Potential Use of Deterrents to Manage Asian Carp in the Upper Mississippi River Basin

Photo by Chris Young, Illinois DNR

A report prepared by the Upper Mississippi River Asian Carp Partnership

Contents

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Introduction and Background

Bighead Carp, Silver Carp, Black Carp, and Grass Carp, collectively referred to as Asian carp for the purpose of this document, are all present in the Upper Mississippi River (UMR). Population densities of Bighead Carp and Silver Carp decrease with increasing distance upstream from Lock and Dam (L&D) 19 (Ann Runstrom, U.S. Fish and Wildlife Service, unpublished data). Grass Carp are regularly captured throughout the system, but total commercial catch of Grass Carp is much greater below L&D 12 and downstream (Michele Marron, Upper Mississippi River Conservation Committee, unpublished data). Black Carp have not been captured above L&D 22, but reproduction has been documented (i.e., capture of young-of-year) in the Middle Mississippi River (Wes Sleeper, Missouri Department of Conservation, unpublished data). All four species of Asian carp are a threat to the ecology of the Upper Mississippi River and pose different management challenges.

Following objectives outlined in the Upper Mississippi River Conservation Committee (UMRCC) 2010 Fisheries Plan, the Fish Technical Section formed an Asian carp ad-hoc committee to provide suggestions for Asian carp management in a cooperative and collaborative manner throughout the multiple jurisdictions in the UMR basin. The ad-hoc committee (UMR Asian Carp Partnership) is composed of representatives from each of the five Upper Mississippi River States (Minnesota, Wisconsin, Iowa, Illinois, and Missouri) and federal agencies (United States Army Corps of Engineers, United States Geological Survey, United States Fish and Wildlife Service, and The National Park Service). In 2016, the UMR Asian Carp Partnership (partnership) recommended, and the U.S. Fish and Wildlife Service (USFWS) facilitated, travel for a team to evaluate the roles of deterrent technologies as part of an overall strategy to slow or stop the expansion of Asian carp in the UMR. The partnership met face-to-face and via teleconference throughout 2016 and further outlined a goal, developed objectives and strategies, and identified possible actions and performance measures. This report is provided as a record of an ongoing discussion of potential control and management actions for Asian carp in the UMR. It fulfills United States Fish and Wildlife Service reporting requirements for funding provided in FY2016.

The team also considered the best available science to evaluate the efficacy, feasibility, and potential locations for deterrents. This report represents significant progress in developing a plan of action for Asian carp management and control in the UMR. Suggestions made in this report are supported by a majority of the state management agencies in the UMR Asian Carp Partnership, but consensus was not reached. Negative impacts to the native fish community and river ecology as a result of the implementation of Asian carp management actions are real and legitimate concerns. In the process of assessing potential deterrents for this report, potential negative consequences were given a precursory evaluation. Prior to implementation of any action to control or deter Asian carp, a thorough evaluation of negative consequences should to be completed to ensure that impacts of the action do not cause more harm than that which would occur from the Asian carp invasion.

Although this report and the efforts of the deterrent team focused on a single management tool (i.e., deterrents) in the mainstem of the UMR, it is unlikely that any single action in the mainstem will be successful in controlling all four species of Asian carp. Recent captures of young-of-year Silver Carp in pools above L&D 19, and recent telemetry and microchemistry data, suggest that the sources of recruits to the emerging populations of Silver Carp and Bighead Carp above L&D 19 are coming from above and below L&D 19 (Comacho 2016; Larson et al. 2017; Kyle Mosel, USFWS, unpublished data; Jim Lamer, Western Illinois University, unpublished data). Since population growth of Silver Carp and Bighead Carp above L&D 19 has multiple drivers, effective management will likely require a multi-pronged effort targeting various life stages in multiple locations. New and innovative tools like deterrents, in conjunction with additional management and control actions, may be necessary to reduce immigration at key pinch points and control population growth upstream of those points. A comprehensive, integrated and adaptive management approach that applies multiple management tools, monitoring, and evaluation will be paramount for any chance of success in controlling the invasion of Asian carp in the UMR. Additionally, smooth progression of this effort will require engaging stakeholders, particularly the navigation industry.

Implementing deterrents for Asian carp in the UMR presents many challenges. The UMR is an interjurisdictional river where local, Tribal, State, and Federal interests must be considered and factored into management decisions in addition to the interests of various user groups and priorities. Commercial navigation is a $673 million industry (USFWS 2015) that contributes to local, national and global economies, employs thousands of people, and transports over 300 million tons of cargo each year (National Research Council 2013). The agricultural, power, petroleum, and manufacturing industries are dependent on the navigation system for shipping grain, coal, petroleum and other products (USFWS 2015). In 1986, Congress recognized the Upper Mississippi River System as a nationally significant ecosystem and a nationally significant commercial navigation system (WRRDA 1986). The ecological needs require any implementation plan to fully consider habitat and river fragmentation, both for individual fish and species, as well as, a consideration of the impacts to gene flow. Natural resource and navigation management actions could be implemented in a manner to minimize or eliminate impacts to the navigation industry and the ecosystem.

People in the communities along the river and across the nation also depend on the UMR for recreation and ecosystem services. Outdoor recreation contributes over $2 billion in annual revenue (USFWS 2015), and many would argue that the value of ecosystem services is immeasurable, and when lost, can never be fully restored. The ecosystem supports over 120 species of native fish, many of which are considered migratory. Migratory fish populations and associated biota are negatively impacted by reduced connectivity due to the locks and dams on the UMR and other dams in the basin that block fish migration to habitats that are necessary to meet life history requirements (Coker 1929). One example is the loss of skipjack herring, and the mussels to which it hosts, to the upper reaches after the construction of L&D19 (Kelner and Sietman, 2000). Since construction of the first dams, interested anglers, concerned citizens, biologists, and resource managers have worked to restore river connectivity and function to benefit native species (Wlosinski et al. 2004). It is a daunting challenge to manage the river so adequate migration opportunities exist for native aquatic populations while simultaneously considering the spread of Asian carp, other priority river system uses, and the jurisdiction and authority of the agencies involved.

Depending upon design and operation, dams can be complete or partial deterrents to upstream fish movement. In some instances, resource managers may identify specific dams as a boundary preventing volitional invasion of aquatic invasive species. Studies on Bighead Carp and Silver Carp swimming performance and flow models suggest that modification of gate operation may reduce the ability of these species to pass through the gates on some of the dams (Hoover et al. 2017). Recent research has been and continues to be conducted on broadband sound, CO_2 infusion, electrical barriers and other technologies to determine their potential efficacy as deterrents. Research on these technologies within lock chambers or lock approaches for Bighead Carp and Silver Carp remains to be done.

Purpose, Goals, Objectives and Strategies

The purpose of this report is to evaluate the most promising deterrent options at pinch-point lock and dams, identify potential pinch point lock and dam sites in the UMR, and suggest next steps for in-situ research. The opinions and suggestions of resource managers with expertise on fish passage and managing fish and Asian carp in the UMR contributed to completing this report. Any recommendations for testing of deterrent technologies should fully consider broad-scale management considerations of other fish and mussel resources, and consider management authorities of the waters in question. Scientists studying Asian carp deterrents were consulted for development of the fact sheets. This report recognizes and supports the value of research performed at other locations. Decisions to implement deterrents should be made with caution, fully considering target and non-target species effects, human health and safety, and potential impacts to economic factors along the river corridor.

Objective 1: Review promising deterrents and their potential effectiveness for application in the UMR.

Strategy 1.1- Identify the suite of potential deterrents and their associated effectiveness.

- Performance measure: Hold a workshop on sound barriers and distribute notes.
- Performance measure: Conduct face-to-face meetings to discuss deterrents and effectiveness.

Strategy 1.2- Consult deterrent experts and summarize the deterrents to include efficacy, selectivity (i.e. impacts to natives), human health and safety, cost, developmental phase and timing, and environmental compliance and permitting.

- Performance measure: Develop fact sheets on each of the deterrent technologies under consideration.
- Performance measure: Develop a table of parameters of interest for each deterrent alternative.

Objective 2: Develop a list of potential locations for deterrents in the UMR based on the characteristics of the lock and dam (L&D) structures and the status of Asian carp populations.

Strategy 2.1- Identify the best locations for deterrent placement based on Asian carp populations.

- Performance measure: Develop distribution maps of the locations and abundance of the various life stages of Asian carp in the UMR.
- Performance measure: Summarize the best available data on L&D site-specific characteristics (e.g. time in open-river, configuration of gate structures, lock characteristics).

Objective 3: Suggest roles and coordinate testing of deterrents for Asian carp in the UMR.

Strategy 3.1 Provide suggestions and a path forward for experimentation with feasible deterrents.

- Performance measure: Provide review on deterrent technologies to agency decision makers.

Evaluation of Priority Deterrent Technologies and Alternatives (Objective 1)

The development of an Asian carp deterrent strategy began with consideration and discussion of the feasibility of numerous technologies. Sound was identified as having significant promise and the team hosted and participated in a workshop to review the most recent research and discoveries related to the use of sound to deter Silver Carp and Bighead Carp. The workshop was followed by a series of face-to-face meetings where the remaining list of technologies was quickly narrowed down to sound, carbon dioxide, and electricity. Additional alternatives discussed and considered include lock closure, gate modifications, and no action. For each technology and alternative, the group produced fact sheets by compiling information on efficacy, species selectivity, developmental phase, environmental compliance and permitting, cost, health and human safety, and approximate time for implementation. This information is provided in the following sections addressing each alternative.

Sound

Overview: Bighead Carp and Silver Carp are ostariophysans (i.e., have Weberian ossicles that connect the "inner ear" and the swim bladder), and are sensitive to sound (Vetter et al. 2015, Vetter et al. 2018). Studies have shown that specific sound can influence the behavior of Bighead Carp and Silver Carp, while some native species show limited or no response (Murchy 2016). Researchers are working on ways to exploit this reaction by creating a sound field that can be used to divert Bighead Carp and Silver Carp from moving upstream in large rivers. Specific sound characteristics and sound pressures will interact with native fishes differently and should be evaluated prior to implementation. Relative to other deterrents, sound may have the least negative impact to native fishes and other wildlife, is comparatively inexpensive, and should have minimal impacts to navigation.

Efficacy: Underwater sound has been used to divert fish away from hydroelectric turbines and water intakes, thus reducing or minimizing entrainment mortality (Knudsen et al. 1994, Maes et al. 2004). In the lab, Silver Carp and Bighead Carp habituate to pure tones quickly but repeatedly flee from boat motor recordings (broadband sound; 0 to 10 kHz) during laboratory trials at 130 dB – 160 dB (Vetter et al. 2015; Vetter et al. 2017; Murchy et al. 2017). Negative phonotaxic responses seem to diminish at water temperatures below 12C and above 30C. Although early evidence suggests that Silver Carp may habituate to a single complex sound stimulus, further study on this subject is necessary (Vetter et al.

2015). A complete evaluation of the efficacy of sound as a deterrent will depend upon a thorough investigation into impacts on non-target species and other unintended negative consequences. Additional lab and pond testing of alternative sounds and frequencies is needed to better identify the best sound specifics to elicit responses in each species of Asian carp. Field trials are needed to confirm that results from pond and laboratory studies are relevant and reproducible in the intended environment.

Selectivity: Until recently, Bighead Carp and Silver Carp were known to be sensitive to sound frequencies up to 3 kHz (Lovell et al. 2006) which is above a threshold detectable by some native fish species (Speares et al. 2011; Mann et al. 2007; Lovell et al. 2006; Lovell et al. 2005). However, a recent study showed that these species can hear up to 5 kHz, similar to other ostariophysans (Vetter et al. 2018; Ladich 1999). Therefore, it is possible that higher frequencies (between 3 kHz and >5 kHz) could be used to elicit a response in Bighead Carp and Silver Carp and further limit behavioral effects on native fishes. In laboratory and pond experiments using underwater boat motor recordings (0 to 10 kHz), multiple species including Largemouth Bass, Paddlefish, Common Carp, Rainbow Trout, Walleye, Bluegill, Channel Catfish, Lake Sturgeon, Bigmouth Buffalo, Grass Carp, Fathead Minnow, and Gizzard Shad exhibited fewer movement responses compared to responses by Bighead Carp and Silver Carp (Murchy 2016). However, other studies on the effects of sound on aquatic life have shown some negative impacts to fish communication, (Radford et al. 2014) hearing (Bluegill, Scholik and Yan 2002a; Fathead Minnow, Scholik and Yan 2002b), predator avoidance behavior (Ambon Damselfish, Simpson et al. 2016), and foraging (Eurasian Perch, Magnhagen et al. 2017; Three-Spined Stickleback and European Minnow, Voellmy et al. 2014). Very little is known about the overall impacts of noise on fishes (see Popper and Hastings 2009). Additional research is warranted to identify specific sound characteristics (e.g., frequency, intensity, duration of exposure) that are most effective at deterring Asian carp and to fully understand what impacts there are to native species.

Developmental phase: Habituation studies and field applications using sound are currently being conducted on Bighead Carp and Silver Carp. Complex sound has been deployed at L&D 8; however, absence of Silver Carp, Bighead Carp and Black Carp at L&D 8 and extremely low densities of Grass Carp, preclude the evaluation of its efficacy on these species at this location. Although development of the technology is advanced and understood enough to initiate planning, proper design and installation of an experimental system will depend upon results of sound studies currently in progress and completion of ambient sound recording and sound propagation modelling at the site. The abundance of Bighead Carp and Silver Carp at L&D 19 presents an ideal study site for a thorough evaluation, and could be completed relatively quickly (within 1-2 years) with appropriate agency approval and permitting. Although additional lab and pond testing of alternative sounds and frequencies is needed to better identify the best sound specifics to elicit responses in each species of Asian carp, an experimental system could be installed with current knowledge of the technology. Ambient sound recording, environmental monitoring, and sound propagation modelling could be part of that experiment, along with engaging the navigation industry with the deterrent team. Such a system would allow for additional studies to further define which specific sound characteristics (e.g., frequency, intensity, duration, and timing relative to lock operation and other sources of ambient sound) may be most effective at deterring Bighead Carp and Silver Carp.

Environmental Compliance and Permitting: Any planning for sound testing would require a case by case evaluation of potential impacts including clear goals and objectives noting potential impacts and conflicts with consideration of best locations. Construction permitting is handled by the USACE and may include seeking approval for installation of equipment using the Section 408 process of Section 14 of the River and Harbors Appropriation Act. The National Environmental Policy Act (NEPA) requires environmental review (i.e., Environmental Assessment, Environmental Impact Statement) consultation with NEPA experts to be a part of any proposed experiment. Local permitting may also be necessary as well as coordination with local fish management agencies e.g. UMRCC, States.

Estimated Cost: Very little information is available on the cost to develop a system that may be effective for Asian carp deterrence on such a large scale. A thorough evaluation of the specific environment where the equipment is to be deployed is necessary to develop the proper design. Ultimately the cost of the system will be dependent on location and type of deterrent tested and is relatively unknown. Evaluation of any experiment will depend on the questions posed. Sound is likely less expensive in comparison to other potential deterrence technologies such as electricity and CO2.

Human Health and Safety: The speakers installed at L&D 8 were initially operated to automatically produce an outboard motor sound of about 170 dB, measured in the water in front of the speakers, when the gates opened. However, after several weeks of operation, a few barge crews reported difficulty hearing their captain speaking on their two-way radios in the immediate vicinity of the open gates when tow engines were also operating. The sound level of the speakers was reduced to about 150 dB underwater in front of the gates, and no further complaints have been received regarding this issue (Peter Sorenson, University of Minnesota, personal communication). An ongoing study, conducted at Brandon Road Lock and Dam on the Illinois River, suggests that sound may need to be projected at 170 - 180 dB to be effective; however, the above water projection of sound can be reduced if speakers are not mounted to the lock gates as they are at L&D 8 (Marybeth Brey, USGS, personal communication). Further study into the most effective speaker configuration is also required.

Approximate Time to Implementation: Habituation and field studies could commence soon, and may be completed within two years. Investigation into the impact of sound on other fish species, completing reviews (if warranted), and obtaining necessary permits will likely take up to three years.

Carbon Dioxide (CO_2)

Overview: Carbon dioxide (CO_2) is one of a suite of Asian carp deterrents in development with proposed utility for multiple application types. Carbon dioxide may benefit Asian carp management by denying access to critical habitat, blocking upstream movement, reducing overwinter survival, and pushing fish into locations to promote harvest/removal.

Efficacy: Carbon dioxide is a naturally occurring compound found to be an effective deterrent and immobilizing agent on various invasive fishes. Research has shown the effectiveness of CO_2 as a deterrent to be similar across species, life-stages, and water temperatures (Ishimatsu et al. 2005; Clingerman et al. 2007; Kates et al. 2012; Dennis et al. 2015; Donaldson et al. 2016; Cupp et al. 2017a).

Additionally, the efficacy for CO_2 as a lethal control for Silver Carp, Bighead Carp, Grass Carp, and Common Carp has been established (Cupp et al. 2017b).

Selectivity: CO_2 is a non-selective control agent that functions by disrupting normal respiration and acid-base regulation (i.e., lowers blood pH).

Developmental phase: USGS, USACE, and the University of Illinois have conducted numerous laboratory and pond tests using CO_2 and Bighead Carp, Silver Carp, and Grass Carp. Field testing was initiated in 2016 and will continue.

Environmental Compliance and Permitting: USEPA Section 18 permit (emergency use) requesting research applications of CO_2 in open water applications including barrier operations is required. The requirement for a Section 18 permit for the proposed 2018 field trial of CO_2 at Lock and Dam 14 in the auxiliary lock has been exempted by USEPA due to the small size of the trial area. USFWS Section 7 consultation is ongoing and a number of studies related to the physiological response of native mussels to CO_2 have been completed. Additional permitting includes Section 404 Clean Water Act, Section 408 Rivers and Harbors Act, Section 10 Rivers and Harbors act as well as NPDES permits. State permits are required and currently delaying progress.

Estimated Cost: Estimated startup costs are unclear at this time. USACE estimated that between 3-5 tons/hour are needed to treat Brandon Road lock with a seven minute interaction time. Accurate cost estimation at other sites would require consideration of specific differences and incorporating them into the estimate, so operational costs may vary substantially across sites. Additionally, pricing for CO_2 varies by State (i.e., gas, liquid, dry ice) and by vendor.

Approximate Time to Implementation: Transition from laboratory to field application is ongoing. Proposed field trials include blocking movement of Asian carp into backwater habitat, enhancing removal efforts, and as a lethal control for Asian carp under-ice. Applications at lock/approach channels to deter the movement of Asian carps are being developed for CY 2018. Implementation is ultimately contingent on regulatory permitting.

Other Considerations: Some applications require large volume CO_2 injection equipment. Delivery and storage of CO_2 would be site specific. Additional research is required to determine impacts on the lock structure. Fish removal post application will need to be addressed, as well as, completing additional research on impacts to non-target species. Potential impacts to navigation need to be identified and addressed.

Electricity

Overview: All fishes are susceptible to electrical shock, with susceptibility dependent on conductivity and fish size. An electric dispersal barrier creates an electric field in the water that repels and may stun fish. An electric barrier consists of steel electrodes mounted across the bottom of the approach channel to a lock and is powered by land-based power generation and distribution equipment. Electrical barriers are used throughout the world, most notably to deter Asian carp from entering the Great Lakes from the Mississippi River Basin through the Chicago Sanitary and Shipping Canal (CSSC). These barriers are the only known barriers in the world in a large body of flowing water designed to completely block the movement of fishes. Asian carp abundance immediately below these barriers is currently extremely low.

Efficacy: Numerous field and lab studies exist and are ongoing that have tested the efficacy of electric fields to stop or guide fishes. Generally, smaller fishes are less susceptible to electric fields. Efficacy can also be affected by water temperature and changing conductivity. Recent research has shown that the potential to inadvertently entrain fishes through electric barriers by passing water craft is a possibility (Davis et al. 2016). Barriers need routine maintenance that sometimes causes them to go down for short periods of time, but generally electrical barriers can have a high degree of effectiveness.

Selectivity: Recent unpublished research indicates that there is a limited amount of species selectivity among the small number of species tested. However, selectivity occurs based on the size of the fish. Electric barriers are most effective on fishes swimming upstream.

Developmental phase: Electrical fields are considered effective management tools for guiding or blocking fish passages with many applications throughout freshwaters of the world (Noatch and Suski 2012). Active research is ongoing to better refine best operating parameters for electric barriers (e.g. pulse length, duration, frequency, power). Current research is also aimed at looking at inadvertent vessel entrainment of fishes, particularly small fishes, at the barrier in the CSSC (Davis et al. in press).

Environmental Compliance and Permitting: Required permits would include NEPA (EA), USCG safety testing and permitting, 401 certification , 408 permitting, local safety testing (e.g. ground currents), and potentially more. Impacts to navigation need to be identified and addressed. Local, regional, state and other permits may be required.

Estimated Cost: Large barriers such as those in the CSSC are expensive to construct and operate (e.g. approximately $20 million or more for construction for a single barrier, over $15 million or more for annual operations and maintenance).

Human Health and Safety: Electrical barriers, depending on their strength, can be dangerous to humans. No known fatalities have been reported, but there are incidences of injuries. The USCG has tested human safety at the CSSC barriers and numerous regulations are in place for keeping mariners safe as they traverse the area and for keeping bystanders away from the barriers. Electric barriers at a lock and dam location may provide additional concerns.

Approximate Time to Implementation: An electrical barrier would take approximately 4 years to completion in a best-case scenario.

Lock Closure

Overview: Lock closure would create a fish barrier at Upper St. Anthony Falls, L&D 1 and L&D 19 on the Upper Mississippi River. These dams have a difference in water elevation from the downstream side of the dam to the upstream side of the dam greater than a 500-year flood discharge, which effectively limits upstream movement of Asian carp to the lock.

Lock closure would include the removal of the upstream gate from the lock and replacement with a permanent concrete wall that ties into the existing gate sill and lock walls to structurally separate the upper pool from the lower pool. Concrete plugs would be placed in each upstream lock culvert intake to permanently close the aquatic pathway through the filling and emptying culverts. The lock at Upper St. Anthony Falls was closed to navigation in 2015; however, the legislative language retained the option to pass flood flows through the lock.

The other dams on the Upper Mississippi River have a combination of roller and/or Tainter gates and many have a spillway. These features provide pathways for fish passage. When higher volumes of water flow down the river, the roller and Tainter gates on the dam are lifted completely out of the water (i.e., open-river conditions). This is important for fish passage because the gated portion of the dam has no hydraulic head under open-river conditions, and it is the best opportunity for fish to move upstream (Wlosinski et al. 2004). There are no barriers that can be applied to the gated section and the submerged spillways which are over half a mile wide at some UMR dams.

Efficacy: Lock closure is 100% effective at preventing natural movement of fish upstream through the lock at the sites identified.

Selectivity: Lock closure is a non-selective obstruction to the upstream movement of all fishes. Passing desired species would require human intervention such as a fish passage structure with manual sorting or capture, truck and transport over the dam.

Developmental phase: This option is not being developed at this time.

Environmental Compliance and Permitting: Prior to implementation, Congressional de-authorization of the 9-foot navigation channel would be required, along with meeting requirements of NEPA, National Historic Preservation Act, Clean Water Act Section 404(b)(1) and Section 408. Local, regional, state and other permits may be required.

Estimated Cost: The rough estimate of closing Lock 19 is approximately one million dollars; however, the cost of closing the lock would likely impact the Midwest economy in excess of one billion dollars (USACE 2004, Meyer et al. 2007). In 2016 alone, 27.7 million tons of agricultural, chemical, and petroleum products and manufactured goods passed through Lock 19 (USACE 2017). These commodities would have to move via land-based modes if the lock was closed.

Human Health and Safety: There would be minimal direct impacts; however, there would be significant impacts if commercial transportation in the upper Midwest is transferred to rail, pipeline and road.

Approximate Time to Implementation: It would take one year after authorization to implement (WRRDA 2014).

Other Considerations: Lock closure would divide the inland waterway and have a significant and permanent impact to navigation and the economy of the Midwest and the nation. Such a proposal would need involvement of state jurisdictions and may be contrary to local and national strategies.

Gate Modifications

Overview: Lock and dam structures impact fish movement resulting in a negative impact on some native fish populations in the UMR (Coker 1929). The extent of impact is based on swimming performance, physiology, and life history requirements of individual species and physical aspects of the L&D such as structure design, hydrologic conditions, and operational procedures (Wilcox et al. 2004). Because of this, the existing L&D system in the UMR might provide opportunities to impede expansion of Asian carp populations. The majority of the dam structures in the system contain tainter and/or roller gates with the exception of L&D 19, L&D 1, and Upper St. Anthony Falls L&D. These three structures are impassable to fish except through the lock chambers. For dams with roller or tainter gates, some are more of a barrier than others based on operating parameters of the gates, especially how often, when, and for how long gates are 100% open during high-water conditions (Figure 1) (Wilcox et al. 2004). Models suggest that fish deterrence at dams with tainter and/or roller gates can be increased by maximizing current velocity through the gates.

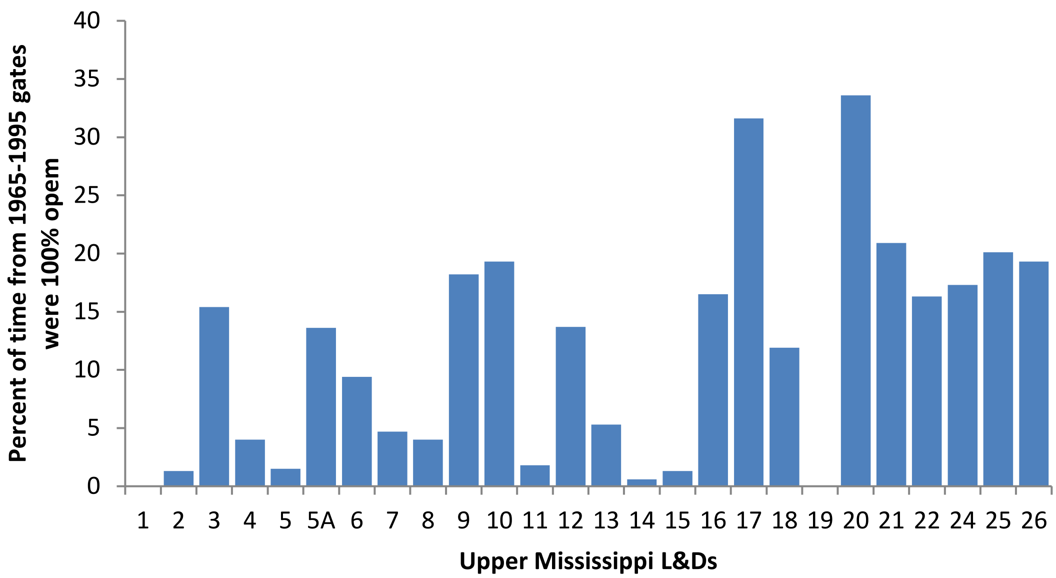

Figure 1. Percent of time all gates of individual Lock and Dams were 100% open (i.e., hydraulic head ~0) during high flow conditions from 1965-1995 (Wilcox et al. 2004).

Efficacy: Concurrent tests of Silver Carp swimming performance (Hoover et al. 2017), other fish passage research and ongoing computer modeling at the University of Minnesota suggest that by making some changes in how the gates are operated, current velocity can be altered so that it exceeds the swimming capabilities of Asian carp (Peter Sorenson, University of Minnesota, personal communication). The maximum effectiveness of current velocity as a deterrent will vary from structure to structure, and decreases as the percentage of time the structure is in open- or near open-river conditions increases because current velocities are reduced during these conditions. Additionally, the University of Minnesota's flow model assumptions and computations need field verification. Studies suggest that Silver Carp, Bighead Carp and other fish move through UMR locks and spillway gates during closed- and open-river conditions (Wlosinski et al. 2004; Tripp et al. 2013) and during times of significant hydrographic changes (Kyle Mosel, USFWS, unpublished data), such as those that occur during open- or near open-river conditions. This could potentially negate efforts to deter Asian carp with gate operations. However, even with minimal effectiveness as a deterrent, altering gate operations may be relatively simple, have few if any negative impacts, and are therefore worthy of consideration, particularly at dams that rarely operate at open-river conditions.

Selectivity: The impact of gate modifications is directly related to individual species swimming capabilities. Data suggest that adult Bighead Carp and Silver Carp have swimming capabilities similar to that of many native large river species (Hoover et al. 2017). Modifications made to impede Bighead Carp and Silver Carp would likely also impact many native species. Consideration of time of year may be important when implementing this strategy.

Developmental phase: Modeling is necessary since physical measurements of current velocities are not possible at the structures. The Sorensen Lab at the University of Minnesota – Twin Cities has developed a model to compute flow velocities through the dam gates. The model was first applied and completed at L&D 8. The lab is currently working on the model for L&D 2. The lab is also currently evaluating the model with funding support from the Minnesota Department of Natural Resources, the USFWS, and US Army Engineer Research and Development Center.

Environmental Compliance and Permitting: U.S. Army Corps of Engineers must accept and implement recommendations from flow modeling and coordination with state and local management agencies would be required.

Estimated Cost: Modeling would cost $100,000 - $150,000 per structure.

Human Health and Safety: Water flows below dams are always hazardous. Adjustments to flow does not decrease or increase this hazard as a whole but may impact localized areas around the structure.

Approximate Time to Implementation: If the suggested operating parameters are within existing water control standards, this alternative can be implemented immediately. If recommended Asian carp control parameters require changes to the water control manual, implementation would take over one year if allowed, or 6 months per structure for modeling.

Other Considerations: Gate operation modifications will not achieve 100% effectiveness. Additional strategies could be explored and applied. Flow modifications address only the dam portion of the structure. Alternative technologies need to be implemented in the lock portion to further reduce movement past the structure. Potential impacts to navigation need to be identified and addressed. Unintended effects for spawning fish habitat, erosion, etc. must be evaluated on a site specific basis.

No Action

Overview: Risk assessments suggest that all four Asian carp species can survive and reproduce in climates similar to those throughout the UMR basin (Kolar et al. 2007, Nico et al. 2005, Fisheries and Oceans Canada 2016). It is anticipated that once established, these species will be permanent components of the fish community, as has happened with numerous established non-indigenous species (Common Carp, Alewife, Sea Lamprey, Zebra and Quagga Mussels, Purple Loosestrife). Consideration of no action should weigh the costs of Asian carp impacts to the UMR ecosystem services, economy, and recreation against the costs and expected negative impacts from implementation of a deterrent. In consideration of a no-action alternative, the fundamental question should be, "Will implementation of a management action negatively impact native species and ecosystems more than established populations of Asian carp?"

Efficacy: Risk assessments suggest that all four Asian carp species can survive and reproduce in climates similar to those throughout the UMR basin (Kolar et al. 2007, Nico et al. 2005, Fisheries and Oceans Canada 2016). No action increases the risk of spread and establishment in the UMR and beyond.

Selectivity: The L&D system has impacted the movement of native species and appears to have slowed the upriver population expansion of Asian carp. Yet, the system has only slowed the progression as evidenced by captures as far north Redwood Falls, MN, in the Minnesota River basin.

Developmental phase: No development is necessary with this alternative.

Environmental Compliance and Permitting: No environmental regulations or permitting requirements need to be met with this alternative.

Estimated Cost: Since no actions would be undertaken, there are no direct costs. There are costs associated with the loss of ecosystem goods and services impacted from the invasion to native ecosystems, recreational value, and river related economics.

Human Health and Safety: Since no actions would be undertaken, there are no direct impacts from actions. The establishment of Silver Carp would pose human safety risks as this is the species that jumps when startled.

Approximate Time to Implementation: This alternative can be implemented immediately.

Other Considerations: Consideration of no action should weigh the costs of Asian carp impacts to the UMR ecosystem services, economy, and recreation against the costs and expected negative impacts from implementation of deterrents. "No action" in regard to deterrents should not be confused with NO ACTION. For example, deterrent strategies should be considered in the context of an integrated approach using all tools available.

Deterrent Locations and Suitability of Locks and Dams as Deterrent Sites (Objective 2)

Status of the Asian carp populations is one primary factor contributing to whether or not a particular dam is a suitable site for a deterrent. Bighead Carp and Silver Carp are established throughout the Lower and Middle Mississippi River and in portions of the UMR. Population assessment sampling for Silver Carp and Bighead Carp in Pools 16-20 of the UMR completed by Western Illinois University (WIU), Iowa State University (ISU), USGS and USFWS in 2013-2016 has provided valuable data on the status of Silver Carp and Bighead Carp populations in this portion of the river. Silver Carp and Bighead Carp are much more abundant downstream from L&D 19 where reproduction, recruitment and high densities characterize the population (Appendix A, figures A-1 and A-2). Both Silver Carp and Bighead Carp can be predictably captured in areas of pools 16-19 (Ann Runstrom, USFWS, unpublished data). Catch rates decrease as sample location moves upstream, reflecting the decreasing population densities as distance upstream from L&D 19 increases. Reproduction of Silver Carp, Bighead Carp and Grass Carp has been documented in this reach with the collection of eggs and larvae each year since 2013 (Larson et al. 2017) Above L&D 15, reports of Bighead Carp and Silver Carp are infrequent and these fish are usually captured by commercial fishers or snagged by anglers. For the first time, significant numbers of young-of-year Silver Carp (47-170 mm) were captured in Pool 18 in August 2016 (Nick Bloomfield, USFWS, unpublished data; Jim Lamer, WIU unpublished data). The Bighead Carp and Silver Carp populations between L&D 19 and 15 are considered transitional from robust core populations (e.g., reproducing, sustaining and emigrating, recruiting to other zones) below L&D 19 to only incidental captures above L&D 15. The deterrent team refers to this transition area as the UMR intensive management zone for Bighead Carp and Silver Carp (Appendix A, figures A-3 and A-4).

For Grass Carp, L&D 5 was identified as the most reasonable location to consider deterrents to upstream migration because Grass Carp are commonly captured below there, especially below L&D 13, and L&Ds 5 and 11 rarely open as compared to Dams 5A through 13 (Figure 1). Grass Carp are widely distributed throughout the UMR, due in part to past stocking practices. Commercial catch reports and agency data suggest densities are much higher below L&D12 than they are upstream (Figure2; Appendix A, Figure A-5). Grass Carp are still legally traded in many States including several States that allow diploid individuals (capable of reproducing). The deterrent team briefly discussed potential for L&D 11 as a deterrent site for Grass Carp, but recognized the need for more recent data of open-river conditions, more reliable population data, and the issue of legal private production of diploids as reasons to not pursue it for consideration at this time.

Black Carp have not yet been captured above L&D 22. Age, ploidy, and microchemistry data provide strong evidence that Black Carp have been reproducing in lower portions of the UMR, perhaps as early as 2010 (Greg Whitledge, Southern Illinois University, and Duane Chapman, USGS, personal communication). In 2015 and 2016, Black Carp reproduction was further documented with catches of young-of-year in the lower reach of the UMR in a drainage ditch off the Castor River Diversion Chanel near Cape Girardeau, Missouri (Quinton Phelps, West Virginia University, personal communication) (Appendix A, Figure A-6). Additionally, 18 diploid sexually immature Black Carp less than 710 mm total length (TL) were captured and reported by commercial fishers near L&D 26 in 2016. Based on these findings, the deterrent team identified the management zone in the mainstem UMR for Black Carp to be from L&D 22 and downstream (Appendix A, Figure A-7). The densities of Black Carp in this zone may be too low to implement removal efforts, but monitoring is occurring.

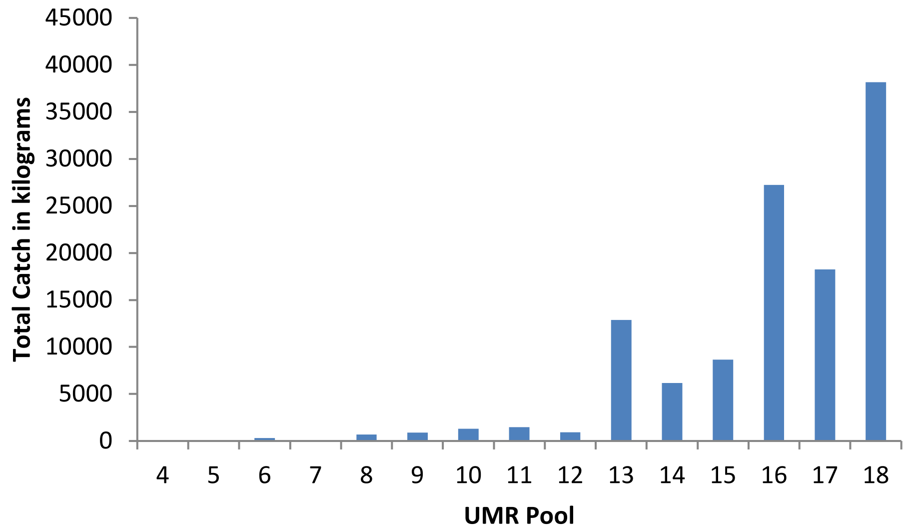

Figure 2. Total commercial catch of Grass Carp captured in the UMR from 2002-2012 as reported to the UMRCC from the States of Illinois, Iowa, Wisconsin, and Minnesota.

Physical characteristics, hydrologic conditions and operational procedures of each L&D also speak to the degree to which each structure may be altered as a potential Asian carp deterrent site. The operational portion of the majority of dams in the UMR system contains Tainter and/or roller gates. The operating parameters of the gates, especially how often, when, and for how long gates are open during high water conditions influence the extent which each dam blocks fish trying to move upstream (Figure 1,Table 1). Silver Carp, Bighead Carp and other fish species are known to move through gates of dams on the UMR (Wlosisnki et al. 2004; Tripp et al. 2013; Kyle Mosel, USFWS unpublished data), especially during times of high flow and low head. L&D's 2, 5, 14, and 15 are seldom in open-river conditions relative to other dams in the system (Wilcox et al. 2004), therefore these structures may restrict fish movement more than dams that are in open-river conditions more often. L&D's 1 and 19 do not have roller or Tainter gates, and the only pathway for upstream fish passage is through the lock chambers. The gated-spillway for these dams has a concrete sill that maintains a vertical drop under all flow conditions which precludes upstream fish passage (Wilcox et al. 2004). Installation of an effective Asian carp deterrent in the lock chamber or lock approach at L&D 19 would reduce upstream passage through the only available pathway at this dam.

Table 1. Summary of L&Ds considered as potential sites for implementation of deterrent measures.

Lock and Dam	Management Zone	Roller Gates			Tainter Gates			Normal Head (m)	Head Gates Open (m)	Pool Elev. (m)	Spillways		Lock Tonnage CY 2016 (in billions)	Percent Time in Open River
		No.	Height (m)	Width (m)	No.	Height (m)	Width (m)				Type of Spillway	Crest Elev. (m)		
2	No	0			19	6.10	9.14	3.7	0.15	209.5	none		10.199	1.3
5	Line Drawn for Grass	6	6.10	18.29	28	4.57	10.67	2.1	0.15	201.2	none		11.202	1.5
14	No	4	6.10	30.48	13	6.10	18.29	3.3	0.64	174.3	none	174.3	23.453	0.6
15	Yes, Bighead,Silver	11	7.92	30.48	0			4.9	0.24	171.0	none	171.0	23.804	1.3
19	Yes, Bighead,Silver, Line Drawn for Black	0			119	3.35	9.75	11.1		157.9	none	157.9	27.691	0.0

Lock and Dam 2

L&D 2 is upstream of Hastings, Minnesota at River Mile 815.2. The project includes a lock, an abandoned lock, power plant, concrete dam structure 722 feet long with 19 Tainter gates, and a 3,000 foot earthen dike. The current lock is 110 feet wide by 600 feet long. The capacity of the power plant is 4.4 megawatts and is owned and operated by the City of Hastings. The Minnesota River is a major tributary in Pool 2 and a significant river resource in the State of Minnesota.

Figure 3. Upper Mississippi River L&D 2 near Hastings Minnesota. USACE photo.

Lock and Dam 5

L&D 5 is located at Mississippi River Mile 738.1 in Minnesota City, Minnesota, 5.5 miles upstream of Fountain City, Wisconsin. The main lock is located along the right descending bank and consists of a single lock chamber 110 feet wide by 600 feet long with an upper pool elevation of 660.0 feet, a tailwater elevation of 651.0 feet, and a vertical lift of 9.0 feet. There are miter gates at each end of the lock chamber and a partial auxiliary lock consisting of an upstream set of miter gates and short concrete riverwall section. The foundation consists of piles in sand and gravel.

The movable dam has six roller gates (20 feet high by 60 feet long), 24 non-submersible Tainter gates (15 feet high by 35 feet long), and four submersible Tainter gates (15 feet high by 35 feet long). The dam consists of a concrete structure 1,619 feet long and an earthen embankment approximately 18,500 feet long, located between the movable dam and high ground on the Wisconsin side of the river. The dam foundation is set on piles in sand.

Figure 4. Upper Mississippi River L&D 5 in Minnesota City, Minnesota. USACE photo.

Lock and Dam 14

L&D 14 is near Pleasant Valley, Iowa, at River Mile 493.3. The site is also 3.6 miles below the head of the rock-bedded, Rock Island Rapids. The LeClaire Lock and the remains of the LeClaire Lateral Canal, built in 1921-1924 to bypass this treacherous stretch of river, are located along the Iowa shore. The main lock's dimensions are 110 by 600 feet. The dimensions of the LeClaire Lock, which is used as an auxiliary lock, are 80 by 320 feet, with a low-water depth of eight feet at the upper sill and seven feet at the lower sill. The main lock's maximum lift is 11 feet with an average lift of 9.8 feet. It takes approximately eight minutes to fill or empty the main lock. The movable dam has 13 non-submersible Tainter gates (20 feet high by 60 feet long) and four submersible roller gates (20 feet high by 100 feet long). The dam system also includes an earth and sand-filled dike. It takes nine hours for water to travel from L&D 13, in Fulton, Iowa, to L&D 14.

Figure 5. Upper Mississippi River L&D 14 near Pleasant Valley, Iowa. USACE photo.

Lock and Dam 15

L&D 15 is located in Rock Island, Illinois, at River Mile 483. The complex stretches across the Mississippi River at one of its narrowest points at the foot of the Rock Island Rapids extending from the northwest tip of the Army's Arsenal Island on the Illinois side, to a small area of flat-bottom land on the Iowa side. A roadway and railroad bridge, joining Davenport and Rock Island, spans the site.

The main lock is 110 feet wide by 600 feet long; the auxiliary lock is 110 by 360 feet. Both have a maximum chamber lift of 16 feet with an average of 13 feet and take about seven minutes to fill or empty. Each lock gate weighs nearly 82 tons. The 1,203-foot-long movable dam is the largest roller dam in the world consisting of 11 non-submersible 100-foot-long roller gates with 11 control houses. Nine gates are 19 feet 4 inches in diameter and two are 16 feet 2 inches. It takes three hours for water to travel from L&D 14, in Pleasant Valley, Iowa, to L&D 15.

Figure 6. Upper Mississippi River L&D 15 in Rock Island, Illinois. USACE photo.

Lock and Dam 19

L&D 19 is at River Mile 364.2 in Keokuk, Iowa. The lock, located on the Iowa shore, is 110 feet wide and 1,200 feet long, twice the size of the standard 9-Foot Channel Project lock. The upper lock gates consist of 23-foot high vertical lift gates, and the lower gates are miter gates, 53-feet 2-inches high. The lower lock gates are conventional miter gates, while the upper service gate is a submersible lift gate. The upper gate includes a concrete sill that extends 36.7 feet from the floor of the lock chamber (elevation 466.7 feet) into the water column (elevation 503.2 feet). When the lock opens for upstream passage or downstream entrance into the lock and the water level is at upstream pool elevation (518.2 feet), the gate submerges and straddles the sill allowing 15 feet of clearance above the sill for vessels (and fish) to pass. The upper gate closes by rising vertically from the sill. Upstream from the upper service gate is a submersible vertical-lift guard gate which serves as an emergency gate in case of failure of the service gate. This gate also serves as a bridge in the roadway to the old dry dock, old lock, powerhouse and dam, and is similar in construction and operation to the service gate with a 36-foot concrete sill extending up from the floor.

The lock's land wall is 2,161 feet long, consisting of an upper 237-foot and lower 605-foot guide wall, and a 1,319-foot main lock wall. The river wall is 1,936 feet, which includes a 532-foot wall downstream of the lower gate pintles.

Maximum lift is 38.2 feet with an average of 36.3 feet, the second highest on the Mississippi River. The highest lift of any lock on the River is at the Upper St. Anthony Falls in the St. Paul District. Filling the lock takes approximately 10 minutes; 9.25 minutes to empty. It takes 12 hours for water to travel from L&D 18, in Gladstone, Illinois, to L&D 19. Pool 19 is the longest of the nine-foot channel navigation system.

An auxiliary lock, which was the original lock completed on June 12 1913, is 110 feet wide by 358 feet long. This lock is no longer in service. The dry dock is also no longer in use and measures 150 feet wide by 463 feet long.

The dam, privately built in 1913, includes 119 rectangular sliding gates. The dam is privately owned and operated by Ameren Missouri. The USACE has no oversight or control of the dam's operation.

Figure 7. Upper Mississippi River L&D 19 in Keokuk, Iowa. USACE photo

Summary

In preliminary trials, CO_2 affected all species and sizes of fish (Ishimatsu et al. 2005, Kates et al. 2012, Dennis et al. 2015, Donaldson et al. 2016, Cupp et al. 2017a, 2017b). The non-selective nature of CO_2 is problematic as there is much uncertainty regarding impacts to native fish populations and native fish passage. Studies have been proposed, but currently efficacy of CO_2 in a lock chamber is not yet known. The initial equipment cost is potentially expensive, there are potential delays in lock operations and the associated economic impact, and there may be limited space for the footprint of the equipment. Finally, further field experimentation would be necessary prior to implementation in the UMR. This deterrent option is not currently available for implementation and may be reconsidered as new information becomes available.

Electricity as a fish deterrent has a proven track record in slowing/stopping fish movement; however, it is expensive to build and operate and may not control smaller fishes. Barges may also entrain fish past barriers, and there are human safety concerns. This group does not suggest implementation of electricity as a deterrent in the UMR *at this time* due to these limitations, especially the human safety concerns associated with application in a lock or lock approach.

The use of sound in a lock or lock approach to deter Asian carp has some advantages over other deterrents considered. Sound is relatively inexpensive to deploy and operate, is seemingly selective for ostariophysan fishes, appears to be highly effective on Silver Carp and Bighead Carp in a laboratory setting, has few environmental compliance issues, and has low human health risks (Lovell et al. 2005; Lovell et al. 2006; Mann et al. 2007; Murchy 2016; Speares et al. 2011; Vetter et al. 2015; Vetter et al. 2017). The technology is not yet proven in a large field setting and has not been evaluated on Black Carp or Grass Carp. Furthermore, there is concern that the technology may deter native fishes. This group suggests further examination of sound as a tool to deter Silver Carp and Bighead Carp at lock approaches in the UMR Basin or other like habitats where research can inform future implementation. Investigations into its effects on Grass Carp and Black Carp are needed Upon the noted research results, management alternatives can be adequately assessed and made to relative management agencies.

Modification of gate operation to deter fish at strategic dams could be simple, expedient, and inexpensive. However, engineering and impacts to fisheries and human safety considerations need to be discussed and evaluated with USACE and others. Should the modelling and swimming performance studies show it is possible to modify gate operations so that conditions exceed the swimming performance of Bighead Carp, Silver Carp, or Black Carp, further investigation is warranted. Risk to native fish populations should be part of the investigation and any field application should be evaluated prior to full implementation. Consideration of the historical hydrograph and related gate settings along with the life history of Asian carp needs to be incorporated into this modelling to determine the overall efficacy of this approach.

With the exception of Upper St. Anthony Falls, L&D 1, and L&D 19, gates at all the UMR dams can be positioned “open” so that there is little to no hydraulic head during high flow situations. When this occurs, the river and the dam are considered to be in “open-river” conditions. The gates at Upper St. Anthony Falls, L&D 1, and L&D 19 have a vertical sill that maintains significant vertical lift (i.e. hydraulic head) and precludes upstream fish passage through the dam portion of the structure even when the gates are open. The lock at Upper Saint Anthony Falls was closed in 2015. This was an exceptional situation where there was very little commercial navigation, the City of Minneapolis supported closure, and there was strong public support. Lock 1 also has very little navigation, but closure would only protect 6 miles of river and there are no tributaries in that reach. Because of the significance to navigation and the economy, it is not feasible to close Lock 19.

Taking no action (i.e., no deterrent action) eliminates the concerns directly associated with installing, testing and operating a deterrent, such as health and safety risks, cost, permitting, and engineering. However, the costs associated with Asian carp expansion in the UMR (e.g. to recreation, fisheries, human safety, and ecosystem services) must be included in the sum cost of no action. Mitigative measures of management and control through harvest and removal needs to be included in such cost/benefit analyses.

Table 2. Summary of parameters of interest for deterrent alternatives under consideration for implementation in the Upper Mississippi River.

Alternative	Species Specific	Cost	Asian carp species	Safety Concerns
Sound	Somewhat	Low to Moderate	Bighead, Silver	Low
CO2	No	Moderate	All	Low
Electricity	No	High	All	High
Lock Closure	No	Unacceptable	All	NA
Gate Modifications	No	Low	All	Low
No Action	No	None Relative to Status Quo	All	NA

Conclusion

The Upper Mississippi River System was recognized by Congress in 1986 as a nationally significant ecosystem and a nationally significant commercial navigation system. Managing the priorities for this unique river requires the participation from many State and Federal agencies and stakeholder groups. President Obama recognized the enormity of the invasive species issue in Executive Order 13751- Safeguarding the Nation from the Impacts of Invasive Species, stating; “It is the policy of the United States to prevent the introduction, establishment, and spread of invasive species, as well as to eradicate and control populations of invasive species that are established. Invasive species pose threats to prosperity, security, and quality of life. They have negative impacts on the environment and natural resources, agriculture and food production systems, water resources, human, animal, and plant health, infrastructure, the economy, energy, cultural resources, and military readiness. Every year, invasive species cost the United States billions of dollars in economic losses and other damages.”

There is no “silver bullet” for managing Asian carp. The need is obvious and the solutions are unclear and complex. There are sections of the UMR that have been significantly impacted by the overabundance of Bighead Carp and Silver Carp, and it is unlikely that these areas will ever be carp free; however, there are management actions that can be taken to limit abundance and reduce the adverse effects in many reaches. Invasive species management can be successful as demonstrated by integrated management actions taken to control Sea Lamprey populations in the Great Lakes which have reduced the negative impacts this invasive has had on Great Lakes fisheries (Lavis et al. 2003, Smith and Tibbles 1980).

The approaches described within this report represent our current understanding of deterrent technologies and recognizes informational needs. The development and testing of new and innovative controls and deterrents through the collaborative research efforts of Federal and State agencies, universities, nongovernmental organizations, and private industry can expand management possibilities in the future. Effective management will require robust monitoring, thorough evaluation of objectives, goal driven research, an adaptive approach, long-term oversight and the financial support of State and Federal agencies.

Potential Use of Deterrents to Manage Asian Carp in the Upper Mississippi River Basin is a starting point by which natural resource managers can consider alternatives to plan and manage the UMR system to prevent further degradation and restore impacted areas. It is intended to inform discussions with a broader audience to protect our natural resources while considering the viewpoints of others using an integrated management strategy. A solution can be achieved only through lasting collaboration between State and Federal agencies and stakeholder groups.

Although this report and the efforts of the deterrent team focused on a single management tool (i.e., deterrents), the team recognizes that it is highly unlikely that a single management action will be successful. We suggest that a comprehensive, integrated and adaptive management approach be taken to manage Asian carp in the UMR. Management zones in the UMR for Silver Carp, Bighead Carp, and Black Carp have been identified as shown in Appendix A. While the role of deterrents is yet to be determined in the UMR, ongoing actions in these zones, such as removal, should continue, and additional controls be considered and applied if feasible and practical. Finally, effective, integrated adaptive management depends on a robust monitoring component to evaluate the effectiveness of current and potential control actions.

Suggestions and Next Steps (Objective 3)

The physical and operational characteristics of L&D 19 that restrict upstream migration of fishes, and the significant differences in population status above and below L&D 19 for Bighead Carp, Silver Carp, and Black Carp make it a strategic location to consider implementation of a barrier. However, prudent testing and implementation of deterrents requires appropriate information to aid management decisions to deploy or not in the lock or lock approach. Microchemistry studies indicate 44% of Silver Carp and 62% of Bighead Carp captured in Pool 19 seemingly originate from natal sources below L&D 19 (Greg Whitledge, Southern Illinois University, unpublished data). However uncertain these data may be, the fact remains that there are very dense populations of Bighead Carp and Silver Carp below L&D 19, and those same species are much less abundant above L&D 19. A tool that effectively reduces the number of Asian carp moving past L&D 19 would certainly be a method that should be given serious consideration. When such a deterrent is applied for long term management, it should be implemented in conjunction with other management actions that are thoughtfully considered and developed in an integrated plan.

Because recruitment (i.e., young fish surviving beyond the first year of life) is occurring in the Bighead Carp, Silver Carp, and Grass Carp populations above L&D 19, a deterrent alone will not be successful in controlling these species in the management zone. An evaluation of potential management tools and opportunities for use is needed. A multi-pronged effort on various life stages and in multiple locations will be necessary to reduce populations in the management zone and prevent the invasion from spreading upstream and throughout the UMR. Any chance at successful management of Asian carp will require coordination with the appropriate resource managers, agencies, and stakeholders, and we suggest that multiple management actions be implemented with a comprehensive adaptive management approach.

The apparent absence of Black Carp above L&D 22 suggests that there is still a chance to effectively control this species below L&D 19. Although three other dams exist between the furthest upstream report of Black Carp and L&D 19, these dams were considered unsuitable for implementation of any deterrent technologies because they have relatively high rates of open-river conditions (i.e., gates out of water). A reduction of Asian carp immigration at Lock 19 could reduce the number of adults available to reproduce and thus potentially reduce recruitment upstream of L&D 19. This reduction would be additive to the numbers reduced by the ongoing removal efforts in the management zone. Sound technology is at a point in development that an experimental system could be designed and installed at L&D19, but this is suggested only with thorough evaluation of design, scope, operational parameters, permitting, and impacts to non-target species after installation. **Note:** ILDNR supports the testing of sound as a potential barrier for Asian carp, but cannot support testing or implementation at L&D 19 due to concerns about negative impacts to native fish species and a lack of specific details about experimental design, and appropriateness of L&D19 to answer the questions in a statistical and robust way. Evaluation of other sites and locations are underway.

References

Coker, R.E., 1929. Keokuk Dam and the fisheries of the Upper Mississippi River (No. 1063) US Government Printing Office.

Comacho, C.A. 2016 Asian carp reproductive ecology along the Upper Mississippi River invasion front. M.S. Thesis. Iowa State University, Ames, Iowa.

Cupp, A.R., R.A. Erickson, K.T. Fredricks, N.M. Swyers, T.W. Hatton, and J.J. Amberg. 2017a. Responses of invasive Silver and Bighead carp to a carbon dioxide barrier in outdoor ponds. Canadian Journal of Fisheries and Aquatic Sciences 74: 297–305 (2017) dx.doi.org/10.1139/cjfas-2015-0472

Cupp, A.R., Z. Woiak, R.A. Erickson, J.J. Amberg, and M.P. Gaikowski. 2017 b. Carbon dioxide as an under-ice lethal control for invasive fishes. Biological Invasions.

Dennis, C.E., D.F. Kates, M.R. Noatch, and C.D. Suski. 2015. Molecular responses of fishes to elevated carbon dioxide. Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology. 187: 224-231.

Davis, J. J., J.Z. LeRoy , M.R. Shanks, P.R. Jackson, F.L. Engel, E.A. Murphy, C.L. Baxter, J.C. Trovillion, M.K. McInerney, and N.A. Barkowski. 2017. Effects of tow transit on the efficacy of the Chicago Sanitary and Ship Canal Electric Dispersal Barrier System. Journal of Great Lakes Research. *In press.*

Davis, J. J., P.R. Jackson, F. L. Engel, J.Z. LeRoy, R.N. Neeley, S.T. Finney, and E.A. Murphy. 2016. Entrainment, retention, and transport of freely swimming fish in junction gaps between commercial barges operating on the Illinois Waterway. Journal of Great Lakes Research, 42(4), 837-848.

Donaldson, M.R., J.J. Amberg, S. Adhikari, A.R. Cupp, N. Jensen, J. Romine, A. Wright, M. Gaikowski, and C.D. Suski 2016. Carbon dioxide as a tool to deter the movement of invasive bigheaded carps. Transactions of the American Fisheries Society 145: 657-670.

Fisheries and Oceans Canada. 2016. Ecological risk assessment of grass carp for the Great Lakes Basin. Science Advisory Report 2016/057. Canadian Science Advisory Secretariat. (Available October 2017 at http://waves-vagues.dfo-mpo.gc.ca/Library/40596679.pdf.

Hoover, J.J., Zielinski, D.P., and P.W. Sorensen. 2017. Swimming performance of adult bighead carp and silver carp. Journal of Applied Ichthyology 33: 54-62.

Ishimatsu, A., M. Hayashi, and K.S. Lee. 2005. Physiological effects on fishes in a high-CO_2 world. Journal of Geophysical Research**.** 110**:** 1-8.

Kates, D., C. Dennis, M. Noatch, C.D. Suski, and D.L. MacLatchy. 2012. Responses of native and invasive fishes to carbon dioxide: potential for a nonphysical barrier to fish dispersal. Canadian Journal of Fisheries and Aquatic Sciences. 69(11):1748-1759.

Kelner, D.E. and B.E. Sietman. 2000. Relic Populations of the Ebony Shell, *Fusconaia ebena* (Bivalvia: Unionidae), in the Upper Mississippi River Drainage. Journal of Freshwater Ecology. 15(3)371-375.

Knudsen, F. R., P. S. Enger, and O. Sand. 1994. Avoidance responses to low frequency sound in downstream migrating Atlantic salmon smolt, *Salmo salar*. Journal of Fish Biology, 45: 227–233. doi:10.1111/j.1095-8649.1994.tb01302.

Kolar, C. S., D. C. Chapman, W. R. Courtenay, Jr., C. M. Housel, J. D. Williams, and D. P. Jennings. 2007. Bigheaded carps: a biological synopsis and environmental risk assessment. American Fisheries Society, Special Publication 33, Bethesda, Maryland.

Ladich, F. 1999. Did auditory sensitivity and vocalization evolve independently in otophysan fishes? Brain, Behavior and Evolution. 53:288-304.

Larson, J.H., B.C. Knights, S.G. McCalla, E. Monroe, M. Tuttle-Lau, D.C. Chapman, A.E. George, J.M. Vallazza, and J. Amberg, 2017. Evidence of Asian carp spawning above a key choke point in the Mississippi River. North American Journal of Fisheries Management 37: 903-919

Lavis, D.S., M.P. Henson, D.A. Johnson, E.M. Koon, and D.J. Ollila (The Finn). 2003. A case history of Sea Lamprey control in Lake Michigan: 1979 to 1999. Journal of Great Lakes Research, 29(1):584-598.

Lovell, J., M. Findlay, J. Nedwell, and M. Pegg. 2006. The hearing abilities of Silver Carp (*Hypopthalmichthys molitrix*) and Bighead Carp (*Aristichthys nobilis*). Comparative Biochemisty and Physiology Part A: Molecular and Integrative Physiology 143: 286-291.

Lovell, J.M., M.M. Findlay, R.M. Moate, J.R. Nedwell, and M.A. Pegg. 2005. The inner ear morphology and hearing abilities of the Paddlefish (*Polyodon spathula*) and Lake Sturgeon (*Acipenser fulvescens*). Comparative Biochemistry and Physiology, Part A 142:286-296.

Maes, J., A.W.H. Turnpenny, D.R. Lambert, J. Nedwell, A. Parmentier, and F. Ollevier. 2004. Field evaluation of a sound system to reduce estuarine fish intake rates at a power plant cooling water inlet. Journal of Fish Biology, 64: 938–946. doi:10.1111/j.1095-8649.2004.00360.

Mann, D., P. Cott, B. Hanna, and A. Popper. 2007. Hearing in eight species of northern Canadian freshwater fishes. Journal of Fish Biology 70: 109-120.

Magnhagen, C., K. Johansson, and P. Sigray. 2017. Effects of motorboat noise on foraging behavior in Eurasian perch and roach: a field experiment. Marine Ecology Progress Series 564: 115-125

Meyer, S., L. Fellin, and P. Stone. 2007. Impact of a lock failure on commodity transportation on the Mississippi or Illinois Waterway, FAPRI-MU Report #30-07. Food and Agricultural Policy Research Institute, Columbia, MO https://mospace.umsystem.edu/xmlui/handle/10355/2683

Murchy, K.A. 2016. Bioacoustic deterrence of invasive Bigheaded carp. M.S. Thesis, University of Minnesota Duluth, Duluth, MN.

K. A. Murchy, A. R. Cupp, J. J. Amberg, B. J. Vetter,K. T. Fredricks, M. P. Gaikowski, and A. F. Mensinger. 2017 Potential implications of acoustic stimuli as a non-physical barrier to silver carp and bighead carp. Fisheries Management and Ecology. 24(3):208-216

National Research Council. 2013. Delta waters: research to support integrated water and environmental management in the lower Mississippi River. National Academies Press, National Academy of Sciences, Washington DC. 128pp.

Nico, L.G., J.D. William, and H.L. Jelks. Black carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society. Bethesda, MD.

Noatch M.R. and C.D. Suski. 2012. Non-physical barriers to deter fish movements. Environmental Reviews 20: 71-80.

Popper A.N. and M.C. Hastings. 2009. The effects of anthropogenic sources of sound on fishes. Journal of Fish Biology 75:455-489.

Radford A.N, E. Kerridge and S.D. Simpson. 2014. Acoustic communication in a noisy world: can fish compete with anthropogenic noise? Behavioral Ecology 25(5): 1022-1030.

Scholik, A.R. and H.Y. Yan. 2002a. The effects of noise on the auditory sensitivity of the bluegill sunfish, *Lepomis macrochirus.* Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology. 133(1):43-52

Scholik, A.R. and H.Y.Yan. 2002b. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas.* Environmental Biology of Fishes 63: 203.

Simpson S.D., A.N. Radford, S.L. Nedelec, M.C.O. Ferrari, D.P. Chivers, M.I. McCormick and M.G. Meekan. 2016. Anthropogenic noise increases fish mortality by predation. Nature Communications. DOI: 10.1038/ncomms10544

Smith, B.R. and J.J. Tibbles. 1980. Sea lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan, and Superior: history of invasion and control, 1936-78. Canadian Journal of Fisheries and Aquatic Sciences. 37:1780-1801.

Speares, P., D. Holt, and C. Johnston. 2011. The relationship between ambient noise and dominant frequency of vocalizations in tow species of darters (Percidae: *Etheostoma*). Environmental Biology of Fishes. 90:103-110.

Tripp, S., R. Brooks, D. Herzog, and J. Garvey. 2013. Patterns of fish passage in the Upper Mississippi River, short communication, River Research Applications. 30: 1056-1064

U.S. Army Corps of Engineers. 2004. Final Integrated Feasibility Report and programmatic Environmental Impact Statement for the UMR-IWW System Navigation Feasibility Study. USACE, Rock Island, St. Paul, and St. Louis Districts.

U.S. Army Corps of Engineers. 2017. Preliminary Waterborne Commerce Statistics for Calendar Year 2016. Institute for Water Resources Navigation and Civil Works Decision Support Center, New Orleans, LA http://www.navigationdatacenter.us/wcsc/pdf/Prelim-wcsc-2016.pdf

U.S. Fish and Wildlife Service. 2015. Upper Mississippi River Economic Assessment, Part 1: 60 County Assessment. Division of Economics, USFWS, 5275 Leesburg Pike, MS:BMO, Falls Church, VA 22041.

Vetter B.J., A.R. Cupp, K.T. Fredericks, M.P. Gaikowski, and A.F. Mensinger. 2015. Acoustical deterrence of Silver Carp (*Hypophthalmichthys molitrix*). Biological Invasions. 17:3383-3392

Vetter B.J., K.A. Murchy, A.R. Cupp, J.J. Amberg, M.P. Gaikowski, and A.F. Mensinger. 2017. Acoustical deterrence of Bighead Carp (*Hypophthalmichthys nobilis*). Journal of Great Lake Research 43:163-171.

Vetter B.J., M.K. Brey, and A.F. Mensinger. 2018. Reexaming the frequency range of hearing in silver (*Hypophthalmichthys molitrix)* and bighead (*H. nobilis*) carp. PLoS ONE 13(3): e0192561

Voellmy I.K., J. Purser, D. Flynn, P. Kennedy, S.D. Simpson, and A.N. Radford. 2014, Acoustic noise reduces foraging success in two sympatric fish species via different mechanisms. Animal Behavior 89:191-198

Wilcox D.B., E.L Stefanik, D.E. Kelner, M.S. Cornish, D.J. Johnson, I.J. Hodgins, S.J. Zigler, and B.L. Johnson. 2004. Improving fish passage through navigation dams on the Upper Mississippi River system. Upper Mississippi River-Illinois Waterway System Navigation Study ENV 54.

Wlosinksi JH, D.B. Wilcox, and C. Surprenant. 2004. Fish passage through dams on the Upper Mississippi River *in* Pitlo J and J. Rasmussen, editors. UMRCC Fisheries Compendium, Third Edition.

Water Resources Reform and Development Act of 1986 (WRRDA 1986). 1986. Pub. L. No. 99-662, 33 U.S. Code 652 Upper Mississippi River System Management Act of 1986.

Water Resources Reform and Development Act of 2014 (WRRDA 2014). 2014. Pub. L. No.113-121,

Appendix A

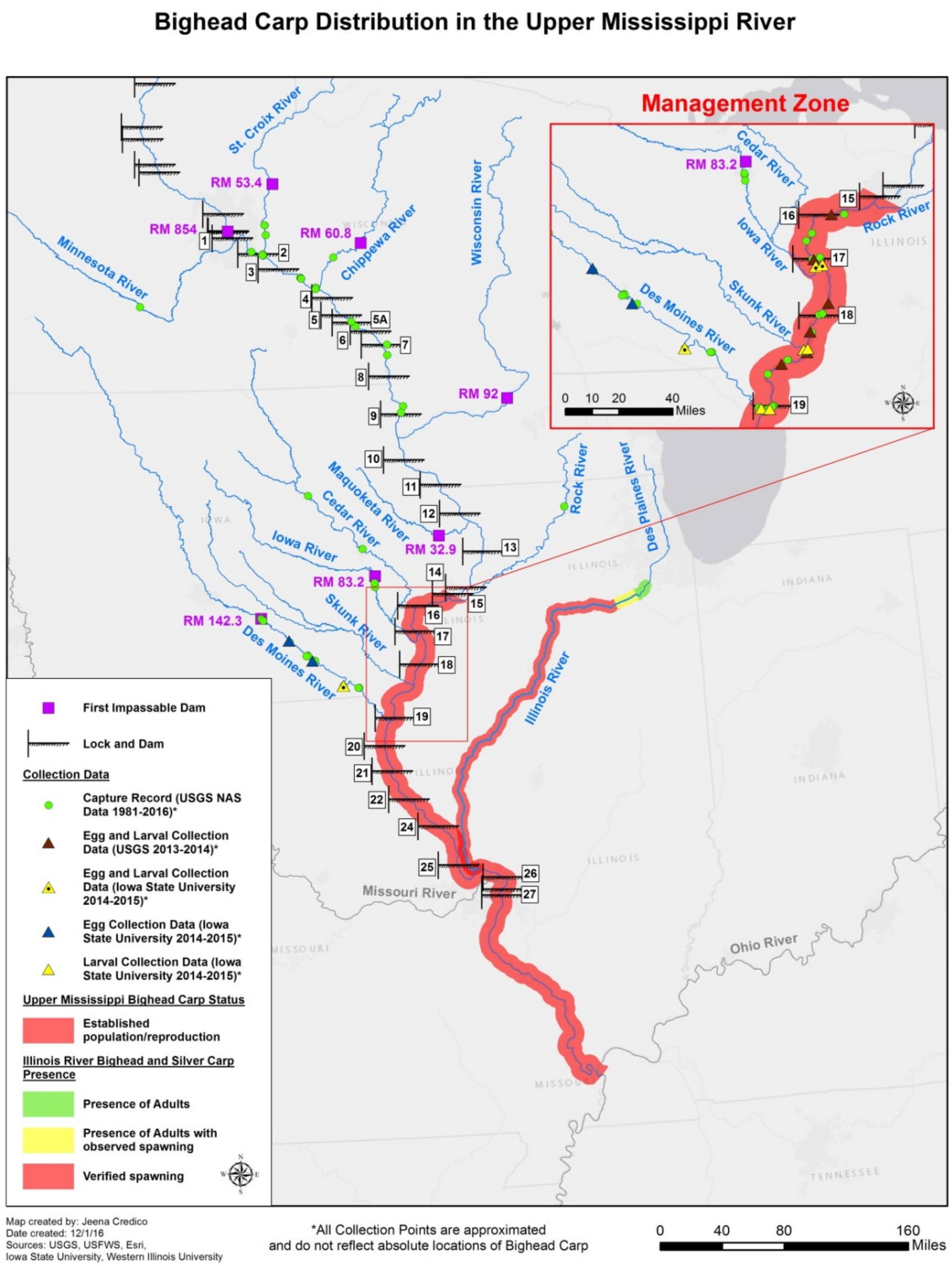

Figure A-1. Bighead Carp distribution and life history stages collected in the UMR through 2016

Silver Carp Distribution in the Upper Mississippi River

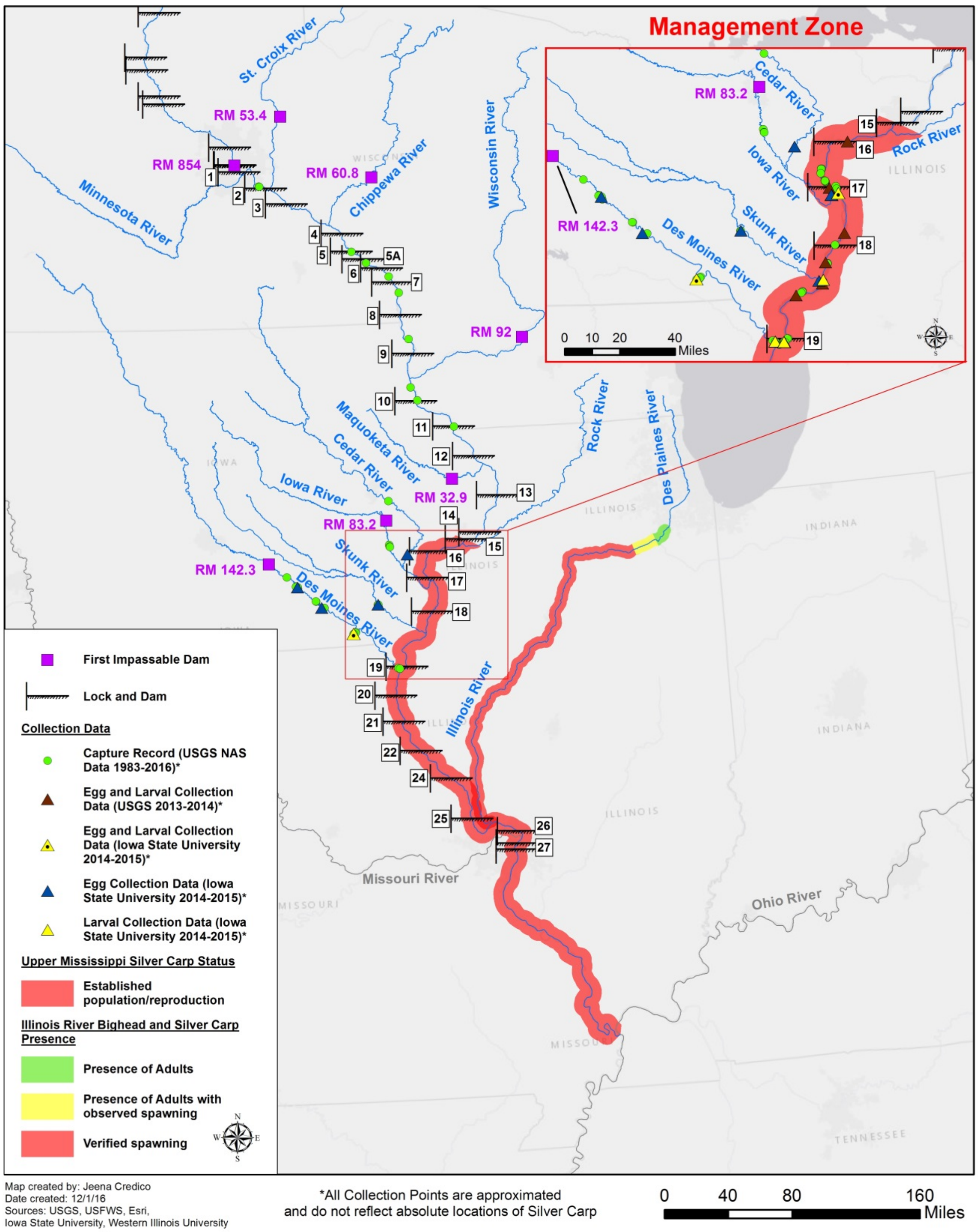

Figure A-2. Silver Carp distribution and life history stages collected in the UMR through 2016.

Bighead Carp Management Zone in the Upper Mississippi River

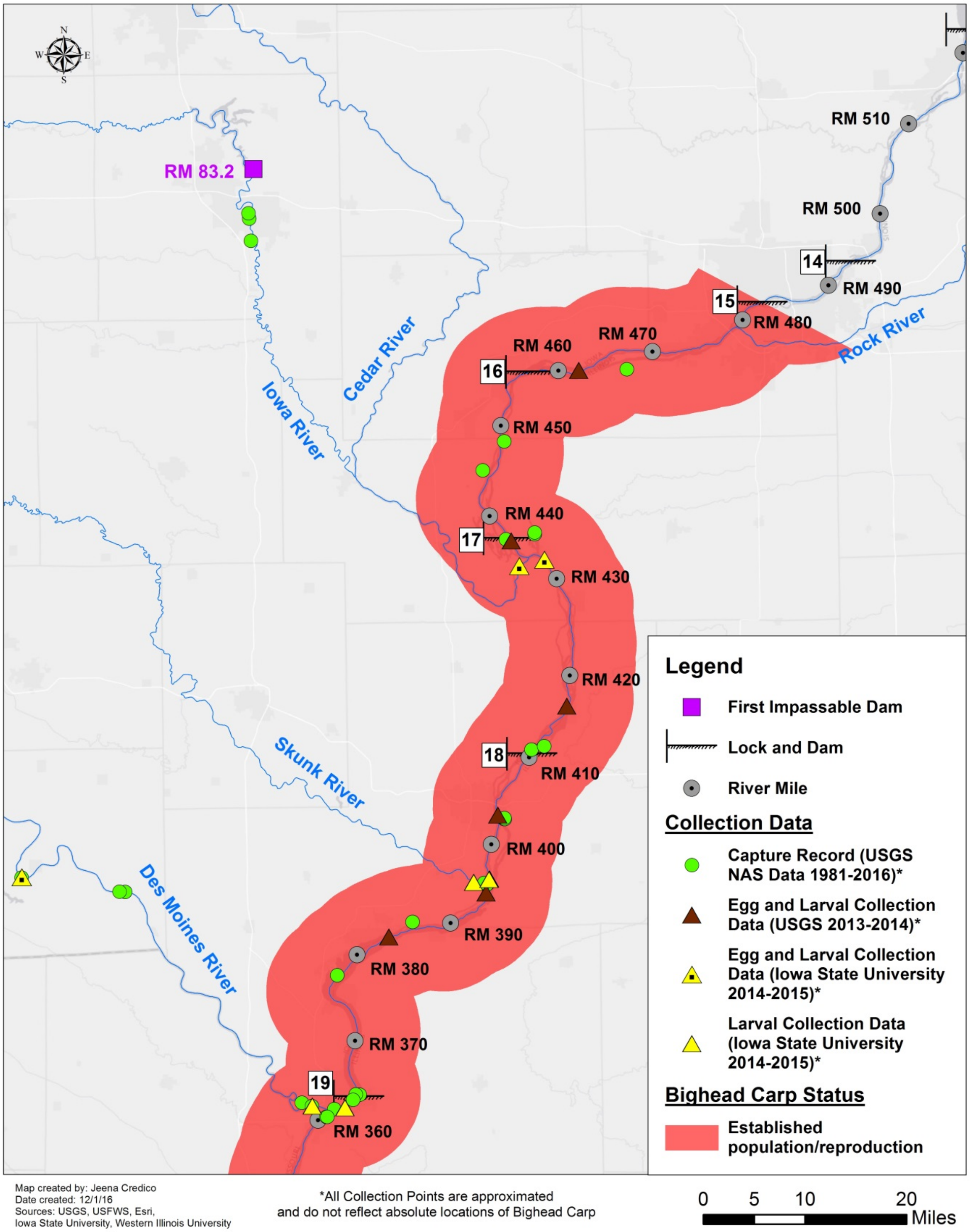

Figure A-3. Management zone for Bighead Carp in the UMR as identified by the deterrent team in 2017.

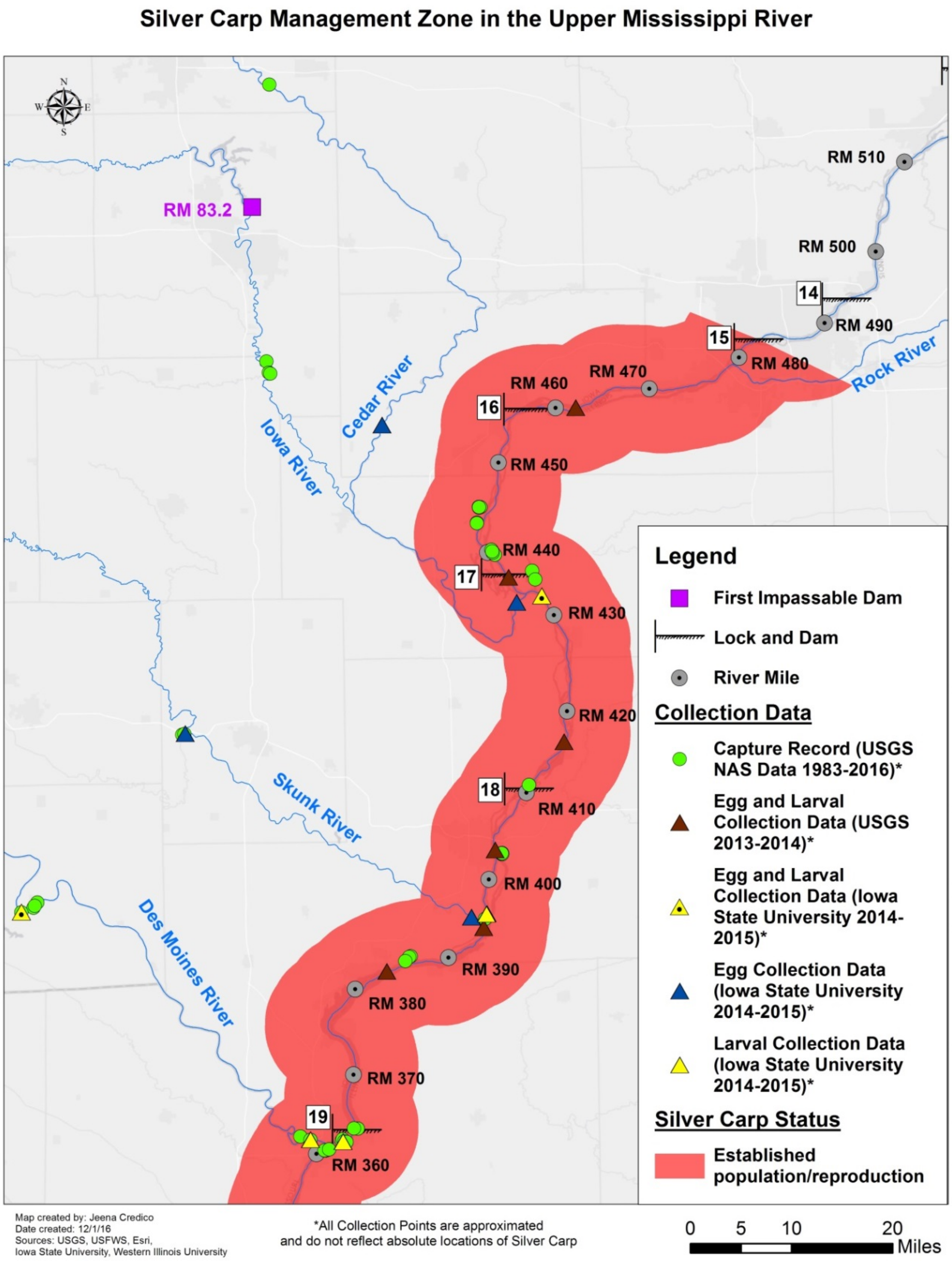

Figure A-4. Management zone for Silver Carp in the UMR as identified by the deterrent team in 2017.

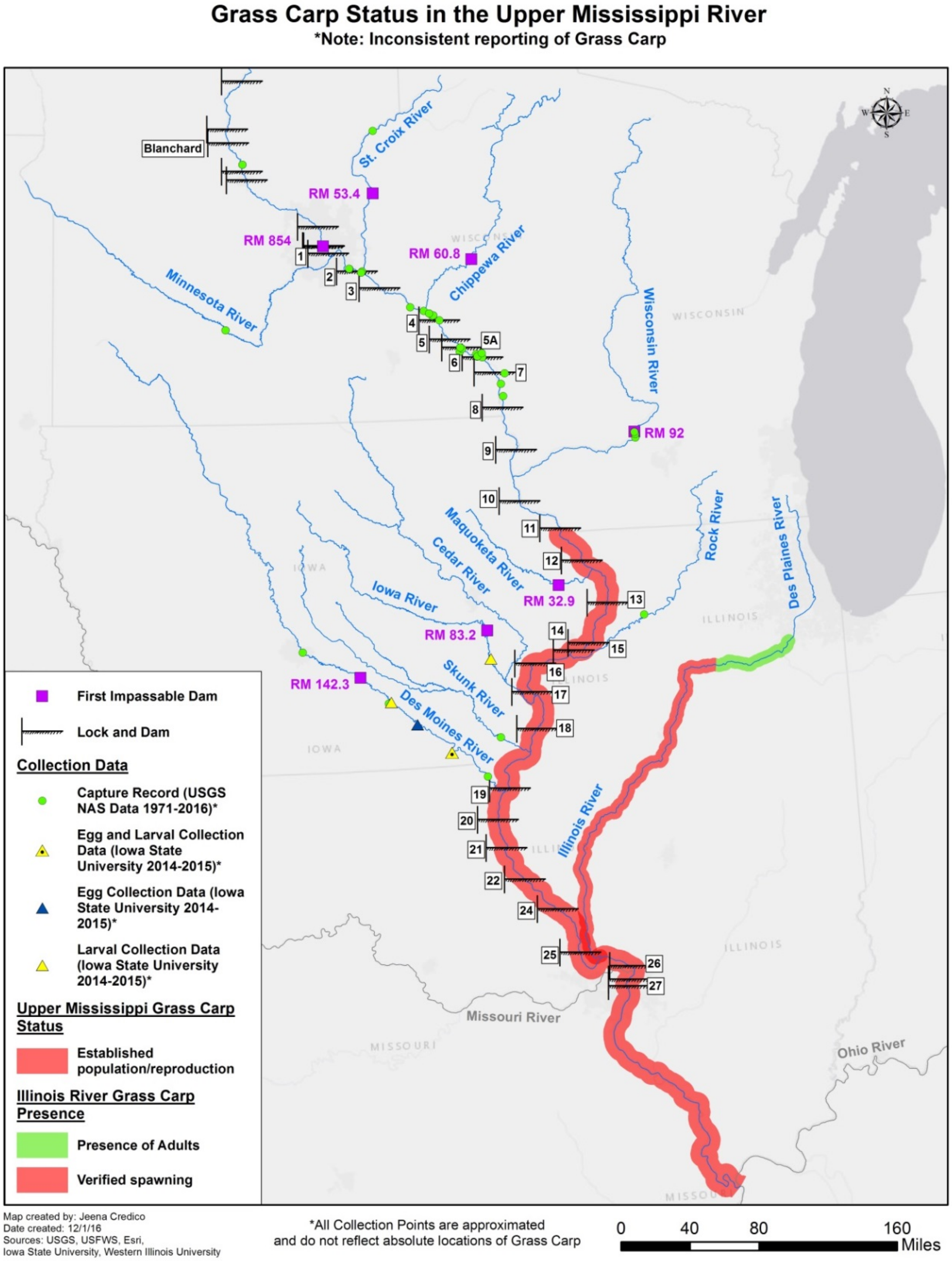

Figure A-5. Grass Carp distribution and life history stages collected in the UMR through 2016.

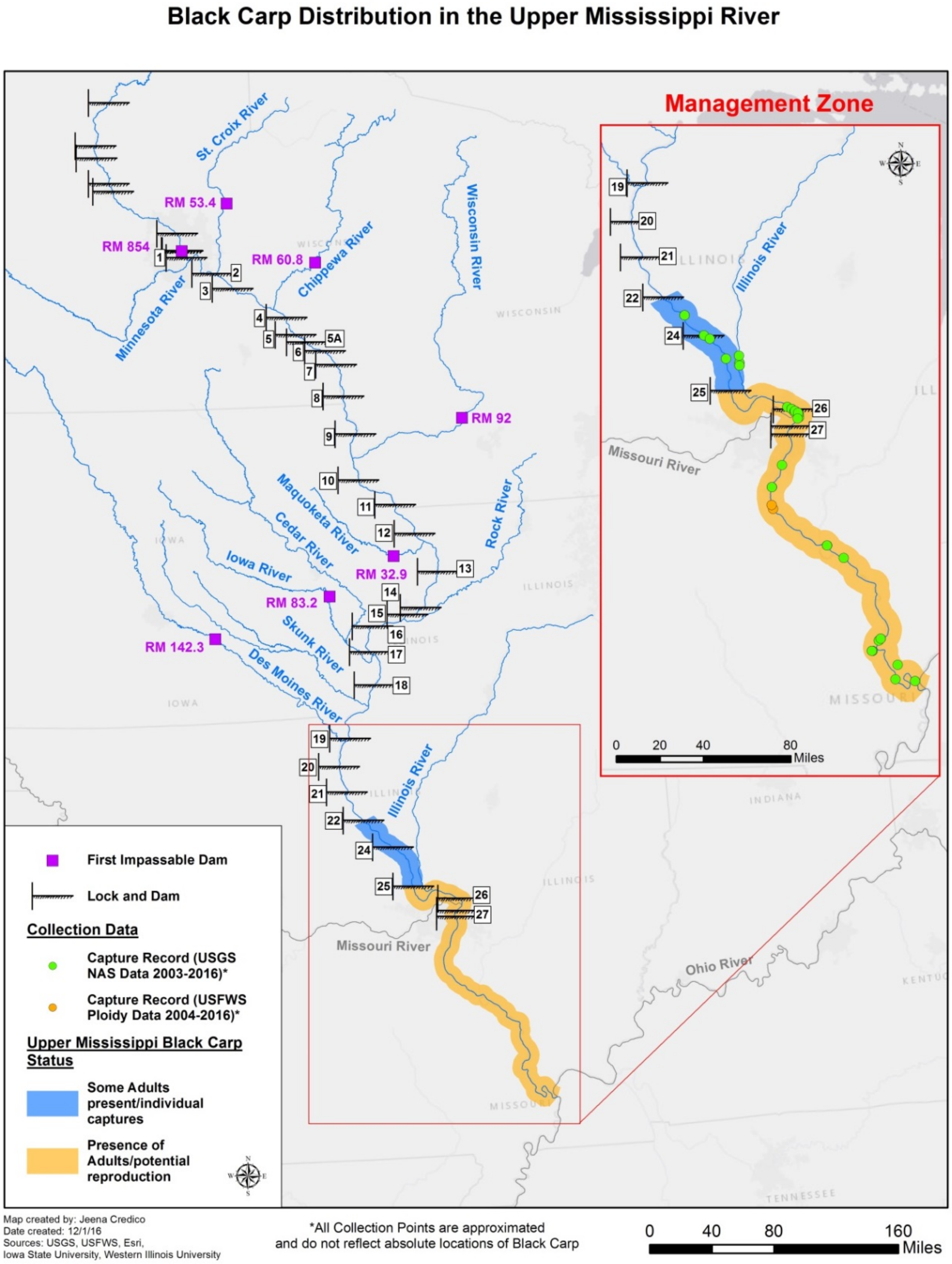

Figure A-6. Black Carp distribution and life history stages collected in the UMR through 2016.

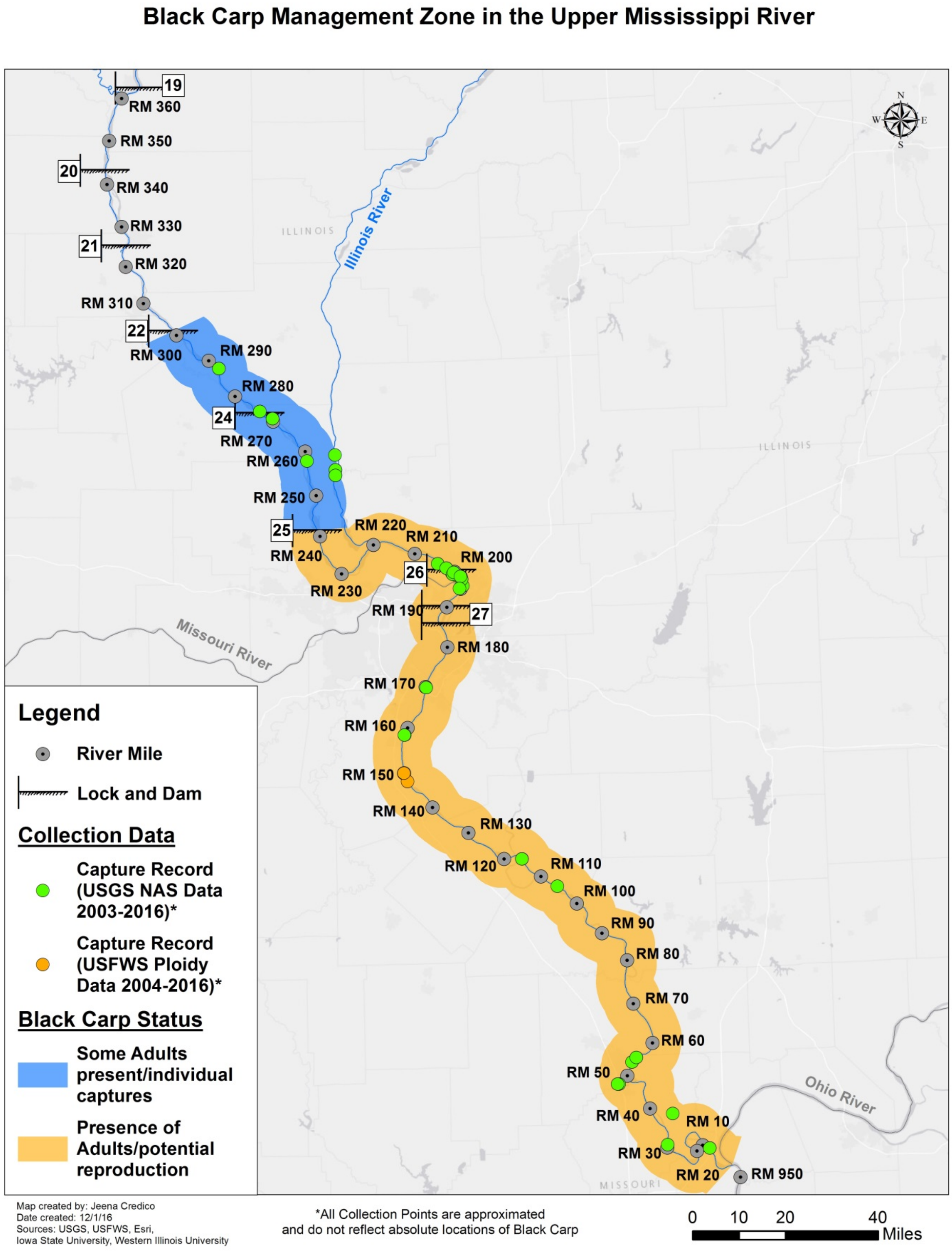

Figure A-7. Management zone for Black Carp in the UMR as identified by the deterrent team in 2017.