The Effects of Recent Flooding Events on Ecological Resources in the Yazoo Backwater Area of Mississippi

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Prepared for:

Board of Mississippi Levee Commissioners

2283 Highway 82 West
Greenville, Mississippi 38701

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EXECUTIVE SUMMARY

I. Introduction

In September of 2019, Pond was engaged by the Board of Mississippi Levee Commissioners (the Board) to evaluate the effects of recent backwater flooding events on various ecological resources within the Yazoo Backwater Area (YBA) of Mississippi. Specifically, Pond reviewed available literature and data to examine several of the observed and potential ecological effects of the YBA continuing without construction and operation of the Yazoo Backwater Pump Project (Pump Project).[1] Pond reviewed scientific literature to assess anticipated outcomes for ecological resources under flood conditions and compiled observational data from within the YBA (or areas comparable to the YBA) to evaluate observed responses of ecological resources to flooding events. Using the literature and observations, Pond inferred how ecological resources may respond to continued backwater flood events or, conversely, how these resources may respond to mitigated flood events associated with the installation and operation of the Pump Project.

II. Ecological Resources Addressed

The YBA hosts a rich variety of ecological resources including wildlife, fisheries, and forests. The YBA contains numerous large tracts of public lands (e.g., wildlife management areas, national wildlife refuges, and national forests), that offer users outdoor recreational activities such as hunting, fishing, boating, birdwatching, camping, hiking, biking, horseback riding, and off-road vehicle use. Privately held properties also offer similar recreation opportunities and include the facilities for cabin rental and hosting a variety of outdoor activities including conservation workshops, conferences, outdoor team-building opportunities, and summer camps. Many of these properties are actively managed to support wildlife and fisheries, sustainable use of forest resources, and public

[1] The Pump Project as used in the Pond study is described in the 2007 Final Supplemental Environmental Impact Statement (EIS) and the Yazoo Backwater Area Reformulation Study Main Report.

outdoor recreation. The recurrent backwater flooding in the YBA directly and indirectly affects these environmental resources.

The four major ecological resources categories examined in this evaluation are: wildlife resources and outdoor recreation (Report A); forest resources (Report B); methylmercury production (Report C); and Asian carp (Report D).[2] These categories were chosen because of their relative importance in ecological health and stability, their role within the natural environment, as well as their importance to for public use, stewardship, and influence on local economy.

II. Summary of Impacts to Ecological Categories

A generalized summary of findings for each resource category is available in the table below. In-depth evaluation of these ecological resources appears in the individual Reports (Reports A-D).

Resource Category	Effects of Flooding	Related Effects	Anticipated Outcome with Reduced Flood Depth & Duration
Wildlife Resources and Outdoor Recreation	- Mortality and displacement. - Reduced recruitment or successful reproduction. - Crowding of wildlife, which leads to inter- and intra-species competition, starvation, forced predation, increased risk of spreading disease (i.e., CWD). - Increased human conflict (i.e., increased vehicle collisions with wildlife, wildlife occupying man-made structures [e.g., houses, barns, and sheds], and damage to levees and roadways from wildlife burrowing or rooting).	- Hunting season closures or modifications. - Damage to and closures of public recreation areas and associated infrastructure. - Potential long-term population effects. - Increased cancellation of bookings of potential users of the public and private lands for recreational uses. - Concern with the unpredictability of hunting season openings/closures (leading to a potential decrease in license sales), and decreased land value. - Spread of invasive feral swine.	- Less wildlife mortality and associated impacts to wildlife populations. - Less displacement of wildlife. - Less crowding of wildlife that leads to competition and the spread of disease. - Less wildlife stranding on patches of high ground or man-made structures, less human-wildlife conflict. - Increased predictability for land management to support wildlife and outdoor recreation use, including repairing damage to infrastructure.
Forest Resources	- Immediate damage and mortality to trees. - Delayed damage and mortality to trees through secondary infections including rot, fungal infections, infestations of wood-boring insects. - Poor health and stress to living trees (i.e., defoliation and reduced root development).	- Reduced timber quality. - Reduced timber prices and sales. - Inability to salvage dead or dying trees. - Increased risk of uprooting, toppling, breakages, and posing a risk to users of public recreation areas. - Decreased land value. - Habitat alteration for forest-dependent species.	- Reduced mortality and flood damage. - Reduced risk of secondary infections and wood-boring insect infestations. - Reduced stress associated with flooding, and potentially increased tree growth. - Increased ability to manage forest resources and establish predictable harvests, and reforestation/ regeneration plans.

[2] Each report was written to be understood individually, resulting in some repetition of background material in the four reports.

Resource Category	Effects of Flooding	Related Effects	Anticipated Outcome with Reduced Flood Depth & Duration
Methylmercury	- Increased methylmercury production (up to 32% during a typical 2-Year flood event).	- Increased methylmercury in the ecosystem available for uptake and bioaccumulation within the food web. - Increased risk to humans eating fish and fish advisories. - Increased risk to wildlife	- Reduced methylmercury production in the YBA. - Reduced associated risks to wildlife and humans.
Asian Carp	- Introduction of Asian carp to new locations (i.e., the spread of an invasive, injurious fish species). - Increased Asian carp competition with native fish and mussels.	- Reduced population, body condition, and biomass of native fishes in waterbodies with Asian carp presence. - Adverse effects to heavily managed sportfish populations and associated recreational opportunities. - Increased risk of Asian carp collisions with recreational boaters and associated bodily harm.	- Reduced risk of continued spread of an invasive, injurious fish species. - Reduced continued introduction of Asian carp into otherwise isolated waterbodies. - Increased ability to limit and control Asian carp spread, and to restore native fisheries.

IV. The Yazoo Backwater Area and Backwater Flooding

This short description of the YBA will assist in setting the context for Pond's study of backwater flooding impacts on ecological resources. In general, unaltered floodplains are connected to adjacent rivers and are subjected to the periodic, often seasonal, exchange of water, nutrients, and organisms through overbank flow. While groundwater and precipitation contribute to the hydrology of floodplains, overbank flow is usually a frequent hydrologic driver within unaltered floodplains. However, as a result of land use changes and man-made flood control measures (e.g., dams, levees, drainage canals, water control structures, etc.), historic floodplains within the Mississippi Alluvial Valley (MAV) – including the YBA – have been separated from their adjacent river systems. The flood control measures perform as intended, to reduce flood damage from Mississippi River flooding. A study of the effect of flooding on natural resources must be conducted in a manner that addresses the existing modified conditions of the floodplain as opposed to the historical conditions.

The YBA of Mississippi is generally bounded by the Mississippi River to the west and bluff hills and the Yazoo River to the east and has been subjected to flooding since time immemorial. However, as with other areas within the MAV, the YBA has been extensively modified to protect the area from overbank flooding from the adjacent Mississippi River. As originally envisioned, the flood control efforts within the YBA included a pumping station which would have allowed surface water trapped on the landward side of the levees, during flood stage on the Mississippi River, to exit the basin and discharge into the Mississippi River. However, the pumping station was never constructed. The existing levee and control structure system protect the YBA from overbank flooding from the Mississippi River; however, when the water control structure (Steele Bayou gate at Hwy 465) is closed, there is no outlet for rivers, streams, and surface waters within the YBA. As a result, surface waters within the YBA begin to “back up” against the existing levee system; resulting in a backwater flood event. Floodwaters within the YBA remain on the landscape until the water level of the Mississippi River recedes and the control structures can be opened to allow the floodwaters trapped behind the levee to escape. Because the backwater flood events are not connected to overbank flooding from the Mississippi River, they do not flow, rise, and fall as would be expected in a natural, connected floodplain system. Rather, the backwater flood events resemble a filling of a bathtub with a closed drain where the water stacks up behind the levee system and creates a stagnant pool. The Steele Bayou Gates may be closed and opened several times during the period of Mississippi River flooding, generally between February and June most years. Floodwaters within the YBA may remain on the landscape for long durations.

The YBA has experienced backwater flooding every year since 2002, except for 2006 and 2012. Backwater flooding events since 2002 have varied in extent and duration, with a record-breaking flood in 2019. The 2019 YBA backwater flooding event exceeded 219 consecutive days with water above 87 feet elevation (NGVD) from January 4 until August 10, 2019 with a peak crest at a record-breaking 98.2 feet on May 23, 2019, which flooded 548,000 acres of the YBA. The YBA again experienced severe backwater flooding in 2020 with flood elevations reaching 96.9 feet on April 23, 2020, flooding approximately 500,000 total acres of land within the YBA. While all backwater flood events likely have some effect on the ecological resources, the extreme nature of the 2019 event (in terms of extent, depth, and duration) led to readily observable adverse effects. As a result, the Pond study focused primarily on effects of this event. This study recognized that (1) information on long term impacts of the 2019 flood is not yet available, and (2) the effects of each flood event may differ in intensity, but the resource categories studied would see adverse consequences if subject to prolonged and repeat flooding.

Individual Reports

Report A - The Effects of Recent Flooding Events on Wildlife Resources and Outdoor Recreation in the Yazoo Backwater Area of Mississippi

Report B - Effects of Flooding on Bottomland Hardwoods in the Yazoo Backwater Area of Mississippi

Report C - Review of Methylmercury Production in Backwater Floodplains and Implications for the Yazoo Backwater Area of Mississippi

Report D - Invasive Asian Carp in the Yazoo Backwater Area of Mississippi

Report A

The Effects of Recent Flooding Events on Wildlife Resources and Outdoor Recreation in the Yazoo Backwater Area of Mississippi

Report A

The Effects of Recent Flooding Events on Wildlife Resources and Outdoor Recreation in the Yazoo Backwater Area of Mississippi

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Abstract

The Yazoo Backwater Area (YBA) of Mississippi has numerous large tracts of public lands that offer users outdoor recreational activities such as hunting, fishing, boating, birdwatching, camping, hiking, biking, horseback riding, and off-road vehicle use. Several privately held properties also offer similar recreation opportunities and include the facilities for cabin rental and hosting a variety of outdoor activities including conservation workshops, conferences, and summer camps. These lands, plus other properties that have been converted from agriculture to forests or wetlands, are actively managed to support wildlife through habitat improvement projects that attempt to improve wildlife populations. Backwater flooding events, like the one experienced in 2019 and currently being experienced in 2020, have resulted in devastating adverse effects to the wildlife resources within the YBA. The depth, extent, and duration of the 2019 flood resulted in direct mortality, displacement and crowding of wildlife seeking refuge on high ground – the levee system, roadbeds, and manmade structures. This situation gave rise to forced predation, interspecies and intraspecies competition, and increased the risk of contagious disease transmission (e.g., chronic wasting disease [CWD]), wildlife damage, and wildlife-human interactions. This resulted in a depletion of wildlife food resources, emaciation, starvation, heat exposure, and death. Raccoons created burrows in the levee system to avoid the heat exposure, consumed turtles while they laid eggs, consumed eggs, and presumably fed on newborn deer fawns. Turkeys starved in the treetops while waiting for floodwaters to recede, and deer died of heat exposure and starvation at designated emergency feeding stations. It is estimated that little-to-no successful reproduction occurred for deer, turkeys, turtles, alligators, and ground-nesting birds in severely affected areas. Large groups of feral swine moved into previously unoccupied areas, aggressively defending their occupied lands, and rooted along the levee structures in search of food, damaging the integrity of the levee system. Hunting seasons were closed or modified across the YBA. Private and public recreation lands were flooded with extensive damage to buildings, sheds, barns, roadways, trail systems, culverts, water and septic systems, and wildlife and habitat management activities could not take place. Potential users of these private or public lands grow increasingly concerned about future trips being canceled as a result of the continued backwater flooding in the YBA, which may affect the economy through a decrease in hunting license sales, decreased use of public lands the associated user fees, and cancelled bookings of conferences, summer camps, weddings, and hunts that are offered at these recreational lands. In addition, land value within the YBA may continue to decline as potential buyers are discouraged from buying properties due to the recent flooding and its effects on the natural resources within. The implementation of the proposed pump program is intended to limit the severity of flooding events. This limitation of extent, depth, and duration should allow for fewer catastrophic events and reduced impacts to wildlife resources and related activities. In addition, the pump system should result in a level of predictability that allows for better management of wildlife resources, public lands, private lands, and secures recreational opportunities within the YBA.

Introduction

The Yazoo Backwater Area (YBA) of Mississippi hosts a diversity of terrestrial and aquatic wildlife including mammals, birds, reptiles, and amphibians. Many of these species are valuable wildlife resources and are managed for consumptive use by the public. The YBA contains numerous large tracts of public lands (e.g., wildlife management areas [WMAs], national wildlife refuges [NWR], national forests [NF]), as well as privately-owned lands that support wildlife resources and provide outdoor recreational opportunities to the public and private users of those lands. Many of these lands are managed specifically to provide suitable habitat (i.e., food, water, cover, and space) for a variety of wildlife species, while others are managed for a combination of outdoor recreation, wildlife habitat, and forestry. This report outlines the existing wildlife resources and recreational lands within the YBA and addresses the extensive adverse effects to wildlife resources observed during and following the severe backwater flood event in 2019.

Existing Wildlife Resources, Recreation Areas, and Hunting Opportunities in the Yazoo Backwater Area

Wildlife within the YBA are diverse and too numerous to name but include a variety of mammals; various birds including waterfowl, wading birds, birds of prey, and neotropical migrants; numerous reptiles and amphibians; fish; and invertebrates. These species include white-tailed deer (*Odocoileus virginianus*), Louisiana black bear (*Ursus americanus luteolus*), American mink (*Neovison vison*), Virginia opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), American alligator (*Alligator mississippiensis*), eastern wild turkey (*Meleagris galloparvo sylvestris*), and numerous others. These wildlife species are valued resources and can be enjoyed from several public and private lands within the YBA.

According to the 1982 Yazoo Area Pump Project Final Environmental Impact Statement (EIS) and the Yazoo Backwater Area Reformulation Study Main Report (USACE, 2007), public areas within the YBA include Delta NF, Yazoo NWF, Issaquena County Game Management Area, Twin Oaks Mitigation Area, Mahannah Mitigation Area, Panther Swamp NWR, and Lake George WMA. Other public lands in the YBA include Phil Bryant WMA, Sunflower WMA, Twin Oaks WMA, and Howard Miller WMA. These lands offer outdoor recreation opportunities and access to hunting, fishing, camping, bird watching, wildlife observations, boating, and trails for hiking, biking, horseback riding, all-terrain vehicle (ATV) riding, and other activities.

The abundance of public lands within the YBA offers numerous opportunities for the public to access the outdoors and the wildlife resources within. In addition to the public lands, hunting and outdoor recreation activities are available on private lands as well. These can include small private hunting clubs or leases, or larger commercial operations like Tara Wildlife, that offer hunting, cabin rentals, summer camps, conferences, and other outdoor activities.

Existing Yazoo Backwater Area Levee Systems and Backwater Flooding

Levees, Channelization, and Water Control

In general, unaltered floodplains are connected to adjacent rivers and are subjected to the periodic, often seasonal, exchange of water, nutrients, and organisms through overbank flow. While groundwater and precipitation contribute to the hydrology of floodplains, overbank flow is usually a frequent hydrologic driver within unaltered floodplains. However, as a result of land use changes and man-made flood control measures (e.g., dams, levees, drainage canals, water control structures, etc.), historic floodplains within the Mississippi Alluvial Valley (MAV) – including the YBA – have been separated from their adjacent river systems. These alterations were designed to reduce flood damage from Mississippi River flooding and perform as intended. A study of the effect of flooding on natural resources must be conducted in a manner that addresses the existing modified conditions of the floodplain as opposed to the historical conditions.

The YBA of Mississippi is generally bounded by the Mississippi River to the west and bluff hills and the Yazoo River to the east and has been subjected to flooding since time immemorial. However, as with other areas within the MAV, the YBA has been extensively modified to protect the area from overbank flooding from the adjacent Mississippi River. As originally envisioned, the flood control efforts within the YBA included a pumping station which would have allowed surface water trapped on the landward side of the levees, during flood stage on the Mississippi River, to exit the basin and discharge into the Mississippi River. However, the pumping station was never constructed. The existing levee and control structure system protects the YBA from overbank flooding from the Mississippi River; however, when the water control structures (Steele Bayou Control Structure and Little Sunflower Control Structure) are closed, there is no outlet for rivers, streams, and surface waters within the YBA. As a result, surface waters within the YBA begin to “back up” against the existing levee system; resulting in a backwater flood event.

Floodwaters within the YBA remain on the landscape until the water level of the Mississippi River recedes and the control structures can be opened to allow the floodwaters trapped behind the levee to escape.

Because the backwater flood events are not connected to overbank flooding from the Mississippi River, they do not flow, rise, and fall as would be expected in a natural, connected floodplain system. Rather, the backwater flood events resemble a filling of a bathtub with a closed drain where the water stacks up behind the levee system and creates a stagnant pool. The Steele Bayou Gates may be closed and opened several times during the period of Mississippi River flooding, generally between February and June most years. Floodwaters within the YBA may remain on the landscape for long durations. The existing levee system and water control structure system within the YBA have resulted in flood waters that no longer rise and fall with the levels of the adjacent river systems. Even after the Mississippi River water levels recede and the gate structure is opened, the recession of floodwaters in the YBA is a relatively slow process, where flows are constrained at a single point of exit (i.e., the Steele Bayou Control Structure). In summary, backwater flooding within the YBA do not reflect the conditions experienced in a natural, connected floodplain where floodwaters rise and fall with the adjacent river system.

Backwater Flooding Events in the YBA

Backwater flooding events within the YBA have serious implications regarding the populations and health of various wildlife resources. The YBA has experienced backwater flooding every year since 2002, except for 2006 and 2012. Backwater flooding events since 2002 have varied in extent and duration, with a record-breaking flood in 2019. The 2019 YBA backwater flooding event exceeded 219 consecutive days with water above 87 feet elevation (NGVD) from January 4 until August 10, 2019 with a peak crest at a record-breaking 98.2 feet on May 23, 2020, which flooded 548,000 acres of the YBA (USACE 2020; Quintana-Ashwell et al. 2019). As of this writing, the YBA is again experiencing backwater flooding in 2020 with flood elevations reaching 96.9 feet on April 23, 2020, flooding approximately 500,000 total acres of land within the YBA.

Effect of Flooding on Wildlife Resources

Under some conditions, periodic flooding can result in post-flood conditions that may benefit wildlife that are resistant to flooding, semi-aquatic, or are capable of rapid recolonization of habitats after floodwaters recede (Ballinger et al. 2005, Lada et al. 2007, Wuczynski and Jakubiec 2013). However, the act of flooding itself has been documented to result in severe losses in terrestrial animals (Anderson et al. 2000, Williams et al. 2001, Jacob 2003, Thibault and Brown 2008, Wuczynski and Jakubiec 2013), where adverse effects such as drowning, increased vulnerability to predators, reduced reproductive success, and depletion of food resources can have detrimental consequences to wildlife populations (Bodmer 1990, MacDonald-Beyers and Labisky 2005, Bodmer et al. 2018). The effects of flooding on terrestrial wildlife vary according to extent, duration, and timing of flooding, depth of floodwaters, and mobility of individual species (Jones et al. 2019).

Less mobile terrestrial species like small mammals may suffer drastic population declines following a flooding event (Anderson et al. 2000, Chamberlain and Leopold 2003). In addition, reptiles, and ground-nesting birds may experience low reproductive success or a total failure of recruitment from nest or nest sites being inundated with floodwaters (Kushlan and Jacobsen 1990, Janzen 1994, Sanders and Maloney 2002, Soriano-Redondo 2016). There is also evidence that episodic extreme weather events can have long-term ecological consequences with potential to transform ecosystems (Gutschick and Bassirrirad 2003, Maron et al. 2015, Soriano-Redondo et al. 2016). For instance, flooding regime can influence the composition of bottomland vegetative communities, and alterations of flood timing and severity can alter habitat quality (Menges 1986, Weller 1987, Cosgriff et al. 2007, Kryzwicka 2015).

Wuczynski and Jakubiec (2013) observed that wildlife mortality in floods are generally proportionate to their local abundance. The authors concluded that the magnitude of mortality (a direct impact) for mammals in a severe flood was determined by the size of the inundated area (i.e., extent of flooding), whereas depth, duration, and timing of flooding was a more important factor in indirect impacts such as declining health and lack of reproduction for wildlife species. The extent of flooding had the largest impact on direct mortality, and floods that extended into the summer season resulted in severe losses to young of year and negatively affected recruitment of wildlife that were stranded on patches of high ground or forced into suboptimal habitats for long durations.

Temporal displacement of wildlife may impose serious energetic costs, and stress from severe flooding events may contribute to indirect mortality factors (Morgan et al. 1995, Stein et al. 2010, Soriano-Redondo et al. 2016, Jones et al. 2019). Short-term energy loss may be reversible if animals can return to high-quality habitat when floodwaters recede; however, animals displaced by flooding and forced into suboptimal habitat for long durations spend more energy in search of food to meet the energy requirements for survival, travel, reproduction, and rearing of young (Norberg 1977, Daan et al. 1996, Soriano-Redondo et al. 2016).

Because many larger-bodied or recreationally important species are the focus of observations, the effects of flooding on species like white-tailed deer, wild turkey, or black bear are heavily documented, particularly in flooding events that remain on the landscape for long durations and/or extend into the reproductive seasons. In general, adult black bears fare well during floods, but cub mortality and subsequent decline in recruitment has been observed when natal dens have been flooded.

In general, white-tailed deer are concentrated and forced to gather and feed in upland areas during times of inundation, which can potentially deplete food resources (Loveless and Ligas 1959, MacDonald-Beyers and Labisky 2005). A study of deer on 61 large tracts of land throughout the Mississippi Alluvial Valley (MAV) between Baton Rouge, Louisiana and Helena, Mississippi has documented the immediate and delayed effects of flooding on deer (Jones et al. 2019). The study concluded that floods in late spring and summer resulted in fawn mortality, reduced fawn survival, and ultimately reduced recruitment. When subjected to flooding, gestating does suffered from heat stress and a lack of nutrition which resulted in poor body condition and lowered lactation rates. Immobile fawns could not evade rising floodwaters and drowned. Mobile fawns consumed less milk when nursing and were likely visible to predators and scavengers.

In response to flooding, turkeys have been observed to spend prolonged periods in trees (Dalke et al. 1946) and, in some cases, complete reproductive failure was observed (Kimmel and Zwank 1985, Zwank et al. 1988, Cobb et al. 1993, Cobb and Doerr 1997). In the Atchafalaya basin of Louisiana, five turkeys were captured, fitted with a global positioning system (GPS) device and a very high frequency (VHF) transmitter and released prior to a catastrophic flooding event (Chamberlain et al. 2013). Within three days of the initiation of the flood, one turkey was killed by a bobcat (*Lynx rufus*). By day four all tagged turkeys were confined to trees to avoid floodwaters. Of the five tagged turkeys, one survived long enough to find high ground and survive the flood, whereas the remaining individuals died within 31 days of the onset of flooding. The tracked movement patterns of the tagged turkeys exhibited periodic movements throughout the landscape, moving from tree to tree in search of dry ground until ultimately succumbing to starvation. Turkeys readily take to the trees during flooding but are not adapted to prolonged living and foraging in the tree canopy (Cobb et al. 1993, Chamberlain et al. 2013). The starvation-based mortality of breeding-age adults and a total lack of successful recruitment has serious implications for the status of turkey populations (Cobb and Doerr 1997) and may result in extirpation of localized populations over a short period (Chamberlain et al. 2013). These effects on wildlife are expected to occur within floodplains experiencing extensive floods that remain on the landscape for long durations or extend into the reproductive or young-rearing seasons.

Effect of Backwater Flooding on Wildlife Resources in the Yazoo Backwater Area

Peer-reviewed studies have not examined the extent of wildlife mortality from the 2019 floods or flooding in 2020, and indirect or long-term effects may not be observed for several years to come. However, several observations from biologists have been recorded regarding the effects of the 2019 flooding on wildlife mortality, health, and reproduction, as well as the impact on hunting and outdoor recreation (MDWFP 2019, Tomlinson 2020). The information described below is consistent with what would be expected based on the previously documented effects of flooding on wildlife within the MAV.

Displacement, Crowding, Competition, and Predation Observed by the Mississippi Department of Wildlife, Fisheries and Parks

Within the YBA, there is a vast network of rivers, stream, canals, and other waterbodies whose water levels rise during a backwater flooding event. The local topography between these networks of waterbodies may create isolated patches of high ground as floodwaters rise. Generally, wildlife will seek high ground by traveling along the front of the advancing floodwaters until high ground is reached. While some individuals are fortunate enough to reach high ground on the landward side of the flood, many others become trapped on islands of high ground located within the rising floodwaters. As the extent and depth of floodwaters increase, many of the patches of previously dry high ground are eventually flooded as well, and wildlife must risk drowning in order to cross floodwaters in search of new high ground. In many parts of the YBA, the most consistently dry high ground available is that of the existing levee system.

In severe backwater flooding events in the YBA, wildlife congregates on the levee system, which results in crowding, interspecies and intraspecies competition for food resources, and predation. The following information was presented by the Mississippi Department of Wildlife Fisheries and Parks (MDWFP) for the U.S. Environmental Protection Agency (EPA) listening session on October 21, 2019 (McKinley 2019) regarding the 2019 record-breaking backwater flood in the YBA.

The MDWFP conducted weekly surveys between mid-June and early August 2019 for wildlife along a 26-mile route of the YBA levee systems beginning at the intersection of Lee Road and State Highway 465 and ending at the Magna Vista. These surveys included live counts of all observed wildlife species, mortality counts, opportunistic necropsies of dead wildlife, and radio telemetry to locate tagged wildlife.

The MDWFP observed groups that contained around 1,200 deer congregated on the YBA levee system, where floodwaters were present on both the riverside and the landside of the levee. When foliage emerged in the spring, deer quickly depleted the limited food resources on and surrounding the levee, where a clear browse-line was evident on trees and shrubs (McKinley 2019).

As summer began, starvation and emaciation continued to be an issue. Along with limited food resources, deer were subject to additional stress during the high summer temperatures. The levee systems are maintained and clear of woody vegetation (trees), and sources of shade or shelter from the elements on dry ground or in shallow water was limited. Patches of shade all held a variety of animals seeking shelter and did not provide seclusion for does birthing fawns. In 2019, the MDWFP estimated fawn survival rate to be around five percent. During the MDWFP surveys, a total of 503 deer mortalities were recorded on the levee between mid-June and early August 2019 (McKinley 2019). These deaths are attributed to either direct mortality, starvation, or stress (i.e., heat exhaustion). These carcasses were within direct line of sight along the narrow, 26-mile levee survey corridor and within a time period of less than two months. This was not considered a comprehensive survey of deer mortality within the YBA; therefore, the expected total mortality across the entire YBA is expected to be much higher than what was easily observed on the levee system.

The spread of chronic wasting disease (CWD) during flooding events within the YBA also is a concern. The first known occurrence of CWD in Mississippi was in 2018 in Issaquena County (i.e., within the YBA; MDWFP 2019). As of March 2019, Mississippi had 19 confirmed cases of CWD-positive deer (MDWFP 2019). CWD has been detected in six counties in Mississippi, including several within the YBA (i.e., Issaquena, Panola, and Tallahatchie). CWD is a contagious neurological disease affecting deer and is always fatal. The disease belongs to a group of diseases known as transmissible spongiform encephalopathies (TSEs), and causes a spongy degeneration of the brains, which results in abnormal behavior, loss of body function and eventually death (CDC 2019). There is no current vaccine or cure.

The transmission vector of CWD is contact with prions (i.e. proteins) that contain the disease (CDC 2019). These prions are found in body fluids like feces, saliva, blood, and urine, and can remain in the environment (e.g., soil and plants) for long periods of time (CDC 2019). Because of the method of transmission of the disease, deer are more likely to be exposed to CWD prions when in crowded conditions, where exposure to body fluids is more likely. These conditions include animals in enclosures, congregated around a food source (i.e., deer feeder), and when forced into close proximity (e.g., restricted to patches of high grounds during flooding events). Following the discovery of CWD in Mississippi, the MDWFP established CWD managements zones and banned supplemental feeding within those zones to reduce concentrations of deer (MDWFP 2019).

The crowded conditions of deer stranded on the levees during the 2019 flood resulted in conditions favorable to the spread of CWD. Deer were concentrated in areas which resulted in increased exposure to prions present in urine, feces, and saliva. The MDWFP responded to the widespread death, starvation, and emaciation of white-tailed deer stranded on levees during the 2019 floods by establishing a supplemental feeding program and issuing temporary feeding permits to local landowners, further concentrating deer around feeders and increasing the risk of spreading CWD. During the opportunistic necropsies of deer carcasses in 2019, there were no positive test results for chronic wasting disease (CWD). These necropsies were performed only on easily accessible carcasses when qualified personnel were present and exact number examined is unknown). These opportunistic necropsies were not intended to signify a formalized study to estimate the occurrence, prevalence, or distribution of CWD within the YBA.

Other observed mortalities during the 2019 levee surveys included raccoons. Dead raccoons were observed along the levee or in surrounding waters during the levee surveys. Surviving racoons were found living in excavated holes within the levee for refuge from other animals and the summer heat, exhibited aberrant behavior, and were generally unaware of human presence until surveyors were within feet of the animal. The surviving and starving raccoons were observed having a direct impact on other species, particularly turtles. Raccoons were observed eating female turtles as they attempted to lay eggs on the levee (McKinley 2019), which was the only high ground available for nesting. Turtle eggs were readily consumed by raccoons as they were being laid. Estimates of dead turtles observed on the levee were in the thousands. As turtle nesting ceased, racoons continued to starve, died, or scavenge for other consumable items. In addition, the hungry raccoons likely fed on newborn fawns (McKinley 2020).

Wild turkeys can temporarily survive floods by staying in treetops and feeding on emerging buds and bugs; however, turkeys cannot survive in treetops for months, and eventually succumbed to starvation during the 2019 flood. Turkeys took to the tress during flooding but ultimately starved in the treetops and died as seen in previous studies (Cobb et al. 1993, Chamberlain et al. 2013). The lack of food resources, the lack dry ground for foraging or nesting, and constant pressure from predators and omnivorous wildlife resulted in high turkey mortality and an assumed total lack of reproduction in 2019 (McKinley 2019). The high mortality of breeding-age adults and a total lack of successful recruitment may result in extirpation of localized populations (Cobb and Doerr 1997, Chamberlain et al. 2013) if severe flooding continues.

The MDWFP presume that there was no reproductive success for racoons and turtles, little-to-no nest success for alligators and ground-nesting birds including wild turkey, and an assumed high mortality to all small animals (e.g., cotton rats) as a direct result of the flooding of 2019 (McKinley 2019). Adult American alligators fared well during the 2019 flood, but nests may have been raided by raccoons. During the wildlife surveys, three black bears were fitted with radio collars and subsequently located with telemetry. All three bears were able to move out of the flood zone and survived the 2019 floods (McKinley 2019).

Other Wildlife Observations in the YBA in Relation to Backwater Flooding

Additional observations (Tomlinson 2020) took place at Tara Wildlife, a private tract of land under intensive management for wildlife habitat, hunting, forestry, and recreation. Tara Wildlife covers approximately 9,000 acres in the Eagle Bend community and includes portions of the Mississippi River Batture and the YBA. Tara's mission is to manage its natural resources in an ecologically and economically sustainable manner while promoting conservation awareness and the wise use of natural resources within a framework of both consumptive and non-consumptive opportunities. Tara property includes a conference center that hosts corporate retreats, business meetings, team building seminars, and conservation workshops. Recreation on Tara property includes nature trails and biking trials, canoeing, birding, photography, skeet shooting range, and hunting and fishing. In addition, Tara has a children's summer camp program, outdoor and archery camps, birding weekends/tours, and hosts the Mississippi River Nature Weekend annual festival.

The observations on Tara Wildlife closely resembled those observed by the MDWFP levee surveys, where deer were observed dead, starving, or exposed to heat. There were some accounts of adult deer dying at one of the emergency feeding stations approved by MDWFP, and a wild turkey falling out of a tree after succumbing to what was presumed as starvation. Other observations included dead and starving small mammals, numerous decomposing animal carcasses, and a general absence of ground-nesting and understory-dwelling species of neotropical migratory birds (Tomlinson 2020). The floodwaters resulted in wildlife crowding on higher ground or in trees, where interactions between species are essentially forced and unnatural (i.e., birds, reptiles, and mammals all seeking refuge within the same tree).

Because Tara is managed for the sustainable use of its natural resources, biologists responded to the 2019 flood by installing 25 trail cameras at strategic locations on Tara property in October and November of 2019 (Tomlinson 2020). A total of 4,987 images captured whitetail deer and were assessed to examine condition of the deer, sex ratio, and fawn presence. In general, deer were in poor body condition. Individuals showed limited mobility between locations, which is likely the result of poor physiology and energetics. The buck to doe sex ratio slightly favored bucks at 52% to 48%. Poor antler growth in bucks was anticipated for 2019 because of the obvious signs of starvation, poor nutrition, and lack of resources. Within the camera images processed, 158 bucks were readily identifiable with distinct characteristics to readily recognize individuals. Of the 158 bucks, few bucks (14 in October; 29 in November) would have met Tara's current harvest requirements for antlered bucks. The adult population for the white-tailed deer herd on Tara wildlife properties is estimated to have declined by 70%, which is attributed to mortalities and reduced reproduction during the 2019 flood (Tomlinson 2020).

As predicted, fawn production and survival on Tara property was low. Presumably, this is attributed to the lack of nutrition and poor health of does while gestating during the 2019 flood conditions, as well as direct predation on fawns. Out of the 4,987 images, only 12 fawns were counted in October with a 42% decrease in sightings in November, when only seven fawns were observed. One of these images was a fawn being carried in the mouth of a coyote. Original estimates of fawn survival were between five and seven percent, but these estimates were conservative and early in the fawning season and survival is likely lower than these estimates. In conclusion, recruitment during 2019 was low and can be attributed to a combination of high adult mortality, low availability of suitable habitat, poor habitat quality, poor nutrition for gestating does, low fawn production, and low fawn survival.

The high mortality and low recruitment during 2019 have resulted in a deer population that is below the carrying capacity of the managed wildlife habitats at Tara (Tomlinson 2020). To alleviate pressure on deer populations following the 2019 flood, Tara Wildlife canceled all remaining deer hunts for the 2018-2019 season, canceled hunting for the 2019-2020 season, and will only allow one month of hunting for the 2020-2021 season with strict harvest limitations (Tomlinson 2020). Future studies will determine whether the 2019 floods resulted in long term or irreversible damage to deer health.

It is possible that wildlife species will return to their pre-2019 biological and physiological potential if habitats can quickly recover and stabilize and future catastrophic flooding does not occur in years to come. However, episodic flooding of vast extents and long durations have been documented to have long-term negative consequences on wildlife populations (Bodmer 1990, Kushlan and Jacobsen 1990, Janzen 1994, Anderson et al. 2000, Williams et al. 2001, Sanders and Maloney 2002, Chamberlain and Leopold 2003, Gutschick and Bassirrirad 2003, Jacob 2003, MacDonald-Beyers and Labisky 2005, Thibault and Brown 2008, Wuczynski and Jakubiec 2013, Maron et al. 2015, Soriano-Redondo et al. 2016, Bodmer et al. 2018). Regardless, there is no doubt that the impacts of the 2019 flood have been severe in the short term.

Feral Swine Presence, Damage, and Potential Issues within the Yazoo Backwater Area

Prior to 2019 feral swine (*Sus scrofa*) sightings on Tara Wildlife property were a rare occurrence and were generally limited to a hunter observing a few individuals every couple of years during other hunting activities (Tomlinson 2020). However, following the 2019 flood, feral swine in groups of 30 to 40 individuals became a common occurrence and occasionally posed a threat to human safety (Tomlinson 2020). The extent of the floodwaters likely pushed groups onto patches of high ground, including the levee system that acted as a corridor, facilitating the movement of swine into areas not previously occupied by the invasive species. Survey crews on Tara Wildlife properties were charged by feral swine while marking timber or assessing wildlife habitat on areas that were no longer inundated. This reaction is presumed to be the feral swine aggressively defending available high ground for space and food resources.

Although not specifically addressed in the previously mentioned MDWFP presentation to EPA, the experiences regarding feral swine at Tara Wildlife and other properties should be addressed when considering the effect of flooding on wildlife. Feral swine are opportunistic omnivores and forage in several ways including above-ground browsing and grazing on leaves, fronds and stems of vegetation, foraging on-ground for fruits, nuts, fungi, small animals, and carrion, as well as below-ground rooting for rhizomes, tubers, bulbs, fungi, and fossorial animals (USDA 2019).

Feral swine directly compete for food resources with native species like bear, deer, and turkey (USDA 2016b, USDA 2016c). Feral swine have been documented to have a 50% dietary overlap with white-tailed deer (MSU 2019). In addition to competing for food resources, swine will often deter native wildlife from entering or foraging in an area and have been seen aggressively excluding deer from feeding in localized areas (USDA 2016c, USDA 2019).

Feral swine also have a direct effect on native wildlife through predation. With feral swine being opportunistic omnivores, they will eat whatever potential food items are available, including nests, eggs, and young of ground nesting birds like northern bobwhite (*Colinus virginianus*), wild turkey, and ruffed grouse (*Bonasa umbellus*), and have been documented killing and eating deer fawns, and pursuing small mammals and reptiles (Timmons et al. 2011, USDA 2016c, USDA 2019). In flood conditions where all wildlife must congregate on high ground, there is limited habitat for foraging, nesting, and young rearing for native wildlife. In the case where flooding extends into the nesting season for reptiles (e.g., turtles, snakes, and lizards) and ground-dwelling birds (e.g., turkey and quail) and the birthing and rearing season for deer, the risk of feral swine consuming the eggs or young of native wildlife increases.

The rooting, trampling, and wallowing behavior of feral swine can destroy vegetation and crops, compact soils, and degrade and damage structures such as roadbeds and levees (USDA 2016a, USDA 2016b). In relation to the flooding experienced in the YBA, wildlife has sought refuge on high ground that were not flooded, which are typically roadbeds and levees. With levee systems being the only available dry habitat, feral swine damage to YBA levee systems was observed across several levees during the 2019 flooding (Walsh 2019). In addition, swine damage to levees has been observed by the Board of Mississippi Levee Commissioners (Mississippi Levee Board) personnel during various flood events since 2006 (Hamrick 2011). Damage and soil disturbance to levees can have serious implications when floodwaters rise and put stress on the levee systems. Pig rooting and wallowing not only creates holes and loosens soils but also uproots vegetation and turf that stabilizes that soil (Hamrick 2011) during precipitation, regular streamflow, or rising and falling floodwaters.

Effect of Flooding on Human-Wildlife Conflict

During flood events, wildlife will seek high ground and shelter to avoid rising floodwaters. As previously mentioned, higher ground in the area typically consists of roadbeds and levees, but also includes man-made structures such as porches and decks of houses, barns, sheds, businesses and other buildings that are sought by various animals (Coblentz 2011, Hamrick and Strickland 2019). Animals attracted to roadbeds pose risks to human safety through increased risk of vehicle collision, especially at night. According to a report released by the Mississippi State University (MSU) Extension Service (Hamrick and Strickland 2019) the 2019 YBA flooding resulted in an observable increase in wildlife-vehicle collisions by May 24, 2019.

Other risks to human safety include stranded wildlife on porches, decks, and yards that may become defensive or aggressive if approached. This includes raccoons, opossums, bears, alligators, venomous snakes, and fire ants (Coblentz 2011, Hamrick and Strickland 2019). In addition, rodents may find their way into homes, nest, and may introduce fleas to houses if infestations are large enough (Hamrick and Strickland 2019). A surge in mosquito populations typically occurs when floodwaters recede, where stagnant pools and puddles of water are formed on the landscape or fill various containers, debris, and other rubbish strewn across the landscape following the flood (Hamrick and Strickland 2019).

Effect of Flooding on Hunting Opportunities and Outdoor Recreation

Effects of Flooding on Public Recreation Areas and Hunting Seasons

The 2019 YBA flood affected seven state WMAs: Phil Bryant WMA, Mahannah WMA, Lake George WMA, Sunflower WMA, Twin Oaks WMA, Howard Miller WMA, and Shipland WMA. Shipland WMA is located on the Mississippi River side of the levee (i.e., riverside) and the remaining six WMAs are located landside of the levee. The 2019 floodwaters prevented any habitat management or habitat enhancement projects on all seven of the WMAs. Five of the WMAs had structures (offices, barns, equipment sheds, etc.) flooded (McKinley 2019).

Similar to State lands, Federal lands also have been partially or fully closed to the public resulting from backwater flooding. Temporary closures resulting from flooding have occurred periodically in the Delta NF, with notable public access closures occurring in 2016, 2018, and 2019 (USDA FS 2020). Even after public access resumed following the recession of floodwaters, many access roads and trails remained closed to vehicular traffic because roads and trails were damaged and in need of repair. In addition, the U.S. Forest Service urged users of the public lands to be cognizant of where they park vehicles, and to constantly survey the tree canopy during recreation because flooding resulted in dense patches of dead or damaged trees that have a high risk of falling (USDA FS 2019).

In addition to closures of public State and Federal lands, the MDWFP closed hunting within several Mississippi Delta areas in 2019. All hunting, except for waterfowl, was closed in certain management zones and WMAs depending on flood stage at different gages along the YBA levee system. In addition, there have been hunting season and bag limit revisions for the 2020 year to alleviate additional pressure on wildlife populations. Mississippi has a hunting or trapping season for certain regulated wildlife that is open in every month of the year, although seasons for most species is between September and April. This ranges from spring squirrel and turkey seasons to the fall and winter deer, rabbit, dove, quail, and waterfowl seasons. Although the 2019 floods occurred in the spring and extended into the summer, the obvious adverse effects on numerous game species resulted in hunting season closures into the fall and winter.

Effects of Flooding on Outdoor Businesses, the Future of Outdoor Recreation, and Land Value

The effects of the 2019 YBA flood on local economics have been addressed by U.S. Department of Agriculture – Farm Service Agency, U.S. Army Corps of Engineers, Mississippi Emergency Management Agency, and MSU Extension, which focuses on agriculture and residential costs and may not capture the full costs (Quintana-Ashwell et al. 2020). The flooding experienced in the last decade has adversely effected business entities such as Tara Wildlife. Continued or recurring extreme flooding events, such as was experienced in 2019, may threaten the survival of privately-owned outdoor recreation areas. This report summarizes effects on certain businesses and public use areas but does not attempt to present a comprehensive quantitative study of economic losses.

In 2019 Tara Wildlife estimated a loss of approximately 1.2 million dollars in gross revenue, resulting from the cancellations and inability to host hunts, summer camps, archery lessons, conservation workshops, conferences, birding and outdoor weekends, weddings, and cabin rentals (Tomlinson 2020). In addition, the flooding of 2019 resulted in damaged buildings and infrastructure including roads, culverts, trails, water supply, and septic systems. The repair of damages further increased the economic loss to Tara Wildlife property.

Wildlife conservation is also a concern, both at Tara Wildlife and the Mississippi Delta area as a whole (Tomlinson 2020). Over the last few decades Mississippi landowners have been encouraged to partake in federal and state financial incentives or assistance programs in favor of reforestation and converting agricultural floodplains to forests. These programs include the Mississippi Wetland Reserve Program (WRP) / Wetland Reserve Easement (WRE) Program and Environmental Quality Incentives Program (EQIP) through U.S. Department of Agriculture and the Reforestation Tax Credit through the Mississippi Forestry Commission. This increases the number of forested tracts, forested wetlands, and overall bottomland hardwood habitat within the YBA. Tara Wildlife's conservation efforts, and other efforts from private landowners, state- and federally- managed properties across the YBA have encouraged the creation and enhancement of wildlife habitats, ultimately attracting and supporting more wildlife. However, attracting additional wildlife to areas that are experiencing severe flooding, like the YBA, may be counterproductive. For instance, Tara and the MDWFP have expended vast resources to enhance the wild turkey population within the YBA since 2008, but those efforts are for naught when backwater flooding events result in direct mortality, reduced poult production, or as in 2019, a complete loss of cohort (McKinley 2020, Tomlinson 2020).

Although the flooding of 2019 was devastating to the wildlife, buildings, and infrastructure at private and public recreation lands, the future economic implications and land value is a concern if backwater

flooding continues in its currently experienced extent and duration (Cooke 2020, Tomlinson 2020). For example, there is currently a large quantity of private lands, leases, and hunting club equity memberships for sale within the YBA; however, there are virtually no sales (Cooke 2020, Tomlinson 2020). Current landowners are attempting to sell the land that they cannot predictably use for recreation, harvesting, or resource management, and prospective buyers are not interested in lands subject to the current level of backwater flood events. As a result, land value across the YBA is expected to decline (Cooke 2020, Tomlinson 2020).
Another primary concern is that potential visitors or hunters will be (and currently are) deterred from planning outdoor recreation on any property (public or private) within the YBA. Backwater flooding may deter people from booking cabins, booking hunts, scheduling conferences, summer camps, etc. Hunters have already been deterred from booking hunts in the YBA because of the long-term risk of cancellation due to flooding, as well as a growing concern for deer infected with CWD (Tomlinson 2020). This concern has now been exacerbated due to the perceived risk that scheduled plans or booked trips could be cancelled due to floodwaters remaining on the landscape for over one-third of a year, as happened in 2019 and again in 2020. In addition, Some hunters have indicated that they plan to hunt in other areas, other states, or not to buy a hunting license at all for Mississippi, which will further harm the economy and reduce the monies used by the state to manage wildlife resources (Tomlinson 2020). Please note that COVID-19 was not a topic of concern during the initial preparation of this report and the observations discussed herein predate the current pandemic. However, the pandemic is expected to further reduce the number of visitors to the public lands and private outdoor recreation areas within the YBA.

Potential Effects of Proposed Pump Installation and Operation within the YBA

The pump operation, as proposed in the Yazoo Area Pump Project EIS, is designed to limit the extent, depth, and duration of backwater flood events within the YBA and to prevent extreme flooding events such as experienced during 2019. Although impossible to precisely determine the effects of pump operation on wildlife resources and outdoor recreation, the following discussion addresses the anticipated benefits that may result from limiting the extent, depth, and duration of backwater flooding events in the YBA. Construction and operation of the proposed pumps would improve predictability of potential flood coverage, severity, and duration within the YBA. This predictability would allow for better management of wildlife resources, as well as better management and use of the public and private lands supporting those resources.

Limiting the extent, depth, and duration of backwater flooding in the YBA is anticipated to result in lower mortality and displacement of wildlife. A reduced displacement of wildlife may curb the spread of disease (e.g., CWD) or invasive species (feral swine) to previously unoccupied areas. In addition, wildlife will be able to seek out high ground other than levees, roadbeds, and human-occupied structures, thus reducing human-wildlife conflict. This may also reduce burrowing of raccoons and rooting of feral swine on levee systems, which poses a large threat to the integrity of those systems and ultimately human safety. Reduced crowding of wildlife species is anticipated to ultimately decrease the associated predation and interspecies and intraspecies competition for space and food resources.

Limiting the duration of backwater flooding is expected to reduce the likelihood that floodwaters would remain on the landscape into the growing season. Growing season floods can adversely affect the growth of vegetation, berries, fruits, and insects that provide an important food resource for a variety of wildlife that may compete for those resources. As shown in 2019, crowded wildlife competes among and between species and quickly consumes available resources resulting in emaciation or starvation. Spring and summer are the time for birthing, hatching, and rearing young for numerous wildlife species, including turtles, deer, and turkeys. The long duration of the 2019 flood had obvious impacts to these species' recruitment, and there was presumably little-to-no reproduction success for these species in 2019. The proposed pump's ability to limit the duration of flooding is expected to decrease predation, increase young of the year survival, as well as increase adult survival and reproductive fitness. Ultimately, this will provide conditions that allow for more predictable and manageable wildlife resources. In addition, public lands will be available to the taxpayers and other users to enjoy the outdoors and the wildlife resources within.

Conclusion

In summary, severe backwater flooding in the YBA, as seen in 2019 and currently being experienced in 2020, can result in wildlife displacement, mortality, crowding of wildlife and associated predation and competition, starvation, heat exhaustion, and decreased reproduction. In addition, there is an increased risk of spreading of contagious diseases and invasive species, as well as increased human-wildlife conflicts such as vehicle collisions, encounters with displaced wildlife, and damage to infrastructure through burrowing or rooting activities. The flooding has also resulted in the damage and necessary repair of public and private infrastructure like roads, trails, culverts, water, and sewer. Furthermore, the extensive management efforts by the state and private conservationists have resulted in great expenditures of time and costs to increase wildlife habitat, enhance wildlife habitat, and support quality management of wildlife populations within those habitats. Efforts to increase wildlife habitat, habitat quality, and quality management of wildlife resources within the YBA may be in vain if severe flooding continues.

Extensive flooding within the YBA also prevents the use of the numerous large tracts of public and private lands for outdoor recreation, including hunting, fishing, birdwatching, camping, hiking, biking, boating, horseback riding, ATV riding, cabin rentals, conservation workshops, outdoor summer camps, and other outdoor gatherings. With a decrease in usage of these lands, comes an economic effect resulting from potential users canceling planned trips, not scheduling new trips, and not purchasing hunting licenses or paying user fees in fear that the area may be flooded at the time of planned visitation.

If the proposed pumps were to be installed and operational, then they would help to limit flood depth, duration, and extent; thereby, alleviating the direct and indirect effects of backwater flooding on wildlife resources and outdoor recreation opportunities. To be clear, the pumps would not eliminate backwater flooding events within the YBA; rather, they would serve to limit the extent, depth, and duration of extreme flood events. This would provide a level of predictability that allows for better wildlife resource management and outdoor recreational opportunities, while reducing risk of wildlife displacement, mortality, poor reproductive fitness, reduced recruitment, spread of disease, spread of feral swine, human-wildlife conflict, and wildlife damage to the existing levee system.

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Report B

Effects of Flooding on Bottomland Hardwoods in the Yazoo Backwater Area of Mississippi

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Abstract
Hydrological manipulation and floodplain alterations have occurred across the globe, and the Mississippi Alluvial Valley (MAV) is no exception. The bottomland hardwood (BLH) forests historically found through the MAV were adapted to the periodic flooding that naturally occurred within the floodplain of the Mississippi River. However, flood plain modification through the construction of levee systems, diversion canals, and the straightening and channelization of streams and rivers has resulted in a change in hydrology throughout these historic floodplains. Consequently, floodplains that historically received water from three sources (overbank flooding, groundwater, and precipitation) now primarily depend on precipitation as the major contributor to soil saturation and inundation. The reduction of flooding in BLH forests has resulted in a gradual shift from flood-tolerant species to flood-intolerant and shade-tolerant tree species. Flooding, although playing an important role in historic, natural BLH systems, can harm trees through direct or indirect means, regardless of flood tolerance of the species. This includes direct mortality or injury from flooding events (e.g., uprooting, toppling, breakage or bark damage), and indirect harm through reduced root development, reduced growth, defoliation, rot, and susceptibility to secondary infections from wood-boring insects and fungus resultant from stress caused by saturated or inundated soils. The extent of damage to trees often is not observed until years following the flooding event. Following the 219-day, recorded-breaking backwater flood within the Yazoo Backwater Area in 2019, extensive tree mortality, secondary infections, damaged timber, and a reduction in timber quality and timber sales were observed. These adverse effects were documented on privately held, managed forest lands, but similar effects may be observed on other forested tracts of land, including National Forests and lands converted to forests as part of the reforestation efforts through mitigation or government incentive programs. The proposed pumps would not eliminate backwater flooding events, but limit the extent, depth, and duration of extreme flood events. As such, the observed effects of pump operation on BLH will vary based on their relative location and topography within the YBA. In some areas still subject to periodic backwater flooding, flooding is expected to remain a selecting force regarding stand composition, where flood-tolerant species will likely continue to dominate. In areas with flooding limited by a pump system, tree growth and survival are expected to increase, regardless of the species' flood-tolerance. Additionally, stem densities are expected to increase within those stands, resulting in a gradual shift towards species that are shade tolerant and flood intolerant. Regardless, a reduction in flooding is anticipated to increase the growth of tree species, regardless of flood tolerance. The operation of the proposed pumps is anticipated to result in reduced flood-related mortality and secondary health issues in BLH forest trees by reducing extent and duration of floodwaters on those forested systems. In addition, the operation of the proposed pumps may result in a more predictable hydrological regime, increasing the ability of BLM forests to be managed, harvested, and regenerated in a sustainable manner.

Introduction

Forested floodplain ecosystems provide floodwater storage and control, recharge groundwater, improve water quality, provide habitat for wildlife, can increase fishery productivity, and are valued timber producers (Jenkins et al. 2010, Capon et al. 2013, King and Keim 2019). In general, flooding is a dynamic process, where flood frequency, duration, depth, and timing can influence seed dispersal, germination, recruitment and regeneration of forests, tree growth rates, and can strongly influence stand structure and species composition within a floodplain forest (Kozlowski 1984, Streng et al. 1989, Tardif and Bergeron 1993, Kozlowski 2002, Pierce and King 2007, Nilson et al. 2010, Rodriguez-Gonzalez et al. 2010, Smith et al. 2013). Flooding also is a major stressor on trees, regardless of flood-tolerance of the species. Flooding can result in mortality, stunted limb and root growth, defoliation, die-back, and secondary health issues like infections from fungal diseases and wood-boring insects (Whitlow and Harris 1979). Flood damage to trees, the importance of flooding of bottomland hardwood (BLH) forests, morphological adaptations and flood tolerance of BLH vegetation, and the ecology of BLH ecosystems has been extensively documented elsewhere (Whitlow and Harris 1979, Kozlowski 1984, Streng et al. 1989, Tardif and Bergeron 1993, Kozlowski 2002, Pierce and King 2007, Nilson et al. 2010, Rodriguez-Gonzalez et al. 2010, Smith et al. 2013, Gee et al. 2014, among others). The purpose of this report is to briefly discuss flood damage to trees, the response of BLH forests to floodplain modification, and potential implications for BLH forests within the Yazoo Backwater Area (YBA) of Mississippi.

Flood Damage to Trees

Flooding can directly and indirectly harm trees through several means including physical damage to trees, acute morphological changes from saturated or inundated soil conditions, and chronic problems associated with repeated flooding and changing environment (Whitlow and Harris 1979; Coder 1994). Floodwater inundation and prolonged soil saturation can result in poor aeration, oxygenation, and gas exchange which can lead to declines in tree health and growth. The severity and extent of flood damage to trees depends on several factors including flood timing (i.e., time of year), flood severity (i.e., depth of water), flood duration, and tree species affected. In general, flooding during the dormant season is less damaging than floods that occur during the growing season or have long durations that extend into leaf-out. In addition, flooding that occurs in warmer months results in warmer floodwaters, which increases microbial activity in the soils, resulting in anoxia, and hinders gas exchange and nutrient uptake of the tree root system. Symptoms of these flooding stressors can be seen in trees through yellowing of leaves, defoliation, reduced leaf size and shoot growth, die-back of limbs or crown, wood decay, and root rot.

The stressors and symptoms mentioned above can leave trees susceptible to toppling during subsequent disturbances (e.g., wind) and breakage or splitting. Weakened or stressed trees are left vulnerable to infection by fungi, molds, and wood-boring insects, which further deteriorate tree health and increases the likelihood of additional damage, breakage, and potentially death. Some of the secondary or indirect damage to trees may be observed in the same growing season as the flooding event, but in many cases the full impact of flooding (including tree mortality) is not realized until the years following the flood.

Status of Floodplains in the Mississippi Alluvial Valley and the Response of Bottomland Hardwood Forests

Levees, Channelization, and Water Control

The modification of historic floodplains through land development and flood management using stream channelization, the construction of levees, and water control systems is common and has occurred throughout the world (Gergel et al 2002, Opperman et al 2009, Steinfeld and Kingsford 2013). The Mississippi River system has been extensively modified through such measures to protect against flood damage. The Mississippi River drainage basin is the fourth largest watershed in the world, covering more than 1,245,000 square miles. According to the Mississippi River Commission, the Mississippi River and Tributaries (MR&T) Project levee system includes approximately 3,787 miles of authorized embankments, levees, and floodwalls within the Mississippi River Alluvial Valley (MAV), with approximately 2,216 miles along the mainstem Mississippi River and remaining levees along backwaters, tributaries, floodways, and diversion canals (USACE, MRC 2020). The MR&T levee systems were constructed to reduce the risk of flooding damage to citizens, homes, farms, infrastructure, and transportation routes.

Altered Hydrology

In general, unaltered floodplains are connected to adjacent rivers and are subjected to the periodic, often seasonal, exchange of water, nutrients, and organisms through overbank flow. While groundwater and precipitation contribute to the hydrology of floodplains, overbank flow is usually a frequent hydrologic driver within unaltered floodplains. However, as a result of land use changes and man-made flood control measures (e.g., dams, levees, drainage canals, water control structures, etc.), floodplains within the Mississippi Alluvial Valley (MAV) – including the YBA – have been separated from their adjacent river systems. These alterations were designed to reduce flood damage from Mississippi River flooding and perform as intended. A study of the effect of flooding on natural resources must be conducted in a manner that addresses the existing modified conditions of the floodplain as opposed to the historical conditions.

In natural, unaltered floodplains, there are three water sources for BLH systems: precipitation, groundwater, and river water via overbank flooding (King and Keim 2019). In general, levee systems reduce flood damage by constraining flows, limiting or eliminating surface connectivity between rivers and their floodplains by preventing overbank flooding in areas that historically exhibited connectivity (Belt 1975, Opperman et al. 2010). The channelization of streams and rivers can result in altered movement of groundwater and an increase in depth to the water table (Sophocleous 2002, King and Keim 2019). The disconnection of rivers from their floodplains due to levees and the lowering of the water table via channelization has resulted in reduced surface water connectivity and lowered groundwater, thus reducing two of the three sources of hydrology for historic BLH systems. As a result, many BLH systems in modified floodplains are mostly reliant on precipitation as the major source of hydrology (Smith and Klimas 2002, Gee et al. 2014, Berkowitz et al. 2019, King and Keim 2019).

Response of Bottomland Hardwood Forests to Altered Hydrology

In unaltered or minimally modified floodplains, the vegetative communities are adapted for the periodic flooding that historically occurred in those floodplains. Continued flooding is a strong control on vegetative species composition because it results in selection of those species with high flood tolerance (Streng et al. 1989, Kroschel et al. 2016), which have adaptations or tolerances to the stressors that flooding imposes. These stressors include the change in microbial activity of the inundated soils which leads to anaerobic soils, phytotoxic compounds within the soil, oxygen deprivation of roots, changes in the availability of nutrients and carbon dioxide, and low redox potential in the soils (Kozlowski 1984, Vartapetian and Jackson 1997). Some adaptions include ability for delayed leaf out, hydrochorous seed (seeds that are dispersed throughout the environment by being transported by water), aerenchyma (spongy tissue that forms pockets or channels of air in leaves, stems, or roots of plants that allow for exchange of gases when in low-oxygen and submerged conditions), and shallow rooting systems when a high water table is present (Wharton et al 1982, Kozlowski 2002, Burke and Chambers 2003).

The effect of altered hydrologic regimes on BLH systems varies depending on location, extent of alteration, existing vegetative community, and other local conditions and topography. The hydrological changes and shifts in vegetation within BLH forests have traditionally been poorly understood. However, such topics are currently active areas of research and the long-term effects, through changes in vegetative species composition, are now being realized (Bejarano et al. 2018, King and Keim 2019).

King and Keim (2019) discuss the findings of research evaluating the effect of hydrological modification on BLM forests. In some altered floodplain systems, there has been an observable shift from more flood-tolerant species to species that are flood-intolerant (Stallins et al. 2010, Gee et al. 2014). Because flooding serves as disturbance that controls recruitment of understory species and can hinder tree growth, there has also been an observed increase in stem densities and decreased mean tree diameters in BLH forests (Hanberry et al. 2012). Flooding disturbances may have been responsible for reducing stem densities and creating openings for regeneration of additional flood-tolerant plants. However, contemporary BLH forests in previously altered floodplains also have shifted to dense stands of shade-tolerant species in the absence of overbank flooding (King and Keim, 2019).

Gee et al. (2014) examined tree growth and recruitment in a leveed BLH forest system in the MAV. Specifically, this study was performed in a ring-levee and pump system in the Yancey Wildlife Management Area (YWMA) in Louisiana near the confluence of the Red, Black, and Mississippi Rivers. Gee et al. (2014) hypothesized that 1) sugarberry (*Celtis laevigata*) would increase in dominance and overcup oak (*Quercus lyrata*) would become less dominant, and 2) overcup oak growth would decline following the construction of the levee and cessation of overbank flooding, whereas sugarberry growth would increase.

In this study, Gee et al. (2014) found that the BLH forests in the study area have shifted regeneration from the more flood-tolerant and shade-intolerant overcup oaks to dense stands of shade-tolerant sugarberry, as anticipated in the first hypothesis. Contrary to the second hypothesis, the reduction of flooding increased the growth rates of the existing overcup oaks within the study area. As expected, sugarberry growth also increased. The interpretation of this increased growth in flood-tolerant overcup oaks is that flooding and prolonged inundation can provide major stressors on trees, and the removal of those stressors result in increased growth rates of trees, regardless of flood-tolerance.

The construction of the levee and pump system limited backwater flooding in the study area, thus reducing flood stress and increasing growth rates of overcup oak, a flood-tolerant species. By eliminating flooding through levee systems and having an increased depth to the water table through channelization, the BLH forest was forced to rely on precipitation as the major source of hydrology (Gee et al. 2014). This reliance on precipitation as a primary source of hydrology has been documented in other modified floodplain systems in the MAV (King and Keim 2019), including the forested wetlands of the YBA (Smith and Klimas 2002, Berkowitz et al. 2019). In the YWMA study location, there was sufficient rain to sustain suitable conditions for overcup oak despite the reduction in flooding. This exhibits that growth of healthy flood-tolerant tree species can still occur in backwater areas with levee and pump systems provided that adequate soil moisture content is available to support those species.

In conclusion, regular flooding in BLH forests result in flood-tolerant species dominating the forest and the reduction in flooding may result in a forest shifting towards species that are less flood-tolerant. However, flooding is a major stressor on trees regardless of flood tolerance. As demonstrated in the Gee et al. (2014) study, the reduced flooding in a backwater system resulted in increased growth of flood-tolerant and flood-intolerant trees alike. Flood tolerant trees are able to persist and benefit from flood-reducing practices as long as other sources of hydrology (i.e., precipitation) are available.

Existing Levee System, Recent Backwater Flooding Events, and Reforestation within the YBA

The YBA of Mississippi is generally bounded by the Mississippi River to the west and bluff hills and the Yazoo River to the east and has been subjected to flooding since time immemorial. However, as with other areas within the MAV, the YBA has been extensively modified to protect the area from overbank flooding from the adjacent Mississippi River. As originally envisioned, the flood control efforts within the YBA included a pumping station which would have allowed surface water trapped on the landward side of the levees, during flood stage on the Mississippi River, to exit the basin and discharge into the Mississippi River. However, the pumping station was never constructed. The existing levee and control structure system protects the YBA from overbank flooding from the Mississippi River; however, when the water control structure (Steele Bayou gate at Hwy 465) is closed, there is no outlet for rivers, streams, and surface waters within the YBA. As a result, surface waters within the YBA begin to “back up” against the existing levee system; resulting in a backwater flood event.

Floodwaters within the YBA remain on the landscape until the water level of the Mississippi River recedes and the control structures can be opened to allow the floodwaters trapped behind the levee to escape. Because the backwater flood events are not connected to overbank flooding from the Mississippi River, they do not flow, rise, and fall as would be expected in a natural, connected floodplain system. Rather, the backwater flood events resemble a filling of a bathtub with a closed drain where the water stacks up behind the levee system and creates a stagnant pool. The Steele Bayou Gates may be closed and opened several times during the period of Mississippi River flooding, generally between

February and June most years. Floodwaters within the YBA may remain on the landscape for long durations.

Backwater Flooding Events in the YBA

The YBA has experienced backwater flooding every year since 2002, except for 2006 and 2012. Backwater flooding events since 2002 have varied in extent and duration, with a record-breaking flood in 2019. The 2019 YBA backwater flooding event exceeded 219 consecutive days with water above 87 feet elevation (NGVD) from January 4 until August 10, 2019 with a peak crest at a record-breaking 98.2 feet on May 23, 2019, which flooded 548,000 acres of the YBA. The YBA again experienced severe backwater flooding in 2020 with flood elevations reaching 96.9 feet on April 23, 2020, flooding approximately 500,000 total acres of land within the YBA.

Reforestation Efforts

Over the last few decades Mississippi landowners have been encouraged to partake in federal and state financial incentive or assistance programs in favor of reforestation and converting agricultural floodplains to forests. These programs include the Mississippi Wetland Reserve Program (WRP) / Wetland Reserve Easement (WRE) Program and Environmental Quality Incentives Program (EQIP) through U.S. Department of Agriculture and the Reforestation Tax Credit through the Mississippi Forestry Commission. These programs have resulted in an increase in the number of forested tracts of land within the YBA.

Effect of Flooding on Bottomland Hardwood Forest Resources within the YBA

Peer-reviewed or quantitative studies have not examined the extent of tree damage or mortality from the 2019 floods or flooding in 2020, and indirect effects may not be observed for several years to come. However, some anecdotal evidence has been recorded regarding the effects of the three consecutive years (2018-2020) of severe backwater flooding on tree health, timber harvest and forestry operations, timber quality, and stand regeneration (Tomlinson 2020).

These observations (Tomlinson 2020) were made across two separate tracts of land, totaling 28,000 acres. These two properties are private lands under intensive management for forestry, hunting, and recreation and include portions of the Mississippi River Batture and the YBA. Tree mortality in the millions of board feet of sugarberry and cottonwood (*Populus deltoides*) have reportedly been observed in the past 12 years (since 2008). In addition to cottonwood, sugarberry/ southern hackberry, a valuable forest and wildlife habitat component of the southern BLH ecosystem, has been steadily declining as a successional component for the past 12 years. These mature (70-80 years old) trees' establishment predates the installation of the current levee and gate system and have generally persisted since the construction of the YBA levee system. However, sugarberry mortality over the last 12 years is attributed to continued stress from continued backwater flooding events on these forested stands (Tomlinson 2020).

In 2019, trees in both the YBA and the Batture suffered significant mortality (Tomlinson 2020). Green ash (*Fraxinus pennsylvanica*) experienced mortality during the 2019 growing season; but to a lesser extent than sugarberry and cottonwood. These species are considered flood-tolerant and are capable of tolerating stressors associated with periodic flooding events; however, the deep floodwaters that remain on the landscape for the long durations experienced in the YBA over the past 12 years are resulting in mortality and dieback in all tree species, regardless of the species' flood tolerance.

In addition to mortality from flooding, these trees have succumbed to rot, fungi, or other secondary infections, and their diminution has left noticeable openings in the successional landscape. In 2019, stands of mature cottonwood, stressed by prolonged inundation, were subsequently infected by granulate ambrosia beetle (GAB, *Xylosandrus crassiusculus*). GAB is a non-native, wood-boring insect that usually kills infected trees by inoculating bores with a fungal disease to provide food for its larvae (Layton, MSU 2012). This 2019 infestation resulted in the death and/or severe degradation of over three million board feet of cottonwood sawtimber. Other trees, including oaks (*Quercus spp*.), were similarly stressed, infected with GAB, and subsequently suffered mortality.

The timber stands discussed herein were not scheduled for intensive harvesting in the short- or long-term. However, the extensive flood damage and mortality to trees resulting from the 2019 flooding prompted intensive harvesting in an attempt to salvage the dead or dying trees that would otherwise remain on the landscape to decompose. On one of the two properties, one timber buyer interested in the salvaged wood planned to purchase at least one million board feet of dead or damaged cottonwood trees; however, the buyer ultimately backed out of the arrangement after observing the extensive damage to the timber resulting from rot, breakage, or GAB infestations. Eventually, another buyer purchased approximately 2.1 million board feet of dead and dying cottonwood for use as soft mats manufactured for industrial development. However, even the salvaged wood was of degraded quality from insect borings, rot and fungal infections. Consequently, salvage value of the timber was worth only one-third as much as its value in a healthy free-to-grow condition. For this particular property, this transaction of salvaged trees was the only timber sale in 2019.

Rising water halted the remaining harvest operations on January 1, 2020. Except for the salvaged timber sale mentioned above, no new timber sales were conducted in 2019, and unharvested timber already sold and under contract had to obtain contract extensions. The current year, 2020, has been a virtual repeat of 2019. Questions as to the viability of completing purchased timber sales or attracting buyers to new timber sales are increasing. Likewise, increased timber mortality from three successive years of severe YBA flooding in 2018, 2019, and 2020 also is a concern, as is the marketability of forest products, which are increasingly difficult to access.

The second property within the YBA usually has 3-4 timber sales per year, but none occurred in 2019. Tracts on which timber had been sold previously, could not be accessed for completion of harvest. Many of the forested tracts, which had been marked for harvest prior to the 2019 floods, remained underwater for most of the year. Timber harvesting equipment could neither access nor operate within these stands to conduct harvesting for the combined values of timber stand improvement and wildlife habitat enhancement. Although the acute effects on forestry economics was observed by some in 2019, the long-term chronic effects across the YBA have not yet been revealed. Tree mortality and degradation will likely become more evident over time, and stress will continue to reduce growth, cause die-back and defoliation, and render trees susceptible to disease, wood-boring insects, fungal infections, and increased risk of toppling, breakage, and secondary mortality. The continued flooding frequency and duration within the YBA has resulted in an uncertain future for forest resources, forestry operations and economics, and the ecology, management, and regeneration of southern BLH forests.

Potential Effects of Proposed Pump Installation and Operation within the YBA

Similar to the previously mentioned levee system at YWMA, the existing levee system within the YBA reduces the risk of overbank flooding from the Mississippi River. However, unlike the YWMA levees, the YBA levee system does not include pumps to remove rising floodwaters resulting from precipitation within the backwater area. As such, flooding within the backwater of the YBA continues to rise until the Mississippi River stage lowers and allows the opening of the YBA gate structures. The exact effect of pump operation, as proposed in the Yazoo Area Pump Project EIS, on BLH forests and forested wetland systems is difficult to predict. To be clear, the proposed pumps would not eliminate backwater flooding events within the YBA; rather, they would serve to limit the extent, depth, and duration of extreme flood events.

A recent study of forested wetland hydrology within the YBA (Berkowitz et al. 2019) concluded that forested wetlands within the YBA are maintained by a combination of precipitation and floodwater inputs, with precipitation providing the water source for 87% of the study locations. The heavy influence of precipitation on soil saturation and inundation was also observed in the BLH forests in the YWMA. If pumps were to operate within the YBA, a trend similar to what was observed in the YWMA (Gee et al. 2014) may be expected. Specifically, this may include increased growth and survival of trees (regardless of their flood-tolerance), an increase in stem densities, and there may be an eventual shift in species composition, depending on local climate, precipitation, and forest management strategies. Because the proposed pumps will not eliminate backwater flooding, areas subject to continued periodic flooding of reduced depth and duration are still expected to continue to be dominated by flood-tolerant species that are adapted to such environment.

Although precipitation and future climate within the YBA are difficult to forecast, operation of the proposed pumps would improve predictability of potential flood coverage, severity, and duration for BLH forests, land managers, and timber operators. This predictability should allow for better management of these BLH systems and the resources within. For example, increased predictability could result in better management of timber operations, thinning or selective cuts, removal of dead, diseased, or undesired tress, scheduled harvests and rotations, and allow for better planning of regeneration and reforestation efforts.

Conclusion

In summary, flooding, particularly like the backwater events experienced in 2019 and currently being experienced in 2020 within the YBA, can result in tree mortality, reduced growth, and poor root structure, leaving stressed trees vulnerable to wood-boring insects, disease, and fungal infections regardless of the flood-tolerance of the affected species. The proposed pumps would not eliminate backwater flooding events, but would limit the extent, depth, and duration of extreme flood events. As such, the observed effects of pump operation on BLH will vary across locations within the YBA. In some areas still subject to periodic backwater flooding, flooding is expected to remain a selecting force regarding stand composition, where flood-tolerant species will likely continue to dominate. In areas where flood extent, depth, and duration would be limited by operation of the pumps, tree growth and survival are expected to increase, regardless of the species' flood-tolerance. Additionally, stem densities are expected to increase within those stands, resulting in a gradual shift towards species that are more shade tolerant and flood intolerant.

As previously discussed, the hydrology within the YBA is highly influenced by precipitation (Berkowitz et al. 2019), and existing flood-tolerant tree species are likely to persist after pump operation if soil moisture stays within suitable levels to support those species. If the proposed pumps were to be installed and operational, then the resulting hydrological conditions would be expected to limit flood extent, depth, and duration; thereby, alleviating the primary and secondary effects of flooding on trees. This would provide a level of predictability that allows for better forest management, timber harvest, and reforestation efforts while reducing the risk of tree mortality and timber damage, ultimately improving the health and sustainability of renewable forest resources within the YBA.

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Report C

Review of Methylmercury Production in Backwater Floodplains and Implications for the Yazoo Backwater Area of Mississippi

Report C

Review of Methylmercury Production in Backwater Floodplains and Implications for the Yazoo Backwater Area of Mississippi

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Abstract

Mercury can be found in deposits throughout the world and can enter the natural environment from various natural and anthropogenic means. Methylmercury is a highly toxic organic form of mercury that is formed in nature by sulfate-reducing bacteria through a process called methylation. Methylmercury is the form of mercury to which humans and animals are most frequently exposed. Bioaccumulation and biomagnification of methylmercury occurs within the food chain and is the leading cause of fish-consumption advisories in the United States. Forested floodplains provide biological hotspots for sulfate-reducing bacteria during times of inundation, where anoxic conditions, warm waters, low redox potential, and abundant organic matter from the forest floor provide conditions favorable for the methylation of mercury. A 2009 study in the Lower Yazoo Basin examined the potential effects on methylmercury production of reforestation efforts in the backwater area. In summary, reforestation efforts (i.e., converting agricultural lands within the floodplain to forested lands) outlined in the Final Environmental Impact Statement (EIS) for the Yazoo Backwater Area (YBA) pump project, combined with proposed pump operation, were anticipated to increase methylmercury production by 3% based on a typical 2-year flood event. The increase in the area of forested floodplains is expected to increase the amount of organic matter on the landscape, but pump operation would limit the extent, depth, and duration of floodwaters, resulting in only a slight increase in methylmercury production. However, if reforestation efforts occur without the proposed pumps in operation, there would be a corresponding increase in methylmercury production of up to 32%. The change in land use would increase organic matter on the landscape and, during typical 2-year flood events, would lead to increased methylmercury production. Reforestation efforts through anticipated mitigation and government assistance programs have increased forested floodplains within the YBA. In addition, backwater floods have continued within the YBA annually since 2009, except for 2012, often at flood levels greater than a typical 2-year flood event. As such, the extent and duration of these flood events likely increase methylmercury production within the YBA. The proposed pump operation would limit the extent, depth, and duration of flooding events; thus, reducing the potential for methylmercury production within the YBA.

Introduction to Mercury

Mercury is an elemental, inorganic metal naturally occurring in deposits found throughout the world. Mercury from earth deposits can enter the environment through both natural sources and anthropogenic means. These include volcanic activity, weathering of rocks and mineral deposits, erosion, evaporation, or burning of fuels for powerplants, waste disposal of mercury-containing products, mining, chemical and metal processing, and other emissions (EPA 2006). Although people can be exposed to mercury though direct contact with mercury and inhalation of mercury vapors, the form of mercury people in the United States encounter most frequently is the ingestion of fish or shellfish containing methylmercury (EPA 2006), a toxic organic compound resulting from combining the inorganic mercury with carbon.

The Production of Methylmercury in the Natural Environment

Various microscopic organisms in the aquatic environment, such as sulfate-reducing bacteria, have the capability to convert mercury to methylmercury through a process called methylation. Methylation is a pathway to convert heavy metals, that may otherwise be unavailable for uptake, into more mobile, lethal, and bioavailable forms. Sulfate-reducing bacteria and other microbes convert inorganic mercury to organic methylmercury, which becomes bioavailable within the food web (Gilmour et al. 1992, Oremland et al. 2000). Bioaccumulation of methylmercury occurs when zooplankton consume the sulfate-reducing bacteria and microbes, which are then consumed by other macroinvertebrates or fish. In turn, larger fish will consume hundreds or thousands of these smaller fish or invertebrates in a lifetime, further accumulating mercury in their body tissues. Eventually, these fish are consumed by larger fish, or other predators like fish (e.g., sharks, tuna, swordfish), birds, mammals, or humans (Lavoie et al., 2013). Long-lived predators tend to carry the heaviest loads of mercury within their tissues, but the sublethal neurological and endocrine system effects of mercury has been observed on other vertebrates of all types with varying orders of magnitude depending on taxonomy and trophic level (Kessler 2013, Evers 2018). The effects of mercury on birds have included fewer eggs per nest, reduced egg size, reduced egg hatching success, and poor fledgling survival (Kessler 2013, Evers 2018). In mammals, mercury accumulation in the body can lead to ataxia (i.e., lack of voluntary muscle control), aberrant behavior, suppression of the immune system, changes in reproductive organ development and sexual maturation, and reduced fertility and embryo development (Evers 2018). In general, these effects of mercury on wildlife can lead to population level ramifications (Evers 2018).

Humans are typically exposed to the adverse health effects through consumption of contaminated fish and shellfish (Weiner et al. 2003, Clarkson 2002, Wren 1986), which can have high levels of methylmercury within their tissues through the process of bioaccumulation. Because of its toxicity and environmental distribution, methylmercury is a health concern and leading cause of fish consumption advisories in the United States, and a public health concern in Mississippi (MDEQ 2018).

Naturally occurring sulfate-reducing bacteria are primary agents for production of methylmercury within the environment (Compeau and Bartha 1985, Gilmour et al. 1992). These bacteria tend to flourish under anoxic, low redox (i.e., oxidative reducing potential) conditions, with organic matter to facilitate the methylation of mercury (Rypel et al. 2008). As such, methylmercury levels tend to be elevated in waters associated with floodplains because of the conditions favorable for methylation (e.g., anoxic conditions, high organic matters, low pH, and proliferation of sulfate-reducing bacteria; Ullrich et al. 2001, Eckley and Hintelmann 2005, Myers 2009). In general, forested floodplains produce higher amounts organic matter than cleared agricultural lands within the floodplain. This higher amount of organic matter provides an abundance of available carbon content for bacteria to produce methylmercury. However, agricultural areas may still provide sources of methylmercury production depending on flood conditions (Rogers 1976). Floodwaters in areas like the Mississippi Delta and Yazoo Backwater Area (YBA), can potentially provide natural microbial hotspots for the bacteria and methylmercury production in flood conditions (MDEQ 2018). Sources of mercury within the YBA is derived from naturally occurring sources on the landscape (i.e., soils), and are readily subject to the process of methylation in flooded conditions. The use of mercury-containing products, land activities exposing mercury, and other anthropogenic sources of mercury within the YBA is unlikely.

Numerous studies have examined the effect of water temperature, period of inundation, and leaf litter on methylation rates (Krabbenhoft et al. 1995, Roulette et al. 2001, Balogh et al. 2005, Hall et al. 2008). One study observed that initial methylation rates can be up to four times higher when incubated at 35°C (95°F) than when incubated at 25°C (77°F) (Guimarães et al. 2006). As discussed by Myers (2009), this temperature difference is similar to ambient temperatures observed in the YBA during late spring versus late winter, inferring that an early June flood is expected to result in higher methylation rates as compared to a late January flood.

The period or duration of inundation also has implications for methylmercury production in floodwaters. The methylation of mercury is usually a concern in permanent waters, including lakes and wetlands. Dry lands, including unflooded floodplains, generally do not produce methylmercury because they lack the conditions necessary to support the sulfate-reducing bacteria that converts mercury into methylmercury. However, when flooded, these locations can provide ideal conditions to initiate the methylation process. Methylation generally begins after seven days of inundation (Wright and Hamilton 1982). After seven days of inundation, microbial activity spikes and sulfate-reducing bacteria have established themselves and are able to process the abundantly available organic matter within the flood waters. Once initiated, the methylation process continues as long as there is a steady supply of organic matter, or until the floodwaters recede. Consequently, the longer the period of inundation, the more methylmercury is produced.

Methylmercury Study in the Yazoo Backwater Area

The existing YBA levee and gate systems protect lands within the YBA from high waters from the Mississippi River, but when the gates are closed, there is no outlet for rivers, streams, and surface waters on the landward side of the levee. As a result, precipitation occurring the YBA begins to “back up” against the existing levee system and results in a backwater flooding event. Floodwaters within the YBA remain on the landscape until the Mississippi

River water levels recede and gate structures can be opened to allow these floodwaters to escape.[1]

A study examining methylmercury in water and fish tissue in the Lower Yazoo Basin was published by the U.S. Army Corps of Engineers (USACE) in 2009 and presented at the 2009 annual Mississippi Water Resources Conference (Myers 2009). The study analyzed the potential for increase in methylmercury concentrations in surface waters and fish tissues based on the anticipated completion of the Yazoo Area Pump Project as addressed in the Final Supplement No. 1 to the 1982 Yazoo Area Pump Project Final Environmental Impact Statement (EIS) and the Yazoo Backwater Area Reformulation Study Main Report (USACE 2007). Specifically, the analysis used a simple linear model that compared the potential for changes in methylmercury based on the proposed changes in land use, flooded acres, and flood duration according to the proposed pump operations and reforestation/mitigation efforts outlined in the EIS.

Methods for the 2009 study included the collection of water samples within the YBA from 2003 to 2008 to observe variations in methylmercury levels in floodwaters in different locations, habitat types, and time of year. Water samples were collected in several existing green tree reservoirs (GTR), floodwaters of the Delta National Forest (DNF), Little Sunflower River, Cypress Bayou, a wheat field, and wetland reserve program (WRP) properties, as well as other locations. Fish tissues collected between 1993 and 2008 were examined for comparison to flood events. Ultimately, the collected water and fish tissue sample data were analyzed to inform predictions about the potential implications for methylmercury levels in relation to the USACE reforestation plan (converting agricultural areas within the floodplain into forested floodplains) and proposed pump operations (acres flooded and flood duration) as discussed in the EIS and the Yazoo Backwater Area Reformulation Study (USACE 2007).

The 2009 study examined differences of methylmercury units within the YBA between 1) baseline (2005) land use conditions, 2) proposed land use conditions after reforestation efforts with proposed pump operation, and 3) proposed land use conditions after reforestation efforts but without operation of the proposed pumps. In line with other studies, the 2009 study within the YBA observed increased levels of methylmercury in forested floodplains as compared to agricultural fields, resulting from the increased organic matter available. Findings revealed that the highest methylmercury concentrations during late winter floods were found in green tree reservoirs (GTRs; i.e., bottomland hardwood forests that are typically flooded in the fall and winter) that were flooded for up to three months. The lowest observed concentrations were in the permanent, flowing receiving waters of the Little Sunflower River and Cypress Bayou. During late spring floods, the highest concentrations were observed within a WRP forest that had been flooded for 50 days. Overall, methylmercury concentrations during spring floods were higher than concentrations observed during winter floods, even in agricultural fields. Methylmercury levels within agricultural fields were anticipated to be near zero; however, levels observed within a Valley Park wheat field during a late spring flood were surprisingly high at 0.65 nanograms per liter (ng/L; which was the same amount of methylmercury detected in green tree reservoirs). This was the result of the spring flood's

[1] Additional information and description of the YBA can be found in Reports A and B.

increased water temperatures, low dissolved oxygen, and longer duration of floodwaters on the landscape.

Within the 2009 study, USACE mentions in-stream water temperature in the YBA is typically 10°C (50°F) in early March and 20°C (68°F) in early May. During the study, observed 24-hour averaged water temperatures in shallow flood waters (less than 1 foot deep) were 23°C (73°F) whereas deeper areas (4 feet deep) near permanent flowing waters were around 17°C (62.6°F) on May 8, 2008. The water temperature in the YBA is typically 10°C (50°F) in early March and 20°C (68°F) in early May (Myers 2009). The warmer floodwaters are likely warm enough to increase biological activity and methylation rates during late spring floods within the YBA and continue to increase as water temperatures rise.

Finally, the 2009 study examined expected methylmercury levels within the YBA based on the proposed reforestation efforts to convert large tracts of flood-prone agricultural land to forested land. Based on 2005 land use, a typical 2-year frequency flood and 5% duration flood, the study examined methylmercury units (i.e., a unit of measure where one acre of forested wetland produces one unit of methylmercury each day of inundation after the initial seven days of inundation) at 1) existing base (2005) conditions, 2) reforested conditions with the proposed pump project implemented as described in the EIS, and 3) reforested conditions without the pump project. The USACE concluded that implementation of the recommended plan in the EIS (i.e., reforestation with pump operation) would result in a slight increase of methylmercury production by up to 3% as compared to existing baseline conditions. Conversely, if reforestation efforts were completed but without pump operation, an increase of methylmercury production of up to 32% would be expected. This conclusion results from the prediction that the conversion of agricultural areas into forested areas through reforestation efforts would create detritus and other conditions in flooded locations suitable to increase in methylmercury production. However, the operation of the proposed pumps would limit the extent, depth, and duration of floodwaters on the landscape which would offset the increased potential for methylmercury production and limit the anticipated increase to 3% over 2005 baseline conditions.

In the 2009 study, methylmercury concentrations in the water column displayed a delayed corresponding response in increased mercury in fish tissues following a 130-day late spring flood in 2008 (Myers 2009). Unpublished data from the USACE Vicksburg District and Engineer Research and Development Center (ERDC) show that floodwater becomes anoxic to less than one foot below the surface and attempts to capture adult fish during these low-oxygen periods have yielded relatively low results, resulting in a small sample size (Myers 2009). In addition, other factors may influence mercury accumulation in fish including fish mobility between locations, local methylation rates, bioaccumulation of mercury in food sources (i.e., zooplankton), and biomass of those various food sources. With many other factors potentially influencing mercury concentrations in fish tissues, no definitive conclusions were made regarding the effect of reforestation efforts on mercury in fish tissues. However, fish tissues did show an increase in mercury content following years that had extensive flooding for long duration in land use areas with high organic matter (i.e., forests). Conclusions of the study outlined that it's possible that methylmercury concentrations decrease throughout the basin during years with less flooding.

Methylmercury production in agricultural fields has often been discounted as a source of methylmercury because agricultural fields typically lack the abundant organic matter that is present in forested floodplains. Although capable of producing methylmercury, the amount of methylmercury produced in agriculture fields has been presumed to be negligible. This assumption was made in the EIS as well as the 2009 study (Myers 2009). Contrary to the assumptions made within the EIS and hypothesis made in the 2009 study, agriculture fields cannot be discounted as sources of methylmercury production, particularly when floodwaters remain on the landscape for long durations and during warmer temperatures (Myers 2009). Agriculture activities do not contribute to mercury within the environment, but the inundated conditions of flooded agriculture filed have been documented to provide condition that contribute to the methylation of mercury already within the environment. In summary, although forested floodplains are capable of producing the highest levels of methylmercury, all flooded lands including agriculture fields can be notable sources of methylmercury production, depending on duration and timing of flooding.

Conclusions and Implications for Recently Observed Flooding in the YBA

The literature and the 2009 study support the widely accepted knowledge that forested floodwaters in the southeastern United States provide biological activity hotspots suitable to support sulfate-reducing bacteria that facilitate the methylation of mercury. This is the result of abundant organic matter, low dissolved oxygen, and increased temperatures. In addition, methylation rates increase with severity and duration of floodwaters on the landscape (i.e., methylation initiates around seven days after inundation). The 2009 study predicted a 32% increase in methylmercury units in the YBA during a typical 2-year flood event if reforestation of agricultural floodplains were to occur, but the pump project was not implemented. Since the 2009 study, additional lands in the YBA have been reforested under various conservation programs, many administered by the U.S. Department of Agriculture (USDA). In addition, Mississippi landowners have been encouraged to partake in federal and state financial incentive or assistance programs in favor of reforestation and converting agricultural floodplains to forests. These programs include the Mississippi WRP / Wetland Reserve Easement (WRE) Program and Environmental Quality Incentives Program (EQIP) through USDA and the Reforestation Tax Credit through the Mississippi Forestry Commission. Essentially, reforestation efforts within the YBA have continued since the EIS and the 2009 methylmercury study, but no pumps are present to limit the extent or duration of flood events.

Based on the literature (Myers 2009) and the reforestation efforts over the past 10 years (through conservation easements and reforestation efforts) combined with frequent floods of long durations, the methylmercury concentrations within the YBA have likely increased and may have reached the 32% increase predicted in the 2009 USACE study. Notably, YBA backwater floods that have occurred in the last decade have surpassed a typical 2-year flood event used as a benchmark in the 2009 study. Since the 2009 study, the YBA has experienced backwater floods annually through 2020, except during 2012. In many years, backwater flooding occurred in late spring or summer. This late spring and summer flooding provide the warm temperatures that tend to increase methylation rates. The operation of the proposed pumps, as outlined in the EIS would result in a decrease in the extent and duration of floodwaters throughout the YBA, which would be expected to reduce the methylation potential.

The 2019 flood event resulted in approximately 548,000 acres flooded in January with waters not receding until August. This extent and duration would have resulted in what can be assumed to be a tremendous spike in methylmercury production. The severity of the flood inundated hundreds of thousands of acres of land with an abundance of organic matter to supply a steady and reliable source of carbon for sulfate-reducing bacteria. The duration of the flood spanned over eight months, where water temperatures steadily increase through the spring and into the summer, dissolved oxygen was reduced, and methylation rates would be anticipated to increase. The exact acreage of the reforested areas has not been assessed or applied to the 2009 model, and methylmercury studies were not conducted during the 2019 flood event. Because of insufficient data, the levels of methylmercury within the YBA during the 2019 flood is unknown but can be anticipated to have been elevated due to the increase in forested floodplains in the YBA, the associated increase in organic matter, increased water temperatures, and extended duration of inundation.

As observed in the 2009 study, mercury concentrations within fish tissues increase following flood events. Although one could conclude the same would be true during the 2019 flood, the unpublished data and information provided from USACE / ERDC suggests that fish presence within the floodwaters is sparse under anoxic conditions. The apparent limited presence of adult fish in the YBA during prolonged flood events resulted in the inability to make definitive conclusions on mercury content within fish tissues. When floodwaters recede, methylmercury moves out of the system to downstream waters and is often diluted in free-flowing waters. However, the presence, toxicity, and environmental implications of methylmercury, once transported downstream from the YBA, have not been examined.

The proposed pump operation is designed to limit the extent, depth, and duration of backwater flood events within the YBA and to prevent extreme flooding events such as experienced during 2019. Although impossible to precisely determine the effects of pump operation on water quality, limiting the extent, depth, and duration of backwater flooding events in the YBA should result in a reduction in methylmercury production potential and the associated adverse effects of methylmercury on wildlife and humans.

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Report D

Invasive Asian Carp in the Yazoo Backwater Area of Mississippi

Report D

Invasive Asian Carp in the Yazoo Backwater Area of Mississippi

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Abstract

Silver carp (*Hypophtalmichthys molitrix*) and bighead carp (*Hypophtalmichthys nobilis*), collectively referred to as Asian carp, are non-native, invasive fish which were first introduced to the United States for aquaculture and water treatment in the 1970s. By the 1980s, these large-bodied fish escaped confinement during flooding events and were introduced to the Mississippi River. With no native predators, high reproductive success, rapid growth rates and an abundant food source of plankton in the productive waters of the Mississippi River network, this invasive species quickly colonized rivers throughout the Mississippi River basin. Asian carp are planktivorous fish, feeding on the microscopic plants (phytoplankton) and animals (zooplankton) that are the foundation of aquatic food webs. In addition to native planktivorous fish, all native fish feed on plankton at some stage of their lifecycle. The filter feeding foraging method of Asian carp has resulted in direct competition with native fishes and mollusks and has been linked to a decline in native fisheries by reducing the population, growth, and relative weights of native fish in waters where Asian carp have been established. Fisheries assessments in oxbow lakes within the Yazoo Backwater Area of Mississippi have observed a substantial decrease in populations of native minnows, gizzard shad, bluegill, crappie, and largemouth bass over time since Asian carp were introduced to those oxbow lakes. In oxbow lakes where Asian carp were present (i.e., Lake Whittington and Tunica Lake), Asian carp comprised 31% and 42% of the total catch, respectively, and were the most abundant species by biomass. Centrarchid (i.e., bass, sunfish, and crappie) biomass declined over 75% in these lakes compared to historic data prior to carp introduction. In addition, Clupeid (i.e., shads and herrings) biomass was reduce by over 90% in these oxbow lakes following Asian carp introduction. Eagle Lake, an oxbow lake in Warren County, MS protected by the existing Yazoo levee systems, is heavily stocked and managed for recreational fishing, and appeared to be free of Asian carp in the same 2017 study. Over time, a slight decrease in Clupeid biomass was observed in Eagle Lake but the biomass of Centrarchids nearly doubled, likely the result of the sportfish management efforts. Following the extensive backwater flooding in 2019, Asian carp were confirmed within Eagle Lake. With the known negative environmental effects of Asian carp introduction, there is a possibility that the fishery in Eagle Lake may suffer the same consequences as Lake Whittington and Tunica Lake. Successful reproduction of Asian carp within Eagle Lake is unlikely occur because the Asian carp require free-flowing and often turbulent waters for eggs to remain suspended in the water column while embryos develop. Eagle Lake does not exhibit connectivity to free-flowing waters required for successful Asian carp reproduction. As such, if floodwaters are kept at bay and do not continuously introduce new Asian carp, then the negative effects on the Eagle Lake fishery could be limited. The proposed pumps for the Yazoo Backwater Area would operate at a level that would reduce the likelihood that additional Asian carp are introduced via backwater floods into the heavily managed recreational fishery of Eagle Lake.

Introduction

Carp belong to the family Cyprinidae; the largest family of freshwater fish in the world. Cyprindae is the minnow family and includes various shiners, dace, chub, rudd, roach, goldfish, and carp. In North America, four of these species are collectively termed Asian carp (NPS 2019): grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), bighead carp (*Hypophtalmichthys nobilis*), and silver carp (*Hypophtalmichthys molitrix*). Although grass carp and black carp are of Asian origin, considered invasive, and pose threats to native fisheries, the focus of this report is on the two Asian carp species of the highest concern in the United States, the silver carp and bighead carp, hereinafter referred to as "Asian carp".

Life History of Asian Carp

The two Asian carp species addressed in this report (silver and bighead carp) are heavy-bodied fish, with a keeled belly, low-positioned eyes, and scaleless heads. They are relatively long-lived with life expectancy around 15 years, with some records of up to 20 years (Smith 2015b). In the United States, Bighead carp and silver carp can reach 100 pounds and 40 pounds or more, respectively.

Asian carp are planktivorous filter-feeders, with a diet typically consisting of primary producers (i.e., phytoplankton) and primary consumers (i.e., zooplankton; Radke and Kahl 2002). These species use specialized gill rakers to sift through large volumes of water to consume a variety of zooplankton, phytoplankton, and occasionally algae and detritus (Borutskiy 1973, Burke et al. 1986, Opuszynski et al. 1991, Dong and Li 1994, Domainzon and Devaux 1999).

In their native waters of Asia, the Asian carp reach sexual maturity in 5 or more years; however, in their nonnative waters of the United States, they have been observed to sexually mature as early as two years (Smith 2015b). Asian carp spawn in rivers in the spring and early summer during periods of high water. Protracted spawning may occur in late summer as well. The eggs are scattered into the water column of turbulent, free-flowing waters, where eggs develop while suspended and drifting downstream (Nico et al. 2020). Asian carp have a high fecundity (number of eggs produced while spawning) and can produce a large number of viable offspring. A 2002 study of adult bighead carp in the lower Missouri River found that bighead carp had a mean fecundity of 226,213, with a maximum fecundity of 769,964 observed (Schrank and Guy, 2002).

Under optimal conditions of nonnative waters, growth of Asian carp is rapid and survival to maturity is high (Kolar et al. 2007, Smith 2015a, Smith 2015b). In the United States, there are very few predators of Asian carp, particularly large adults. Native piscivorous fish and birds may be able to forage on juvenile stages of Asian carp (Smith 2015b). However, the rapid growth of the carp limits the period of time they are susceptible to predation by piscivorous fish and birds.

The Introduction of Asian carp in the United States

Asian carp are native to eastern Asia (Jennings 1988; Xie and Chen 2001) and were imported to the United States in the 1970s for aquaculture and use in sewage treatment facilities (Freeze and Henderson 1982, Kolar et al. 2007, Smith 2015a). Asian carp escapement originated in Arkansas, where periodic flooding in the 1970s and 1980s resulted in the release of these invasive fish into the Mississippi

River and its associated tributaries and backwaters (Smith 2015a). The Mississippi River drainage basin is the fourth-largest watershed in the world, covering more than 1,245,000 square miles. The Asian carp's fast growth, young sexual maturity, and high fecundity combined with suitable habitat conditions, have resulted in their successful invasion and colonization of rivers and streams throughout the Mississippi River network.

Threats and Impacts of Asian carp in Mississippi and throughout the United States

As previously mentioned, the diet of Asian carp consists nearly exclusively of phytoplankton and zooplankton. Phytoplankton are plant-like organisms that process sunlight through photosynthesis. Zooplankton are animal organisms that primarily feed on phytoplankton and provide the food source for most larval fish species. Plankton are considered the foundation of aquatic food webs, and are critical food sources for many larval fish, aquatic insects, and mussels.

The spread and establishment of Asian carp has resulted in a decline of native fishes (Shrank et al. 2003, Williamson and Garvey 2005, Sampson et al. 2009). Asian carp directly compete with native planktivorous fish like gizzard shad (*Dorosoma cepedianum*), bigmouth buffalo (*Ictiobus cyprinellus*), paddlefish (*Polyodon spathula*) and pallid sturgeon (*Scaphirhynchus alba*; Minkley et al. 1970, Lazzaro 1987, Jennings and Zigler 2000, Schrank et al. 2003, Sampson et al. 2009). A dietary study among the two species of Asian carp, gizzard shad, bigmouth buffalo, and paddlefish in backwater lakes on the Illinois and Mississippi rivers (Sampson et al. 2009) found a significant dietary overlap between the invasive Asian carp and native gizzard shad. In addition, Asian carp directly compete for zooplankton with juvenile bass (*Micropterus spp.*), crappie (*Pomoxis spp*.), and bluegill (*Lepomis machrochirus*), which are considered primary sportfish (Conover et al. 2007, Garvey et al. 2007, Garvey et al. 2012, Freedman et al. 2012).

In addition to competing with adult planktivorous fish, Asian carp consume the same plankton that all fish species require at some stage during their lifecycle. Larval and juvenile fish consume zooplankton until they have grown enough to forage on larger food items such as aquatic insects. A recent study on the upper Mississippi River system (Chick et al. 2019) provided empirical evidence of a negative effect of invasive carp on native sportfish populations. The analyses suggest the mechanism for native sportfish decline is the direct competition for zooplankton in the larval and juvenile stages of the sportfish. This study also suggests that recruitment of juvenile sportfish appear to be constrained to reaches where Asian carp are not present.

Plankton also are the primary food source for native Unionid mussels. Unionids are a diverse family of freshwater mussels belonging to the family Unionidae. North America has the highest diversity of freshwater mussels in the world with 298 species, which is over one third of Unionid species worldwide (William and Neves 1995, Williams et al. 2017, USFWS 2019). Of these 298 North American species, 29 have gone extinct, 83 are federally threatened or endangered, with about 65-70% of species being imperiled (i.e., populations that have declined at such a rate that they are at risk of extinction; William and Neves 1995, Williams et al. 2017, USFWS 2019). There are 84 freshwater mussel species in Mississippi, and three federally listed species with potential ranges that include the YBA counties of

Warren, Issaquena, Yazoo, Sharkey and Humphreys (USFWS 2020).

In a recent experiment (Tristano et al. 2019), silver carp were found to have direct, exploitative competition for food sources with native fatmucket mussels (*Lampsilis siliquoidea*). During this experiment, fatmucket mussels exhibited slower growth rates when silver carp were present as compared to when silver carp were absent. The difference is attributed to the carp outcompeting the mussels for food resources. Competition with Asian carp may contribute to additional stress on already imperiled mussel species that are subject to population decline from habitat loss, sedimentation, changes in hydrologic cycle, poor water quality, and competition with other invasive species [i.e., zebra mussels (*Dreissena polymorpha*), and Asian clams (*Corbicula fluminea*)]. In general, the Asian carp's fast growth rate, high reproductive success, and direct competition of resources with native fauna results in a disruption of the food webs and is a major stressor on biodiversity, energy flow, and productivity of aquatic ecosystems (Laird and Page 1996).

Human safety is a concern in waters where Asian carp have been established. Silver carp are sometimes referred to as "jumping" carp and have been documented to cause human injury including concussions, broken bones, lacerations from fins, and back injuries (Smith 2015b). When startled or stimulated by boat engines, these carp can leap up to 10 feet out of the waters and can collide with humans and boats, which poses a risk to recreational boaters. The risk of collision with Asian carp could lower consumer expenditures and license sales, but data for this anticipated impact have not been well-documented.

The U.S. Fish and Wildlife Service (USFWS) has declared all Asian carp as injurious wildlife species in the Lacey Act of 1900 (18 U.S.C. 42). An injurious wildlife species, as described by the USFWS, is one that has been demonstrated to be harmful to either the health and welfare of humans, interests of forestry, agriculture, or horticulture, or the welfare and survival of wildlife or the resources wildlife depend upon. The reasoning for listing Asian carp as injurious wildlife species is twofold. First, the Asian carp are known to cause human injury as described above. Second, Asian carp threaten populations of native fish and mollusks through competition, predation, and altering the food web of aquatic ecosystems. This threat includes the direct impacts to protected or imperiled fish and mollusk populations, sportfish populations, and subsistence and commercial fisheries. The indirect impacts include the economic effects to the recreational and commercial fishing industries, where the reduction in sportfish or food fish populations would lower the quality of fishing experiences and reduce fishing success.

Presence and Threats of Asian carp in the Mississippi and Yazoo Backwater Area[1]

Asian carp have known occurrences in at least 11 of Mississippi's rivers (Smith 2015b). Within the Yazoo Backwater Area (YBA), rivers with known Asian carp populations include the Mississippi, Big Sunflower, Yazoo, Yalobusha, Tallahatchie, Coldwater, and Yocana rivers. Other rivers in Mississippi with known Asian carp populations include the Tombigbee, Wolf, Pearl, and Big Black Rivers.

[1] Additional information and description of the YBA can be found in Reports A and B.

The Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) has conducted multiple fishery assessments within oxbow lakes located within the YBA. Oxbow lakes are bodies of water that are formed when a meandering stream or river experiences continued lateral erosion and eventually bypasses one or more meanders to form a new, straighter channel. The bypassed meander(s) become cutoff from the active channel which results in a U-shaped (or serpentine-shaped if multiple meanders are bypassed), free-standing body of water. Primary sources of hydrology for oxbow lakes, in general, are precipitation and groundwater.

One of the MDWFP studies assessed the effects of silver carp introductions on white crappie (*Pomoxis annularis*) and largemouth bass (*Micropterus salmoides*) in four floodplain oxbow lakes within the YBA between 2010 and 2015 (Aycock 2015). The four floodplain oxbow lakes assessed were Bee Lake, Wolf Lake, Little Eagle Lake, and Belzoni Cutoff. MDWFP compared fisheries data collected prior to and after invasive Asian carp introductions that took place during extensive backwater flooding in 2011 to determine impacts to native fisheries in these four lakes. For crappie and largemouth bass, the catch-per-unit-effort (CPUE), and relative weight declined over time when Asian carp were introduced. In addition, the growth rate of crappie was reduced following carp introduction. This study concluded that the presence of Asian carp has a negative effect on crappie and bass populations. This is the result of outcompeting and reducing the population of crappie and bass, as well as reducing the growth and condition (i.e., weight) of these native fish.

Another study performed by MDWFP included the examination of fisheries data collected from three large oxbow lakes within the YBA to determine the effects of Asian carp presence on native fish populations (Washington 2018). This study compared fisheries data collected in the 1980s and 1990s with data collected in 2016, 2017, or 2018 to evaluate species composition and biomass in Lake Whittington, Tunica Lake, and Eagle Lake. Lake Whittington and Tunica Lake are oxbow lakes that have a connection to the Mississippi River during flood conditions. Conversely, Eagle Lake is an oxbow lake that is protected by the levee system in the YBA, and typically does not connect to the Mississippi River during flood events.

The study found drastic changes in the fisheries of Lake Whittington and Tunica Lake, which appear to be the result of Asian carp introduction between the initial and subsequent surveys. Lake Whittington was surveyed in 1984, 1991, 1992, and again in 2016 and 2018. During the 1980s and 1990s study, no Asian carp were observed during the fisheries assessments. However, during the most recent assessment, Asian carp were the most abundant species by biomass at approximately 200 pounds/acre and comprised 31% of the fisheries catch. Tunica Lake was sampled in 1991 and again in 2017. No Asian carp were collected during the 1991 survey. However, in the 2017 survey, silver carp were the most abundant species by biomass at approximately 385 pounds/acre and comprised 42% of the total catch. Between the 1980s and 1990s and the 2016, 2017, and 2018 surveys, Lake Whittington and Tunica Lake experienced a decline in Centrarchid (i.e., bass, sunfish, and crappie) biomass by over 75%. In addition, Clupeid (i.e., shads and herrings) biomass was reduced by over 90%.

Similar trends were not observed in Eagle Lake. Eagle Lake is a heavily managed sport fishing lake located in Warren County, landside of the YBA levee system which protects it from Mississippi River flooding. Eagle Lake does not have major natural inlets or outlets but is connected to Steele Bayou via the Muddy Bayou control structure which regulates water levels. The Muddy Bayou control structure was constructed as a fish and wildlife mitigation feature to improve fisheries in Eagle Lake (USACE 2019). Asian carp are known to occur in Steele Bayou, but the Muddy Bayou control structure is operated by the U.S. Army Corps of Engineers (USACE) in such a way so that the gate structure opening is too narrow and with increased water velocities that prevent Asian carp from entering the lake (Killgore 2011). Eagle Lake was sampled in 1991, 1992, 1993, 1994 and again in 2017. No Asian carp were observed during any of the surveys. In Eagle Lake, the Clupeid biomass declined slightly by 17% and Centrarchid biomass almost doubled. This change in fisheries community is likely linked to the extensive sportfish stocking and management at Eagle Lake over the last 15 years.

In summary, the MDWFP determined that when Asian carp are present in a lake, and able to reproduce successfully, they tend to dominate the fish community. Native Clupeids and Centrarchids cannot outcompete Asian carp for food resources and ultimately decline in population, growth, and relative weights.

At the time of the latest (2017) MDWFP fisheries survey in Eagle Lake, there was no evidence of Asian carp within the 4,700-acre oxbow lake. However, during the extensive 2019 flooding within the YBA, the Muddy Bayou structure was overtopped with floodwaters and Asian carp were observed swimming across Eagle Lake Shore Road and entering Eagle Lake (Simmons 2019, MDWFP 2019). Following the 2019 flooding, Asian carp have been observed jumping in Eagle Lake when startled from boat motors and have been confirmed by MDWFP (Riecke 2020) and the USACE Engineer Research and Development Center (Killgore 2020). With Asian carp now confirmed to be present within Eagle Lake, the fishery may experience the same fate as Lake Whittington and Tunica Lake, where the native fishery has been drastically altered. Eagle Lake is a prime sportfishing destination with considerable sportfish stocking and management efforts over the last several decades. Therefore, a decline in the native sportfish populations could have significant economic consequences.

Although the introduction of Asian carp into Eagle Lake could have drastic environmental consequences, Asian carp do not have the ability to reproduce in an oxbow lake that does not have connectivity to flowing bodies of water. The common understanding is that spawning Asian carp require free-flowing water and eggs require a long stretch of unbroken river current in which to drift and stay suspended in the water column as they develop (Nico et al. 2020). Although some reports document Asian carp's ability to spawn in shorter lengths of river (Murphy and LaVista 2013), the eggs of Asian carp attempting to spawn in stagnant water will eventually settle to the bottom of the waterbody and die. Therefore, Asian carp may be able to live out their lives in Eagle Lake, but they are not likely to successfully reproduce. Although successful reproduction may not take place, Asian carp are long-lived and may negatively affect native fish populations during their long lifecycle. Introduced carp will eventually die of old age or may be manually removed from the system. Therefore, in the absence of new introductions into Eagle Lake, the negative effects on the native fishery are expected to be relatively moderate or short-lived compared to periodic reintroduction of carp or successful reproduction by carp in the lake.

The MDWFP assessments of Eagle Lake have shown that the lake has a healthy fisheries structure and has remained free of Asian carp through the 1990s and into 2017. Although numerous flood events have occurred over the last several decades, Eagle Lake's location behind the existing river levee has protected it from riverside flooding while the gate structure on Muddy Bayou protects it from backwater flooding. This protected location has prevented the introduction of Asian carp into the lake. Extensive flooding in 2011 introduced Asian carp into numerous oxbow lakes in the YBA, including the aforementioned Lake Whittington, Tunica Lake, Bee Lake, Wolf Lake, Little Eagle Lake, and Belzoni Cutoff, as well as Beulah, Ferguson, Desoto, Washington, Log Loader and Moon lakes, with additional reports of Asian carp presence in Broad Lake, Lake Chotard, and Albemarle Lake (Aycock 2011). However, the 2011 flooding did not appear to introduce Asian carp into Eagle Lake where the species were not observed in 2017.

Conclusion

The likely cause of Asian carp introduction into Eagle Lake is the extensive backwater flooding in 2019. The backwater flooding peaked at 98.2 feet; overwhelming the gate structure at Muddy Bayou and spilling floodwaters into Eagle Lake. The Pump Project would install pumps capable of removing water from the YBA at approximately 14,000 cubic feet per second. To be clear, the proposed pump project will not eliminate backwater flooding, but is designed to limit the extent, depth, and duration of backwater flood events within the YBA and to prevent extreme flooding events such as experienced during 2019. Although impossible to precisely determine the effects of pump operation, the reduced extent, depth, and duration of flooding would have likely prevented the floodwaters from reaching Eagle Lake and allowing invasion of Asian carp.

In addition, the future operation of the proposed YBA pump project would reduce the chance of introducing additional Asian carp into Eagle Lake. Because Asian carp may not be likely to reproduce successfully in Eagle Lake, additional introductions through recurrent flooding or intentional release would be the primary way that the species could persist within the system. Construction and operation of the proposed pump project would prevent the severe backwater flooding that would reintroduce Asian carp into Eagle Lake, and similarly positioned lakes, protecting the future of this valuable recreational fishery.

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