A Conservation Science Agenda for a Changing US Upper Midwest and Great Plains

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SUPPLEMENTAL INFORMATION

Table S1. Full list of science gaps critical to implementing conservation strategies to protect land and water, tackle climate change, provide food and water sustainably, and address socioeconomic issues for people and nature in the Upper Midwest and Great Plains region. For three lists (Freshwater – Protect Land and Water, Grassland – Protect Land and Water, Forest – Tackle Climate Change), questions were ranked as one list, and weighted averages were used to calculate the score. For the other six lists, questions were ranked using pairwise comparisons, and simple averages across the pairs were used for the final score. We used natural breaks in the scores to categorize the 50 questions into a high, medium and low priority.

Science Needs for 'Protect Land and Water'		**Score**	**Priority**
Forest	How do we integrate geophysical data—including data on landform diversity, local connectedness and wetlands—with forest condition data to create a forest restoration action map?	13.00	High
	What are the most important plant functional traits (e.g. seed size and dispersal mechanism) for ecosystem reorganization under a changing climate? Can we use an understanding of functional traits related to water use and evapotranspiration to help forests adapt to more frequent and severe droughts?	10.50	Medium
	In light of climate change, how should patch size, arrangement, and connectivity of forest patches be considered in ranking priorities for conservation?	6.50	Low
Freshwater	How does changing land cover in grassland and forest systems (due to climate, land use, management, policy, etc.) influence water budgets, flows, and water quality in lakes and streams in those landscapes? What are the cultural and economic drivers behind the changing land uses and what can we do to address those?	7.38	High
	How much nutrient, sediment and water runoff reduction is achieved in rivers and streams when upland vegetation is protected from conversion compared to its loss to different land uses?	6.38	High
	What is the minimum threshold needed for protection and restoration of natural infrastructure (forests, wetlands, soil health, natural floodplains) to ensure watersheds are resilient to climate change?	6.25	High
	How will climate change affect the hydrologic regime and ecosystem services provided by prairie region streams and wetlands—as well as land use change in the surrounding uplands? What actions can be taken to boost the adaptive capacity of freshwater features embedded in grasslands?	6.00	Medium
	What are the economic values of the water-based ecosystem services that land protection provides? How do we design market/policy instruments to protect those services? These instruments may include water funds, trading, impact investing, and regulation.	5.88	Medium
	How do changes in shallow groundwater, soil water, and groundwater from altered hydrology affect aquatic and wetland communities and the ecosystem services they provide? What are the most effective	4.94	Medium

	strategies for avoiding these impacts, or restoring function that has been lost?		
	What is the quantifiable benefit that TNC conservation lands provide to freshwater systems (e.g., restored hydrology; nutrient and sediment reductions needed to restore water quality in lakes, rivers and streams)?	3.81	Low
	Are there potential unintended consequences from management and policy "solutions" that we can anticipate and avoid? For example, how do we manage riparian and wetland ecosystems to be phosphorus sinks and not sources?	2.75	Low
	How will investments and changes in energy infrastructure and production affect water resources in priority areas for freshwater conservation?	1.63	Low
Grassland	What levels of native diversity are required to maintain ecosystem services in our grasslands, and how do we achieve that goal in the most cost-effective way?	7.61	High
	How do we ensure adaptability of our remnant and restored grasslands in fragmented landscapes?	6.22	High
	How can we use our TNC conservation lands as a portfolio of control and adaptive management sites to document ecosystem response to global change and influence partner organizations and private landowners?	5.70	Medium
	What adjustments in timing, frequency, intensity, and types of disturbances are needed for forward-looking management in temperate grasslands?	5.57	Medium
	What is the impact of resilient grassland and wetland complexes on water quality at site and landscape scales? How can we leverage this knowledge for conservation?	4.83	Medium
	What are the ecological, economic and social tradeoffs among different disturbance methods in grasslands?	4.74	Medium
	What landscape and local actions will maintain healthy pollinator populations in our grasslands and what are the trade-offs among those actions?	4.39	Medium
	What are the ecological impacts of the surrounding row crop agricultural systems on remnant and restored grasslands?	3.09	Low
	What are the ecological and economic tradeoffs for deterring woody encroachment into grasslands with changing climate, disturbance regimes, and land use patterns?	2.87	Low

Science Needs for 'Tackle Climate Change'		**Score**	**Priority**
Forest	How can we prioritize forest landscapes and sites for restoration using mapped compositional and structural categories and other data? How much of the forest is "stuck" in an undesirable state with high brush density and low tree reproduction, and what are the best strategies for shifting these sites to a more productive state?	8.56	High
	What are the policy and/or market mechanisms that could advance needed forest restoration and adaptation work? For example, federal fire policy could more effectively use prescribed fire as	7.89	High

	restoration tool. Carbon markets could provide incentives for improved forest management.		
	How can we be more cost-efficient in forest restoration implementation? What are the relative costs and benefits of establishing a large number of scattered restoration plantings compared to a smaller number of larger planting projects? Is there a tradeoff in ecosystem services that results from these distinct approaches?	7.44	High
	What is the relationship between increasing the adaptive capacity of the region's forests to sequestering carbon from the atmosphere while at the same time providing timber for societal needs?	6.89	Medium
	For the highest priority compositional and structural categories, what are the management strategies that restore and maintain forest complexity and adaptive capacity in a changing climate?	6.78	Medium
	How do the species composition and structure of northern forests reorganize in a rapidly changing climate and what are the implications for carbon accumulation, water flows, and biological diversity? What is the role of functional diversity in maintaining these and other forest ecosystem services, such as enhanced climate resilience, soil health, water filtration and flood buffering? How will natural disturbance regimes, including fire and wind influence forest conditions under climate change?	6.11	Medium
	What are the economic consequences for the timber industry of business as usual versus adaptive-ecological forest practices in northern Great Lakes forests and its associated streams and lakes in a changing climate?	5.78	Medium
	What demands will be made on seedling nurseries to meet the needs of reforestation/adaptation to climate change? How can we change the "culture" of production to accommodate species and seed sources most appropriate to future climates?	5.00	Medium
	Does promoting natural regeneration of diverse tree species also help reduce management costs over the long term? Natural regeneration may reduce costs for site preparation, planting, reduction of shrub competition (i.e. "release"), and herbivory protection but at the expense of leaving commercially valuable seed trees following many logging operations.	4.22	Low
	How do we incorporate knowledge of plant functional traits into adaptive forest management? What is the role of prescribed fire and natural disturbance emulation in adaptive management? What are the plant functional traits we should focus on to predict species responses and monitor change and effectiveness?	4.00	Low
	How do the variabilities of soil, topography, and climate interact with plant functional traits and influence reorganization under climate change in northern forests?	3.33	Low
Freshwater	How do changes in water use and availability with climate change impact the viability of our working lands in priority grasslands and forests? Might these changes (e.g., lower productivity) drive further land conversion/perennial loss, and in turn further degrade hydrology, water quality and aquatic health? What kinds of strategies might help landowners and land managers modify practices in response to changes in water availability?	11.00	High
	How will climate change influence hydrology, stream flows, water quality, and aquatic systems, both directly through changes to temperature and precipitation and indirectly through changes to land use and	9.5	Medium

	land cover?		
	How will market trends driven by water scarcity, shifting costs of commodity production, energy infrastructure and production affect demand for land and water? Will water scarcity in parts of the Upper Midwest and Great Plains drive pressures for expansion of irrigated agriculture, dairy, manufacturing agricultural crop and dairy production which divert water from aquatic ecosystems?	6.5	Low
Grassland	What are the economic consequences of degradation of existing grassland and wetland complexes or the loss of this system to conversion (e.g., loss of productivity, decreased soil health, increased risk of extinction for pollinators or functional diversity, increased runoff, etc.)?	15.00	High
	Are there economic consequences to a private livestock operator's bottom line to maintaining soil health or productivity in resilient grassland and wetland complexes and are there cultural or social obstacles to implementing best practices?	13.25	High
	What are the carbon benefits of managing resilient grassland and wetland complexes?	10.25	Medium
	How can we target best practices for carbon storage, sequestration and restoration for forest, grassland and agricultural systems on conservation lands?	9.50	Low
	Which grassland disturbance regimes have the greatest benefits for soil health and productivity?	9.25	Low

Provide Food and Water Sustainably		**Score**	**Priority**
Freshwater	How do different conservation actions (e.g., protection, restoration) rank both ecologically and economically to achieve the same desired outcomes for habitat, nutrient and sediment loss, and water storage/runoff? How much perennial cover and wetland/riparian/floodplain restoration is needed to meet basin-wide nutrient reduction goals and sustain aquatic community health?	10.50	High
	How do we quantify the full range of watershed ecosystem services from protection versus restoration? How do the public versus private benefits break down across different spatial and temporal scales, and under different institutional arrangements for water management? Can we establish criteria for evaluating and prioritizing "protection" versus "restoration" based on which provide greater benefits and lower costs to society as a whole?	8.50	Medium
	What is the necessary extent and location of wetland restoration efforts to achieve measurable nutrient and flow reduction?	8.00	Low
Grassland/Agriculture	What are the most cost-effective strategies and best management practices for restoring hydrology/reducing nonpoint source loads in agricultural watersheds?	14.00	High
	How much increased water and carbon storage, hydrologic restoration, and productivity does soil organic matter provide to both natural and managed systems?	9.00	Low

Socioeconomic Interactions	**Score**	**Priority**

All Systems	What is the full range of watershed and ecosystem services that provide economic, social, and/or ecological benefits? How can we best quantify the economic value of these benefits and internalize them into decision-making? Can we quantify tradeoffs between different scenarios in terms of costs and benefits to public and private beneficiaries?	12.75	High
	What are the socioeconomic barriers to the uptake of new information or best management practices for all the science questions outlined?	12.25	High
	What are the economic benefits from changes to water quality, flood reduction, drought mitigation, carbon storage, and soil health provided by creating resilient grassland and wetland complexes, and can we leverage this knowledge for conservation?	12.25	High
	Will economic downturns and/or increased vulnerability to weather-related disasters increase or reduce local social and economic capacity to sustain conservation efforts?	7.00	Medium
	What is the threat posed by mining to forests, grasslands, and freshwater? What is the feasibility of using mitigation hierarchies to minimize mining impacts to natural areas and ecosystem services?	5.75	Low

APPENDIX 1 Author Contributions

MA lead the initial draft of the paper. MC, KB, MW, CL, CD, MD, BK, BP, JP, and HP all contributed to the initial writing and organization of the paper. All authors contributed substantially to the content and question generation in the paper as well as read and reviewed the final manuscript.