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Research Article

Public risk perceptions associated with Asian carp introduction and corresponding response actions

Jessica S. Kahler[1], Rain Wuyu Liu[2], Tammy J. Newcomb[3], Seth Herbst[3] and Meredith L. Gore[4,*]

[1]*Department of Sociology and Criminology, University of Florida, Gainesville, FL 32611, USA*
[2]*Department of Communication, University of Arizona, Tucson, AZ 85721, USA*
[3]*Department of Natural Resources, Fisheries Division, Lansing, MI 48933, USA*
[4]*Department of Fisheries and Wildlife Michigan State University, East Lansing, MI 48824, USA*

Author e-mails: *jkahler@ufl.edu (JSK), rainliu@email.arizona.edu (RWL), NewcombT@michigan.gov (TJN), HerbstS1@michigan.gov (SH), gorem@msu.edu (MLG)*

**Corresponding author*

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Abstract

Biological invasion pathways are strongly influenced by human behavior. This research aimed to build new understanding about public perceptions and expectations for possible management responses that might be used after detection of Asian carp in the Laurentian Great Lakes. Although the species are as yet unestablished, our research worked to inform communication that could be publicly responsive in the event of an invasion. Our objectives were to: 1) determine public risk perceptions associated with Asian carp; 2) determine public risk perceptions associated with different types of management responses to an Asian carp invasion; and 3) identify types of risk-related information and communication that would influence community support for different types of eradication or control approaches. Objectives were achieved by using a two-phase approach. Phase one utilized an online, voluntary, self-administered survey with 2788 responses received from a convenience sample of Laurentian Great Lakes Basin residents. Phase two included three "Thinkshops" of fishing and boating stakeholders in southern Michigan. Across all hypothetical Asian carp invasion scenarios, the application of rotenone to a large area was the most frequently selected management response. When impacts from Asian carp and their management were discussed, study participants supported framing risks in terms of environment and economy. Insights herein provide new evidence that can help narrow the gap between how invasion risks are perceived and responded to by natural resource managers to reduce social conflicts over, and potentially address, invasive species threats more rapidly.

Key words: aquatic invasive species, biological invasions, biosecurity, Laurentian Great Lakes, human dimensions, invasion ecology, invasive species

Introduction

Biological invasions can be a major driver of environmental change, arising from intentional and unintentional introductions of species from their indigenous ranges to new locations (Shackleton et al. 2019). A scientific understanding of human behavior is critical for effective natural resource management and to improve human's ability to predict and adapt to environmental change (Gore 2011). This is particularly true for the

proportion of nonnative species that spread extensively in their new ranges and become invasive (e.g., Williamson and Fitter 1996). Invasion pathways and vectors are strongly influenced by human behavior and have been extensively researched in order to build defendable and sustainable management solutions. We know social conflicts over solutions to invasive species problems tend to be context-specific, varying across public value systems and expert risk perceptions (Estévez et al. 2014). Information about the socio-cultural context of invasive species management can be lacking for decision-makers although it is known to influence public support for management (Kapitza et al. 2019). The institutional and policy context of invasive species management can influence risk perceptions among the public and decision-makers (Shackleton et al. 2019). We also know public judgement of government credibility can influence the public's support or opposition to control efforts (Warner and Kinslow 2011).

Risk perception is defined as the intuitive judgments made by laypersons as opposed to technical assessments made by subject matter experts (Slovic 1987; Wald et al. 2019). Risk perception can influence public attitudes about biological invasions support for response actions, media coverage of risk, risk management, and trust in management organizations (Estévez et al. 2014; Gore et al. 2007). Factors influencing perceptions of risk associated with wildlife are generally well understood (e.g., Gore et al. 2007, 2009), as are insights about how risk perceptions spread through social networks via contagion (i.e., virility) and how risks are framed by mass media (Muter et al. 2009, 2012). Insight about what influences individuals' risk perception can help guide risk communication, particularly the content of messages (Muter et al. 2012; Warner and Kinslow 2011). The study of human dimensions related to biological invasions is growing with an increasing number of species-specific case studies (e.g., Shackleton et al. 2019). Research on public perceptions of potential future invasion-related risks is more limited. For example, Estévez et al. (2014) studied public perceptions associated with biological invasions, specifically the variations in risk perceptions of anticipated impacts from biological invasions and lack of confidence in resource agencies to respond appropriately.

Risk perception knowledge associated with biological invasions is overwhelmingly anchored to species that have *already* been introduced or that are established but lacking for taxa that pose future potential invasion threats. These knowledge gaps create unnecessary blind spots for evidence-based decision making and ultimately constrain the ability of invasion biology insights to inform response actions (e.g., Kapitza et al. 2019; Warner and Kinslow 2011). The unique attributes of a biological invasion along with the associated response actions and decisions (i.e., programs and policies), discussed below, help develop insights for using human dimensions to prevent new and rapidly respond to biological invasions. In addition these insights can inform resource management agencies on how

to most effectively communicate with stakeholders when control actions in response to infestations are required.

Assessing risk and responding to Asian carp threats in the Great Lakes Basin

Asian carp is a colloquial term referring to a group of invasive fish species posing a concern for the socioecological systems of the Laurentian Great Lakes Basin (hereafter Basin) (Stern et al. 2014). There are four species of Asian carp posing risks in the Basin: Bighead carp (*Hypothalmichthys nobilis*), Silver carp (*Hypothalmichthys molitrix*), Black carp *(Mylopharyngodon piceus)*, and Grass carp *(Ctenopharyngodon idella)*. These species have the potential to inflict harm economically (e.g., commercial, tribal, recreational fisheries), environmentalally (e.g., cascading food web issues), and on human health and wellbeing (e.g., boating and water recreation). Bighead and Silver carp escaped from southern aquaculture ponds in the 1970s and later became established in the Mississippi River Basin. Following their establishment these two species have dominated their adopted ecosystem, representing 97% of the total fish biomass in some places (Hansen 2011). Similarly, Black carp also escaped from an aquaculture facility and, while not as abundant as Silver or Bighead carp, are found throughout the Mississippi and Illinois Rivers (Conover et al. 2007). Despite widespread dispersal since their original establishment, there is no evidence of individual or established populations of Bighead, Silver, or Black carp anywhere in the Basin (Conover et al. 2007). The possession of live Bighead, Silver, or Black carp is legally prohibited in all Basin states and provinces regardless of the purpose. Grass carp, introduced for vegetation control in private waters and subsequently escaped to public waters, have been present in the Basin for more than 30 years and only recently have been found to be reproducing in Lake Erie (Chapman et al. 2013). Response and control actions are ongoing. Presently, only Grass carp that are triploid, or nonreproducing, are permitted in some of the Great Lakes states for stocking in private waters, but legally prohibited in others.

Cascading ecological effects from Asian carp on the Basin's fisheries are forecasted to result in damages extending beyond declines in commercially valuable fish populations and include negative impacts on recreational boating and degraded habitat for hunted and/or migratory waterfowl (Stern et al. 2014). Because there currently is no evidence of any live Bighead, Silver, or Black carp in the Basin, the focus remains on preventing their entry via human-assisted and natural dispersal vectors such as bait bucket introduction or infrastructure, primarily the Chicago Area Waterway (USACE 2018), respectively. State fisheries agencies in the Basin are working not only to prevent the entry, but also to prepare strategies for responding to detection detections of Asian carp. Gore et al. (2016a) provided a review of current Asian carp policy, policy preferences, and

invasion background in the region. A range of deterrence and sanctioning instruments exist, including fines and imprisonment for rule violators; the criminal justice system can treat some intentional introductions as felonies.

Decision-makers have developed a risk-based response plan in anticipation of the chance that Asian carp are detected in Basin waters; many of the risk response strategies include the application of piscicides such as rotenone at some scale when Asian carp are initially detected. Understandably, stakeholders are cognizant about the risks (e.g., assessed, perceived, communicated) associated with using piscicides in Michigan waterways (Gore et al. 2016a).

These aforementioned considerations inform a range of risk management, response and control actions for Asian carp, resulting in a scaled approach for deploying eradication strategies and tactics depending on results from ecological invasion science (e.g., the presence of environmental DNA *versus* a single fish *versus* a fish in spawning condition, multiple juvenile fish, eggs or larvae). Regardless of the risk response *tactic*, any Asian carp response *action* is accompanied by social and political dimensions. Lethal control of invasive species can provoke public controversy (e.g., Crowley et al. 2017; Verbrugge et al. 2013; Warner and Kinslow 2011). Both preventative and responsive risk management of Asian carp requires a synthesis of ecological knowledge and human dimensions insights of which the latter is very scant (see Carlson and Vondracek 2014; Hula et al. 2017; Kokotovich and Andow 2017). Uncertain public perceptions related to control activities may hinder the rapid implementation of the appropriate risk response actions. Consequently, government agencies may be less likely to quickly respond, or respond effectively and efficiently if public support for that action is lacking.

The future potential impacts from Asian carp-related risks in the Basin presents an opportunity to fundamentally advance insight about public risk perceptions and risk communication in at least three ways. First, the developing nature of Asian carp risks within the Basin enables study on the emergence and progression of public risk perceptions over time as the distribution of aquatic invasive species within the Basin evolves and associated information about the invasion manifests. Second, the uncertainty associated with the likelihood and intensity of establishment of Asian carp in the Basin and range of response options provides an opportunity for studying questions about risk perception and communication within the context of uncertainty. Third, Asian carp invasion and resulting response actions represent a scenario at the intersection of economic, environmental, and human health-related risks. We sought to address these questions using Michigan as a case study because Michigan has the largest amount of jurisdiction waters of the Basin and would incur the greatest biological, social, and institutional costs resulting from the colonization and establishment of Bighead or Silver carp

in the Basin. Also, these two species are the closest to the Great Lakes and present the most immediate threat (Cudmore et al. 2012). Accordingly, we set the following objectives for this study, specifying Bighead and Silver carp but using the colloquial standard of Asian carp; 1) determine public perceptions of Asian carp risks for human health and well-being, environmental consequences, and economic outcomes; 2) determine public perceptions of the risks associated with different hypothetical response strategies to Asian carp infestation scenarios; and 3) identify types of risk-related information and communication that would influence community support for differing control/eradication approaches. For the remainder of this paper, the use of the term Asian carp is specific to Bighead and Silver carp.

Materials and methods

Objectives 1 and 2 were achieved using a two-phase, multi-method study design. Phase one was an online, voluntary, self-administered survey implemented from October 11 through November 24, 2016 (Vaske 2008). Phase two involved three "Thinkshops" (i.e., a multi-hour face-to-face meeting designed to facilitate critical examination about risks with an intended product of deliberation, contemplation and consideration) with natural resource stakeholders in southern Michigan in February 2017. Phase two Thinkshops were also used to achieve objective 3. Southern Michigan was selected due to a greater perceived risk for Asian carp introduction in these watersheds based on proximity to established populations in Illinois and Indiana waters and habitat that is suitable for these species. All individuals for phases one and two were over 18 years of age. The methods and analyses were approved by the Michigan State University Human Subjects Protection Program (IRB#16-492). A copy of the survey questions and measurement scales can be obtained through the last author.

The phase one online self-administered survey used a modified standard four-wave sampling (Vaske 2008) approach to contact individuals that were voluntary subscribers to one of five listservs administered by the Michigan Department of Natural Resources (MDNR) and with potential relevance to Asian carp such as quiet water activities and fishing (e.g., subscribers to the furbearer trapping listserv were not intentionally invited to participate). MDNR listservs are free to anyone with a valid email address and interested individuals receive information about fishing and water-related natural resources issues at monthly or periodic intervals as determined by the MDNR, the listserv administrator; in this regard the potential lists of study participants were self-selecting. Subscribers may also be geographically based outside the State of Michigan or even the United States. Combined these listservs had 994,632 unique subscribers of which an initial 3,000 potential participants were randomly selected using a random number generator. We used a modified systematic random sampling approach (Singleton et al. 1993). This type of probability sampling

is simple and direct. Our modifications were based on a lack of available lists of members in the Basin who are impacted by Asian carp (because they have not invaded) and a desire to gain broad coverage in drawing our sample population (Singleton et al. 1993). Our goal was to employ a sampling frame that reflected the target population of people with the potential to be impacted by the introduction of Asian carp (Singleton et al. 1993). We recognize our sampling design is the only representative of the individuals on the voluntary listservs. The main advantage of our sampling design was decreased bias on the part of researchers in selection of cases. Several iterations of weekly reminders were sent over emails to those selected participants that did not click the survey link and the online survey website, hosted by the online survey platform Qualtrics, limited responses to one per IP address.

The survey included three sections. The first section asked participants their opinions regarding Asian carp and possible invasion response actions by fisheries managers in Michigan's lakes and streams, including inland waters. This section used seven-point Likert-type scales adapted from previous research (Gore et al. 2016a; Muter et al. 2013). The response options varied in their human and resource intensity and were of interest to MDNR. The second section had participants rank the future potential risks associated with potential environmental, economic, and human health risks posed by Asian carp and potential response options in Michigan. These questions were adapted from previous wildlife-related and risk perception studies (Gore et al. 2007; Sjöberg 2000) and risks were ranked high to low using numerical scales (1 = lowest risk). In the final section, participants were asked to rank a range of response activities under ten different possible real-world Asian carp invasion scenarios. The Asian carp invasion scenarios ranged in intensity based on the life history stage (e.g., eggs, juveniles, adults), number, and distribution. For each of the ten scenarios, participants were asked to rate the extent to which 11 response responses were appropriate. Sociodemographic information was collected at the end of the survey. Descriptive statistics, correlations and analysis of variance were conducted on survey data using SPSS v 25 (IBM 2017).

For phase two, MDNR fisheries biologists identified eight to twelve individuals they considered to be knowledgeable about fisheries and Asian carp management in the Basin who could attend a half-day "Thinkshop" about their management within one of two watersheds (either River Raisin St. Joseph River) identified as being at a high perceived risk of invasion in Michigan. The individuals attending each of the three Thinkshops (N = 28, n = range 7–11) cannot be described in detail because of research ethics protocols. However, examples of participants included local Agricultural Extension Officers, community leaders, angling company owners, river outfitters and guides; these individuals were also chosen for their track record of cordiality and professionalism in order to enable as much free

exchange of ideas as possible. Thinkshops were facilitated by the last author to be as inclusive and permissive of diverse ideas as possible, held at either an MDNR regional office or public library and participants were provided with a $25 Visa gift card for their participation. All participants signed an informed consent form, and the Thinkshops were digitally recorded to facilitate data analysis. Participants were encouraged to think about, verbally discuss, and critique how MDNR could optimally communicate about each scenario, including general communication considerations as well as source, channel, and receiver considerations. Participants were provided with index cards to submit written feedback if they preferred not to speak during the Thinkshop.

Results

Insights from a voluntary, web-based survey

Survey responses were received from 2,788 people using IP addresses assigned to the United States (n = 2,783), Canada (n = 4) , and Mexico (n = 1) and all eight states in the Basin. That we received responses from so many "stakeholders of interest" as well as "stakeholders of place" is unsurprising given the fact we used a listserv to recruit respondents, the listserv was publicly accessible and free, and Michigan is well known for fishing and quiet water activities. Many people have second homes in Michigan yet reside full time out of state (e.g., Nevada) and even out of the country (e.g., Mexico). Respondents were overwhelmingly male (n = 2631; 92%), married (n = 2380; 84%), and homeowners (n = 2592; 97%) with an age range of 18 to 97 years. Our sample had a normal educational distribution and was heavily skewed toward white participants (n = 2698; 94.1%). Our research objectives were not to generate predictions for the general public but rather to gain the perspective from members of the public that would potentially choose to actively engage in the issue, that is, stakeholders of interest. Participants were asked to identify the water-related activity they most often participated in within Michigan's rivers, lakes and streams and the top three were fishing (n = 2124; 74.1%), boating (n = 318; 11.1%), and swimming (n = 178; 6.2%).

Results from a one-sample t-test showed the mean (M = 6.63, SD = 0.60) of six attitudinal questions about Asian carp were significantly higher than the mid-point (4 = neutrality) of the scale, indicating significant negative attitudes among participants toward Asian carp ($t = 232.925$, $df = 2870$, $p < 0.001$). Risks to the environment from Asian carp, which included eating food sources for native fish and causing declining numbers and size of valuable sports fishes, were considered to be medium-high risks (Figure 1). Perceptions of risks to the socio-economy in Michigan from Asian carp varied. There were high perceptions of risks toward reduced sports fishing revenue and commercial fishing (Figure 2). Opinions about Asian carp control varied, and the consensus was low with standard deviations ranging

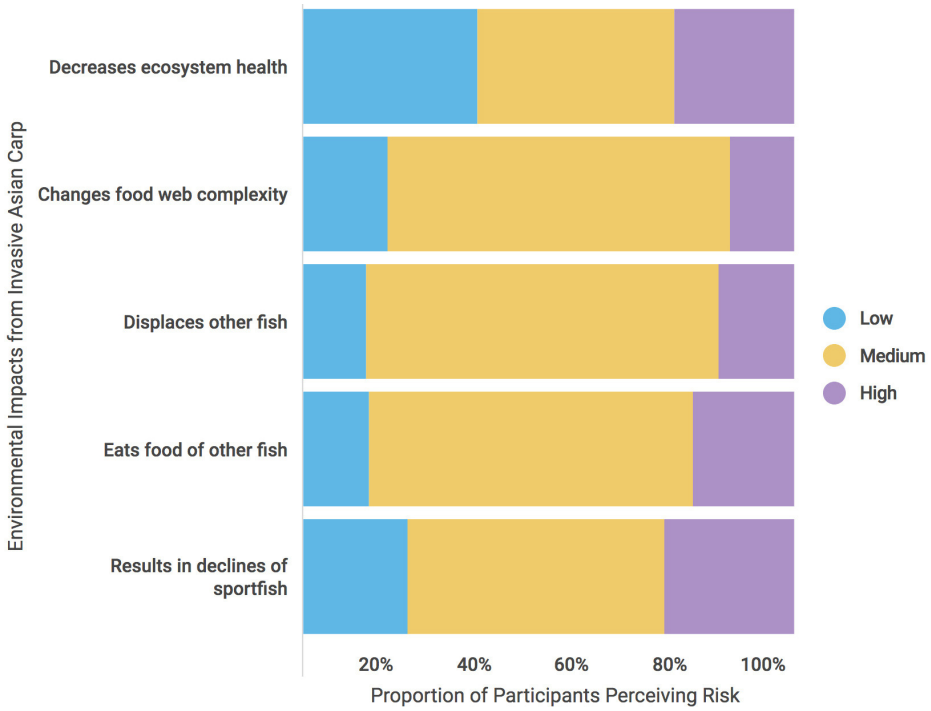

Figure 1. Proportion of participants perceiving five different types of environmental impacts from a potential invasion of Asian Carp in Michigan as being low, medium or high risk, 2017 (n = 2,788).

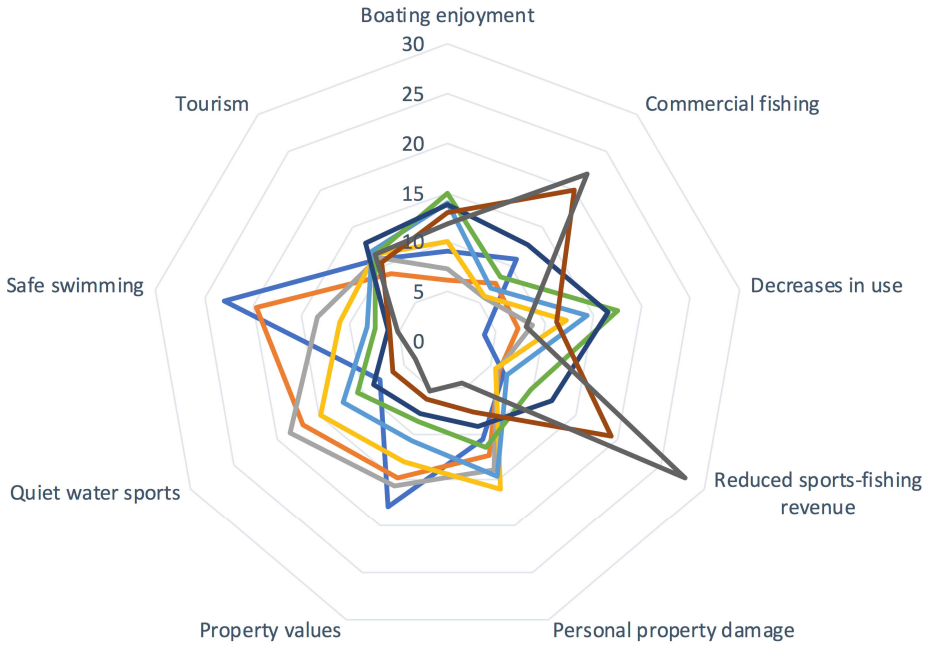

Figure 2. Percentage of participants perceiving risk associated with nine different socio-economic risks from a potential Asian carp invasion in Michigan, 2017 (n = 2,788). Color-coded peaks on the radar indicate a higher percentage of participants perceived that socio-economic risk as being more salient to the biological invasion compared to other risks depicted with the same color.

from 1.50 to 1.75 for most indicators. Respondents who agreed that science was the best way to approach Asian carp management were faintly supportive of (any type) Asian carp control actions if eDNA was detected ($r = .060$, $p < .01$). Respondents had a low agreement with the statement that

Table 1. Mean responses from participants regarding management strategies based on detection of Invasive Asian carp in the Great Lakes Basin, 2017 (n = 2,788). Responses were recorded on 7-point Likert-type scales with 1 being low and 7 being high.

Opinions Regarding Invasive Asian carp Management	Mean	Std. Error	Std. Dev.
I feel that I have control over the risks from invasive carp.	2.24	0.03	1.50
If there is a problem with invasive carp, the fisheries management agencies responsible for management will respond accordingly.	4.19	0.03	1.74
I trust the fisheries management agencies involved in invasive carp management to manage invasive carp appropriately.	4.44	0.03	1.75
I believe that I have the opportunity to voice my opinions about invasive carp management in Michigan.	5.30	0.03	1.68
Science if the best way to approach invasive carp management.	5.59	0.03	1.51
Problems involving invasive carp are increased by human development, such as canals that connect rivers and lakes.	6.18	0.02	1.16
Invasive carp management should be a top priority for fisheries managers in Michigan.	6.49	0.02	0.91
Managing the risks from invasive carp in Michigan will be important in the future.	6.79	0.01	0.60

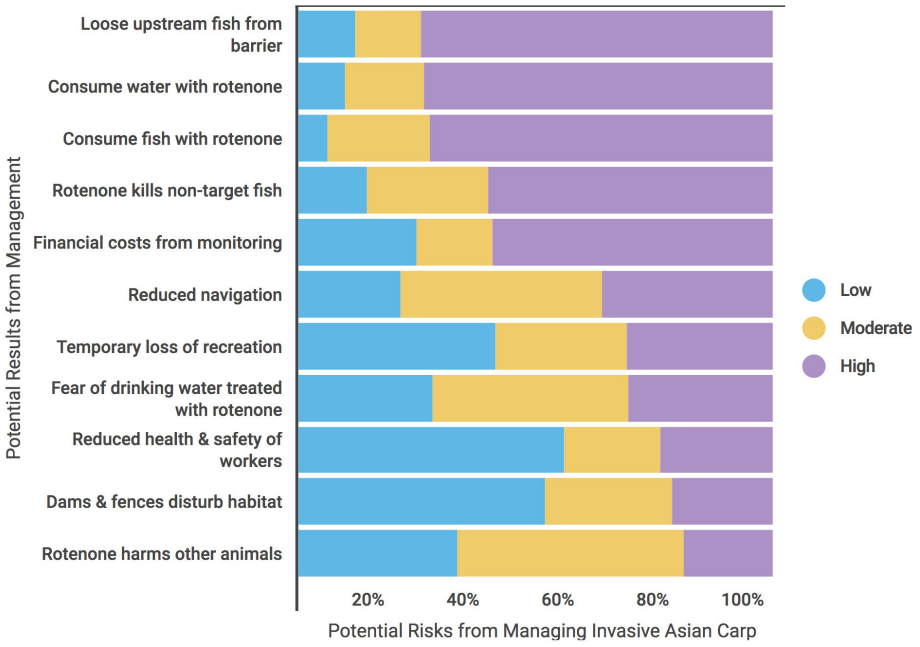

Figure 3. The proportion of participants perceiving risk associated with eleven different management responses to a potential invasion of Asian carp in Michigan as being low, medium or high risk, 2017 (n = 2,788).

they had control over risks from Asian carp, and moderate agreement that fisheries agencies responsible for Asian carp management will respond accordingly and trust the agency to do so. The highest level of agreement and consensus related to the opinion that management of Asian carp in Michigan would be important in the future (M = 6.79; SD = 0.60) (Table 1).

Regarding risks from potential Asian carp response actions in Michigan, three of the top five risks were related to rotenone, a registered piscicide under the U.S. Environmental Protection Agency. The majority of participants rated risks from drinking water treated with rotenone (73.5%) and consuming rotenone-exposed fish (72.3%) as high. However, the highest risk from Asian carp response actions, according to participants, was the loss of upstream fish from installing physical barriers (Figure 3). When examining the range of response actions, ranging from "record the incident and take no action"

Table 2. Percentage of survey participants preferring different management responses based on their perceptions of most and least common evidence of biological invasion from Asian carp, Michigan, 2017 (n = 2,788). Responses were recorded using 7-point Likert-type scales where 1 was low and 7 was high agreement. Percentages depicted in table include pooling of "strongly agree," "somewhat agree" and "agree" response options.

Management response	Most common threat scenario (% agreeing)	Least common threat scenario (% agreeing)	Rank	Supporting Management Response (average %)
Manually apply rotenone to a large geographic area	MDNR finds 20 adults (47.8)	Report of jumping carp (6.1)	1	25.2
Active manual removal	Commercial fisherman finds 1 adult (30.0)	Report of jumping carp (12.3)	2	19.6
Intensive monitoring using established scientific detection methods	Person walking finds 1 dead on shore; Single eDNA found (27.7)	MDNR finds 20 adults (4.2)	3	14.5
Manually apply rotenone to a specific geographic area	Recently hatched carp found in river by researcher (24.8)	Report of jumping carp (2.5)	4	11.3
Erect a physical barrier such as an electric fence or earthen dam	18 juveniles found in river (18.4)	Report of jumping carp (3.2)	5	10.8
Limited monitoring using established scientific techniques	Single eDNA found (24.7)	MDNR finds 20 adults (0.4)	6	7.3
Raise awareness of the general public via education and communication	Report of jumping carp (16.4)	MDNR finds 20 adults (0.9)	7	5.6
Increase law enforcement monitoring and enforcement of laws	Commercial fisherman finds 1 adult (6.1)	MDNR finds 20 adults (1.0)	8	2.9
Record the event in database and take no action	Report of jumping carp (11.0)	Recently hatched carp found in river by researcher (0.3)	9	2.2
Implement regulations at a state, regional, or other level	Commercial fisherman finds 1 adult; Single eDNA found (1.1)	MDNR finds 20 adults (0.2)	10	0.6

to the "application of rotenone to a large area," there were a few patterns evident based on where (e.g., Lake Michigan, southeastern river) and what stage of invasion (e.g., juveniles, adults, multiple, single) the Asian carp detection scenario was presented to the respondents (Supplementary Material Table S1). There was low support across all Asian carp invasion scenarios for the implementation of regulations and increased enforcement. In contrast, there was increasing support for the application of rotenone to large areas within the context of rivers and when multiple adults were found. Across all Asian carp invasion scenarios, the application of rotenone to a large area was the most chosen response action with an average of 25% of participants choosing this response action. This response was especially preferred (47.8%) under the scenario of MDNR detecting 20 adults in a river but had lower support (6.1%) for a layperson's report of a single jumping carp. Removal and intensive monitoring were the second and third most popular response action across all scenarios (Table 2).

Results from Thinkshops on communicating about an Asian carp introduction and resulting response actions

Looking across Thinkshop results to intentionally identify commonalities, participants unanimously agreed on the importance of communicating with the public regarding a possible invasion and Asian carp response actions in a transparent and timely (e.g., days over weeks or months)

fashion. These participants felt it was important to communicate the preventative actions already being implemented by managers, the details of Asian carp management plans, and the negative consequences of not taking response actions regarding risk to environment, economy, and human health and safety. Participants also identified "red flags" that they felt could be avoided in communicating messages to the public, particularly messages that use words that may trigger negative emotions or perceptions (e.g., chemical, toxicant), and jargon that may be unfamiliar. Regarding message dissemination, participants from all Thinkshops mentioned the importance of the perceived expertise and trustworthiness of the information sources and expressed the preference for a unified message from a group source comprised of different authorities and academic or research institutes (Table S2).

Discussion

The intentional and unintentional anthropogenic spread of species to areas outside of their native range is certain to continue in the future. Many biological invasions have the potential to inflict great and irreversible harm to ecosystem services, human well-being, and bio-economies. Invasive species control by management agencies carries with it a suite of non-target risks on the environment, economy, and society (Cole et al. 2019; Wald et al. 2019; Warner and Kinslow 2011). The scope and scale of the socio-environmental consequences of biological invasions and their management have resulted in new and increased resources for managers to assess and mitigate those risks (e.g., Michigan's "Great Lakes Invasive Carp Challenge 2018" for innovating novel technologies to prevent movement). A scientific understanding of the human dimensions of biological invasions and invasion responses are essential factors in the risk management equation – both for top-down and bottom-up risk management. In this study, we explored public perceptions of risk associated with a possible invasion of Asian carp as well as risk perceptions associated with possible control options for an invasion; in this regard our study complements the biological invasion literature (e.g., Cole et al. 2019; Kapitza et al. 2019) with new anticipatory learning. Results from this work have implications for benchmarking risk communication about invasion control activities, specifically how government agencies, as risk messengers, may "frame" evidence of the risk (Entman 1993; Elliott 2003) and the need for control after an invasion has begun, and how messengers can proactively anticipate stakeholders' concerns about invasions and their control in order to avoid social conflicts (Crowley et al. 2017; Estévez et al. 2014; Mehmet et al. 2018).

Some invasive species control programs do not generate social conflict in the context within which they are implemented (e.g., Estévez et al. 2014; Thresher and Kuris 2004; Thresher et al. 2019). Only a subset results in public controversy, for example sea lamprey control in the Basin is widely

supported (Thresher et al. 2019) and genetic biocontrol technologies with relevance to invasive species are widely perceived as negative because of the association with GMOs (Sharpe 2014). Across both routine and controversial situations risk communication about invasion biology messaged by government agencies can be confounded by divergent risk perceptions. This is because communication is often unidirectional in that government agencies are *pushing* messages to the public (Warner and Kinslow 2011); just because risk communication is unidirectional does not mean that it is unable to reflect public perceptions. Risk messages from authorities to the public about invasive species and their control ideally reflect how the public perceives the problem. Demonstrating this understanding is an essential component of effective risk management (Slovic 1987).

Risk management of biological invasions may involve promoting risk-reducing behaviors among publics to help stop or blunt an invasion. Risk communication can use fear appeals, one type of persuasive communication, as a means to prompt people to adopt certain behaviors by stimulating a physiological and emotional response to a salient and serious threat such as Asian carp (see Muter et al. 2013). Fear appeals is a message design theory that predicts how individuals may respond to certain risk messages (i.e., accept or reject a message, adopt or not adopt a recommended behavior). In order to respond or be motivated to (re)act to an invasive species message, a person has to perceive they are susceptible to a severe threat and capable of performing a recommended behavior that is effective at averting the threat (McLeod et al. 2019). Insights herein help quantify and qualify these components for risk communication. For example, most participants in our study were aware of Asian carp and held negative attitudes about them even though at the time of data collection an invasion was not underway. Perceptions of environmental and socio-economic risks were higher than human health and well-being-related perceptions. This is somewhat unusual as human-health related risks often are rated highest across risks (Gore et al. 2016b). Additional research, particularly with a random sample of participants, could help equivocate this finding.

We also note that perceptions of risk associated with Asian carp differed from those associated with Asian carp response activities. These differences portend a need for multiple and different risk communication messages. When *environment* is the risk target, messages about Asian carp could focus on declines in the number and size of popular sport fish; control activity messages could focus on nontarget fish species being killed by rotenone. When *economy* is the risk target, messages about Asian carp could focus on decreased opportunities for revenue that come with sport fishing; control activity messages could focus on the permanent loss of fish upstream from installation of physical barriers such as dams. Finally, when *health and safety* is the risk target, messages could focus on lower-quality recreational boating and fear of damage from jumping fish; control activity messages

could focus on people being afraid to drink water treated with rotenone. Risk messages do not have to be constrained by the objective of building awareness of a potential Asian carp invasion or its impacts. When impacts are discussed, risk messages can frame impacts in terms of environment *and* economy. According to study participants, such dual-topic framing will be highly salient. This is because high-risk perception-based messages are more salient to and likely to be processed by stakeholders (Triezenberg et al. 2016). Despite the perceived risks from control activities, such as piscicides (i.e., rotenone), to human health and non-target species, the application of chemicals to specific or large areas was the preferred response action in over half of the Asian carp invasion scenarios. This may not be the management agency's preferred control activity and so if piscicides are *not* used in the event of an Asian carp invasion, messages that explain the decision may be very useful to reduce the potential for negative public conflict or lack of support for the agency's other control activities. Promoting alignment between public perceptions of management risks with managers' risk activities could be accomplished using principles from persuasive communication, which ultimately promote a particular outcome (Gore and Knuth 2009; Mehmet et al. 2018; Muter et al. 2013).

It is noteworthy that participants identified the same invasion control activities as being acceptable across different invasion scenarios that represented a gradient of low to high biological invasion risks based on the professional judgement from MDNR fisheries biologists. This means participants agreed multiple response actions could be appropriate in response to Asian carp, not a single action. Indeed, participants identified five response actions across all scenarios by order of resource intensity (e.g., either the cost, labor, time or other resources needed to engage in activity). Decision-makers can consider this assessment of public opinion about certain response activities alongside other variables such as ecological impact, cost, or political will when prioritizing decisions about response alternatives. Some response options, such as "record the incident" or "raise awareness through education and communication", did not rate highly. It is important to note that just because a response option was not highly ranked in response to a particular scenario, participants did not perceive them as being not useful. Rather, the response activity ranking delineates upper bounds of intensity participants feel is appropriate in a given scenario. It is also possible that participants assumed these less-intensive control activities would also be taking place in addition to the more intensive activities. Some Thinkshop participants affirmed they held such an assumption.

If and when Asian carp establish in the Basin, quantitative human dimensions inquiry could be undertaken to confirm general public sentiment about insights presented herein. Our data from a self-selecting group of stakeholders suggests risk communication about Asian carp is

warranted even though the biological invasion has not yet occurred. This may be evidence of the risk information and seeking processing phenomenon known as information sufficiency (e.g., Clarke 2009), which is requisite for the public to hold an accurate attitude and make correct decisions about an issue. An additional inquiry could use fear appeals theory to evaluate risk communication messages associated with Asian carp (e.g., measure changes in perceived severity, susceptibility, self-efficacy, and response-efficacy). Future research could also include longitudinal studies of Asian carp-related risk perceptions, which offer unique opportunities to examine how these perceptions evolve over time and would contribute to theory. Longitudinal studies can provide insights into the evolving nature of perceptions regarding emergent and ongoing risks, which include how those perceptions drive changes in behavior and policy preferences.

It appears to be widely taken as "a given" that plant and animal biological invasions will continue into the future with a great impact to the environment, socioenvironmental economy, and human health and safety (Ricciardi et al. 2017). It is uncertain, however, if communication and other public engagement processes, if begun early enough, could help public agencies anticipate public concerns about invasive species management actions. Research herein provides evidence for anticipatory learning about the human dimensions of Asian carp that can ultimately be combined with other invasion science insights and post-tested if and when Asian carp invade Michigan's lakes and rivers.

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Author contributions

MG and TN conceived the project; MG secured and managed research ethics approval; RL and MG led sample design and methodology with feedback from TN and SH, SH and MG led implementation of Thinkshops with support of TN; RL, JK and MG conducted data analysis and interpretation with support of TN and SH; all authors contributed to the original drafting of the manuscript led by JK, MG led all authors as they reviewed and edited manuscript

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Supplementary material

The following supplementary material is available for this article:

Table S1. Percentage of survey participants preferring different management actions in response to different types of evidence of biological invasion across different geographic locations in Michigan, 2017.

Table S2. Participants across three Thinkshops (n = 30) provided feedback about the scope, messages, messengers and channels for effective risk communication associated with biological invasion of Asian Carp in Michigan (2017).

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