Bouska, K. L., G. Lindner, C. P. Paukert, and R. B. Jacobson. 2016. Stakeholder-led science: engaging resource managers to identify science needs for long-term management of floodplain conservation lands. *Ecology and Society* 21(3):12. http://dx.doi.org/10.5751/ES-08620-210312

Research

Stakeholder-led science: engaging resource managers to identify science needs for long-term management of floodplain conservation lands

Kristen L. Bouska [1,2], *Garth A. Lindner* [1], *Craig P. Paukert* [3] *and Robert B. Jacobson* [4]

ABSTRACT. Floodplains pose challenges to managers of conservation lands because of constantly changing interactions with their rivers. Although scientific knowledge and understanding of the dynamics and drivers of river-floodplain systems can provide guidance to floodplain managers, the scientific process often occurs in isolation from management. Further, communication barriers between scientists and managers can be obstacles to appropriate application of scientific knowledge. With the coproduction of science in mind, our objectives were the following: (1) to document management priorities of floodplain conservation lands, and (2) identify science needs required to better manage the identified management priorities under nonstationary conditions, i.e., climate change, through stakeholder queries and interactions. We conducted an online survey with 80 resource managers of floodplain conservation lands along the Upper and Middle Mississippi River and Lower Missouri River, USA, to evaluate management priority, management intensity, and available scientific information for management objectives and conservation targets. Management objectives with the least information available relative to priority included controlling invasive species, maintaining respectful relationships with neighbors, and managing native, nongame species. Conservation targets with the least information available to manage relative to management priority included pollinators, marsh birds, reptiles, and shore birds. A follow-up workshop and survey focused on clarifying science needs to achieve management objectives under nonstationary conditions. Managers agreed that metrics of inundation, including depth and extent of inundation, and frequency, duration, and timing of inundation would be the most useful metrics for management of floodplain conservation lands with multiple objectives. This assessment provides guidance for developing relevant and accessible science products to inform management of highly dynamic floodplain environments. Although the problems facing managers of these lands are complex, products focused on a small suite of inundation metrics were determined to be the most useful to guide the decision making process.

Key Words: *floodplain management; inundation; large rivers; Mississippi River Basin; nonstationarity*

INTRODUCTION

Floodplains owe their high biodiversity and productivity to dynamic spatial and temporal interactions with the adjacent river (Bayley 1995, Tockner et al. 2000, Tockner and Stanford 2002). Floodplains provide productive soils, suitable topography, and abundant water resources that have historically driven agricultural, urban, and industrial development on these lands. The widespread construction of levees to protect human uses from floods have reduced the frequency of inundation of floodplains, yet contributed to increased river stages during flood events and increased discharges downstream of leveed areas (Di Baldassarre et al. 2009, Remo et al. 2009, Heine and Pinter 2012). Recent, extreme floods on the large rivers have prompted reconsideration of the role of floodplains in regulating flooding processes, mitigating flood damages, and providing conservation values (Sparks 1995). As a result, large tracts of floodplains have been reconnected in large rivers in Europe (Buijse et al. 2002, Pahl-Wostl 2006, Hein et al. 2016) and the United States (U.S. Fish and Wildlife Service 2014). Within the state of Missouri USA, for example, approximately 35,000 hectares of floodplain lands have been acquired by state and federal agencies along the Missouri and Mississippi rivers, and additional lands are under various conservation easements (USGS, *unpublished data*). The majority of these properties have been converted from agricultural production to natural land cover and managed for conservation.

Management strategies of floodplain conservation lands range conceptually from active to passive (Galat et al. 1998). Actively managed floodplain lands typically rely on infrastructure, such as pumps, gates and constructed wetlands, for manipulating water levels on the floodplain (Fredrickson and Taylor 1982). Conversely, passively managed floodplains rely on river-floodplain connectivity during high river stages for managing inundations (Galat et al. 1998). Floodplain management objectives and conservation targets may differ with the type of management strategy, but are generally met with a series of both short- and long-term management decisions. Short-term management decisions (seasonal to annual), such as whether to pump water to or from the property, are commonly more adaptable than long-term management decisions and dictated by seasonal hydrologic and climatic conditions. Long-term management decisions (multiyear to centennial), such as the type of forest to restore, often rely on an understanding of the range, variability, and projections of hydroclimatic conditions, that are derived from observed historical data (Stanturf et al. 2000).

Floodplain management is inherently difficult because of constantly changing interactions of floodplains with their rivers, wide ranges of variability, and anthropogenic modifications of in-channel conditions and throughout contributing drainage areas (Adams and Perrow 1999, Hughes et al. 2005). Challenges of managing floodplains are compounded when hydroclimatic stationarity cannot be assumed, and changing climate, land use,

[1]Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, University of Missouri, [2]Upper Midwest Environmental Sciences Center, U.S. Geological Survey, [3]U.S. Geological Survey Missouri Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife Sciences, University of Missouri, [4]Columbia Environmental Research Center, U.S. Geological Survey

and/or water use combine to alter the magnitude, duration, and timing of hydrologic events (Olsen 2006). Relying on past hydrologic records to guide management practices is problematic under nonstationary conditions, because the historical conditions that have driven a system to its present state may not be the same conditions that will drive the system in the future (Milly et al. 2008). For example, dam construction has significantly altered hydrologic regimes worldwide over the past century, whereas climate change may drive future changes in hydrologic regimes. Therefore, problems may arise because the infrastructure and accompanying land uses designed for specific hydroclimatic conditions from the period of record may not support future hydroclimatic conditions. Incongruities between design specifications and driving conditions will lead to untenable land use decisions, ultimately leading to possible project failure and wasted resources. Analysis of trade-offs between different management actions across a range of future conditions may aid in identifying flexible and robust management actions (Poff et al. 2016, Singh et al. 2015).

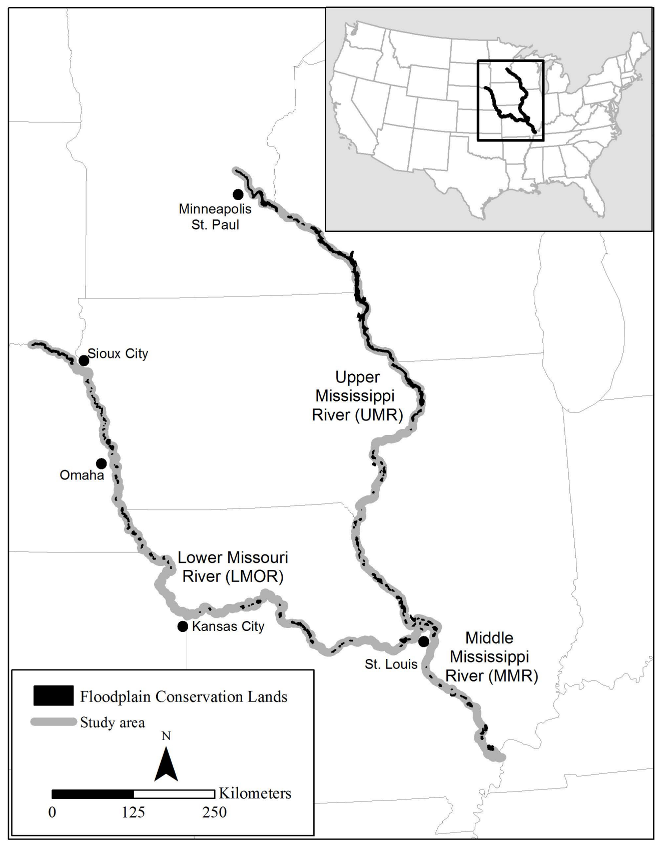
Increased scientific knowledge of nonstationarity in river-floodplain systems can provide guidance to floodplain managers; however, the scientific process, although well intentioned, often occurs in isolation from management. Scientific questions and results are often relevant to management, but rarely match management needs. Further, communication barriers between scientists and managers is a commonly cited obstacle to application of scientific knowledge (Wright 2007, Kocher et al. 2012). Coproduction of scientific knowledge, where research questions arise from interactions between researchers and information users, has led to successful use of that scientific knowledge in incorporating climate science in forest management (Lemos and Morehouse 2005, Dilling and Lemos 2011, Littell et al. 2012). With the coproduction of science in mind, our objectives were to (1) document management priorities of floodplain conservation lands, and (2) identify science needs required to better manage the identified management priorities under nonstationary conditions, i.e., climate change. Our approach was to determine management priorities, science needs, and constraints on using scientific information through stakeholder queries and interactions and to evaluate if priorities and science needs were consistent across the study area. We hypothesized that aspects of hydrology would emerge as common science needs across management priorities, given hydrology is a key driver of floodplain ecosystems. We highlight the collaborative process we used to identify science needs and discuss how these results provide guidance for developing relevant and accessible science to inform management of highly dynamic floodplain environments that often have multiple management objectives.

METHODS

Study area

The project focused on floodplain conservation lands along the Upper Mississippi River (UMR), the Middle Mississippi River (MMR), and the Lower Missouri River (LMOR), USA (Fig. 1). The selected major river sections present a wide range of both natural and human-induced hydrologic and geomorphic variation and, as such, provide results that may be transferable to other large rivers (Table 1). The UMR (1060 kilometers) flows from the headwaters to the confluence with the Missouri River and is impounded with a series of 29 navigation locks and dams that create pools with relatively low variability in stage relative to the other two study sections (Schramm et al. 2015). The stage of the navigation pools can be managed to a limited extent by the U.S. Army Corps of Engineers (USACE) to influence connectivity to floodplains, but ultimately the regulation structures on the UMR have artificially maintained high water levels relative to historical conditions (Theiling and Nestler 2010).

Fig. 1. Floodplain conservation lands within the Upper Mississippi River (UMR), Middle Mississippi River (MMR), and Lower Missouri River (LMOR) were the focus of this research.



The LMOR is a 1300 kilometer (km) reach downstream of Gavin's Point Dam to the confluence with the Mississippi River near St. Louis, Missouri. The river is unchannelized in the 94 km between Gavin's Point Dam and Ponca, Nebraska, yet floodplain connectivity is compromised by channel incision (Jacobson and Galat 2006). Downstream of Ponca, Nebraska, river training structures (wing dikes) have confined the historically wide, shallow, and braided channel to a narrow and deep single thread channel, effectively creating a self-scouring channel (Jacobson et al. 2015). The river is largely disconnected from the adjacent floodplain through an extensive series of levees and channel incision. Connectivity between the main channel and the floodplain generally increases in the downstream direction along the LMOR. The LMOR is downstream from the largest reservoir system in North America with 91 km^3 of total storage (U.S. Army Corps of Engineers 2006). The mainstem reservoir system is

Table 1. Defining attributes of the river-floodplain dynamics of the three study reaches.

	Upper Mississippi River (UMR)	Lower Missouri River (LMOR)	Middle Mississippi River (MMR)
Generalized river habitat	Series of riverine and impounded habitats	Unchannelized (94 km downstream of Gavins Point Dam) and Channelized (1200 km downstream of Sioux City, Iowa)	Channelized
Floodplain connectivity	Connected upstream with increasing extent of levees downstream	Leveed (1200 km downstream of Sioux City, Iowa)	Leveed
Dominant navigation structures	Locks and dams	River training structures (i.e., wing dams)	River training structures (i.e., wing dams)
Flow regime alterations	Navigation pools stabilize and increase water levels resulting in reduced interannual flow variability and increased low flows	Upstream dams have reduced interannual flow variability, decreased spring pulses, and increased summer low flows	Channelization and floodplain disconnection have increased river stage during high-flow events and decreased stage during low-flow events
Drainage area (km^2)	Upstream: 95,000 km^2 (St. Paul, MN) Downstream: 1,800,000 km^2 (St. Louis, MO)	Upstream: 724,000 km^2 (Yankton, SD) Downstream: 1360000 km^2 (St. Charles, MO)	Upstream: 1,800,000 km^2 (St. Louis, MO) - Downstream: 1,840,000 km^2 (Thebes, IL)
Mean annual discharge (m^3/sec)	Upstream: 350 m^3/sec Downstream: 5500 m^3/sec	Upstream: 750 m^3/sec Downstream: 2500 m^3/sec	Upstream: 5500 m^3/sec Downstream: 6000 m^3/sec

managed by the USACE for multiple purposes; management for floodplain connectivity, however, has been considered contradictory to the USACE flood-control mandate (Jacobson and Galat 2008). The hydrologic signal from scheduled reservoir operations and releases is attenuated, but remains discernible throughout the full length (Galat and Lipkin 2000).

The MMR is defined as 305 kilometers of the Mississippi River from the confluence of the Missouri River to the confluence with the Ohio River. Similar to the LMOR, the MMR lacks navigation dams and is channelized through river training structures. Levees constrain floodplain connectivity and preclude the lower return interval floods from accessing much of the floodplain in this section, much of which is used for agriculture (Remo et al. 2009). The MMR experiences higher variability in flow conditions relative to the UMR because (1) reservoir storage is relatively low throughout the UMR drainage basin, including tributaries, and (2) dam operation signals from the UMR and LMOR have effectively attenuated upon reaching the MMR because of cumulative additions from tributaries.

Participants

We developed a three-step interactive approach to document management priorities and science needs of floodplain conservation lands (Fig. 2). Our target stakeholders were natural resource managers of floodplain conservation lands owned or managed by federal and state natural resource agencies (Appendix 1); these agencies provide public access to lands for recreation and hunting, as well as managing lands for ecosystem benefits. Governance structure of these properties differs by agency; therefore, our list includes personnel with a wide range of expertise and roles in the management of floodplain properties.

Data collection

We designed and distributed an online survey (Appendix 2) via email to all identified resource managers in the fall of 2014 and asked them to prioritize and rate information available to achieve selected management objectives and conservation targets (Table 2). This initial survey and selection of objectives and targets were developed with input from knowledgeable academic, state, and federal scientists and resource managers in addition to publicly available management plans. Objectives reflect broader management goals while conservation targets reflect species or biotic communities that are often used as measures of conservation success. For our purposes, conservation targets reflect both species and communities in need of conservation (e.g., threatened species, game species) and control (e.g., invasive species). Additional questions focused on the importance of selected sources of scientific information, and constraints on obtaining and using scientific information. Structured survey questions with scaled responses (i.e., low, medium, high priority) allowed for quantitative analysis of survey results.

Fig. 2. Our objective to identify management priorities and science needs for long-term management of large-river floodplain conservation lands were met with a three-step process of interacting with floodplain managers through online surveys and a workshop.

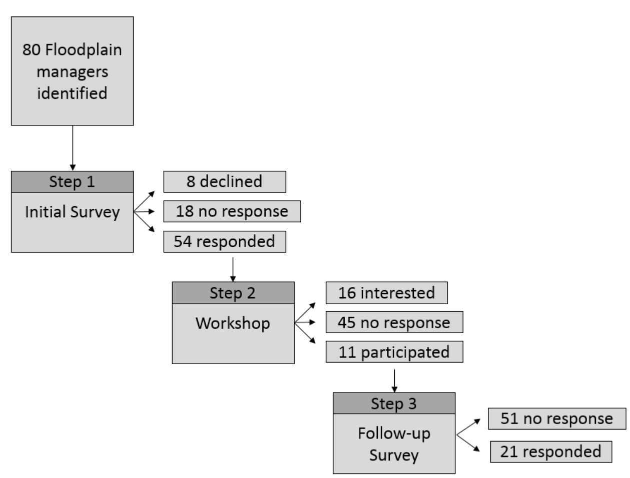


Table 2. Lists of selected management objectives, conservation targets, information sources, and constraints in floodplain management included in the first survey to 80 floodplain managers in the Lower Missouri and Upper and Middle Mississippi rivers.

Survey question topic	Included responses for question topic
Management objectives	Maintain respectful relationships with neighbors
	Control invasive species
	Provide public recreation opportunities
	Manage endangered/ threatened species
	Manage other native, nongame species
	Restore wetlands
	Manage game species
	Restore bottomland forests
	Restore bottomland prairies
	Maintain current conditions
	Restore hydrology
	Nutrient cycling/improve water quality
	Reconnect river to floodplain
	Improve soil health
	Flood risk reduction
	Contaminant retention
	Agricultural production
Conservation targets	Waterfowl
	Terrestrial invasive species
	Song birds
	Bald Eagles (*Haliaeetus leucocephalus*)
	Shore birds
	Marsh birds
	Pollinators
	Reptiles
	White-tailed deer (*Odocoileus virginianus*)
	Amphibians
	Aquatic invertebrates
	Wild Turkey (*Meleagris gallopavo*)
	Aquatic invasive species
	Cottonwoods (*Populus* spp.)
	Game fish
	Northern Bobwhite (*Colinus virginianus*)
	Pallid sturgeon (*Scaphirhynchus albus*)
	Least Tern (*Sternula antillarum*)
	Piping Plover (*Charadrius melodus*)
	Ring-necked Pheasant (*Phasianus colchicus*)
Sources of new scientific information	Peer-reviewed literature datasets
	White papers
	Internal
	Collaboration with internal research staff
	Collaboration with external researchers
	Professional association meetings
	Word of mouth
	More experienced staff
Constraints in obtaining or utilizing new scientific information	Time
	Funding (ability to travel to meetings, etc.)
	Credibility of scientific information
	Credibility of scientific process
	High uncertainty in results
	Research not applicable because of spatio-temporal differences
	Access to scientific journals
	Disconnect between research and management activities
	Socio-political factors

We hosted a two-day workshop in March 2015 with identified floodplain conservation land managers. The workshop goals were to identify high-priority science needs and tools that would assist complex decision making of floodplain lands in the face of nonstationary conditions and environmental change. We shared and discussed the findings from the initial online survey, presented historic climate trends and climate projections for the major river systems, and discussed how projections of climate change might influence management priorities. Discussions were facilitated by the authors. We explicitly asked participants to provide input on the types of scientific information they currently use and what types of scientific information would be informative to management, particularly while reflecting on projections of climate change or other sources of nonstationarity. Discussions were recorded by two note-takers and on flip charts by the workshop facilitators.

In April 2015, a summary of the workshop and a follow-up online survey (Appendix 3) were emailed to all previously surveyed floodplain conservation land managers. The purpose of the survey was to solicit information from individuals not represented at the workshop on science needs and frequency of use and informational value, i.e., whether it informs planning and/or management, of different types of scientific information in decision making. The follow-up survey also included questions on how management agencies incorporate climate change, a source of nonstationarity, into management plans and what types of scientific products and formats would be most useful for transferring knowledge to managers. Both online surveys were developed and distributed using Qualtrics (http://www.qualtrics.com/) and reviewed and approved by the University of Missouri Institutional Review Board (Project #1213966).

Data analysis

We aggregated individual responses from the initial survey by river reach to test the effect of reach (categorical) and objective/target on priority score, i.e., low (1), medium (2), high (3), using two-way analysis of variance (alpha = 0.05). Because of consistent prioritization across reaches, differences in mean priority scores between objectives, aggregated across river reaches, were tested using Tukey's honest significant difference (HSD). Priority scores and information availability scores had different response scales, therefore they were standardized, each separately for management objectives and conservation targets. The standardized information value, I_S, was subtracted from the standardized priority value, P_S, to assess the information available to manage an objective or target relative to its priority, IP_S.

$$I_s = (I_i - I_{min})/(I_{max} - I_{min})$$

$$P_s = (P_i - P_{min})/(P_{max} - P_{min}) \qquad (1)$$

$$IP_s = P_s - I_s$$

Where, I_i refers to information value for objective i,
I_{min} refers to the minimum information value among all objectives,
I_{max} refers to the maximum information value among all objectives,
P_i refers to priority score for objective i,
P_{min} refers to the minimum priority score among all objectives, and
P_{max} refers to the maximum priority score among all objectives.

High values of IP_S suggest that managers believe there is sufficient information available to manage an objective or target relative to its management priority, whereas low values suggest limited information relative to priority.

The second survey had fewer respondents, therefore we aggregated individual responses across reaches. We tested for differences in frequency of use and information value of different types of scientific information in addition to differences in information value and need for different inundation metrics using one-way analysis of variance. All statistical analyses were performed using computing environment R (R Core Team 2014).

RESULTS

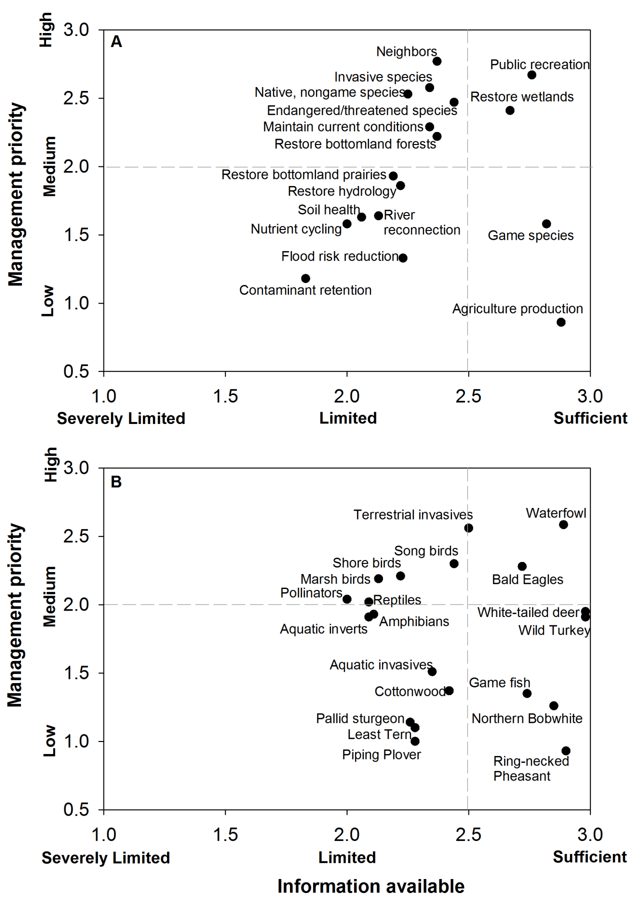
Initial survey

We identified 80 individuals managing 155 floodplain conservation lands, totaling approximately 2400 km². Our initial survey had a response rate of 68%, with 54 individuals completing the survey. Eight individuals declined the survey invitation because of new responsibilities or inexperience and were removed from the list of floodplain managers. The respondents managed a total of 125 properties (80% of floodplain conservation lands identified). Approximately 81% of floodplain conservation lands along the Upper Mississippi River were represented (51/63), 67% of Middle Mississippi River properties (8/12), and 80% of Lower Missouri River properties (66/83). Seventeen percent (9/54) of the respondents represented federal agencies, 81% (44/54) represented state agencies, and 2% (1/54) represented a nonprofit organization.

There was an effect of management objective ($F_{16, 967}$ = 29.27, p < 0.001) and river reach ($F_{2, 967}$ = 6.55, p = 0.002) on priority scores, but no interaction effect between objective and river reach ($F_{32, 935}$ = 0.94, p = 0.56). Objectives with the highest priority scores included maintaining good relationships with neighboring land owners, providing public recreation opportunities, controlling invasive species, managing native nongame species, and managing endangered and threatened species (Tukey's HSD p < 0.05; Fig. 3A). Objectives with the lowest priority ranking included agricultural production, contaminant retention, and reducing flood risk. LMOR consistently had higher priority scores across all objectives in comparison to the UMR and MMR (Tukey's HSD p < 0.05), but the lack of an interaction effect suggests objective prioritization was ranked similarly across river reaches. Additional management objectives were identified by survey participants and included determining and meeting objectives of private landowners, timber production, birding, pecan production, education and interpretation, identifying alterations from historical conditions, linking private and public land conservation, oak savanna restoration, and reducing sediment deposition.

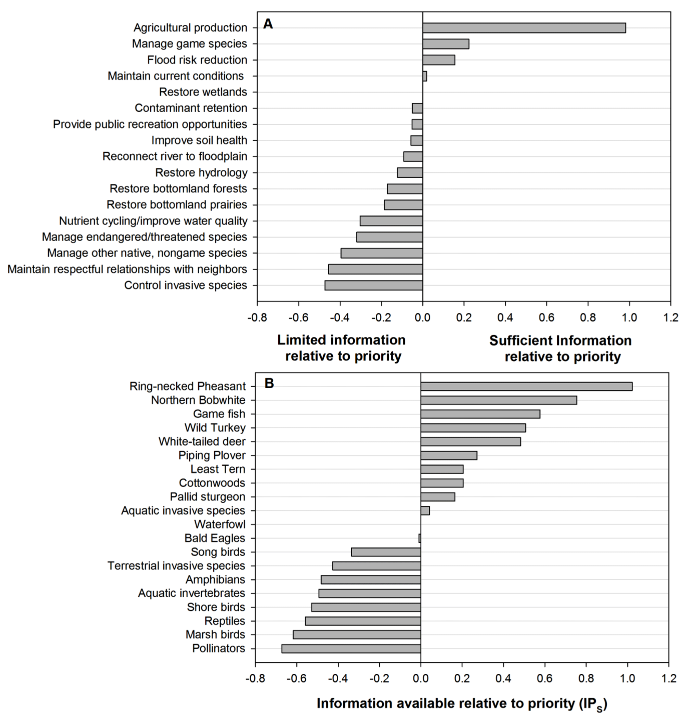
There was an effect of management objective ($F_{16, 859}$ = 11.21, p < 0.001) and river reach ($F_{2, 859}$ = 9.63, p < 0.001) on the perceived availability of information, but no interaction effect ($F_{32, 827}$ = 0.67, p = 0.92). Sufficient information was thought to be available to manage for agricultural production, game species, recreational opportunities, and wetlands while objectives with the least information available to manage include contaminant retention, nutrient retention, and restoration of bottomland prairies (Tukey's HSD p < 0.05; Figure 3A). More information was perceived to be available in the LMOR and UMR compared to the MMR (Tukey's HSD p < 0.05), but no interaction effect suggests objectives were ranked in terms of information availability similarly across river reaches. Standardized information availability scores relative to standardized priority scores reveal sufficient information relative to priority for agricultural production, managing game species, flood risk reduction, maintaining current conditions, and restoring wetlands, and limited information relative to priority for all other objectives (Fig. 4A). Objectives with the least information available relative to priority include controlling invasive species, maintaining respectful relationships with neighbors, and managing native, nongame species.

Fig. 3. Average survey responses (N = 54) across the study area for management priority and level of scientific information available to manage for selected (A) objectives and (B) conservation targets on floodplain conservation lands. Dashed lines are breakpoints to differentiate between high and low priorities and sufficient and limited amounts of information available.



Priority scores differed by conservation target ($F_{19, 1118}$ = 18.18, p < 0.001) and river reach ($F_{2, 1118}$ = 30.72, p < 0.001). Priority scores of conservation targets were consistent among river reaches ($F_{38, 1080}$ = 1.36, p = 0.07), however the proximity of the p-value to the significance value suggests there may be slight differences by reach. Upon closer examination, Ring-necked Pheasant (*Phasianus colchicus*) and Piping Plover (*Charadrius melodus*) had higher priority in the LMOR compared with other reaches, and pallid sturgeon (*Scaphirhynchus albus*), Least Tern (*Sternula antillarum*), and Northern Bobwhite (*Colinus virginianus*) had higher priority in the LMOR and MMR compared to the UMR. Targets with the highest priority across reaches included waterfowl, invasive plants, song birds, and Bald Eagles (*Haliaeetus leucocephalus*; Tukey's HSD $p < 0.05$; Fig. 3B). The LMOR had higher priority scores across targets than MMR and UMR (Tukey's HSD $p < 0.05$). Additional conservation targets identified by participants included willows, bottomland hardwoods, fish spawning areas, swamp white oak (*Quercus bicolor*), silver maple (*Acer saccharinum*), furbearing mammals, aquatic vegetation, mast-producing floodplain forest species, endangered plant species, and Mourning Doves (*Zenaida macroura*).

Fig. 4. Information available relative to priority for (A) management objectives and (B) conservation priority. Values on x-axis were calculated by first standardizing priority and information available scores, then subtracting the standardized priority value from the standardized information available value.



Perceived information availability differed by conservation targets ($F_{19,967} = 15.63$, $p < 0.001$) and river reach ($F_{2,967} = 2.44$, $p = 0.03$), but perceived information availability for conservation targets was consistent among river reaches ($F_{38,929} = 0.68$, $p = 0.93$). Sufficient information is available to manage for white-tailed deer, Wild Turkey (*Meleagris gallopavo*), Ring-necked Pheasant, and waterfowl, but limited information is available to manage for pollinators, aquatic invasive species, reptiles, amphibians, and marsh birds (Tukey's HSD $p < 0.05$; Figure 3B). Perceived information availability was generally greater in the LMOR compared to MMR, with neither being different from the UMR (Tukey's HSD $p < 0.05$). Ring-necked pheasant, Northern Bobwhite (*Colinus virginianus*), game fish, Wild Turkey, and white-tailed deer had the greatest perceived information available relative to management priority whereas pollinators, marsh birds, reptiles, song birds, aquatic invertebrates, and amphibians had the least perceived information available relative to management priority (Fig. 4B).

Information from more experienced within-agency personnel was a significantly more important source of scientific information than word of mouth, peer-reviewed literature, white papers, and internal datasets ($F_{7,448} = 3.951$, $p < 0.001$; Tukey's HSD $p < 0.05$); however, all sources of information were rated between important and very important. Time, funding, and disconnect between science and management activities were significantly more constraining to managers on their ability to obtain or use new scientific information in management decisions than credibility of scientific information, credibility of scientific process, and access to scientific journals ($F_{9,560} = 15.57$, $p < 0.001$; Table 3).

Table 3. Mean value and standard deviation from 57 survey respondents for how limiting (1 = not limiting, 4 = very limiting) different constraints are when incorporating new scientific information into the decision-making process. An analysis of variance and Tukey's HSD test was performed on each dataset to determine statistical differences in mean rank between metrics. Superscript letters that differ indicate ranks that differ at alpha = 0.05.

Constraint	Mean	Standard deviation
Time	3.47^{d}	0.89
Disconnect between research and management activities	3.05^{cd}	1.09
Funding	3.04^{cd}	1.00
Socio-political factors	3.00^{bcd}	1.21
Research not applicable due to spatial and temporal differences	2.79^{bc}	0.96
Uncertainty in scientific results	2.53^{abc}	1.05
Access to scientific journals	2.39^{ab}	1.18
Credibility of scientific information	2.02^{a}	1.06
Credibility of scientific process	1.91^{a}	1.17

Workshop

Eleven state, federal, and nongovernmental resource managers participated in the two-day floodplain science needs workshop in St. Charles, MO on 30 and 31 March 2015. Seven managers were associated with properties on the MMR, four with the LMOR, one with the UMR, and one with the Illinois River, a major tributary of the Mississippi River. An additional 16 managers expressed interest in attending, but either had travel restrictions or time conflicts.

We anticipated managers would select objectives or conservation targets with little information available relative to management priority for which to develop conceptual models. However, it became clear through our discussions that floodplain conservation lands were generally managed for multiple objectives and selecting a single objective or target was not an efficient pathway to determine overall science needs to manage these properties. There was consensus among managers that primary abiotic factors, particularly metrics of floodplain inundation, were the variables of greatest interest to understand and predict as they drive secondary abiotic factors and define habitat for biota. However, managers were less concerned about needing models for biological endpoints linked to the abiotic factors, primarily because they were more comfortable identifying the biological link themselves for the biotic endpoint of interest.

Follow-up survey

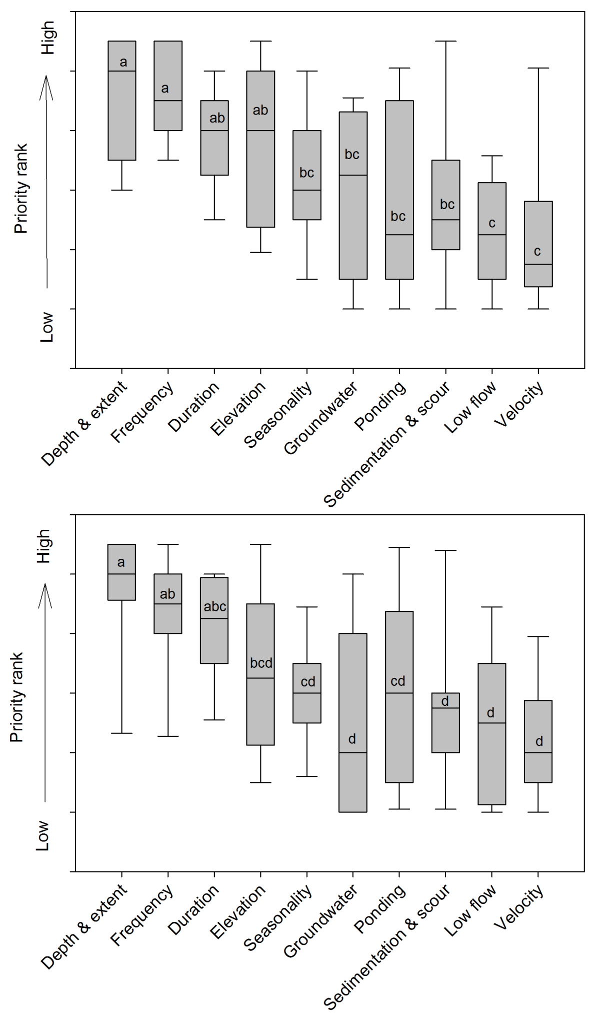
Twenty-one floodplain managers participated in the follow-up survey to the workshop. Of these participants, 13 (62%) managed properties on the LMOR, four (19%) on the UMR, 3 (14%) on the MMR, and 1 (5%) on the Illinois River. Thirteen managers (62%) self-associated with an active management of their lands while the remaining 8 (38%) self-associated with passive management.

There were significant differences in the frequency of use ($F_{3,80}$ = 8.628, $p < 0.001$) of scientific information identified in the workshop as commonly used for management of floodplain conservation lands. Topography and elevation were used significantly more than hydrogeomorphic classifications of habitat or metrics on inundation, although this is likely due to limited availability of the latter two types of information (Tukey's HSD $p < 0.05$). The informational value attributed to types of information did not differ, with all types of information identified as informative to planning and management decisions ($F_{3,65}$ = 2.217, $p = 0.100$). Additional types of information identified by respondents as commonly used in management decisions included species occurrence from monitoring or existing databases, known wildlife needs, accessibility, location of levees, land cover and vegetation types, public recreation uses, and whether the property is in an incising or aggrading reach of the river.

Depth and extent of inundation at different river stages, frequency of inundation, and duration of inundation were significantly higher in informational value than flow velocities at different river stages ($F_{9,189}$ = 4.138, $p < 0.001$ Tukey's HSD $p < 0.05$). Depth and extent of inundation at different river stages, frequency of inundation, duration of inundation, and elevation were higher ranked in priority than flow velocities at different river stages and river stages associated with low flow events ($F_{9,175}$ = 9.691, $p < 0.001$; Tukey's HSD $p < 0.05$; Fig. 5A). There were similar differences in prioritization of inundation metrics when making management decisions in consideration of nonstationary conditions (e.g., climate change, $F_{9,190}$ = 9.79, $p < 0.001$; Fig. 5B). The scientific products most useful to managers included layers in a geographical information system that would allow for dynamic interaction (100% of respondents), hydrologic model output files (65%), portable document format (PDF) files of maps for static interaction (55%), online map-viewer (35%), and smartphone application (25%).

Eighty percent of survey participants responded that their agency does not incorporate climate change into management plans or decisions for their floodplain lands. However, 70% of survey participants responded that they may have research needs pertaining to how climate change might influence decisions or objectives on the properties they manage. Of particular concern are changes to flow regimes, water level management, vegetation community changes, sedimentation, and groundwater changes. When asked if managers had observed or have been informed of changes on their lands related to climate change, 25% of survey participants noted changes such as an increased occurrence of extreme precipitation events, increased base flows, a change in the timing of peak flows, expanding species ranges, or a change in timing of waterfowl migration.

Fig. 5. Boxplots of rankings from 21 respondents to the follow-up survey on the development priority of various metrics identified as science needs in our workshop for (A) current management and (B) management under projected climate changes. An analysis of variance and Tukey's HSD test was performed on each dataset to determine statistical differences in mean rank between metrics. Letters within each box that differ indicate ranks that differ at alpha = 0.05. Metrics (see Appendix 3 for full description of each metric) included depth and extent of floodplain inundation at different river stages, frequency of inundation, duration of inundation, elevation, seasonality of inundation, groundwater table associated with low and high flows, extent of seep-driven and precipitation-driven ponding on "dry" side of levee, locations of high probability of sedimentation or scour, stages associated with low flow events, and flow velocities on floodplain at different stages.



DISCUSSION

Floodplain conservation lands are managed for a variety of complex and competing purposes, yet our study found that the majority of resource managers agree that an understanding of inundation patterns is fundamental to manage multiple objectives and targets. In particular, depth and extent of inundation at different river stages, frequency of inundation, and duration of inundation were perceived as key metrics to understand across the floodplain for improving management outcomes. This understanding can be applied to determine disturbance regimes and habitat suitability for vegetation communities (Auble and Scott 1998, Shafroth et al. 2002), moist soil units for waterfowl foraging habitat (Twedt 2013), and implications for fish nursery habitat (Sommer et al. 2001). Even with an understanding of the potential range of variability in river hydrogeomorphic conditions under climate change projections, managers maintain that depth, extent, frequency, and duration of inundation are the top priorities to understand for long-term management of floodplain conservation lands.

An increasing awareness of the role floodplain connectivity has on ecosystem functions and services has spurred interest in restoration of floodplain connectivity (Opperman et al. 2009, Schindler et al. 2014). Floodplain connectivity in this context includes surface-water and groundwater processes that result in exchange of organisms, nutrients, and organic matter between the main channel and the floodplain. Additionally, increased frequency of flooding in areas has raised concerns regarding a need to better understand flood risk (Gilles et al. 2012). Although flood-risk reduction was not a high priority objective in management of conservation lands, flood-risk reduction through flood water storage is an important ecosystem service that may benefit private land owners and urban centers located within the floodplain (Jacobson et al. 2015, Schober et al. 2015). As such, flood-risk reduction may be an underutilized argument in support of conservation management.

Understanding the relationships between inundation and ecological processes is an active and growing field of research because patterns of floodplain inundation are known to be primary drivers of ecological processes in floodplain ecosystems. For example, the ability to map areas of inundation at regional scales has recently provided information on extent of inundation for different flow return intervals (Chojnacki et al. 2012, Theiling and Burant 2013). In ungaged areas, remotely sensed data are being increasingly used to understand temporal inundation dynamics (Ward et al. 2014, Thomas et al. 2015). Spatially-explicit inundation information can be linked to known species responses to identify suitable habitat for species of interest (Jacobson et al. 2011) and evaluate changes in habitat availability under different management and climate change scenarios (Matella and Merenlender 2015). Two-dimensional hydrodynamic models have been employed to identify appropriate species to plant in restoration planning (Leyer et al. 2012). Our surveys provide evidence that managers recognize the linkage between inundation and ecological processes. The emphasis on inundation metrics supports the need for conservation agencies to invest in additional expertise in hydrology and geomorphology, or alternatively, to develop access to the expertise through collaborations with other agencies or institutions (Vaughan et al. 2009).

Understanding the influence of nonstationarity, in the form of climate change, on inundation metrics has significant implications for the management of floodplain lands. Although management plans for floodplain conservation lands rarely included more than a mention of climate change, shifting climate trends have been noted and acknowledged by many natural resource managers. The majority of resource managers surveyed have interest in understanding how climate is likely to change over time, and these changes may have dramatic effects to the biota in these river-floodplain systems (Paukert and Galat 2010). As one survey participant responded, “If climate change is going to affect the properties I manage before I retire, I want to know about it.” Recent U.S. Presidential executive orders (The White House 2013) guide and encourage all federal agencies to address climate change adaptation, however a lack of management-relevant climate change science, time, and funding remain obstacles to implementing adaptation (Kemp et al. 2015).

Our survey also revealed that time, funding, and a perceived disconnect between research and management communities limited the ability of resource managers to use new scientific information in management decisions. Kemp et al. (2015) found that federal agencies tasked with incorporating climate chance science into management of public lands were faced with similar limitations. Similarly, lack of information at relevant scales and budget constraints were the most limiting constraints for federal public land managers to adapt to climate change in mountainous Colorado (Archie et al. 2014). Although resource limitations of time and funding are often controlled by forces outside the realm of influence of individual managers and scientists, disconnections between research and management communities is a constraint that both resource managers and scientists can work to remove through regular communication and collaboration. The U.S. Forest Service has attempted to overcome this obstacle through the creation of climate change coordinator positions (Kemp et al. 2015) and science-management partnerships (Littell et al. 2012). The participating managers in our workshop were eager to help scientists understand the difficulties inherent to managing floodplains, and to aid in the identification of science products that meet their needs, suggesting partnerships between managers and researchers can identify science needs, specify relevant temporal and spatial scales, and determine user-friendly product formats.

Our survey results also reveal additional information gaps that may be limiting managers’ ability to effectively manage for objectives such as controlling invasive species, maintaining respectful relationships with neighboring land owners, managing native, nongame species, managing endangered and threatened species, and promoting nutrient cycling. Similarly, there was limited information relative to priority of several conservation targets including pollinators, marsh birds, reptiles, shore birds, aquatic invertebrates, and amphibians. These limitations suggest that monitoring and pilot studies may be needed to gain information on floodplain ecosystem functions, habitat needs, and the role of management actions on these objectives and targets. Although many of the objectives and targets identified as information-limiting were also identified as low priorities, the priority ranking may be, at least partially, a result of limited understanding of how to effectively manage for an objective or target. In the case of pollinators, limited information available to understand recent population crashes (Vanbergen and Insect Pollinators Initiative 2013) has heightened interest and investment in pollinator research (Pollinator Health Task Force 2015). Along the same lines, a Midwest Marsh Bird Working Group was formed in 2012 to support regional marsh bird conservation through understanding impacts of management actions on marsh bird populations (Larkin et al. 2013).

Maintaining positive relationships with neighboring landowners was the highest scored priority across the study area. Many of the private lands in large river floodplains are in agricultural production and, therefore, landowners often have a different set of needs from the river than floodplain conservation land managers. Although the focus of our survey was on public lands, private lands make up a majority of floodplains in the Midwest as well as other large rivers in the world. The prevalence of privately-held agricultural lands in the floodplain and how those lands are managed is reflected in a 2012 survey of large river scientists and stakeholders who overwhelming (94%) agreed that current floodplain management does not support river-ecosystem needs (K. Lubinski and S. Gillespie, U.S. Geological Survey, *unpublished data*). Several of our survey participants noted the importance of determining the needs and values of private landowners and using that information to better link public and private land conservation programs. Research on private landowner management practices and values are limited, however, a survey of private landowners within the floodplain of the Missouri River in central Missouri identified rowcrop production, leaving land for children and grandchildren, soil conservation, and scenic beauty as the most important short- and long-term goals (Treiman and Dwyer 2004). Understanding the values of private land owners in the floodplain, as well as the larger community of people who live near rivers and their floodplains, could help natural resource managers communicate the optimal management actions to implement on public lands to support those values and also aid in developing novel approaches to encourage conservation practices on private lands (Raymond et al. 2015).

Given the complexities of managing floodplain conservation lands resulting from river-floodplain interactions, anthropogenic modifications, and the mosaic of private lands in the landscape, our research highlights the need for a few, relatively simple metrics of inundation to better manage these lands. The inundation metrics identified are evidence for the need to understand key drivers, i.e., hydrology, of river-floodplain ecosystems and, therefore, are likely related to the various objectives and conservation targets for which floodplain conservation lands are managed.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/8620

Acknowledgments:

We acknowledge and thank the numerous resource managers who took the time to participate in the surveys and workshop. Our advisory team, Keith Goyne, Lisa Webb, David Galat, Kenneth Lubinski, provided helpful advice and guidance as we developed surveys and planned the workshop. We also thank Tom Bell and Frank Nelson for guidance they provided to this project. We appreciate Sonja Wilhelm Stanis for reviewing survey questions and Drew Fowler for taking notes at the project workshop. We thank the Missouri Department of Conservation for use of their facility at the August A. Busch Conservation Area for our workshop. We thank Lama BouFajreldin for early review of this manuscript. This work was funded by the Northeast Climate Science Center (Project number: G14AC00308). The survey was approved by the University of Missouri Institutional Review Board (Project #1213966). The Missouri Cooperative Fish and Wildlife Research Unit is jointly sponsored by the Missouri Department of Conservation, the University of Missouri, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Wildlife Management Institute. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government..

LITERATURE CITED

Adams, W. M. and M. R. Perrow. 1999. Scientific and institutional constraints on the restoration of European floodplains. Pages 89-97 *in* S. B. Marriott and J. Alexander, editors. *Floodplains: interdisciplinary approaches.* The Geological Society of London, London, UK.

Archie, K. M., L. Dilling, J. B. Milford, and F. C. Pampel. 2014. Unpacking the 'information barrier': comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West. *Journal of Environmental Management* 133:397-410. http://dx.doi.org/10.1016/j.jenvman.2013.12.015

Auble, G. T., and M. L. Scott. 1998. Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. *Wetlands* 18(4):546-556. http://dx.doi.org/10.1007/bf03161671

Bayley, P. B. 1995. Understanding large river-floodplain ecosystems: significant economic advantages and increased biodiversity and stability would result from restoration of impaired systems. *BioScience* 45(3):153-158. http://dx.doi.org/10.2307/1312554

Buijse, A. D., H. Coops, M. Staras, L. H. Jans, G. J. Van Geest, R. E. Grifts, B. W. Ibelings, W. Oosterberg, and F. C. J. M. Roozen. 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology* 47:889-907. http://dx.doi.org/10.1046/j.1365-2427.2002.00915.x

Chojnacki, K. A., M. A. Struckhoff and R. B. Jacobson. 2012. Land capability potential index (LCPI) and geodatabase for the Lower Missouri River Valley. *U.S. Geological Survey Data Series* 736.

Di Baldassarre, G., A. Castellarin, and A. Brath. 2009. Analysis of the effects of levee heightening on flood propagation: example of the River Po, Italy. *Hydrological Sciences Journal* 54 (6):1007-1017. http://dx.doi.org/10.1623/hysj.54.6.1007

Dilling, L., and M. C. Lemos. 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change* 21:680-689. http://dx.doi.org/10.1016/j.gloenvcha.2010.11.006

Fredrickson, L. H.,, and T. S. Taylor. 1982. *Management of seasonally flooded impoundments for wildlife.* U.S. Fish and Wildlife Service, Washington, D.C., USA.

Galat, D. L., L. H. Frederickson, D. D. Humburg, K. J. Bataille, J. R. Bodie, J. Dohrenwend, G. T. Gelwicks, J. E. Havel, D. L. Helmers, J. B. Hooker, J. R. Jones, M. F. Knowlton, J. Kubisiak, J. Mazourek, A. C. McColpin, R. B. Renken, and R. D. Semlitsch. 1998. Flooding to restore connectivity of regulated, large-river wetlands: natural and controlled flooding as complementary processes along the lower Missouri River. *BioScience* 48 (9):721-733. http://dx.doi.org/10.2307/1313335

Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. *Hydrobiologia* 422:29-48. http://dx.doi.org/10.1023/A:1017052319056

Gilles, D., N. Young, H. Schroeder, J. Piotrowski, and Y. Chang. 2012. Inundation mapping initiatives of the Iowa Flood Center: statewide coverage and detailed urban flooding analysis. *Water* 4 (1):85-106. http://dx.doi.org/10.3390/w4010085

Hein, T., U. Schwartz, H. Habersack, I. Nichersu, S. Preiner, N. Willby, and G. Weigelhofer. 2016. Current status and restoration options for floodplains along the Danube River. *Science of the Total Environment* 543:778-790. http://dx.doi.org/10.1016/j.scitotenv.2015.09.073

Heine, R. A., and N. Pinter. 2012. Levee effects upon flood levels: an empirical assessment. *Hydrological Processes* 26:3225-3240. http://dx.doi.org/10.1002/hyp.8261

Hughes, F. M. R., A. Colston, and J. O. Mountford. 2005. Restoring riparian ecosystems: the challenge of accommodating variability and designing restoration trajectories. *Ecology and Society* 10(1):12. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art12/

Jacobson, R. B. and D. L. Galat. 2006. Flow and form in rehabilitation of large-river ecosystems: an example from the Lower Missouri River. *Geomorphology* 77:249-269. http://dx.doi.org/10.1016/j.geomorph.2006.01.014

Jacobson, R. B., and D. L. Galat. 2008. Design of a naturalized flow regime–an example from the Lower Missouri River, USA. *Ecohydrology* 1(2):81-104. http://dx.doi.org/10.1002/eco.9

Jacobson, R. B., T. P. Janke, and J. J. Skold. 2011. Hydrologic and geomorphic considerations in restoration of river-floodplain connectivity in a highly altered river system, Lower Missouri River, USA. *Wetlands Ecology and Management* 19:295-316. http://dx.doi.org/10.1007/s11273-011-9217-3

Jacobson, R. B., G. Lindner, and C. Bitner 2015. The role of floodplain restoration in mitigating flood risk, Lower Missouri River, USA. Pages 203-243 *in* P. F. Hudson and H. Middlekoop, editors. *Geomorphic approaches to integrated floodplain management of lowland fluvial systems in North America and Europe.* Springer, New York, New York, USA. http://dx.doi.org/10.1007/978-1-4939-2380-9_9

Kemp, K. B., J. J. Blades, P. Z. Klos, T. E. Hall, J. E. Force, P. Morgan, and W. T. Tinkham. 2015. Managing for climate change on federal lands of the western United States: perceived usefulness of climate science, effectiveness of adaptation strategies, and barriers to implementation. *Ecology and Society* 20(2):17. http://dx.doi.org/10.5751/es-07522-200217

Kocher, S. D., E. Toman, S. F. Trainor, V. Wright, J. S. Briggs, C. P. Goebel, E. M. MontBlanc, M. Eugénie, A. Oxarart, A., D. L. Pepin, T. A. Steelman, A. Thode, and T. A. Waldrop. 2012. How can we span the boundaries between wildlife fire science and management in the United States? *Journal of Forestry* 110 (8):421-428. http://dx.doi.org/10.5849/jof.11-085

Larkin, D. J., R. S. Brady, B. M. Kahler, K. E. Koch, D. G. Krementz, M. J. Monfils, G. J. Soulliere, and E. B. Webb. 2013. Collaborative research on secretive marsh birds in the midwest region: linking monitoring and wetland management. Technical Report No. 2013-1. Upper Mississippi River and Great Lakes Region Joint Venture, Bloomington, Minnesota, USA.

Lemos, M. C., and B. J. Morehouse. 2005. The co-production of science and policy in integrated climate assessments. *Global Environmental Change* 15(1):57-68. http://dx.doi.org/10.1016/j.gloenvcha.2004.09.004

Leyer, I., E. Mosner, and B. Lehmann. 2012. Managing floodplain-forest restoration in European river landscapes combining ecological and flood-protection issues. *Ecological Applications* 22(1):240-249. http://dx.doi.org/10.1890/11-0021.1

Littell, J. S., D. L. Peterson, C. I. Millar, and K. A. O'Halloran. 2012. U.S. National Forests adapt to climate change through science-management partnerships. *Climatic Change* 110 (1):269-296. http://dx.doi.org/10.1007/s10584-011-0066-0

Matella, M. K., and A. M. Merenlender. 2015. Scenarios for restoring floodplain ecology given changes to river flows under climate change: case from the San Joaquin River, California. *River Research and Applications* 31(3):280-290. http://dx.doi.org/10.1002/rra.2750

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer. 2008. Stationarity is dead: whither water management? *Science* 319:573-574. http://dx.doi.org/10.1126/science.1151915

Olsen, J. R. 2006. Climate change and floodplain management in the United States. *Climatic Change* 76:407-426. http://dx.doi.org/10.1007/s10584-005-9020-3

Opperman, J. J., G. E. Galloway, J. Fargione, J. F. Mount, B. D. Richter, and S. Secchi. 2009. Sustainable floodplains through large-scale reconnection to rivers. *Science* 326:1487-1488. http://dx.doi.org/10.1126/science.1178256

Pahl-Wostl, C. 2006. The importance of social learning in restoring the multifunctionality of rivers and floodplains. *Ecology and Society* 11(1):10. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art10/

Paukert, C. P., and D. L. Galat. 2010. Warmwater rivers. Pages 699-730 *in* W. Hubert and M. Quist, editors. *Inland fisheries management in North America.* American Fisheries Society, Bethesda, Maryland, USA.

Poff, N. L., C. M. Brown, T. E. Grantham, J. H. Matthews, M. A. Palmer, C. M. Spence, R. L. Wilby, M. Haasnoot, G. F. Mendoza, K. C. Dominique, and A. Baeza. 2016. Sustainable water management under future uncertainty with eco-engineering decision scaling. *Nature Climate Change* 6:25-34. http://dx.doi.org/10.1038/nclimate2765

Pollinator Health Task Force. 2015. *Pollinator research action plan.* The White House, Washington, D.C., USA.

R Core Team. 2014. *R: A language and environment for statistical computing.* R Core Team, Vienna, Austria. [online] URL: https://cran.r-project.org/

Raymond, C. M., A. M. Lechner, M. Lockwood, O. Carter, R. M. B. Harris, and L. Gilfedder. 2015. Private land manager capacity to conserve threatened communities under climate change. *Journal of Environmental Management* 159:235-244. http://dx.doi.org/10.1016/j.jenvman.2015.04.048

Remo, J. W. F., N. Pinter, and R. Heine. 2009. The use of retro- and scenario-modeling to assess effects of 100+ years of river engineering and land-cover change on Middle and Lower Mississippi River flood stages. *Journal of Hydrology* 376 (3-4):403-416. http://dx.doi.org/10.1016/j.jhydrol.2009.07.049

Schindler, S., Z. Sebesvari, C. Damm, K. Euller, V. Mauerhofer, A. Schneidergruber, M. Biró, F. Essl, R. Kanka, S. G. Lauwaars, C. Schulz-Zunkel, T. van der Sluis, M. Kropik, V. Gasso, A. Krug, M. T. Pusch, K. P. Zulka, W. Lazowski, C. Haintz-Renetzeder, K. Henle, and T. Wrbka. 2014. Multifunctionality of floodplain landscapes: relating management options to ecosystem services *Landscape Ecology* 29(2):229-244. http://dx.doi.org/10.1007/s10980-014-9989-y

Schober, B., C. Hauer, and H. Habersack. 2015. A novel assessment of the role of Danube floodplains in flood hazard reduction (FEM method). *Natural Hazards* 75(1):33-50. http://dx.doi.org/10.1007/s11069-013-0880-y

Schramm, H. L., W. B. Richardson, and B. C. Knights. 2015. Managing the Mississippi River floodplain: achieving ecological benefits requires more than hydrological connection to the river. Pages 171-201 *in* P. F. Hudson and H. Middlekoop, editors. *Geomorphic approaches to integrated floodplain management of lowland fluvial systems in North America and Europe.* Springer, New York, New York, USA. http://dx.doi.org/10.1007/978-1-4939-2380-9_8

Shafroth, P. B., J. C. Stromberg, and D. T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications* 12(1):107-123. http://dx.doi.org/10.1890/1051-0761(2002)012[0107:rvrtad]2.0.co;2

Singh, R., P. M. Reed, and K. Keller. 2015. Many-objective robust decision making for managing an ecosystem with a deeply uncertain threshold response. *Ecology and Society* 20(3):12. http://dx.doi.org/10.5751/es-07687-200312

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58:325-333. http://dx.doi.org/10.1139/f00-245

Sparks, R. E. 1995. Need for ecosystem management of large rivers and their floodplains. *BioScience* 45(3):168-182. http://dx.doi.org/10.2307/1312556

Stanturf, J. A., E. S. Gardiner, P. B. Hamel, M. S. Devall, T. B. Leininger, and M. E. Warren. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. *Journal of Forestry* 98(8):10-16.

The White House 2013. *Executive Order - Preparing the United States for the impacts of climage change.* Office of the Press Secretary.

Theiling, C. H., and J. T. Burant. 2013. Flood inundation mapping for integrated floodplain management: Upper Mississippi River System. *River Research and Applications* 29(8):961-978. http://dx.doi.org/10.1002/rra.2583

Theiling, C. H., and J. M. Nestler. 2010. River stage response to alteration of Upper Mississippi River channels, floodplains, and watersheds. *Hydrobiologia* 640:17-47. http://dx.doi.org/10.1007/s10750-009-0066-5

Thomas, R. F., R. T. Kingsford, Y. Lu, S. J. Cox, N. C. Sims, and S. J. Hunter. 2015. Mapping inundation in the heterogeneous floodplain wetlands of the Macquarie Marshes, using Landsat Thematic Mapper. *Journal of Hydrology* 524:194-213. http://dx.doi.org/10.1016/j.jhydrol.2015.02.029

Tockner, K., F. Malard, and J. V. Ward. 2000. An extension of the flood pulse concept. *Hydrological Processes* 14 (16-17):2861-2883. http://dx.doi.org/10.1002/1099-1085(200011/12)14:16/17<2861::AID-HYP124>3.0.CO;2-F

Tockner, K., and J. A. Stanford. 2002. Riverine flood plains: present state and future trends. *Environmental Conservation* 29:308-330. http://dx.doi.org/10.1017/S037689290200022X

Treiman, T., and J. Dwyer. 2004. Will landowners adopt reforestation practices? Answers from the Missouri River floodplain. Pages 288-296 *in* D. Yaussy, D. M. Hix, P. C. Goebel, and R. P. Long, editors. Proceedings of the 14th Central Hardwood Forest Conference, Wooster, Ohio. Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania, USA.

Twedt, D. J. 2013. Foraging habitat for shorebirds in southeastern Missouri and its predicted future availability. *Wetlands* 33:667-678. http://dx.doi.org/10.1007/s13157-013-0422-0

U.S. Army Corps of Engineers. 2006. *Missouri River mainstem reservoir system, master water control manual, Missouri River Basin.* U.S. Army Corps of Engineers, Omaha, Nebraska.

U.S. Fish and Wildlife Service. 2014. Big Muddy National Fish and Wildlife Refuge comprehensive conservation plan. U.S. Department of the Interior, Fish and Wildlife Service, Region 3, Bloomington, Minnesota, USA.

Vanbergen, A. J. and Insect Pollinators Initiative. 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment* 11:251-259. http://dx.doi.org/10.1890/120126

Vaughan, I. P., M. Diamond, A. M. Gurnell, K. A. Hall, A. Jenkins, N. J. Milner, L. A. Naylor, D. A. Sear, G. Woodward, and S. J. Ormerod. 2009. Integrating ecology with hydromorphology: a priority for river science and management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19:113-125. http://dx.doi.org/10.1002/aqc.895

Ward, D. P., A. Petty, S. A. Setterfield, M. M. Douglas, K. Ferdinands, S. K. Hamilton, and S. Phinn. 2014. Floodplain inundation and vegetation dynamics in the Alligator Rivers region (Kakadu) of northern Australia assessed using optical and radar remote sensing. *Remote Sensing of the Environment* 147:43-55. http://dx.doi.org/10.1016/j.rse.2014.02.009

Wright, V. 2007. Communication barriers to applying federal research in support of land management in the United States. Gen. Tech. Rep. PNW-GTR-726. Pages 55-62 *in* C. Miner, R. Jacobs, D. Dykstra, and B. Bittner, editors. *International conference on transfer of forest science knowledge and technology.* USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA.

Appendix 1. List of federal and state natural resource management agencies that manage conservation lands within the floodplain of the study area and with personnel asked to participate in our surveys and workshop.

U.S. Fish and Wildlife Service

U.S. National Park Service

U.S. Forest Service

U.S. Army Corps of Engineers

Illinois Department of Natural Resources

Iowa Department of Natural Resources

Kansas Department of Wildlife, Parks, and Tourism

Minnesota Department of Natural Resources

Missouri Department of Natural Resources

Missouri Department of Conservation

Nebraska Game and Parks Commission

Wisconsin Department of Natural Resources

Appendix 2. The initial survey sent to floodplain managers to compile and document management objectives and targets of floodplain conservation lands along the Upper Mississippi River, Middle Mississippi River, and Lower Missouri River.

Q1 Please select the management agency you currently work for:

- ❍ US Army (Go to Q2)
- ❍ US Fish and Wildlife Service (Go to Q3)
- ❍ US Forest Service (Go to Q4)
- ❍ US National Park Service (Go to Q5)
- ❍ Illinois Department of Natural Resources (Go to Q6)
- ❍ Iowa Department of Natural Resources (Go to Q7)
- ❍ Kansas Department of Wildlife, Parks, and Tourism (Go to Q8)
- ❍ Minnesota Department of Natural Resources (Go to Q9)
- ❍ Missouri Department of Conservation (Go to Q10)
- ❍ Missouri Department of Natural Resources (Go to Q11)
- ❍ Nebraska Game and Parks Commission (Go to Q12)
- ❍ Wisconsin Department of Natural Resources (Go to Q13)
- ❍ Other (Go to Q14) ____________________

Q2 Please identify the U.S. Army properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Fort Leavenworth, KS
- ❑ Other ____________________

Go to Q16

Q3 Please identify the U.S. Fish and Wildlife Service properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Big Muddy National Fish and Wildlife Refuge
- ❑ Boyer Chute National Wildlife Refuge
- ❑ Clarence Cannon National Wildlife Refuge
- ❑ Desoto National Wildlife Refuge
- ❑ Great River National Wildlife Refuge
- ❑ Middle Mississippi River National Wildlife Refuge
- ❑ Port Louisa National Wildlife Refuge
- ❑ Trempealeau National Wildlife Refuge
- ❑ Two Rivers National Wildlife Refuge
- ❑ Upper Mississippi River Wildlife and Fish Refuge
- ❑ Other ____________________

Go to Q16

Q4 Please identify the U.S. Forest Service properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Shawnee National Forest
- ❑ Other ____________________

Go to Q16

Q5 Please identify the U.S. National Park Service properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Mississippi National River and Recreation Area
- ❑ Missouri National Recreation River
- ❑ Other ____________________

Go to Q16

Q6 Please identify the Illinois Department of Natural Resources properties of which you are actively engaged in managing (conservation lands within the floodplain of the Upper and Middle Mississippi River only).

- ❑ Big River State Forest
- ❑ Cape Bend State Fish and Wildlife Area
- ❑ Cedar Glen State Natural Area
- ❑ Chouteau Island State Fish and Wildlife Area
- ❑ Delabar State Park
- ❑ Devil's Island State Fish and Wildlife Area
- ❑ Elton Hawks Bald Eagle Refuge Nature Preserve
- ❑ Henderson Creek State Fish and Wildlife Area
- ❑ Horseshoe Lake Nature Preserve
- ❑ Mississippi River Sand Hills Natural Area
- ❑ Mississippi River State Fish and Wildlife Area
- ❑ Union County State Fish and Wildlife Area
- ❑ Other ____________________

Go to Q16

Q7 Please identify the Iowa Department of Natural Resources properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Allen Green Refuge
- ❑ Auldon Bar WMA
- ❑ Blackbird Bend WMA
- ❑ Blackhawk Bottoms WMA
- ❑ Blackhawk Point WMA
- ❑ Boyer Bend WMA
- ❑ California Bend State Wildlife Refuge
- ❑ Copeland Bend WMA
- ❑ Dakota Bend WMA
- ❑ Deer Island State Game Management Area
- ❑ Fawn Island WMA
- ❑ Fish Farms Mounds WMA
- ❑ Frazer's Bend WMA
- ❑ Galland School State Park Preserve
- ❑ Gifford State Forest
- ❑ Glover's Point WMA
- ❑ Green Island WMA
- ❑ Ivy Island WMA
- ❑ Kains Lake WMA
- ❑ Lansing WMA
- ❑ Louisville Bend WMA
- ❑ Lower Blencoe Bend WMA
- ❑ Lower Hamburg Bend WMA
- ❑ Middle Decatur Bend WMA
- ❑ Mile Long Island WMA
- ❑ Mines of Spain State Recreation Area
- ❑ Mississippi River Island State WMA
- ❑ Monona Bend WMA
- ❑ New Albin Big Lake WMA
- ❑ Nottleman Island WMA
- ❑ Odessa WMA
- ❑ Omadi Bend WMA
- ❑ Omaha Mission Bend WMA
- ❑ Pecan Grove State Preserve
- ❑ Pigeon Creek WMA
- ❑ Pool Slough WMA
- ❑ Princeton WMA
- ❑ Rand Bar WMA
- ❑ Snyder Bend WMA
- ❑ Soldier Bend WMA
- ❑ St. Mary's Island WMA
- ❑ Tieville Bend WMA
- ❑ Three Rivers WMA
- ❑ Tyson Bend WMA
- ❑ Upper Blencoe Bend WMA

- ❑ Upper Bullard Bend WMA
- ❑ Upper Decatur Bend WMA
- ❑ Upper Monona Bend WMA
- ❑ Waukon Junction WMA
- ❑ Wilson Island Recreation Area
- ❑ Winnebago Bend WMA
- ❑ Yellow River State Forest
- ❑ Other ____________________

Go to Q16

Q8 Please identify the Minnesota Department of Natural Resources properties of which you are actively engaged in managing (conservation lands within the floodplain of the Upper Mississippi River only).

- ❑ Kellogg-Weaver Dunes State Natural Area (TNC)
- ❑ Pool 4 Wildlife Management Area
- ❑ Frontenac State Park
- ❑ Other ____________________

Go to Q16

Q9 Please identify the Kansas Department of Wildlife, Parks, and Tourism properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River only).

- ❑ Benedictine Bottoms
- ❑ Other ____________________

Go to Q16

Q10 Please identify the Missouri Department of Conservation properties of which you are actively engaged in managing.

- ❑ Anderson CA
- ❑ Baltimore Bend CA
- ❑ BK Leach CA
- ❑ Brown CA
- ❑ Buck and Doe Run CA
- ❑ Columbia CA
- ❑ Corning CA
- ❑ Cuivre Island CA
- ❑ Deroin Bend CA
- ❑ Diana Bend CA
- ❑ Dupont Reservation CA
- ❑ Dupree Memorial CA
- ❑ Eagle Bluffs CA
- ❑ Franklin Island CA
- ❑ Grand Pass CA
- ❑ Howell Island State Wildlife Area
- ❑ Liberty Bend CA
- ❑ Lower Hamburg Bend CA
- ❑ Magnolia Hollow CA
- ❑ Marais Temps Clair CA
- ❑ Marion Bottoms CA
- ❑ Monkey Mountain CA
- ❑ Nishnabotna CA
- ❑ Pelican Island Natural Area
- ❑ Plowboy Bend CA
- ❑ Prairie Slough CA
- ❑ Red Rock Landing CA
- ❑ Rose Pond CA
- ❑ Rush Bottoms CA
- ❑ Sandy Island CA
- ❑ Seventy-Six CA
- ❑ Shanks Conservation Area/ Ted Shanks Wildlife Management Area
- ❑ Smoky Waters CA
- ❑ St. Stanislaus CA
- ❑ Tate Island CA
- ❑ Thurnau CA
- ❑ Upper Mississippi CA
- ❑ Weldon Spring CA
- ❑ Windy Bar CA
- ❑ Wolf Creek Bend CA
- ❑ Worthwine Island CA
- ❑ Other ____________________

Q11 Please identify the Missouri Department of Natural Resources properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River and Upper and Middle Mississippi River only).

- ❑ Wakonda State Park
- ❑ Weston Bend State Park
- ❑ Other ____________________

Go to Q16

Q12 Please identify the Nebraska Game and Parks Commission properties of which you are actively engaged in managing (conservation lands within the floodplain of the Lower Missouri River only).

- ❑ Aspinwall Bend WMA
- ❑ Brownville Bend WMA
- ❑ Elk Point Bend WMA
- ❑ Gifford WMA
- ❑ Hamburg Bend WMA
- ❑ Indian Cave State Park
- ❑ Kansas Bend WMA
- ❑ Langdon Bend WMA
- ❑ Middle Decatur Bend WMA
- ❑ Mulberry Bend WMA
- ❑ Omadi Bend WMA
- ❑ Peru Bottoms WMA
- ❑ Ponca State Park
- ❑ Randall W. Schilling WMA
- ❑ William Gilmour WMA
- ❑ Wiseman WMA
- ❑ Other ____________________

Go to Q16

Q13 Please identify the Wisconsin Department of Natural Resources properties of which you are actively engaged in managing (conservation lands within the floodplain of the Upper Mississippi River only).

- ❑ Lake Pepin Wildlife Area
- ❑ Merrick State Park
- ❑ Mississippi Islands Wildlife Area
- ❑ Nelson Dewey State Park
- ❑ Nelson - Trevino Bottoms State Natural Area
- ❑ Perrot State Park
- ❑ Pierce County Islands Wildlife Area
- ❑ Rush Creek State Natural Area
- ❑ Trempealeau Lakes Fishery Area
- ❑ Van Loon Wildlife Area
- ❑ Whitman Bottoms Floodplain Forest State Natural Area
- ❑ Whitman Dam Wildlife Area
- ❑ Wyalusing Hardwood Forest State Natural Area
- ❑ Wyalusing State Park
- ❑ Other ____________________
  Go to Q16

Q14 Please provide the name of the agency or organization who owns or manages the floodplain conservation land property.

Q15 Please provide the name and general location description of the property/properties.

Q16 Please identify the management priority and intensity of management of the following objectives for the property or majority of the properties you identified in the previous question.

	Management priority				Management intensity			
	None	Low priority	Medium priority	High priority	None	Passive mgmt	Equal mix of passive & active mgmt	Active mgmt
Restore hydrology	❍	❍	❍	❍	❍	❍	❍	❍
Reconnect river to floodplain	❍	❍	❍	❍	❍	❍	❍	❍
Restore bottomland forests	❍	❍	❍	❍	❍	❍	❍	❍
Restore wetlands	❍	❍	❍	❍	❍	❍	❍	❍
Restore bottomland prairies	❍	❍	❍	❍	❍	❍	❍	❍
Provide public recreation opportunities	❍	❍	❍	❍	❍	❍	❍	❍
Maintain respectful relationships with neighbors	❍	❍	❍	❍	❍	❍	❍	❍
Flood risk reduction	❍	❍	❍	❍	❍	❍	❍	❍
Nutrient cycling/ improve water quality	❍	❍	❍	❍	❍	❍	❍	❍
Improve soil health	❍	❍	❍	❍	❍	❍	❍	❍
Contaminant retention	❍	❍	❍	❍	❍	❍	❍	❍
Agricultural production	❍	❍	❍	❍	❍	❍	❍	❍
Manage game species	❍	❍	❍	❍	❍	❍	❍	❍
Manage endangered/ threatened species	❍	❍	❍	❍	❍	❍	❍	❍
Manage other native, nongame species	❍	❍	❍	❍	❍	❍	❍	❍
Control invasive species	❍	❍	❍	❍	❍	❍	❍	❍
Maintain current conditions	❍	❍	❍	❍	❍	❍	❍	❍

Q17 Based on your experience, please rate the level of scientific information available on each objective (in general, not just on the identified properties).

	Scientific information available			
	No opinion	Severely limited information available	Limited information available	Adequate information available
Restore hydrology	❍	❍	❍	❍
Reconnect river to floodplain	❍	❍	❍	❍
Restore bottomland forests	❍	❍	❍	❍
Restore wetlands	❍	❍	❍	❍
Restore bottomland prairies	❍	❍	❍	❍
Provide public recreation opportunities	❍	❍	❍	❍
Maintain respectful relationships with neighbors	❍	❍	❍	❍
Flood risk reduction	❍	❍	❍	❍
Nutrient cycling/ improve water quality	❍	❍	❍	❍
Improve soil health	❍	❍	❍	❍
Contaminant retention	❍	❍	❍	❍
Agricultural production	❍	❍	❍	❍
Manage game species	❍	❍	❍	❍
Manage endangered/ threatened species	❍	❍	❍	❍
Manage other native, nongame species	❍	❍	❍	❍
Control invasive species	❍	❍	❍	❍
Maintain current conditions	❍	❍	❍	❍

Q18 Are there other management objectives for the selected properties that we missed?

❍ Yes (Go to Q19)

❍ No (Go to Q21)

Q19 Please identify (write in) any additional objectives, their management priority and intensity of management for the property or majority of properties you identified in the previous question.

	Management priority				Management intensity			
	None	Low priority	Medium priority	High priority	Not managed	Passive mgmt	Equal mix of passive and active mgmt	Active mgmt
Objective 1	❍	❍	❍	❍	❍	❍	❍	❍
Objective 2	❍	❍	❍	❍	❍	❍	❍	❍
Objective 3	❍	❍	❍	❍	❍	❍	❍	❍
Objective 4	❍	❍	❍	❍	❍	❍	❍	❍
Objective 5	❍	❍	❍	❍	❍	❍	❍	❍
Objective 6	❍	❍	❍	❍	❍	❍	❍	❍

Q20 Based on your experience, please rate the level of scientific information available on each of the additional objectives (in general, not just on the identified properties).

	Scientific information available			
	No opinion	Severely limited information available	Limited information available	Adequate information available
Objective 1	❍	❍	❍	❍
Objective 2	❍	❍	❍	❍
Objective 3	❍	❍	❍	❍
Objective 4	❍	❍	❍	❍
Objective 5	❍	❍	❍	❍
Objective 6	❍	❍	❍	❍

Q21 Please indicate the priority and management intensity of the following conservation targets for the property or majority of the properties you selected.

	Management priority				Management intensity			
	None	Low priority	Medium priority	High priority	Not managed	Passive mgmt	Equal mix of passive and active mgmt	Active mgmt
Pallid sturgeon	❍	❍	❍	❍	❍	❍	❍	❍
Least tern	❍	❍	❍	❍	❍	❍	❍	❍
Piping plover	❍	❍	❍	❍	❍	❍	❍	❍
Aquatic invasive species	❍	❍	❍	❍	❍	❍	❍	❍
Terrestrial invasive species	❍	❍	❍	❍	❍	❍	❍	❍
Deer	❍	❍	❍	❍	❍	❍	❍	❍
Turkey	❍	❍	❍	❍	❍	❍	❍	❍
Pheasant	❍	❍	❍	❍	❍	❍	❍	❍
Waterfowl	❍	❍	❍	❍	❍	❍	❍	❍
Quail	❍	❍	❍	❍	❍	❍	❍	❍
Game fish	❍	❍	❍	❍	❍	❍	❍	❍
Bald eagles	❍	❍	❍	❍	❍	❍	❍	❍
Song birds	❍	❍	❍	❍	❍	❍	❍	❍
Shore birds	❍	❍	❍	❍	❍	❍	❍	❍
Marsh birds	❍	❍	❍	❍	❍	❍	❍	❍
Aquatic invertebrates	❍	❍	❍	❍	❍	❍	❍	❍
Pollinators	❍	❍	❍	❍	❍	❍	❍	❍
Amphibians	❍	❍	❍	❍	❍	❍	❍	❍
Reptiles	❍	❍	❍	❍	❍	❍	❍	❍
Cottonwoods	❍	❍	❍	❍	❍	❍	❍	❍

Q22 Based on your experience, please rate the level of scientific information available on each objective (in general, not just for the properties selected).

	Information available			
	No opinion	Severely limited information available	Limited information available	Adequate information available
Pallid sturgeon	❍	❍	❍	❍
Least tern	❍	❍	❍	❍
Piping plover	❍	❍	❍	❍
Aquatic invasive species	❍	❍	❍	❍
Terrestrial invasive species	❍	❍	❍	❍
Deer	❍	❍	❍	❍
Turkey	❍	❍	❍	❍
Pheasant	❍	❍	❍	❍
Waterfowl	❍	❍	❍	❍
Quail	❍	❍	❍	❍
Game fish	❍	❍	❍	❍
Bald eagles	❍	❍	❍	❍
Song birds	❍	❍	❍	❍
Shore birds	❍	❍	❍	❍
Marsh birds	❍	❍	❍	❍
Aquatic invertebrates	❍	❍	❍	❍
Pollinators	❍	❍	❍	❍
Amphibians	❍	❍	❍	❍
Reptiles	❍	❍	❍	❍
Cottonwoods	❍	❍	❍	❍

Q23 Are there other conservation targets for the selected properties that we missed?

❍ Yes (Go to Q24)

❍ No (Go to Q26)

Q24 Please identify any additional conservation targets and indicate their priority and management intensity of the following conservation targets for the property or majority of properties you selected.

	Management priority				Management intensity			
	None	Low priority	Medium priority	High priority	Not managed	Passive mgmt	Equal mix of passive and active mgmt	Active mgmt
Target 1	❍	❍	❍	❍	❍	❍	❍	❍
Target 2	❍	❍	❍	❍	❍	❍	❍	❍
Target 3	❍	❍	❍	❍	❍	❍	❍	❍
Target 4	❍	❍	❍	❍	❍	❍	❍	❍
Target 5	❍	❍	❍	❍	❍	❍	❍	❍
Target 6	❍	❍	❍	❍	❍	❍	❍	❍

Q25 For any additional conservation targets, please rate the level of scientific information available on each objective, based on your experience (in general, not just for the properties you selected).

	Information available			
	No opinion	Severely limited information available	Limited information available	Adequate information available
Target 1	❍	❍	❍	❍
Target 2	❍	❍	❍	❍
Target 3	❍	❍	❍	❍
Target 4	❍	❍	❍	❍
Target 5	❍	❍	❍	❍
Target 6	❍	❍	❍	❍

Q26 Are there management plans or overarching guiding documents in place for the property/properties selected?

- ❍ Yes, up to date plans available
- ❍ Yes, old plans available but not up to date
- ❍ No, we are currently in the planning process
- ❍ No, and not in planning process

Q27 Would you be able to provide the most current management plan(s) or guiding document(s) in the form of a website link, digital copy (e-mailed), or hard copy?

- ❍ Yes
- ❍ No

Q28 If available online, please provide website link below.

Q29 Please rate the importance of the following sources when incorporating new scientific information into the decision-making process.

	Not important	Slightly important	Important	Very important	No opinion
Peer-reviewed literature	❍	❍	❍	❍	❍
White papers	❍	❍	❍	❍	❍
Internal datasets	❍	❍	❍	❍	❍
Collaboration with internal research staff	❍	❍	❍	❍	❍
Collaboration with external researchers	❍	❍	❍	❍	❍
Professional association meetings	❍	❍	❍	❍	❍
Word of mouth	❍	❍	❍	❍	❍
More experienced staff	❍	❍	❍	❍	❍

Q30 Are there other sources in which new scientific information is incorporated in to the decision-making process?

❍ Yes (Go to Q31)

❍ No (Go to Q32)

Q31 Please identify other sources of new scientific information and rate their importance when incorporating new scientific information into the decision-making process.

	Not important	Slightly important	Important	Very important	No opinion
Source 1	❍	❍	❍	❍	❍
Source 2	❍	❍	❍	❍	❍
Source 3	❍	❍	❍	❍	❍
Source 4	❍	❍	❍	❍	❍

Q32 Please rate the following constraints based on how they limit your ability to obtain or utilize new scientific information in management decisions.

	Not limiting	Slightly limiting	Limiting	Very limiting	No opinion
Time	❍	❍	❍	❍	❍
Funding (ability to travel to meetings, etc.)	❍	❍	❍	❍	❍
Credibility of scientific information	❍	❍	❍	❍	❍
Credibility of scientific process	❍	❍	❍	❍	❍
High uncertainty in results	❍	❍	❍	❍	❍
Research not applicable due to spatial and temporal differences	❍	❍	❍	❍	❍
Access to scientific journals	❍	❍	❍	❍	❍
Disconnect between research and management activities	❍	❍	❍	❍	❍
Socio-political factors	❍	❍	❍	❍	❍

Q33 Are there other constraints that limit your ability to obtain or utilize new scientific information in management decisions?

❍ Yes (Go to Q34)
❍ No (Go to Q35)

Q34 Please identify additional constraints and rate them based on how they limit your ability to obtain or utilize new scientific information in management decisions.

	Not limiting	Slightly limiting	Limiting	Very limiting	No opinion
Constraint 1	❍	❍	❍	❍	❍
Constraint 2	❍	❍	❍	❍	❍
Constraint 3	❍	❍	❍	❍	❍
Constraint 4	❍	❍	❍	❍	❍

Q35 What capacity does your agency have to conduct and/or fund targeted research to better meet management objectives?

❍ Low capacity
❍ Medium capacity
❍ High capacity

Appendix 3. The post-workshop follow-up survey to prioritize research needs of floodplain conservation lands along the Upper Mississippi River, Middle Mississippi River, and Lower Missouri River.

Q1 Please identify the major river section(s) that the floodplain properties you manage are located.

- ❍ Upper Mississippi
- ❍ Middle Mississippi
- ❍ Lower Missouri
- ❍ Other ____________________

Q2 In general, would you consider the management activities on the floodplain properties to be predominantly active or passive?

- ❍ Active management
- ❍ Passive management

Q3 Please rank the following types of information based on your frequency of use and informative value in making management decisions on floodplain properties. Please add additional variables that you use to make decisions.

	Frequency of use				Informative value			
	Not available to my knowledge	Available but not used	Used occas-ionally	Used commo-nly	Does not inform planning or manageme nt decisions	Informs planning decisions	Informs management decisions	Informs planning and management decisions
Topography and elevation	❍	❍	❍	❍	❍	❍	❍	❍
Soil type	❍	❍	❍	❍	❍	❍	❍	❍
Hydro-geomorphic (HGM) classification of habitat	❍	❍	❍	❍	❍	❍	❍	❍
Metrics of floodplain inundation	❍	❍	❍	❍	❍	❍	❍	❍
Other	❍	❍	❍	❍	❍	❍	❍	❍

Q4 Do you know of sources of environmental data, either biotic or abiotic, on public floodplain properties?

❍ Yes
❍ No

Q5 Please share the source of environmental data, type of data collected, and location of collection sites.

Q6 Please rank the potential informative value of the following types of scientific information in relation to managing floodplain properties. Additionally, please rank the priority in which you would like to see the following metrics developed (1 = highest priority). Add additional variables you would find useful to make management decisions on floodplain properties.

	Informative value				Priority Rank
	Would not inform planning or long-term management decisions	Would inform planning decisions	Would inform long-term management decisions	Would inform planning and long-term management decisions	Select Rank (1-10)
Depth and extent of floodplain inundation at different river stages	❍	❍	❍	❍	❍
Frequency of inundation - how often does a floodplain flood	❍	❍	❍	❍	❍
Seasonality of inundation	❍	❍	❍	❍	❍
Duration of inundation - how long does water stay on a floodplain	❍	❍	❍	❍	❍
Stages associated with low flow events	❍	❍	❍	❍	❍
Flow velocities on floodplain at different river stages	❍	❍	❍	❍	❍
Elevation	❍	❍	❍	❍	❍
Locations with high probability of sedimentation or scour from flood events	❍	❍	❍	❍	❍
Extent of seep-driven and precipitation-driven ponding on "dry" side of the levee	❍	❍	❍	❍	❍
Groundwater table associated with low and high flows	❍	❍	❍	❍	❍
Other	❍	❍	❍	❍	❍

Q7 What type of product output(s) from this project would you find useful?

- ❑ Environmental variables or indices (i.e., water, depth, and soil type) as layers in a Geographical Information system (i.e., ArcGIS) that would allow for dynamic interaction
- ❑ Environmental variables or indices (i.e., water, depth, and soil type) as PDF/paper maps that would allow for static interaction
- ❑ Biological model outputs
- ❑ Hydrologic model outputs
- ❑ Online mapviewer
- ❑ Smartphone or tablet application
- ❑ Other ____________________

Q8 Does your agency incorporate climate change into management plans for floodplain properties?

- ❍ Yes
- ❍ No

Q9 Does your agency incorporate climate change into management decisions on floodplain properties?

- ❍ Yes
- ❍ No

Q10 Do you have research needs pertaining to how climate change might influence management decisions or objectives on the floodplain properties you manage?

- ❍ Yes
- ❍ No
- ❍ Not sure

Q11 Please describe your research needs pertaining to how climate change might influence management decisions or objectives on the properties you manage.

Q12 Have you seen or been informed of changes or trends associated with climate change on the properties you oversee?

- ❍ Yes
- ❍ No

Q13 Please identify the changes or trends on these properties that you associate with climate change.

Q14 In light of the information available regarding trends and projections in climate, hydrology, and extreme floods and droughts, please rank the priority in which you would like to see the following metrics developed (1 = highest priority). Add additional variables you would find useful to make management decisions regarding climate change impacts on floodplain properties.

	Priority Rank
	Select Rank (1-10)
Depth and extent of floodplain inundation at different river stages	
Frequency of inundation - how often does a floodplain flood	
Seasonality of inundation	
Duration of inundation - how long does water stay on a floodplain	
Stages associated with low flow events	
Flow velocities on floodplain at different river stages	
Elevation	
Locations with high probability of sedimentation or scour from flood events	
Extent of seep-driven and precipitation-driven ponding on "dry" side of the levee	
Groundwater table associated with low and high flows	
Other	

Q15 Please provide additional feedback that you would like to share regarding the objectives of the survey or specific questions.