false sense of confidence or certainty to resource managers. Such studies may be most helpful as a simple gauge of general directionality and trends; climate and habitat ("bio-climate envelopes") modeling are by no means exact sciences and cannot make up for good monitoring and habitat assessment over time. Only one known study focuses on the Great Plains region, and then only on five endemic species (Peterson 2003).

Several general conclusions can be drawn from a survey of avian climate change impacts studies within and outside of the PLJV region:

1) Species will respond differently from one another to climate change and at different rates (Peterson 2003), but most Great Plains species will show a general northern range extension over time. That is, breeding and overwintering sites on the southern end of the range will decrease in number and breeding and overwintering sites will likely increase in number to the north. Similar altitudinal patterns are seen in mountainous regions, though this is less important for the PLJV region. On the other hand, some species will be observed shifting southwards. The causes of such discrepancies are unknown. It is even possible that they may result from a loss of northern range, altering the geographic range center. Or simple demographic stochasticity may be in play. Even controlled physiological ecology studies have been challenged to untangle the complex relationships between physiology, behavior, inter-species interactions, and climate change (Matthews & Parmesan 2008).

2) More studies have focused on other areas of the U.S. than the Great Plains for bird distributions. Across the eastern two-thirds of North America, bird ranges appear to be generally shifting northwards by about 2 km/year (Hitch & Leberg 2007). Again, this is a very broad generalization, but given the lack of geographic relief in the Great Plains this rate probably represents a minimum estimate for the PLJV region.

3) One study of 150 species in eastern North America found that about equal numbers of species were expected to increase and decrease in abundance (~25 to 30%), based on modeling (Matthews et al. 2004). Thus, our view of avian communities as relatively fixed rather than

"assemblages" may itself need to change (Schaefer et al. 2008). Groups of species we assume "belong" together will be impacted at very different rates. New communities will be forming.

4) The species most vulnerable to climate change are those with already restricted ranges, specialized habitat needs, and (generally) migrant species. Some range shifts could be up to 1000 km north in North America. Migrants will see climate shifts in both overwintering and breeding habitats, as well as their migratory matrix (Huntley et al. 2006). Migration timing is changing in many, perhaps most, species (Parmesan & Yohe 2003). In some cases, migration distances may themselves be increasing (Huntley et al. 2006).

5) Detecting changes in abundance will be very problematic, as birds have often responded to climate change in the past by rapidly moving their ranges (Huntley et al. 2006). In effect, determining if bird surveys are showing changes in movement patterns or range or actual increases or declines in population will be almost impossible to distinguish over short time scales (<10 years) (Bart et al. 2007).

6) The mechanisms driving climate impacts are often so complex and so specific to particular species that they may not be usefully applied to other species (Saether et al. 2004). Unless a species has listed status or is likely to develop listed status soon, it may not be worthwhile to pursue mechanistic physiological ecological research. Phenological mismatches for serial life-history events (breeding, migration onset/cessation, fledging) are all timed events, often set by one or more different "clocks" (with different "alarms") that may be receiving conflicting cues during a period of rapid climate change (Winkler et al. 2002, Dever & Clark 2007). Some demographic impacts on particular species may be quite dramatic.

Because of the difficulty in making predictions about bird species impacts in the PLJV region, this report will focus primarily on habitat impacts, which are likely to be the most important engines of climate impacts for species throughout the region. These habitats follow from the definitions described by PLJV staff (2006).

Freshwater Ecosystems

Overview

The freshwater systems of the PLJV region occupy a vast geographic area, ranging from eastern New Mexico to southern Wyoming and from the eastern front of the Rocky mountains to central Nebraska (Smith 2003). Aquatic systems have special vulnerabilities to shifts in climate regime that are quite distinct from terrestrial ecosystems (Matthews & Aldous in press). Aquatic habitats are literally defined by the presence of water, so changes in the amount of water from shifts in inflows or outflows can radically alter habitat quality and the species that can be supported as a result.

In the Great Plains, extensive groundwater exists in large aquifers such as the Ogallala, but surface water systems in general are not naturally connected to these reservoirs except as recharge inlets (Smith 2003, Gurdak et al. 2007). Before the period of widespread irrigation, almost all freshwater ecosystems in the PLJV region derived their water from precipitation; this has become the norm again in most regions with the widespread adoption of new irrigation techniques (Luo et al. 1997, Six et al. 2004, Tsai et al. 2007). Even in regions with high playa lake density, groundwater connections may be relatively limited, depending on soil conditions (though groundwater connectivity is far higher in the sandhills wetlands) (Gersib 1991, Mangan et al. 2004, Mason 2004). Indeed, one study suggested that aquifer recharge rates varied systematically on internannual, interdecadal, and longer timescales, based largely on climate conditions (Gurdak et al. 2007). The implication for water on the surface is that most freshwater ecosystems in the PLJV region are hydrologically simple (Williams 2006).

This simplicity is useful for resource managers since climate change is altering a wide range of factors that influence hydrology. Many elements of precipitation have been changing since at least 1945 (Dore 2005), including its timing, form (rain versus snow/ice), amount, and intensity (Karl & Knight 1998, Karl & Trenberth 2003, Lambert et al. 2004, IPCC 2007, Wentz 2007). Air temperature has altered in most regions of the world in recent decades. Evapotranspiration (ET) rates have also changed as a result of complex interactions. Large-scale weather systems such as ENSO (El Niño Southern Oscillation) and PDO (Pacific Decadal Oscillation) that appear to drive multi-year weather cycles in North America are changing in their intensity and frequency (Tolan 2006, IPCC 2007a). Finally, climate variability itself is changing — thus, weather globally is becoming less "stable," with more frequent extremes (such as droughts and cold days) and more-extreme extremes (Groisman et al.

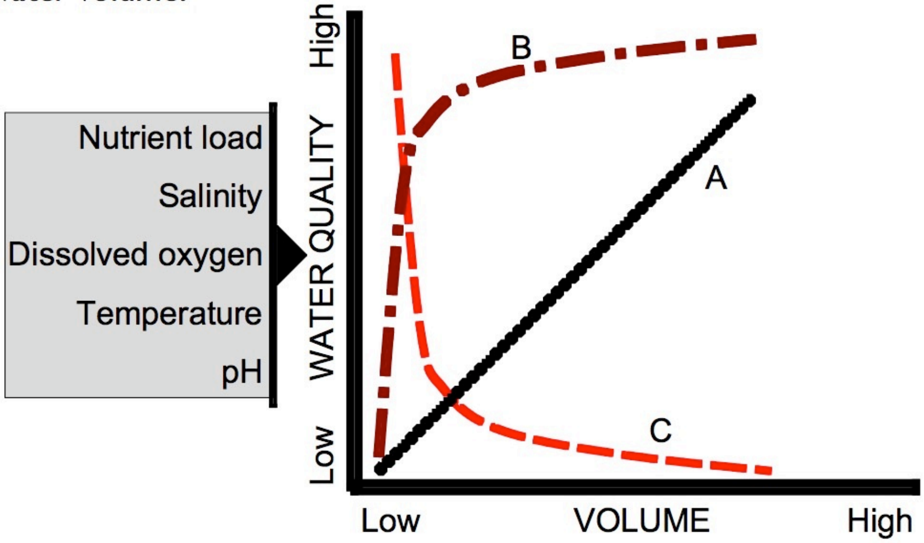
1999, Easterling et al. 2000).

Since shifts in precipitation and ET are the primary drivers of climate impacts in the PLJV region, the predictors of regional vulnerability reflect the ability of freshwater ecosystems to capture and retain water. For simplicity, these controls have been summarized along two axes: size (that is, relative volume) and current hydroperiod/flow regime, also known as hydropattern. Long hydropattern aquatic ecosystems have traditionally been referred to as "permanent" systems, retaining some water in all but the most severe droughts. Short hydropattern systems have been variously called seasonal, ephemeral, or temporary. However, the hydropattern concept is a continuum, and few systems fall completely into one extreme or the other. Vernal pools and playas are examples of the most ephemeral ecosystems, holding water for a matter of days, weeks, or months and drying up each year in all but the most-wet years. Large rivers and lakes, of course, are the most permanent, though even these tend to show some degree of impermanence when viewed over longer timescales. These categories are important distinctions for species since fish in particular tend to be excluded from more-ephemeral systems, which tend to be dominated by invertebrates (Semlitsch & Bodie 1998, Williams 2006).

A subtle but vital concept with hydropattern is that many species rely on a predictable change in volume (and/or flow rate in rivers and streams) that occurs annually. Thus, species in "permanent" or semi-permanent ecosystems depend on a "pulse" in flow or volume (or in the timing of "turnover" and thermal stratification in lakes and reservoirs, which is often linked to water volume) to signal phenological events such as breeding, dispersal, or adult maturation. Generally speaking, species found in ecosystems that regularly run dry (or nearly so) are more acclimated and adapted to high variability and similarly use variability to cue behavior. Part of the crisis of climate change for both groups is that these cues are becoming less reliable (Snodgrass et al. 2000, Allen & Ingram 2002, Brinson & Malvarez 2002, Poff et al. 2002).

Moreover, freshwater ecosystems have a strong tendency to vary in water quality with shifts in volume in a nonlinear fashion, often passing from one relatively stable state to another relatively stable state, such as from oligotrophic macrophyte-dominated to eutrophic algal-dominated (Janse 1997, Murdoch et al. 2000, Magnuson et al. 1997, Brönmark & Malvarez 2002). Thus, in **Figure 2,** most water quality variables of biological interest do not follow trajectory *a* but *b* or *c*. Indeed, pattern *b* is more often seen with nonsaline freshwater systems, and *c* is more typical with saline freshwater systems (where salinity declines with increasing water volume, making these systems less clement for saline-adapted species).

Figure 3. Water quality often has a nonlinear relationship with water volume.



CLIMATE PREDICTIONS FOR FRESHWATER ECOSYSTEMS

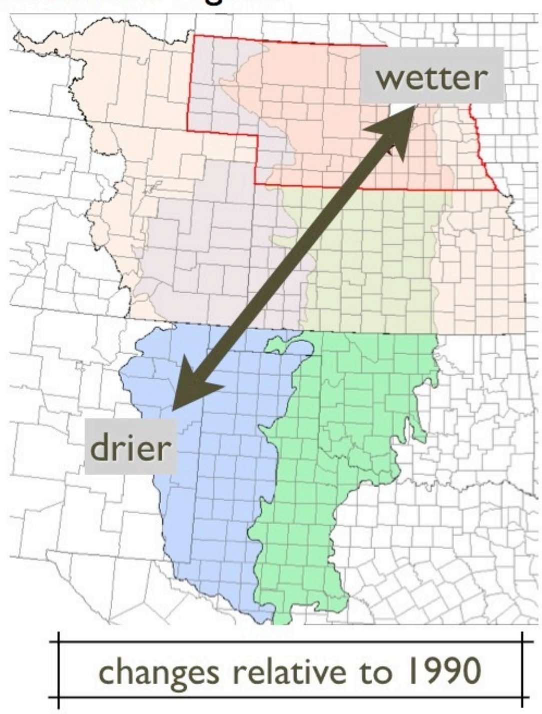
Impacts on freshwater habitats are listed in **Table 1.** Modeling confidence for the Great Plains as a whole is higher than for other regions of North America (Covich et al. 1997, IPCC 2007). Less snow will fall in winter and will begin falling later and melt earlier; more winter precipitation will fall as rain rather than in frozen form. There is likely to be decreasing annual precipitation amounts generally, with the largest decreases in the southern and (especially) the southwestern portions of the PLJV region (IPCC 2007). The eastern New Mexico playas may be especially threatened with historically low precipitation levels, dropping up to 20 to 30% of 1990 levels between 2050 and 2100 (IPCC 2007), reaching "dust bowl conditions" within years to decades (Seager et al. 2007). This trend should be viewed as *high confidence* (>80% likelihood).

The central Great Plains may, in contrast, may see a significant increase in precipitation amounts, especially during the summer. Climate models suggest that the Great Plains Low-level Jet (LLJ) that transfers Gulf moisture to the central plains is likely to strengthen, particularly in spring precipitation (+2 to +12% increase on a decadal basis) and summertime nocturnal precipitation (IPCC 2007b). As a result, there will be an even steeper moisture gradient that develops between eastern New Mexico and the Kansas-Nebraska region (Ting & Wang 1997). Over coming decades, regional increases in precipitation in the northern and eastern portions of the PLJV region are likely to be less than 10% by

2100 (IPCC 2007b). However, given the lack of sharp topographic relief across the PLJV region, precipitation will almost certainly continue to be a "random walk," with great local variation in amounts and intensity (Nippert et al. 2006). Thus, there will continue to be both highly local droughts and regional flooding (Covich et al. 1997, Ojima et al. 1999). The dividing line between the decreased precipitation to the southwest and increased precipitation to the northeast are only *medium confidence* (40 to 60%), although this gradient will develop with *high confidence* at a scale spanning all of the Great Plains and the Midwestern U.S. (**Figure 4**).

One study of southeastern Colorado (Elgaali et al. 2007) suggested that under a variety of climate models water demand by plants increased with time, but models differed widely in terms of their predictions about the availability of water to meet that demand. This level of uncertainty is not likely to be resolved soon, and regular monitoring of precipitation trends should be implemented across the region by PLJV staff (see final recommendations).

Figure 4. Projected climate trends over the Playa Lakes Joint Venture region.



That said, runoff patterns may show dramatic responses to small shifts in precipitation regime. One study in western Oklahoma showed that a 33% increase in mean annual precipitation resulted in a 100% increase in runoff (Garbrecht et al. 2006), a finding generally supported by modeling research (Zhang 2005, 2007). Given the higher rate of precipitation variability and intensity, runoff could become a potentially destructive force, especially in such erosion-sensitive areas such as the sandhills wetlands (Mason et al. 2004).

Droughts will become more severe throughout the PLJV region, especially in the southern and southwestern playas. Dry decades such as the 1930s and 1950s will become more common (Seager et al. 2007). The large-scale multi-year weather pattern ENSO is decreasing in frequency and shifting towards a more neutral pattern and may prove less of a climate factor in coming decades (IPCC 2007).

Developing precise predictions for the freshwater systems in the PLJV region is a great challenge. Even in simple systems like the playa lakes themselves, some authors have suggested that developing high-confidence predictions will be extremely difficult for freshwater systems simply because individual catchments tend to show high variability that is difficult to model and characterize (Winter & LaBaugh 2003, Winder & Schindler 2004, Blenckner 2005). For standing water (lentic) systems, there may be a number of distinct alternate stable states under a single climate regime for nutrient concentration, temperature, clarity, and biota (**Figure 2**; Janse 1997). Perhaps the most difficult issue to resolve is the relative balance between precipitation and ET trends over coming decades. Ultimately, these two variables will determine water quantity, and water quantity will determine water quality.

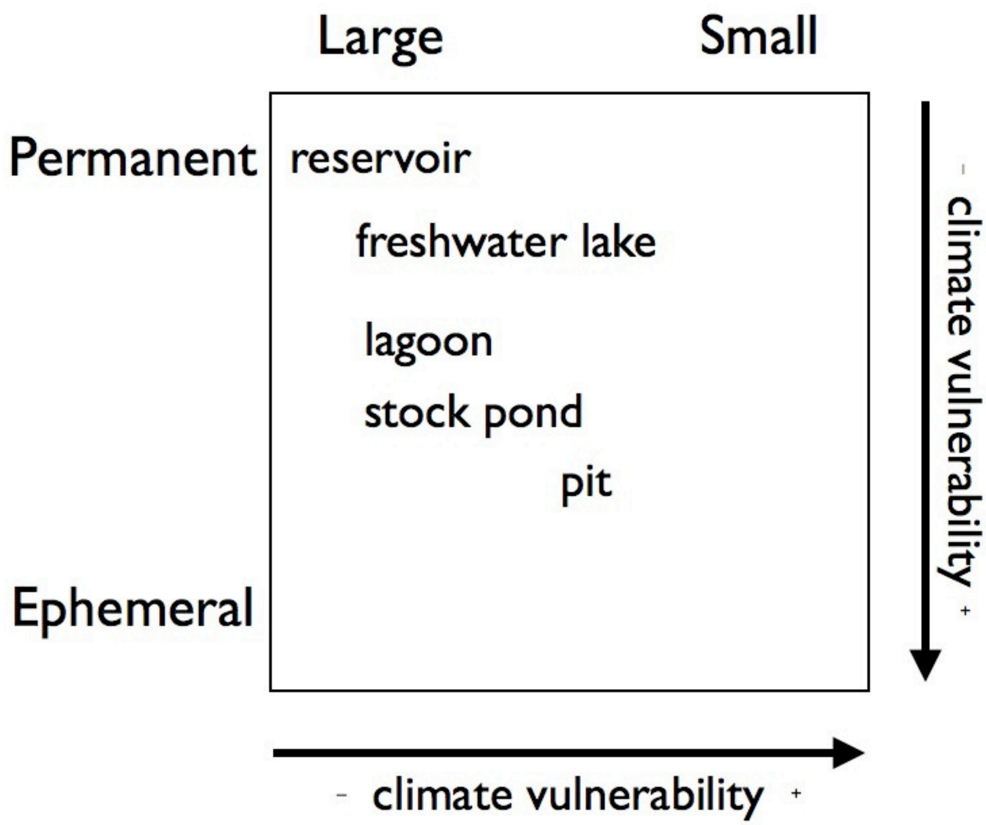
Given these caveats, hydroperiods are likely to already be shortening during summer and early fall, depressing the number of playas absolutely and the volume of those still seasonally extant. This pattern is quite similar to projections for vernal forest pools in the northeastern U.S. (Brooks 2004). In contrast, spring may actually see more playas and more water-full playas across the landscape relative to the 20th century as a result of elevated precipitation levels, with winter showing less ice cover, more fast-runoff events, and higher sedimentation rates (Hostetler & Small 2000).

OPEN-WATER HABITATS

Impacts & Vulnerability

Climate vulnerability in open-water habitats will be buffered somewhat from climate variability such as droughts, shifts in the timing of precipitation, or increases in ET simply because of their high total volume. The least vulnerable systems will be those with the largest volume and, when volumes of given systems are equal, the lowest surface-to-volume ratio (**Figure 5**). Vulnerability here is defined as the presence of a particular habitat rather than the quality of that habitat or the resulting state of the organisms within. Thus, dug water-holding pits should become less abundant relative to reservoirs and lakes, but the species that are found in pits are likely to be more adapted to variable water quality and may thus be somewhat buffered from climate change for a few decades. A significant change in large systems, however, is the likely shift in water column turnover rates. Most large temperate lentic systems are bimictic, with spring and fall "turnovers" and stable thermal stratification between turnover periods. These turnover periods are particularly critical for redistributing nutrients within large aquatic ecosystems. Increases in temperature and drops in summer/fall water volume may fundamentally alter these cycles, reducing overall productivity (Blenckner et al. 2002).

Figure 5. Open-water habitats climate vulnerability.



Summer may also prove to be a difficult period for open-water systems. Some aquatic species retreat to cooler, deeper water during warm periods. However, extreme warm air and water temperatures may restrict or eliminate these habitats. Shifts in the species composition or abundance of fish, in particular, are likely to result in major changes in the trophic structure of open-water habitats, especially those that are not closely managed (as on private lands). Generalist invasive exotic species (bass, bullfrogs) are likely to benefit over native (or "more-native" species). The presence of carnivorous fish has been shown to have an important influence on zooplankton grazers such as *Daphnia* spp., and reduced grazers can lead to algal blooms, reducing overall water quality for most native species.

The impacts for waterbirds (including shorebirds and waterfowl) from these trends are quite important (Sorenson et al. 1998). Fall and winter are likely to see less water volume, resulting in more shallow/littoral habitat. With lower productivity levels, littoral prey species may be less abundant and access to fish species may be more restricted as well. Waterfowl will be concentrated in smaller clusters during winter, with higher winter temperatures that are favorable to the more rapid transmission of avian diseases, a pattern already seen in drought years in the PLJV region and nearby (Smith, Higgins, and Tucker 1990, Smith & Higgins 1990). Shifts to an algal-dominated eutropic state from a macrophyte-dominated oligotrophic state will reduce available food resources for even herbivorous bird species.

Recommendations

Reservoirs may need to be managed for higher volume levels/lower releases during summer and fall, though this may have negative impacts for downstream species dependent on fall flows. Resource managers and extension services may need to recommend that newly constructed systems be deeper than current specifications, with lower surface-to-volume ratios. Invasive fish species should be suppressed as much as possible, and emergent vegetation should be promoted whenever possible (a challenge in ranching areas). Monitoring of avian disease outbreaks for overwintering species may need to become a regular practice with interventions developed for severe outbreaks. Ideally, preventative plans for such outbreaks should be developed.

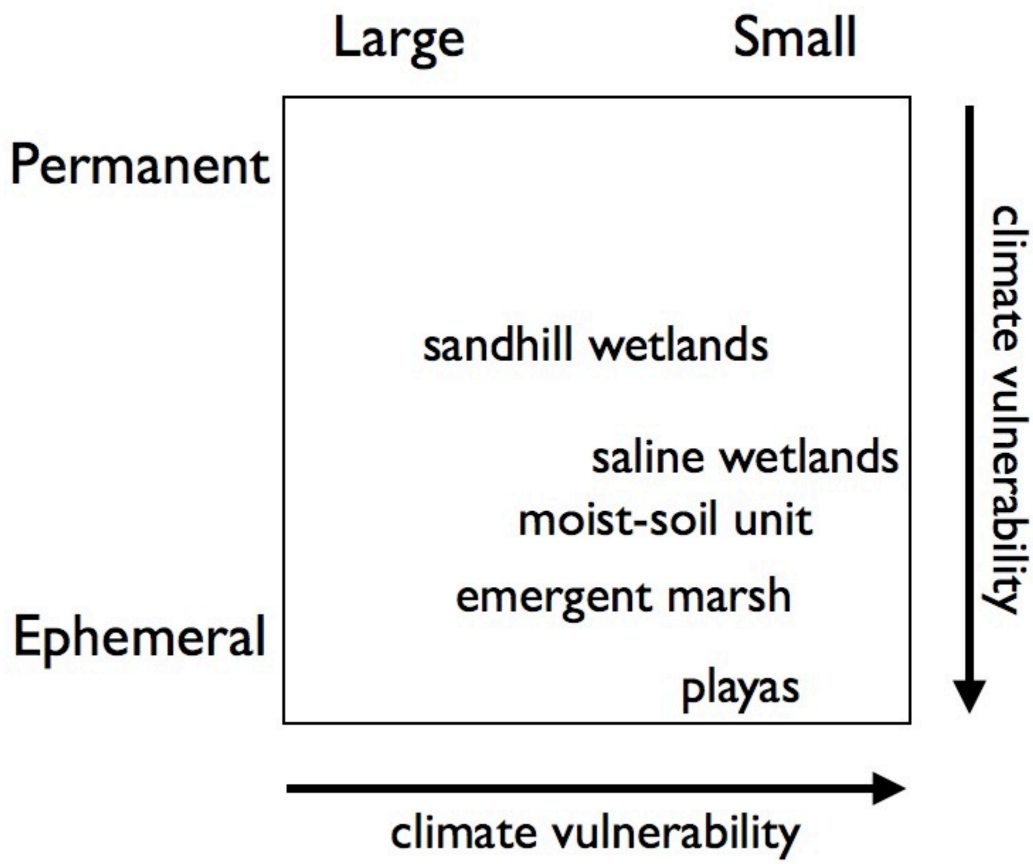
WETLANDS

Impacts

Great Plains wetlands have already faced huge challenges from habitat destruction, eutrophication, and sedimentation (Dahl 1990, Gibbs 2000, Smith 2003), but climate change presents a series of new challenges (Conly & Van der Camp 2001, Matthews & Aldous in press). In contrast to open-water habitats elsewhere, most PLJV region wetlands are small and shallow and as a result they are far more sensitive and less buffered to hydrological shifts and state changes from climate impacts (**Figure 6)**. Hydrological impacts on PLJV region wetlands can be divided into two major types. First, changes in the balance of inflows and outflows will alter the water quality and hydroperiod of **individual systems**.

Thus, increases in precipitation, decreases in ET, or changes in the timing of rain will alter how long a given body holds water and how much water it contains. For the most part, water volume will also determine water quality as described above.

Figure 6. Wetland habitats climate vulnerability.



Second, as a result of individual-level impacts, at a **landscape level** the absolute number of wetlands will change including their distribution across the landscape. Here, a distinction must be made between playas as geological and soil features and playas as wetlands. While playa numbers in geological terms (baring human modification or sedimentation process) may remain relatively constant, the number of those that contain water and are functioning wetlands will change, and this latter change will largely be a function of climate. Increased precipitation will raise the number of water-bearing playas in a given region, potentially extending the hydroperiod of small playas, while the reverse is also true.

The most dramatic impact will almost certainly stem from increasing drought frequency, which will reduce the abundance of wetlands throughout the region. Thus, landscape-level processes are probably the most important to observe. Moreover, conditions now referred to as "severe droughts" are likely to become the normal climate in the southwestern portions of the PLJV region. Most models are in agreement that this region will undergo a drop in precipitation on the order of the regional pre-Columbian climate regime of the 1200s. Semi-arid habitats in this area may become desert, with decade-spanning periods of low precipitation (Seager et al. 2007).

An important uncertainty, however, is for the eastern and northern portions of the PLJV region. Large-scale climate modeling suggests increases in annual precipitation in this area, which means that the gradient between the southwestern and northeastern areas of the PLJV region may become even more extreme and dramatic. Drawing clear lines of demarcation is extremely difficult. Will the Southern High Plains, for instance, be far enough east to receive much more precipitation, remain unchanged, or become more like eastern New Mexico today? In either case, the thermal regime of the Southern High Plains is mostly likely to "migrate" north by mid century, potentially reaching Nebraska by this period.

The playas are mostly small (<10 ha), shallow (<1 m), and disconnected wetlands. The period in which they hold water — their hydropattern or hydroperiod — varies widely on a seasonal basis. In a few regions, some playas may have limited connectivity with one another through groundwater or, during periods of high precipitation, through surface runoff, though such patterns are not widely found. For the most part, playas as surface features are believed to exist as hydrologically isolated "islands" of water. Under even relatively natural conditions, most of their water is derived from precipitation in their nearby catchment area, and most of their outflows are accounted for by ET and groundwater/aquifer recharge in the regions like the Southern High Plains (Smith 2003). Many playas have been deepened (i.e., pitted) by landowners to adjust their ability to retain water.

Current trends for increasing summertime precipitation suggest that hydropatterns could increase in the northern and northeastern regions of the PLJV region, shifting more-ephemeral playas to a more-permanent state, and providing playas that are now more-permanent and deeper with more water. However, many models suggest that, although summertime temperatures have not increased significantly over the 20th century, summers should be warmer in coming decades, elevating ET rates. The interaction between these two processes in "normal" precipitation years is difficult to gauge, but during drought years ET should dominate. Artificially deepened playas are likely to retain more water for longer periods than non-modified playas, though their limited littoral habitat and limited emergent vegetation will make them generally less appealing to wildlife.

The interaction of increased precipitation intensity and the more widespread use of no-till agriculture is difficult to gauge; the amount of research in this area is quite limited (Six et al. 2004). Playas embedded in landscapes using traditional methods of cultivation will see much higher sedimentation rates, however (Tsai et al. 2007). The synergies between increasingly shallow playas and increased drought frequency will accentuate the functional rate of playa loss during dry years.

The sandhills wetlands have a higher degree of groundwater connectivity relative to most playa networks, which means that they will be less sensitive and more resilient to temperature and precipitation extremes than the playas, at least over the next decade or two. However, even slight changes in erosion rates could free the sandhills to move as they have in past millennia (Mason et al. 2004).

The most climate-sensitive wetlands in the PLJV region will be those that respond quickly to ET and precipitation — especially the playas (**Figure 6**). Increased drought or flood frequency may tend to either eliminate these habitats or shift them into larger types of standing water systems.

Saline wetlands often exhibit highly specialized arthropod taxa and may have difficulty re-establishing populations if a particular wetland dries out, causing local extinctions. As suggested in **Figure 2** (line c), the special qualities of these wetlands tend to be erased as water quantity increases, reducing salinity. Thus, as with moist-soil units and emergent marshes, flooding and droughts will both tend to have adverse effects on these habitats. Bird species that depend heavily on saline wetland species will also be adversely affected.

Recommendations

Critical wetland habitat managed by state or federal authorities may require some level of direction intervention over coming decades, such as managing water level through groundwater pumping. For areas like the sandhills wetlands that are such critical overwintering and spring habitat, this may be the only option during dry years. The construction or maintenance of small cattle tanks may also be another venue for working with landowners with surface-water resources with wetland-like resources.

The sandhills may be uniquely sensitive to elevated drought frequency/severity since these wetlands are currently fixed in position by vegetation. Conservation strategies almost certainly should focus on promoting fire- and drought-resistant plant species, since this critical habitat could literally dissolve in the wind and rain.

A major uncertainty independent of climate is the future of wetlands currently considered "safe" under the Conservation Reserve Program (CRP). The status of the program could change in scope or degree of protection with policy and legislative shifts — for better or for worse. The loss of a program like CRP in coming decades could be catastrophic for migratory and overwintering birds, as well as aquatic species dependent on the playas. Migratory flyways in the central U.S. and Canada are likely to shift in an eastern direction, potentially leading to other difficulties and higher migratory mortality (Dingle 1996). If possible, additional wetlands in the northern and eastern portions of the PLJV region should be added to the CRP umbrella should be concentrated. Ideally, the CRP (or other programs) should be extended in scope to promote additional practices to maximize wetland hydroperiods and abundance during severe droughts. In some regions, this may again involve the supplementing surface water with groundwater pumping or removing accumulated sediments.

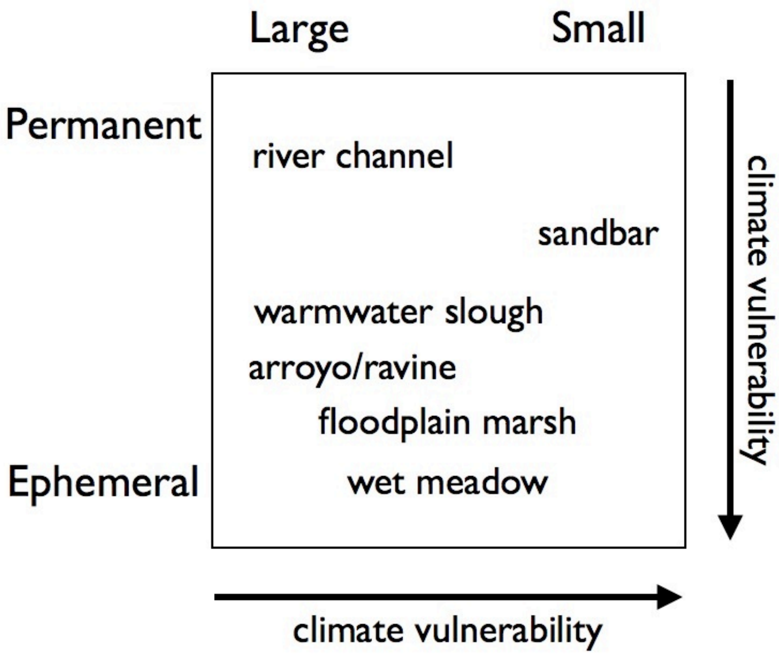
In addition, more traditional "restoration" approaches must be maintained and even accelerated: reducing sedimentation rates through grass buffer strips, nutrient and herbicide/pesticide pollution, and promoting emergent vegetation growth. These will reduce overall pressure on the species in these systems, allowing them to respond to a (hopefully) reduced suite of threats.

RIVERINE SYSTEMS

Impacts & Vulnerabilities

As with open-water habitats, large and permanent flowing-water (lotic) systems will be more buffered from climate impacts than small and ephemeral bodies of water (**Figure 7**). An extension of this principle is that catchment size can also be a shield, with larger catchments potentially more insulated than small catchments, all else being equal (Matthews & Aldous in press). Two lotic-specific factors are worth noting. First, natural flow regimes will be altering, with lower flows in late summer and early fall likely and higher winter and spring flows. Second, for lotic systems that serve as markers or routes for seasonal migration, isolated pools of water or dry beds could increase the costs of southerly movement. Indeed, during severe droughts some rivers are likely to become standing-water systems or even completely dry.

Figure 7. Riverine habitats climate vulnerability.



Higher flash flooding frequency will also be an important factor for lotic systems, especially for bird species that breed and nest in riparian zones or that forage in these areas. For birds that forage in the main channel, more flash flooding will increase disturbance rates for aquatic insect species as a result of channel scouring, tending to reduce the number of insect species present. Flash flooding may also make some riparian vegetation restoration attempts more problematic and tend to channelize rivers and streams with very high water levels and much greater sediment loads/deposition patterns. In general, well established riparian vegetation should act as a shield and anchor against flash flooding and should be promoted when possible.

Somewhat related are the widely observed changes in high elevation warming, which reduces the duration of freezing temperatures in winter and shifts the form of cold-season precipitation to rain over ice/snow. This issue is likely to already be impacting large lotic systems in the PLJV region such as the Canadian, Red, and Arkansas rivers. These systems receive significant amounts of water volume from spring melt-offs, particularly in the headwaters and upper reaches of these rivers. However, these impacts will be concentrated in winter and early spring and primarily effect the low-order portions of these rivers rather than the middle and lower reaches.

Warmwater sloughs, floodplain marshes, and wet meadows are likely to be extremely sensitive to changes in climate regime, especially decreases in precipitation or increases in ET. In many ways, these systems function like small to medium wetlands and may prove capable of shifting to hypereutrophic states during summers. For wet meadows in particular, shifts in near-surface groundwater levels could also trigger the complete local loss of these habitats, which will have important implications for upland shore bird species. Changes in hydroperiod will almost certainly alter vegetation community of each type.

Arroyos/ravine habitats are characterized by flash flooding and high erosion rates, often with highly channelized conditions. These characteristics will be accentuated with increased flash flooding rates. Moreover, some drought-resistant plant and animal species may have difficulty adjusting to future extreme droughts, particularly in the southwestern portions of the PLJV region.

Recommendations

For lotic systems that are managed by dam or irrigation authorities, drought years will present difficult choices between human and ecosystem needs. Difficult drought-year choices for dam managers may also be present when balancing the needs of species that favor reservoir habitats and species found downstream. Flood control will present a different set of issues during wet years, potentially stressing reservoir capacity. For large-scale systems, the only appropriate solution is the strong advocacy of climate-change aware environmental flow policies and the development of contingency plans before crisis events.

Smaller lotic systems will have fewer and less comprehensive solutions available, especially intermittent and ephemeral streams. The promotion of native riparian and emergent vegetation will assist with both flood control and buffering extremely high water temperatures. Warmwater sloughs may benefit from increased connectivity with mainstream flows to flush nutrients and improve overall water quality. The abundance of some specialized habitat types such as wet meadows will decline without very active intervention.

Terrestrial Ecosystems

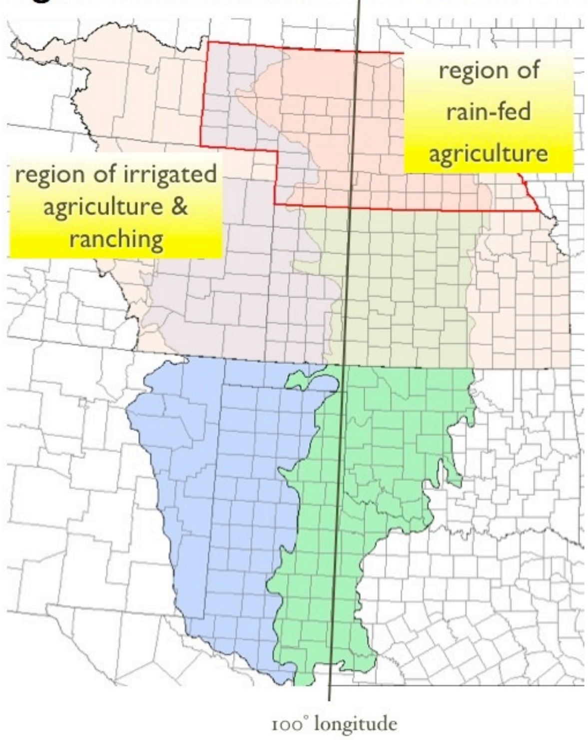
Overview

Terrestrial systems in the PLJV region have arguably been even more heavily modified than freshwater systems since the onset of European settlement through habitat fragmentation and invasive species. Anthropogenic climate change presents a different set of challenges in terrestrial systems as well. During past periods of climate change, regions like the Great Plains were highly responsive to shifts in climate (Mannetje 2007), and unlike aquatic systems relatively few dispersal barriers facilitated range shifts.

All of the important climate predictions mentioned in the freshwater overview are relevant with terrestrial systems as well: winter temperatures are rising relative to summer but summer temperatures rise more quickly in the future; precipitation is increasing in the northeastern portions of the PLJV region and decreasing in the southwest; and late summer and early fall are likely to be increasingly dry. Drought frequency and intensity in particular should be growing, with more extreme precipitation events (Covich et al. 1997, IPCC 2007).

Unfortunately, the climate change literature on terrestrial Great Plains ecosystems has been narrowly focused on issues that are not very relevant to resource managers. Many of the studies to date have focused on shifts in the soil carbon content with warmer air temperatures, for instance, rather than how prairies as intact ecosystems can or will respond to new climate regimes. Clearly, plant productivity, species abundance, and species ranges will alter as a result of these changes. One long-term prairie study (Nippert et al. 2005) suggested that annual precipitation increases tended to increase net primary productivity (NPP), with growing-season precipitation being the strongest predictor for both total and grass NPP, followed by soil moisture variability

Figure 8. Traditional climate-driven divisions between agricultural zones in the Great Plains.



(higher SMV = higher NPP) and the rate of change in soil moisture (higher Δ = higher NPP). Other precipitation variables showed nonsignificant relationships with NPP. These results contrast with other recent studies spanning shorter time periods (<<15 years), but long-term ecological research is likely to prove the most effective means of evaluating the full complexity of climate change impacts on whole ecosystems.

Much of what happens with habitats is going to depend on the emerging economic patterns of this region and how land-use patterns are altered as a result. Projected impacts on terrestrial associations are listed in **Table 2.** However, three human-specific trends may be quite important in determining how natural ecosystems adapt to climate change:

1) Agricultural patterns have traditionally been driven by precipitation reliability in the PLJV region, with the 100th meridian being the longstanding divide between rain-fed farming (to the east) and ranching (to the west) (**Figure 8**). The advent of inexpensive pumping of aquifers for irrigation effectively altered this line, pushing the division to the west. Increasing efficiency in irrigation methods further lowered the costs of dry-land farming, though now the overexploitation of aquifer resources and increasing fuel and fertilizer costs may once again alter the economics of irrigation. Likewise, ranching be a more viable alternative to row-crops in the more eastern portions of the PLJV region (Harrington 2005).

2) Human population density has been dropping in many regions of the PLJV region, with large cities generally increasing in size at the expense of rural areas and small towns and cities. This trend began in the 1930s and is likely to accelerate in the near future (McLeman & Smit 2006). Urban footprints are thus becoming more concentrated over fewer centers, and those centers are growing bigger. While not necessarily a result of climate change, human population declines will have a powerful effect on climate adaptation responses on natural and managed ecosystems. For instance, groundwater withdrawals are likely to decline in volume and intensity, and the rate of modification of surface features (e.g., stormwater systems, maintenance of "thirsty" plant species) should slow or even reverse. This trend is probably a net benefit for terrestrial ecosystems.

3) Fire suppression practices may alter as a result of trends (1) and (2). Most of the PLJV region before widespread cultivation saw fire as an important disturbance mechanism, particularly for prairie regions (Fuhlendorf & Engle 2004, Nippert et al. 2006). With warmer air

temperatures and drier soil moisture, especially during severe multi-year droughts, fire could once again become a significant component of disturbance in PLJV region ecosystems. Indeed, extensive fire suppression is the primary mechanism for the conversion of grasslands to shrubland savannah (and from shrublands into woodlands), which promotes the encroachment of woody plants into prairie systems (Fuhlendorf & Engle 2004).

The interaction between these three variables may be even more significant than the contribution of any single factor. Thus, if irrigation efficiency can be maintained at economically justifiable costs across the PLJV region, then continued fire suppression in the face of elevated precipitation levels may lead to a further increase in shrubland abundance. The conversion of crop lands to cattle ranching has historically been associated with incursion of exotic invasive grasses and the promotion of ungrazed woody species, so a decline in cultivation may be associated with more increasing juniper abundance or more frequent fires.

There are also likely to be complex side effects from managing these changes and impacts. For instance, many exotic invasive grasses respond more rapidly and successfully to fire disturbance than native grass and shrub species, so attempts to control woody encroachment may fuel the conversion of native or semi-native grasslands to exotic-dominated ecosystems (Knick et al. 2005). In any case, habitat complexity is critical for species richness and climate adaptation, and habitats should be managed for multiple contemporaneous successional stages and structural complexity (Lee 2006).

Another important risk will come from the movement of "native invasive" herbivores, a threat that is extremely difficult to quantify or predict (Ward & Masters 2007). Mountain pine beetles, for instance, are a major predator of western pine species but their northern range limit has been limited by winter temperatures. With higher winter temperatures, they've been able to destroy millions of acres of forests in British Columbia and Alaska, regions where they were previously unknown or rare, while simultaneously increasing the risks of cataclysmic fires from the masses of dead standing timber and lower summer precipitation rates (Carroll et al. 2004). Nearer the PLJV region in the central Rocky mountains, increasing drought frequency appears to be fueling higher rates of insect outbreaks and fires (Bigler et al. 2007). As a result, it is safe to infer that groups such as nematode, insects, and other arthropod species that may be native to North America but exotic to the PLJV region are already probably moving north and/or east. Species invasions have long been known as extremely difficult to stop or slow down, and those caused by climate change may be among the most challenging kinds of invasions since the impetus driving the range shift is not a one-off event but a strengthening pulse.

SPARSELY VEGETATED AREAS: BADLANDS, CLIFFS, & ROCKS

Impacts & Vulnerabilities

Vegetation is an anchor for soil, and the combination of increased flood and drought frequency is likely to maintain (or even reduce) plant coverage and elevate soil erosion. Moreover, the degree and types of vegetation cover across the PLJV region will be changing over the next century as many species shift their ranges. Drought-intolerant plants in particular will become much less abundant in the southwestern portions of the PLJV region, probably within a decade. And the amount of sparsely vegetated land in the PLJV region will be increasing in at least that region.

Recommendations

Soil moisture levels can be somewhat increased by trying to slow runoff patterns across the landscape, which will eventually result in more vegetation cover. Likewise, planting drought- and fire-resistant species may be a means of reducing soil erosion rates.

GRASSLANDS

Impacts & Vulnerabilities

Grasslands make up the largest historical component of the PLJV region. As suggested from the long-term study cited above, grassland productivity should generally increase with higher rates of spring precipitation (Nippert et al. 2006). However, to assume that this trend will be continuous across the coming century is a risk in itself. Many plant species have shown powerful changes in physiology and phenology simply with higher levels of atmospheric carbon dioxide in experimental manipulations, even at relatively modest increases from 380 ppm to 450 ppm or higher (Antle et al. 2004), and complex feedback mechanisms between land use and surface temperature and precipitation that are extremely difficult to model are likely as well (Mahmood et al. 2006, Juang et al. 2007). Insects are highly sensitive to changes in thermal regime; worldwide, they have been seen as among the first animal species to show climate responses (Parmesan 2006). For the PLJV region, there are two implications. First, the regional abundance and composition of insect plant pollinators and herbivores (and predators of herbivores) will accentuate direct thermal impacts on grasslands. Second, avian species that prey on insects will experience changes in the abundance and phenology of prey species.

Unlike woodlands, forests, and shrublands, grasslands are extremely well adapted to fire disturbance, though the abundance of different grassland types is influenced by fire frequency. Generally speaking, higher rates of burning should increase the abundance of grasslands. The critical (and most elusive) question, however, is what kind of grasslands will follow burns? Differential climate impacts on grass species mean that some species may be responding more rapidly or in surprising ways. These responses may be almost impossible to predict.

Prairie dog communities will surely be impacted by climate change, but the kinds of impacts are difficult to predict, with extremely limited (and highly speculative) literature. However, at least one author suggests that the herbivory of prairie dogs may prove to be a useful buffer for grassland systems to climate change (Curtin 2006), so that promotion of prairie dog population vitality may be a powerful means of developing grassland climate resilience.

Recommendations

Grasslands have been shifting to other types of ecosystems (and agro-ecosystems) for so long that near-term strategy may need to continue to focus on restoration techniques and suppression of exotic invasives. However, historic guidelines for relative species abundance and community composition may be less useful in developing restoration targets, and these communities will seem less and less familiar in coming decades. Emphasis may need to be on reducing exotic invasives rather than "native invasives," which are likely to be engaged in range shifts.

Development of disturbance regimes such as grass fires in managed areas should attempt to match local historic patterns in the near term, but consideration should be given for facilitating range shifts in the grasslands across the landscape as natural drought and fire periodicity shift.

FORESTS & WOODLANDS

Impacts & Vulnerabilities

PLJV region forests and woodlands vary widely in their tolerance to fire and droughts, and many have been heavily impacted by shifts in land use. Fire and droughts should be more important impacts for these ecosystems than flooding (Motha & Baier 2005). Ponderosa pine woodlands, for instance, are exceptionally well adapted to all but large intense burns. Such fires tend to be fueled by the accumulation of undergrowth and debris, particularly as a result of fire suppression practices; this problem is most widespread across the western U.S. Tree density is also associated with fire intensity, with woodlands less likely to experience ecosystem-transforming fires than more-dense forests.

Junipers, cedars, and mesquites, on the other hand, are far less tolerant of fire, and they make up much of the vanguard of woody encroachment on prairie systems in the Great Plains, especially in the southern and southwestern regions. Pinyon is more tolerant of fire and may be more resilient to increases in fire frequency, though higher fire intensity can kill pinyon pines more easily than ponderosa forests (Miller & Tausch 2001).

Shelterbelts — especially those consisting of non-native species that may be less resistant to drought — may be less exposed to fire disturbance but more sensitive to declines in soil moisture and drought severity/frequency shifts. One study of such "linear forests" and climate change found a massive variation in potential impacts, generally increasing in biomass but otherwise showing little consistent patterns across climate models or types of shelterbelts (Guo et al. 2004).

Impacts on individual hillside woodlands could be particularly difficult to predict as microclimatic variations could either counteract or accentuate local and regional climate trends. Thus, south-facing slopes will tend to be drier than nearby flatlands, while soil-moisture levels will likely be higher in north-facing slopes.

Cross timbers forests — like sand shinnery shrublands mentioned below — are resistant to fire disturbance and may require burns to maintain their habitat structure and seedling productivity (Therrell & Stahle 1998, Clark & Hallgren 2003, Engle et al. 2006).

Recommendations

Generally speaking, the conservation focus for PLJV region forests and woodlands should be restoration in the short-term to reduce overall pressures on these ecosystems. Strategically, though, the focus should be on facilitating species range movement and ecosystem transformation. The effects of increased precipitation, altered soil moisture, elevated CO_2 levels, and new fire regimes are extremely difficult to predict via modeling, especially at scales less than, for instance, the whole of the Great Plains (Polsky 2004). Such a scale is not useful for resource managers and planners. Nonetheless, we know that these ecosystems are moving and changing. Overall strategies should include gradual promotion of higher rates of disturbance, the reduction of exotic invasives, and acknowledgment that these forests will be attempting to move northwards.

SHRUBLANDS

Impacts & Vulnerabilities

As with woodlands, shrublands will be heavily influenced by changes in fire and drought frequency and land-use shifts. Shrublands in general are intermediate in their ability to response to fire than grasslands and forests/woodlands but show much variety between types of shrublands. Most sensitive should be mesquite savannah/shrublands, followed by sage-dominated systems, sand shinnery shrublands, and high grass shrublands. Mesquite could be sensitive enough in places to become grassland under more frequent fire regimes.

Recommendations

Fire suppression is an important component of mesquite savannah and shrublands, and aggressive attempts to reduce invasive grass invasions in sagebrush ecosystems should be maintained and extended. Shinnery oak habitats have suffered from fire suppression and may in effect need an increase in natural fire frequency — and less fire suppression (Harrell et al. 2001, Boyd & Bidwell 2002), at least in the near term. High grass shrublands are likely to need a similar treatment. Beyond 2020, this strategy is likely to need revisiting, however, as droughts should become significantly more severe.

Agricultural Ecosystems

OVERVIEW

The impacts on agricultural systems in the PLJV region contain the most uncertainty of all of the major areas discussed in this report, and here we are most likely to err on the side assuming that current trends will continue in a straight line. Climate on some levels helps to define the agriculture of the region. Agricultural habitat impacts are summarized in **Table 3.** Several trends are worth attending to in agro-ecological systems:

1) Crop types are likely to change throughout the PLJV region and the Great Plains generally. Several models show more and higher-quality arable land opening up at higher latitudes in Canada and Russia, and the range of optimal varietal (i.e., subspecies/breed) suitability for current varieties of grain crops should be shifting generally north and east (Izaurralde et al. 2003, Weiss et al. 2003, Hi et al. 2005, IPCC 2007). However, tariff and trade policy, international economics trends, emerging new markets, and shifting costs associated with modern U.S. intensive agriculture could alter the range of optimal financial suitability. An area of particular uncertainty is the costs associated with irrigation and intensive groundwater use, particularly as aquifers become harder to access. Human decisions matter in this region (Burke et al. 1991).

2) New technological solutions to climate change. Current corn varieties, for instance, may rapidly become unsuitable with a warming climate. However, genetic engineering techniques may develop new varieties that are more suitable for emerging climate regimes and pest threats. Indeed, this may prove the only means of maintaining the agricultural viability of the southern and southwestern regions of the PLJV region.

3) Even with rapid responses by the agricultural industry, the relative balance of ranching and cultivation is likely to change as the economics of water use, distribution, and pumping change (e.g., pumping may become more expensive as international energy prices increase), and within cultivated crops, the selection of crops will itself be shifting.

4) A few observers (e.g., Murdoch et al. 2000, Harrington 2005) have suggested that annual crops may not be a wise use of the Great Plains in future climates and that perennials and/or biofuel crops may be a more productive use of land.

5) International treaties in the near future will be extending the Kyoto Protocol and other mechanisms to reduce greenhouse gas concentrations. The Great Plains may become a tool in this process as a carbon sink to mitigate U.S. carbon impacts through carbon sequestration or developing "living carbon" pools such as forests.

> The tools for reducing carbon emissions are at present quite limited, so habitat impacts from this possibility are highly speculative for now.

Some observers have taken extreme positions about the future of the U.S. Great Plains, suggesting that climate change will make parts of the region economically unfeasible for agriculture (e.g., Harrington 2005). In contrast, several groups are already considering how to implement climate adaptation into current agricultural outreach/extension services (Cutforth et al. 2007, Antle et al. 2004). Studies focused on specific crops have shown some interesting trends. For instance, Hu et al. (2005) showed that over the past 70 years wheat harvesting dates had advanced about 0.8 to 1.8 days per decade. A study of 78 German crops over a 50-year period saw similar rates of advance (Estrella et al. 2007).

The variability between models in precipitation uncertainty has been crippling in preparing more detailed impact projections. Zhang (2005) modeled wheat in the future for Oklahoma, showing that productivity did not drop much under most climate scenarios, but this study assumed that no precipitation was lost during the growing season. However, another study focused on grains in southeastern Colorado suggested that water use rates would increase over coming decades, with no clear pattern under any scenario on whether precipitation would be able to compensate for the higher usage. Thus, irrigation may become more important for some/many crops in the PLJV region (Elgaali et al. 2007). Izaurralde et al. (2003) found that dryland corn productivity increased, decreased, or remained stable under various scenarios. In the same models, soybean yield decreased and wheat tended to increase.

Additional uncertainty surrounds the so-called CO_2 fertilization effect. Some plants respond to elevated levels of atmospheric CO_2 with higher growth rates (Antle et al. 2003). However, the effect is not universal, and manipulations in experimental conditions do not represent actual field growth impacts.

General Recommendations

Perhaps the most critical issue for regional resource managers and planners to bear in mind is that the climate has already changed and will continue to do so. Indeed, the pace of change will only quicken. It may be useful to think of the region entering several new "climates" over the coming 200 years.[2] Understanding and detecting impacts will come less from complex modeling projects than from on-the-ground studies to monitor changes in habitat and wildlife populations, as well as office-based studies examining climate trends from weather data across the region. A few general suggestions may be worthy of consideration:

1) Develop a climate center for the PLJV focused on quantifying trends within the region. A handful of studies have attempted to tease out climate trends from historical data (for eastern Colorado, for instance: Pielke et al. 2001). This method can assist in determining regional climate, detecting realized climate impacts, and developing climate adaptation conservation plans for over the near-term (5 to 15 years from the present). Remote sensing may be a useful means of making comparisons across years. Studies examining habitat impacts during very wet or very dry years may also help estimate the severity of impacts on birds and habitats.

2) Closely monitor land-use shifts, such as the prevalence of fire, the climate adaptability of cultivation, and the relative balance between ranching and cultivation. Again, remote sensing will be a useful tool. Coordination with extension agents and state-level agricultural economists may also prove fruitful.

3) Monitor species abundance, but be sensitive to potential changes in distribution that may be masked as population increases or decreases locally. We know that bird ranges will be changing. The key is to detect species that are in clear decline, and the best means of doing this may be to monitor key habitat attributes as well as species.

4) New climate-related risks will be emerging for particular species, perhaps even species with populations that have been viewed until now as stable or abundant. When evaluating risks to a species, you must always ask if the climate component can be counteracted, or should we instead focus our efforts elsewhere and on other species? In effect, we will surely lose some species in the PLJV region to climate change. The goal, however,

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[2] To clarify, the evolution of climate will likely occur as both a series of slow changes (e.g., gradually increasing climate variability, gradually increasing mean air temperature) and, potentially, as a series of major, step-wise changes, such as through major alterations in the periodicity and intensity of PDO or ENSO cycling (IPCC 2007). These latter changes are both quite likely to occur and extremely difficult to predict with specificity with much confidence. As a result, "perceived climate" should pass through several periods over coming centuries, even if these boundaries cannot be delineated clearly by modeling.

should be to help as many as we can and to use (limited) conservation resources as wisely as possible.

5) Consider working with agricultural extension services focused on climate adaptation. There may be ways to assist farmers and rural communities to adapt to climate change impacts that also benefit wildlife. Perhaps the most basic approach is simply to make farmers more aware of the reality of climate change, why climate change matters, and how a shifting climate will influence all of us over coming decades. However, reducing the impact of farming practices (such as lowering nutrient runoff and preservation of emergent and riparian vegetation for wetlands) will help bird habitats retain more resilience across the playa lakes region.

6) Habitat restoration will become much more theoretically problematic with time. Indeed, "restoration" of "historic" habitats will become untenable by 2020 in most areas since the ambient climate of most areas of the PLJV region will unprecedented relative to at least the last 650,000 years, and perhaps more than 1.5 million years. Historic models will be important for guidance but we must also be very open minded that climate will fundamentally alter many aspects of habitat. Humility about what we "know" now about these ecosystems is strongly recommended in strategic planning, much less what these habitats will be like in 2050.

7) Attempts to focus attention on particular properties or reserves may become difficult in coming decades, since most 20th century conservation planning assumed that the climate regimes that made these reserves special and significant will be altering, sometimes in fundamental ways, and some defining climatic elements may be altering these systems. Attempts to create climate refugia are unlikely to be successful. Conservation planning in the 21rst century should look to the landscape scale, not the reserve scale, for the most effective interventions. In some cases, planning choices will be emotionally difficult. We may need to transfer attention from some historically important habitats in the southern and southwestern regions of the PLJV region to the northern and eastern regions; the latter will be a better return on investment.

8) Connectivity of habitats and plant and animal species will be extremely important during a period of rapid climate change. Some species (such as large-seeded tree species like oaks) may have great difficulty shifting their ranges, requiring our intervention and assistance in promoting range shifts. Rapid-responders (such as many bird species) may particularly need us to assist with the movement of core elements (such as wetlands and plant species) of their habitat.

Supplemental Data: Tables

Key to tables 1, 2, and 3

- **L**: Low risk of impacts, defined as less than 30 percent risk of major climate change alteration of habitat and/or habitat quality

- **M**: Medium-level risk of impacts, defined as 30 to 60 percent risk of major climate change alteration of habitat and/or habitat quality

- **H**: High-level risk of impacts, defined as greater than 60 percent risk of major climate change alteration of habitat and/or habitat quality

Note that changes in habitat do not necessarily mean that shifts will be either deleterious or positive for birds using these habitats, merely that the habitat will be substantively changed, which is assumed to have important impacts on the species using that habitat. Thus, these are largely *qualitative* estimates of habitat sensitivity to climate change.

TABLE 1. AQUATIC DIVISION CLIMATE IMPACTS

"Aquatic Division"				
"TYPE"	**ASSOC.**	**CONDITION**	**1975–2015**	**2015–2030**
Open Water	Reservoirs Lakes Ponds	Freshwater lake	L	H
		Lagoon	L	H
		Pit	L	H
		Reservoir	L	M
		Stock pond	L	H
Wetlands	Playas	Wet	M	H
		Wet pit only	L	H
		Dry	M	H
	Sandhills Wetlands	NA	L	H
	Other Wetlands	Moist-soil unit	M	H
		Emergent marsh	M	H
		Saline	M	H
Riverine Systems	Riverine Systems	Riparian canopy (early successional w/o understory)	L	M
		Riparian canopy (early successional with understory)	L	M
		Riparian canopy (late successional w/o understory)	L	M
		Riparian canopy (late successional with understory)	L	M
		Exotic Riparian shrubland	L	M
		Native Riparian shrubland	L	M
		River channel	L	H
		Unvegetated sandbar	L	M
		Warmwater slough	L	H
		Wet meadow	M	H
		Floodplain marsh	M	H
	Arroyo/ Ravine	NA	M	H

TABLE 2. TERRESTRIAL DIVISION CLIMATE IMPACTS

"Terrestrial Division"				
"TYPE"	**ASSOC**	**CONDITION**	**1975–2015**	**2015–2030**
Sparsely Vegetated	Badlands/ Cliffs/ Outcrops	NA	L	H
Forests/ Wood-lands	Forest/ Woodland (upland)	Shelterbelts	L	H
		Eastern Red Cedar	M	H
	Pinyon/ Juniper	NA	L	M
	Ponderosa Pine	Few trees, grassy understory	L	L
		Many trees, little grassy understory	L	L
	Crosstimber Woodland	NA	L	M
	Hillside Woodland	NA	L	M
	Juniper	NA	M	H
	Juniper/ Mesquite	NA	M	H
Grass-lands	Mixed Grass	Few shrubs/Low grass	L	L
		Few shrubs/High grass	L	L
		Many shrubs/Low grass	L	M
		Many shrubs/High grass	L	M
		Prairie Dog Colony	Unknown	Unknown
	Sandhills Grasslands	Few shrubs/Low grass	L	L
		Few shrubs/High grass	L	L
		Many shrubs/Low grass	L	M
		Many shrubs/High grass	L	M
	Shortgrass	Few shrubs/Low grass	L	L
		Few shrubs/High grass	L	L
		Many shrubs/Low grass	L	M
		Many shrubs/High grass	L	M
		Prairie Dog Colony	Unknown	Unknown
	Tallgrass	Few shrubs/Low grass	L	L
		Few shrubs/High grass	L	L
		Many shrubs/Low grass	L	M
		Many shrubs/High grass	L	M
Shrub-lands	Mesquite Savannah	Savannah	M	M
		Shrubland	M	M
	Shinnery	Few shrubs/Low grass	L	L
		Many shrubs/ Low grass	L	M
		Few shrubs/High grass	L	L
		Many shrubs/High grass	L	M
	Sand Sage	Low grass	L	L
		High grass	L	L

TABLE 3. ANTHROPOGENIC DIVISION CLIMATE IMPACTS

"Terrestrial Division"/Anthropogenic				
"TYPE"	**ASSOC**	**CONDITION**	**1975–2015**	**2015–2030**
Agricul-tural	Cropland	Alfalfa	L	M to H
		Corn	L	M to H
		Fallow	L	M to H
		Hay	L	M to H
		Millet	L	M to H
		Sorghum	L	M to H
		Soybeans	L	M to H
		Sunflowers	L	M to H
		Wheat	L	M to H
		Peanuts	L	M to H
		Pasture	L	M to H
		Other	Unknown	Unknown
		Sod Farm	L	M to H
	CRP	Native grasses	L	M
		Non-native grasses	L	M

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